

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**Insect bioactive capabilities of *Epichloë festucae* var *lolii* AR48
infected *Lolium perenne***

A thesis presented in partial fulfilment of the requirements for
the degree of

Doctor of Philosophy

In

Biochemistry

At Massey University, Manawatū
New Zealand

Taryn Angela Miller

2018

ABSTRACT

As the modern world expands and develops, new innovative methodologies for more efficient and environmentally friendly agricultural practices are required. Loss of crops through abiotic (*e.g.* drought) and biotic (*e.g.* herbivory) stresses has a major effect on the success of an agricultural industry. For animal production pasture crops are a key aspect of animal husbandry and directly affects yield and health. Symbiotic fungi belonging to the genus *Epichloë* form associations with cool season forage grasses and have been exploited as a new innovative method for insect pest management. Ryegrass infected with the asexual *E. festucae* var *lolii* strain AR48 has insect bioactivity against both the stem boring fly (SBF-*Ceradontha australis*) and cutworm moth caterpillar (CC -*Agrotis ipsilion*). The bioactive/s targeting both insects is currently unknown. The aim of this thesis was to identify the gene/s and/or bioactive/s present in AR48 infected ryegrass that have bioactivity against the SBF and/or CC. Two approaches were taken; the known insect bioactive secondary metabolite pathways in *Epichloë* were investigated in AR48 through bioinformatics and mass spectrometry, and the gene 'makes caterpillars floppy' (*mcf*), encoding an insect toxin like protein, was investigated through reverse genetics and insect bioactivity trials.

A new indole diterpene compound (IDT) was identified in AR48 infected plant material and this compound was absent in other *Epichloë* strains that do not have SBF and CC bioactivity. The same *mcf* gene allele as that present in the *E. typhina mcf* model, previously identified as having CC bioactivity, is present and predicted to be functional in AR48. The other *Epichloë* strains also have *mcf* genes predicted to be functional, however the *mcf* allele is different to the bioactive *E. typhina mcf* model. Overall, this project was able to identify a new IDT compound with potential insect bioactivity as well as identify two *Epichloë mcf* gene alleles that potentially have differing insect bioactivities.

ACKNOWLEDGEMENTS

I would first like to thank my supervisors Barry Scott, Richard Johnson and Gill Norris, for their wealth of knowledge and experience that has been invaluable. I truly appreciate the support and encouragement that they have provided, especially during the tough times that inevitably arise in a PhD. It has been a large undertaking, and I would not have been successful without them.

I would also like to thank my colleagues at both Massey University and AgResearch. Specifically, Wade Mace for his specialised skills in mass spectrometry that have played an important role in the success of my PhD. Also, Alison Popay and Joanne Jenson for providing both the knowledge as well as insects for the insect trials. Finally, Catherine McKenzie for her statistic skills used to analyse the insect trial results. Other people I would like to thank are Anouck de Bonth, Christine Voisey, Debbie Hudson, Jaspreet Singh, Aslinur Ozturk, and Natasha Forester for their advice as well as friendship that has been so important throughout my PhD. Finally, thank you to all the staff members whoms interactions over the years, no matter how minor, are valued.

A PhD is not just the achievement of excellence in scientific knowledge and technique, it is also a journey of personal development that cannot be completed without a network of loving and supportive family and friends. I have been blessed to be in a lab at Massey where I have made lifetime friends. Our “boss” and lab manager Arvina has not only been irreplaceable in her experience and time given to teach me molecular techniques, she has also become a very close friend and her support and belief in me has been indispensable. To my PhD buddies, Nazanin, Berit and Kim, having you beside me has made my PhD experience worth every moment, whether it’s getting coffee together, chatting about our science problems, crying over our failures or laughing over our successes, thank you. Finally, Yonathen and Dan, thank you for the advice and support as well as the many games nights spent together. I could not have chosen a better lab to do my PhD in, so thank you.

I would also like to thank Rachel Miller and Mackenna Dent, you are my closest friends, and I value all the times we have spent together, whether it's just hanging out or for support, and I truly treasure our friendship.

It has been a long 10 years of study to get to where I am now, and all of this could not have been possible without my loving, caring, and supportive family. Thank you so much Mum and Dad for always believing in me, even when I did not, and providing advice in all aspects of my life. I could not have asked for more loving parents. Thank you to my brother Gareth and Auntie Anita, you both have been so supportive, and I have always cherished our time together. Also, thank you to the West Family you have become a second family to me, and I am very appreciative of the support and the family dinners that we have had together.

Finally, I would like to thank my partner Andrew West. You have been by my side every step in my PhD journey and life, and without fail you have supported me, encouraged me and believed in me. I mean this in every sense; I truly could not have done this without you. There are no words to describe your impact on my life.

Thank you to Massey University and AgResearch for both funding and the opportunity.

TABLE OF CONTENTS

1.0 Introduction.....	1
1.1 <i>Epichloë</i> endophyte as a commercialised bioprotectant.....	3
1.1.1 Insect pests of <i>Lolium perenne</i>	3
1.1.2 Commercialisation of <i>Epichloë</i> as an insect biocontrol agent.....	5
1.1.3 Novel insect bioprotection of <i>Epichloë festucae</i> var <i>lolii</i> AR48 infected ryegrass.....	7
1.2 <i>Epichloë</i> endophyte molecular characterisation.....	10
1.2.1 <i>Epichloë</i> in culture and <i>in planta</i> morphologies.....	10
1.2.2 <i>Epichloë</i> asexual and sexual life cycles.....	11
1.2.3 Establishment and maintenance of <i>Epichloë</i> -host symbiosis.....	13
1.2.4 Fungal secondary metabolite gene clusters.....	14
1.2.5 Regulation of fungal secondary metabolites.....	15
1.2.6 <i>Epichloë in planta</i> induced bioactive alkaloids.....	17
1.2.6.1 <i>Epichloë</i> ergot alkaloids.....	19
1.2.6.2 <i>Epichloë</i> 1-Aminopyrrolizidines.....	19
1.2.6.3 <i>Epichloë</i> pyrrolopyrazines.....	20
1.2.6.4 <i>Epichloë</i> indole-diterpenes.....	21
1.3 <i>Penicillium</i> and <i>Epichloë</i> indole-diterpene characterisation.....	21
1.3.1 <i>Penicillium</i> indole-diterpenes.....	22
1.3.2 <i>Epichloë</i> indole-diterpenes.....	24
1.4 Makes caterpillars floppy (Mcf) as a possible <i>Epichloë</i> insect bioactive....	27
1.4.1 <i>Photorhabdus luminescens</i> Mcf.....	27
1.4.2 <i>Pseudomonas fluorescens</i> FitD.....	29
1.4.3 <i>Epichloë</i> Mcf.....	29

1.5 AR48 infected <i>Lolium perrene</i> insect bioactivity.....	30
1.5.1 Agromyzidae characterisation.....	30
1.5.1.1 Agromyzidae life cycle.....	31
1.5.1.2 Distribution of Agromyzidae New Zealand.....	31
1.5.1.3 <i>Cerodontha australis</i> characterisation.....	32
1.5.1.4 Economic impact and control management of Agromyzidae.....	33
1.5.2 Noctuidae characterisation.....	35
1.5.2.1 <i>Agrotis ipsilon</i> characterisation.....	35
1.5.2.2 <i>Agrotis ipsilon</i> life cycle.....	36
1.5.2.3 Economic impact and control management of <i>Agrotis</i> <i>ipsilon</i>	37
1.6 Aims.....	39
 2.0 Materials and Methods.....	 41
 2.1 Molecular and biological materials.....	 43
2.1.1 Details of strains used in this study.....	43
2.1.2 Details of plasmids used in this study.....	46
2.1.3 Details of primers used in this study.....	47
 2.2 Sterile conditions.....	 50
 2.3 Analyse the bioactive secondary metabolite pathways in <i>Epichloë festucae</i> var <i>lolii</i> AR48 and <i>Epichloë festucae</i> Fg1.....	 50
2.3.1 <i>Epichloë festucae</i> growth conditions.....	50
2.3.2 <i>Penicillium paxilli</i> growth conditions.....	50
2.3.3 <i>Epichloë festucae</i> genomic DNA extraction.....	50
2.3.4 <i>Epichloë festucae</i> crude DNA extraction.....	51
2.3.5 <i>Penicillium paxilli</i> crude DNA extraction.....	52
2.3.6 <i>Epichloë festucae</i> glycerol stocks.....	52

2.3.7 <i>Penicillium paxilli</i> glycerol stocks.....	52
2.3.8 <i>Penicillium paxilli</i> protoplasting preparation.....	52
2.3.9 <i>Penicillium paxilli</i> protoplast transformation.....	53
2.3.10 <i>Penicillium paxilli</i> spore stocks.....	54
2.3.11 Bioinformatics analysis of <i>Epichloë festucae</i> insect bioactive genes.....	54
2.3.12 <i>Lolium perenne</i> seed accession.....	54
2.3.13 <i>Lolium perenne</i> seed DNA extraction.....	54
2.3.14 Simple sequence repeat (SSR) polymerase chain reaction (PCR)	55
2.3.15 SSR genotyping.....	55
2.3.16 DNA sequencing.....	55
2.3.17 Indole-diterpene extraction from <i>Epichloë festucae</i> herbage and seed.....	56
2.3.18 Indole-diterpene extraction from <i>Penicillium paxilli</i> cultures.....	56
2.3.19 Chromatography of indole-diterpene extracts for triple quadrupole (TSQ) analyses.....	56
2.3.20 Chromatography of indole-diterpene extracts for triple quadrupole (TSQ) analyses.....	57
2.3.21 Mass spectrometry analysis TSQ of indole-diterpenes from <i>Epichloë festucae</i>	57
2.3.22 Mass spectrometry analysis LTQxl of indole-diterpenes from <i>Epichloë festucae</i>	57
2.3.23 Mass spectrometry analysis LTQxl of indole-diterpenes from <i>Penicillium paxilli</i>	58
2.3.24 Fragmentation in tree generation for <i>Epichloë festucae</i> indole- diterpenes.....	59
 2.4 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in <i>Epichloë festucae</i> var <i>lolii</i> AR48 infected ryegrass.....	 59
2.4.1 Bioinformatics analysis of makes caterpillars floppy (mcf).....	59

2.4.2 <i>Escherichia coli</i> growth conditions.....	60
2.4.3 <i>Escherichia coli</i> plasmid extraction.....	60
2.4.4 Chemically competent <i>Escherichia coli</i> DH5α cells.....	60
2.4.5 <i>Escherichia coli</i> DH5α cell transformation.....	60
2.4.6 <i>Escherichia coli</i> glycerol stocks.....	61
2.4.7 <i>Escherichia coli</i> plasmid design.....	61
2.4.8 <i>Epichloë festucae</i> protoplast preparation.....	61
2.4.9 <i>Epichloë festucae</i> protoplast transformation.....	62
2.4.10 <i>Epichloë festucae</i> spore isolation.....	62
2.4.11 <i>Lolium perenne</i> growth conditions.....	63
2.4.12 <i>Lolium perenne</i> seed sterilisation.....	63
2.4.13 <i>Lolium perenne</i> seedling inoculation.....	63
2.4.14 <i>Epichloë festucae</i> infected <i>Lolium perenne</i> plant immunoblotting.....	64
2.4.15 <i>Epichloë festucae</i> infected <i>Lolium perenne</i> plant macroscopy....	64
2.4.16 <i>Epichloë festucae</i> infected <i>Lolium perenne</i> plant microscopy....	64
2.4.17 DNA gel extraction.....	65
2.4.18 DNA column purification.....	65
2.4.19 DNA Qubit.....	65
2.4.20 DNA Nanophotometer.....	65
2.4.21 PCR.....	66
2.4.22 DNA agarose gel electrophoresis.....	66
2.4.23 Gibson assembly.....	66
2.4.24 Clone checker.....	66
2.4.25 Restriction analysis.....	67
2.4.26 <i>Epichloë festucae</i> Fg1 <i>mcf</i> whole gene replacement construct...	67
2.4.27 <i>Epichloë festucae</i> Fg1 <i>mcf</i> 5' gene replacement construct.....	67
2.4.28 <i>Epichloë festucae</i> var <i>lolii</i> AR48 <i>mcf</i> gene complementation construct.....	68
2.4.29 <i>Epichloë festucae</i> var <i>lolii</i> AR48 <i>idtP</i> gene complementation construct.....	68

2.4.30 <i>Epichloë festucae</i> var <i>lolii</i> AR48 <i>idtQ</i> gene complementation construct.....	68
2.4.31 DIG probe preparation for Southern blotting.....	68
2.4.32 Genomic DNA preparation for Southern blotting.....	69
2.4.33 Gel electrophoresis for Southern blotting.....	69
2.4.34 DNA blotting for Southern blotting.....	70
2.4.35 Hybridization of the probe for Southern blotting.....	70
2.4.36 Stringency washes for Southern blotting.....	71
2.4.37 Immunological detection for Southern blotting.....	71
 2.5 Test the insect bioactivity capabilities of <i>Epichloë festucae</i> var <i>lolii</i> AR48 and <i>Epichloë festucae</i> Fg1 infected ryegrass.....	71
2.5.1 Stem boring fly whole plant choice trial plant preparation.....	71
2.5.2 Stem boring fly preparation.....	72
2.5.3 Stem boring fly whole plant choice trial.....	72
2.5.4 Cutworm moth caterpillar whole plant choice trial plant preparation.....	73
2.5.5 Cutworm moth caterpillar preparation.....	73
2.5.6 Cutworm moth caterpillar whole plant choice trial.....	73
2.5.7 Cutworm moth or porina caterpillar detached tiller no choice trial plant preparation.....	74
2.5.8 Porina caterpillar preparation.....	74
2.5.9 Cutworm moth or porina caterpillar detached tiller no choice trial.....	74
2.5.10 Light brown apple moth caterpillar artificial diet no choice trial plant preparation.....	75
2.5.11 Light brown apple moth caterpillar preparation.....	75
2.5.12 Light brown apple moth caterpillar artificial diet no choice trial.....	75

3.0 Results.....77

3.1 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1.....79

- 3.1.1 Analysing the functionality and presence of the bioactive secondary metabolite genes in the genome of AR48 and Fg1 through bioinformatics.....79
- 3.1.2 Detection of the bioactive secondary metabolite compounds in AR48 and Fg1 infected ryegrass through mass spectrometry.....88
- 3.1.3 Analysing the structure of any newly identified compounds through mass spectrometry.....89
- 3.1.4 New indole-diterpene compound three synthesis through *Penicillium paxilli* complementation.....90

3.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass.....99

- 3.2.1 Analysing the distribution and functionality of the *mcf* gene within the *Epichloë festucae* species through bioinformatics.....99
- 3.2.2 Analysing the distribution and functionality of the *mcf* gene within the *Epichloë* genus through bioinformatics.....100
- 3.2.3 Analysing the location of the *mcf* gene within the *Epichloë* genus through bioinformatics.....105
- 3.2.4 Analysing the distribution, functionality, and location of the *mcf* gene outside the *Epichloë* genus through bioinformatics.....108
- 3.2.5 Analysing domain composition of Mcf/FitD proteins through bioinformatics.....112
- 3.2.6 Analysing the potential bioactivity of Mcf through reverse genetics of *Epichloë festucae* Fg1.....117
- 3.2.7 Analysing the potential bioactivity of Mcf through reverse genetics in *Epichloë festucae* var *lolii* AR1 and *Epichloë festucae* var *lolii* AR37.....119

3.3 Test the insect bioactivity capabilities of <i>Epichloë festucae</i> var <i>lolii</i> AR48 and <i>Epichloë festucae</i> Fg1 infected ryegrass.....	125
3.3.1 Design and perform a stem boring fly (<i>Cerodontha australis</i>) whole plant choice bioactivity trial on a range of wild type <i>Epichloë</i> -infected ryegrass.....	125
3.3.2 Design and perform a cutworm moth caterpillar (<i>Agrotis ipsilon</i>) whole plant choice bioactivity trial on a range of wild type <i>Epichloë</i> -infected ryegrass.....	129
3.3.3 Design and perform a cutworm moth caterpillar (<i>Agrotis ipsilon</i>) detached tiller no choice bioactivity trial on a range of wild type and <i>mcj</i> deletion <i>Epichloë</i> -infected ryegrass.....	132
3.3.4 Design and perform a a porina caterpillar (<i>Wiseana</i> spp) detached tiller no choice bioactivity trial on a range of wild type <i>Epichloë</i> -infected ryegrass.....	137
3.3.5 4 Design and perform a light brown apple moth caterpillar (<i>Epiphyas postvittana</i>) bioactivity trial on a range of wild type <i>Epichloë</i> -infected ryegrass.....	140
 4.0 Discussion.....	145
 4.1 Analyse the bioactive secondary metabolite pathways in <i>Epichloë festucae</i> var <i>lolii</i> AR48 and <i>Epichloë festucae</i> Fg1.....	147
4.1.1 Fg1 as a model AR48 strain.....	147
4.1.2 AR48 and Fg1 <i>in planta</i> insect bioactivity potential predicted through bioinformatics.....	148
4.1.3 AR48 and Fg1 new indole-diterpene compound three structure predicted through mass spectrometry.....	150
4.1.4 AR48 and Fg1 new indole-diterpene compound three synthesis predicted through bioinformatics.....	152

4.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass.....157

4.2.1 Mcf gene characterisation in *Epichloë*.....157

4.2.2 Proposed role of *Epichloë* Mcf.....159

4.2.3 *Epichloë festucae* Fg1 Δ mcf characterisation.....161

4.3 Test the insect bioactivity capabilities of *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1 infected ryegrass.....162

4.3.1 AR48 and Fg1 new indole-diterpene potential bioactivity.....162

4.3.2 *Epichloë* Mcf infected ryegrass potential bioactivity.....163

4.3.3 Difference in AR48 and *Epichloë festucae* var *lolii* AR47 infected ryegrass bioactivities.....166

4.3.4 Potential alternative bioactives for AR48 infected ryegrass novel insect bioactivity.....167

4.3.5 Comparison between different insect bioactivity trial methodologies.....168

5.0 Conclusion.....175

5.1 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1.....177

5.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected Ryegrass.....178

5.3 Test the insect bioactivity capabilities of *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1 infected ryegrass.....178

5.4 Overall conclusion of the project.....179

6.0 Future experiments.....181

6.1 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1.....183

6.1.1 AR48 and Fg1 genome assembly.....183

6.1.2 AR48 and Fg1 new indole-diterpene compound three ` structure.....183

6.1.3 AR48 and Fg1 new indole-diterpene compound three synthesis pathway.....184

6.1.4 AR48 and Fg1 new indole-diterpene compound three phylogenetic distribution.....184

6.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass.....185

6.2.1 *Epichloë* mcf allelic variants.....185

6.2.2 *Epichloë* Mcf domain functions and bioactivity mechanism.....185

6.2.3 *Epichloë* Mcf in culture, in planta, and target insect localisation.....186

6.3 Test the insect bioactivity capabilities of *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1 infected ryegrass.....186

6.3.1 *Epichloë festucae* AR48 and Fg1 new indole-diterpene compound three insect bioactivity.....186

6.3.2 *Epichloë festucae* Fg1 mcf reverse genetics.....187

7.0 Limitations.....189

7.1 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1.....191

7.1.1 AR48 and Fg1 new indole diterpene three unresolved structure.....	191
7.1.2 AR48 and Fg1 new indole diterpene three unresolved synthesis pathway.....	191
7.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in <i>Epichloë festucae</i> var <i>lolii</i> AR48 infected ryegrass.....	192
7.2.1 <i>Epichloë</i> limited genetic manipulation capabilities.....	192
7.2.2 <i>Epichloë</i> in planta only expressed secondary metabolites.....	193
7.3 Test the insect bioactivity capabilities of <i>Epichloë festucae</i> var <i>lolii</i> AR48 and <i>Epichloë festucae</i> Fg1 infected ryegrass.....	193
7.3.1 <i>Epichloë festucae</i> var <i>lolii</i> complex interaction between bioactive secondary metabolite profiles and insect bioactive capabilities.....	193
7.3.2 Non-model system insect species.....	194
8.0 Appendices.....	195
9.0 References.....	279

LIST OF FIGURES

Figure 1.1:	Stem boring fly (SBF- <i>Cerodontha australis</i>) bioactivity observed in an Argentine stem weevil (ASW- <i>Listronotus bonariensis</i>) plot trial.....	8
Figure 1.2:	The detection of cutworm moth caterpillar (CC- <i>Agrotis ipsilon</i>) bioactivity in a range of perennial ryegrass (top label) and endophyte (bottom label) combinations under laboratory conditions 2008.....	9
Figure 1.3:	The detection of cutworm moth caterpillar (<i>Agrotis ipsilon</i>) bioactivity in a range of perennial ryegrass and endophyte combinations under laboratory conditions 2012.....	10
Figure 1.4:	Fungal intercalary growth.....	11
Figure 1.5:	Diagram of both asexual and sexual life cycles of <i>Epichloë</i> species.....	13
Figure 1.6:	Simplified biochemical pathways that have been proposed for the production of secondary metabolites produced by <i>Epichloë</i> species....	18
Figure 1.7:	Ergot alkaloid (EAS) gene cluster in <i>Epichloë festucae</i> E2368.....	19
Figure 1.8:	Loline (LOL) gene cluster in <i>Epichloë festucae</i> E2368.....	20
Figure 1.9:	The structure of peramine (A) and the corresponding <i>perA</i> gene in <i>Epichloë festucae</i> Fl1 (B).....	21
Figure 1.10:	Indole diterpene (IDT/LTM) gene cluster in <i>Epichloë festucae</i> Fl1.....	21
Figure 1.11:	Simplified proposed paxilline biosynthetic pathway in <i>Penicillium paxilli</i>	23
Figure 1.12:	Indole diterpene (IDT/LTM) gene cluster in <i>Epichloë festucae</i> Fl1 strain.....	25
Figure 1.13:	Proposed lolitrem B biosynthetic pathway in <i>Epichloë festucae</i> Fl1 strain.....	26
Figure 1.14:	Comparison of makes caterpillars floppy (mcf)-like proteins.....	27
Figure 1.15:	Schematic diagram of the morphology of Diptera.....	34
Figure 1.16:	<i>Ceradontha australis</i> (stem boring fly-SBF)	34
Figure 1.17:	<i>Agrotis ipsilon</i> (cutworm moth (CM) and cutworm moth caterpillar (CC))	37

Figure 3.1:	Organisation of indole-diterpene (IDT) genes in different <i>Epichloë festucae</i> strains.....	81
Figure 3.2:	Indole-diterpene (IDT) <i>IdtF</i> and <i>idtK</i> gene alignment in different <i>Epichloë festucae</i> strains.....	82
Figure 3.3:	<i>PerA</i> gene alignment for different <i>Epichloë festucae</i> strains.....	83
Figure 3.4:	Simple sequence repeat (SSR) dendrogram of <i>Epichloë festucae</i> strains using 23 loci.....	84
Figure 3.5:	Amino acid sequence alignment of indole-diterpene (IDT) <i>IdtP</i> in <i>Epichloë festucae</i> strains AR48, Fg1, Fl1, E2368, AR1, AR37, and AR5 using Geneious.....	86
Figure 3.6:	Amino acid sequence alignment of indole-diterpene (IDT) <i>IdtQ</i> in <i>Epichloë festucae</i> strains AR48, Fg1, Fl1, E2368, AR1, AR37, and AR5 using Geneious.....	87
Figure 3.7:	Liquid chromatography mass spectrometry (LC-MS) analysis of indole-diterpenes (IDTs) from <i>Epichloë festucae</i> infected ryegrass.....	92
Figure 3.8:	Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of paxitriol from <i>Epichloë festucae</i> Fl1 infected ryegrass.....	93
Figure 3.9:	Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of terpendole E from <i>Epichloë festucae</i> Fl1 infected ryegrass.....	94
Figure 3.10:	Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of new indole-diterpene compound three from <i>Epichloë festucae</i> AR48 and Fg1 infected ryegrass.....	95
Figure 3.11:	Simplified lolitrem B pathway in <i>Epichloë</i> . Genes (single letter <i>e.g.</i> indole-diterpene (IDT) = <i>idtP</i> = P) next to associated reaction.....	98
Figure 3.12:	Analysis of the predicted makes caterpillars floppy (<i>mcf</i>) gene structure in a range of <i>Epichloë festucae</i> strains.....	102
Figure 3.13:	Analysis of the predicted makes caterpillars floppy (<i>mcf</i>) gene structure in a range of <i>Epichloë</i> species.....	104
Figure 3.14:	Identification of genes surrounding makes caterpillars floppy (<i>mcf</i>) within the <i>Epichloë festucae</i> Fl1 genome of chromosome 7.....	106
Figure 3.15:	Analysis of makes caterpillars floppy (<i>mcf</i>) syntony in <i>Epichloë</i>	107

Figure 3.16:	Identification of other fungal makes caterpillars floppy (<i>mcf</i>) genes outside <i>Epichloë</i>	110
Figure 3.17:	Domain analysis of makes caterpillars floppy (Mcf) and <i>P. fluoresces</i> insect toxin (FitD) proteins using online tools (Pfam, InterPro Scan, Phyre2 or Hhpred) in a range of species.....	116
Figure 3.18:	Strategy for deletion of the whole <i>Epichloë festucae</i> Fg1 makes caterpillars floppy (<i>mcf</i>) gene.....	121
Figure 3.19:	Strategy for deletion of the 5' end of the <i>Epichloë festucae</i> Fg1 makes caterpillars floppy (<i>mcf</i>) gene.....	122
Figure 3.20:	NBT/BCIP strained Southern blot of <i>Bam</i> H1 genomic digest (1 µg) of <i>Epichloë festucae</i> Fg1 wild type (WT) and makes caterpillars floppy (<i>mcf</i>) gene deletion (Δmcf) (#117) strains probed with digoxigenin (DIG)-11-dUTP linear pTM05 insert probe.....	123
Figure 3.21:	Culture phenotype of <i>Epichloë festucae</i> Fg1 wild type (WT) and makes caterpillars floppy (<i>mcf</i>) gene deletion (Δmcf) strains.....	124
Figure 3.22	Stem boring fly (SBF- <i>Cerodontha australis</i>) whole plant choice trial (SWPC) set up.....	127
Figure 3.23:	Stem boring fly (SBF- <i>Cerodontha australis</i>) whole plant choice trial (SWPC) results.....	128
Figure 3.24:	Cutworm moth caterpillar (CC- <i>Agrotis ipsilon</i>) whole plant choice trial (CWPC) set up.....	130
Figure 3.25:	Cutworm moth caterpillar (CC- <i>Agrotis ipsilon</i>) whole plant choice trial (CWPC) results.....	131
Figure 3.26:	Cutworm moth caterpillar (CC- <i>Agrotis ipsilon</i>) detached tiller no choice trial (CDTN) set up.....	134
Figure 3.27:	Cutworm moth caterpillar (CC- <i>Agrotis ipsilon</i>) detached tiller no choice trial (CDTN) survival rate (%) results.....	135
Figure 3.28:	Cutworm moth caterpillar (CC- <i>Agrotis ipsilon</i>) detached tiller no choice trial (CDTN) daily weight change results.....	136
Figure 3.29:	Porina caterpillar (PC- <i>Wiseana</i> spp) detached tiller no choice trial (PDTN) results.....	139

Figure 3.30:	Light brown apple moth caterpillar (LBAM- <i>Epiphyas postvittana</i>) artificial diet no choice trial (LADN) results.....	143
Figure 4.1:	Schematic of the diversity of early pathway indole diterpene (IDT) compounds produced by the four core genes (G, C, M, and B- coloured) in fungi.....	155
Figure 4.2:	Simplified lolitrem B pathway in <i>Epichloë</i>	156
Figure 4.3:	Graphical representation of the genomic location of secondary metabolite genes that produce bioactive compounds, in <i>Epichloë</i> <i>festucae</i> Fl1 complete assembled genome.....	170
Figure 4.4:	Proposed mode of action for the <i>Epichloë</i> makes caterpillars floppy (Mcf) protein based on the <i>Clostridium difficile</i> TcdA and TcdB toxins.....	171

LIST OF TABLES

Table 1.1:	Comparison of economically important insect pests of ryegrass in New Zealand.....	4
Table 1.2:	AgResearch commercialised insect biopesticide <i>Epichloë</i> species.....	7
Table 2.1:	Indole-diterpenes analysis by triple quadrupole (TSQ) selected reaction monitoring the following chromatogram segments.....	57
Table 2.2:	Indole-diterpenes analysis by linear ion trap (LTQxl) selected reaction monitoring the following chromatogram segments.....	58
Table 3.1:	Genome assemble statistics of AR48 and Fg1.....	79
Table 3.2:	Mass spectrometry indole-diterpene (IDT) compound profiles of extracts from ryegrass pseudostem infected with different <i>Epichloë festucae</i> strains (ppm).....	91
Table 3.3:	Average intensity of indole-diterpene (IDT) compounds identified in <i>Penicillium paxilli</i> wild type, $\Delta paxP$ (KO-knock-out), and $\Delta paxP$ complemented with <i>paxP</i> from <i>Penicillium paxilli</i> or <i>idtP</i> from <i>Epichloë festucae</i> strains AR48 or FI1 (ppm)	97
Table 3.4:	Average intensity of indole-diterpene (IDT) compounds identified in <i>Penicillium paxilli</i> wild type, $\Delta paxQ$ (KO-knock-out), and $\Delta paxQ$ complemented with <i>paxQ</i> from <i>P. paxilli</i> or <i>idtQ</i> from <i>Epichloë festucae</i> strains AR48 or FI1 (ppm).....	98
Table 3.5:	Location of makes caterpillars floppy (<i>mcf</i>) in the genomes of fungi outside the <i>Epichloë</i> genus using reference genes as location markers.....	111
Table 3.6:	Characteristics of published Mcf/FitD proteins.....	112
Table 3.7:	Makes caterpillars floppy (Mcf)/ <i>P. fluorescens</i> insect toxin (FitD) protein domain predictions using online tools that predicts using primary protein structure.....	113
Table 3.8:	Makes caterpillars floppy (Mcf) and <i>P. fluorescens</i> insect toxin (FitD) protein domain predictions using online tools that predicts using secondary protein structure.....	115

Table 4.1:	Overall insect bioactivities of <i>E. festucae</i> strains against a range of insects using different methodologies.....	172
Table 4.2:	Comparison of the different parameters between the insect trials used in this study.....	173

LIST OF APENDICES

Appendix 1:	Alignment of indole-diterpene (IDT) protein sequences from <i>Epichloë festucae</i> species.....	200
Appendix 2:	Unique amino acid changes in indole-diterpene (IDT) IdtP and IdtQ from <i>Epichloë festucae</i> strains AR48 and Fg1, when compared in an alignment of corresponding genes in <i>E. festucae</i> strains Fl1, E2368, AR1, AR37, and AR5.....	202
Appendix 3:	Phyre2 analysis of <i>Epichloë festucae</i> strains AR48 and Fg1 IdtP sequences aligned to the top 10 hits looking at non-conserved amino acid changes in pocket predictions.....	203
Appendix 4:	Phyre2 analysis of <i>Epichloë festucae</i> strains AR48 and Fg1 indole-diterpene (IDT) IdtQ sequences aligned to the top 10 hits looking at non-conserved amino acid changes in pocket predictions. Underlined amino acid changes are shared with E2368.....	205
Appendix 5:	<i>Epichloë festucae</i> strains AR48 and Fg1 mass spectrometry raw data of new indole-diterpene (IDT) peaks. Initial screening was undertaken using the TSQ (triple-quad) with multiple reaction monitoring (MRM) optimised for the indole diterpene products from <i>Epichloë</i> endophytes (parent-18 <i>m/z</i> and 130 <i>m/z</i> core).....	209
Appendix 6:	Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of paxitriol from <i>Epichloë festucae</i> Fl1 infected ryegrass.....	212
Appendix 7:	Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of terpendole E from <i>Epichloë festucae</i> Fl1 infected ryegrass.....	214
Appendix 8:	Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of new indole-diterpene (IDT) compound three from <i>Epichloë festucae</i> AR48 and Fg1 infected ryegrass.....	218
Appendix 9:	<i>Penicillium paxilli</i> <i>paxP</i> complementation construct (pSS1, 7930 bp)	219
Appendix 10:	<i>Epichloë festucae</i> AR48 indole diterpene (IDT) <i>idtP</i> complementation construct (pTM06, 11818 bp).....	220

Appendix 11: <i>Epichloë festucae</i> Fl1 indole-diterpene (IDT) <i>idtP</i> complementation construct (pSS56, 5572 bp)	221
Appendix 12: Geneticin construct (pDB49, 7458 bp). NptII (geneticin resistance gene)	222
Appendix 13: <i>Penicillium paxilli</i> <i>paxQ</i> complementation construct (pSS2, 8270 bp). NptII (geneticin resistance gene)	223
Appendix 14: <i>Epichloë festucae</i> AR48 indole-diterpene (IDT) <i>idtQ</i> complementation construct (pTM07, 11970 bp)	224
Appendix 15: <i>Epichloë festucae</i> Fl1 indole-diterpene (IDT) <i>idtQ</i> complementation construct (pSS58, 5743 bp)	225
Appendix 16: <i>Epichloë festucae</i> Fl1 <i>perA</i> complementation construct (pDB05, 16340 bp)	226
Appendix 17: <i>Penicillium paxilli</i> (<i>pax</i>) complementation raw data of A) known indole-diterpenes compound and B) unknown indole-diterpene (IDT)-like compounds.....	228
Appendix 18: Alignment of makes caterpillars floppy (<i>mcf</i>) genes from a range of <i>Epichloë festucae</i> strains using the alignment function of Geneious...	236
Appendix 19: Alignment of makes caterpillars floppy (Mcf) proteins from a range of <i>Epichloë festucae</i> strains using the alignment function of Geneious...	239
Appendix 20: Alignment of makes caterpillars floppy (<i>mcf</i>) genes from a range of <i>Epichloë</i> strains across multiple species using the alignment function of Geneious.....	263
Appendix 21: Alignment of makes caterpillars floppy (Mcf) proteins from a range of <i>Epichloë</i> strains across multiple species using the alignment function of Geneious.....	270
Appendix 22: Alignment of makes caterpillars floppy (Mcf) proteins from a range of fungal species across multiple species using the alignment function of Geneious.....	272
Appendix 23: Whole <i>Epichloë. Festucae</i> makes caterpillars floppy (<i>mcf</i>) gene deletion construct (pTM03, 7489 bp)	273

Appendix 24: 2 kb <i>Epichloë festucae</i> Fg1 5' of makes caterpillars floppy (<i>mcf</i>) gene deletion construct (pTM05, 8673 bp). Hph (hygromycin resistance gene)	274
Appendix 25: Hygromycin resistant gene construct (pANS7-1, 4777 bp).....	275
Appendix 26: PCR confirmation of #117 transformant (Δmcf Fg1/pTM05).....	276
Appendix 27: <i>Epichloë festucae</i> var <i>lolii</i> AR48 makes caterpillars floppy (<i>mcf</i>) gene complementation construct (pTM04, 14377 bp). Hph (hygromycin resistance gene).....	277
Appendix 28: Hygromycin construct (pDB48, 7702 bp). Hph (hygromycin resistance gene).....	278

ABBREVIATIONS

%	Percentage
°C	degrees Celsius
3-GGI	3-geranylgeranyl indole
A600	Absorbance at 600 λ
aa	Amino acid
ACP	Acyl carrier protein domain
ADN	Artificial diet no choice
Amp	Ampicillin
AmpR	Ampicillin resistance
ASW	Argentine stem weevil
AT	Acyltransferase domain
Bcl-2	B-cell lymphoma 2
BH3	Bcl-2 domain three
BLAST	Basic Local Alignment Search Tool
BLASTn	BLAST search against a nucleotide database with a nucleotide sequence
BLASTp	BLAST search against a protein database with a protein sequence
BLASTx	BLAST search against a protein database with a translated nucleotide sequence
Bp	base pairs
BS	Blocking solution
C	Condensation domain
CADN	Cutworm moth caterpillar artificial diet no choice
CC	Cutworm moth caterpillar
cDNA	Complementary DNA
CDTN	Cutworm moth caterpillar detached tiller no choice
CDYE	Czapek Dox yeast extract
CHEF	Contour-clamped homogeneous electric field electrophoresis
CM	Cutworm moth
cm ²	centimetres squared
CNF	Cytotoxic necrotizing factors
CoA	Coenzyme A
COMP	Gene complementation
CPD	Cysteine protease domain
CPD 2	Cysteine protease domain two
CPD1	Cysteine protease domain one
CT	Common toxic
CWPC	Cutworm moth caterpillar whole plant choice
CY	Cyclisation domain
CZ	Cell division zone
DH	Dehydratase domains
DMAPP	Dimethylallyl pyrophosphate
DMSO	Dimethyl sulfoxide
DNA	Deoxyribonucleic acid
DNase	Deoxyribonuclease

dNTP	Deoxyribonucleotide triphosphate
DSIR	Department of Scientific and Industrial Research
DTN	Detached tiller no choice
E	Epimerization domain
EAS	Ergot alkaloid
EDTA	Ethylenediaminetetraacetic acid
EZ	Expansion zone
FAD	Flavin adenine dinucleotide
FASTA	Fast-all
Fit	Fluorescens Insect Toxin
FPP	Farnesyl pyrophosphate
g	Gram
<i>g</i>	Acceleration due to gravity
Gen	Geneticin
GenR	Geneticin resistance
GGPP	Geranylgeranyl pyrophosphate
HGT	Horizontal gene transfer
hph	Hygromycin resistance conferring gene
Hyg	Hygromycin
HygR	Hygromycin resistance
IDT	Indole-diterpene
IGP	Indole-3-glycerol phosphate
IPP	Isopentenyl diphosphate
kb	Kilo base pairs
KR	Ketoreductase domains
KS	Keto-synthase domain
L	Litre
LADN	Light brown apple moth caterpillar artificial diet no choice
LB	Lysogeny broth
LBAM	Light brown apple moth caterpillar
LCMS	Liquid-chromatography mass spectrometry
LOL	Loline locus/gene cluster
LTM	Lolitre locus/gene cluster
M	Moles per litre
MIDAS	Modular Idempotent DNA Assembly System
m/s	Meters per second
Mcf	Makes caterpillars floppy
MEP	2-Methyl-D-erythritol-4-phosphate
mg	Milligram
mins	Minutes
MITes	Miniature inverted transposable elements
mL	Millilitre
mM	millimoles per litre
mm	Millimetre
MQ	Milli-Q water
mRNA	Messenger RNA

MS	Mass spectrometry
MT	Methyltransferase domains
ng	Nanograms
NMR	Nuclear magnetic resonance
<i>nptII</i>	Geneticin resistance gene
NRPS	Non-ribosomal peptide synthetase
NZGL	New Zealand Genome Limited
OM	Osmoregulation buffer
OX	Oxidation domain
PADN	Porina caterpillar artificial diet no choice
Pax	Paxilline
PC	Porina caterpillar
PC1	Physical containment one
PC2	Physical containment two
PCR	Polymerase chain reaction
PD	Potato dextrose
PDTN	Porina caterpillar detached tiller no choice
PEG	Polyethylene glycol
PER	Peramine
PIPES	Piperazine-N,N'-bis(2-ethanesulfonic acid)
PKS	Polyketide synthase
PM	Porina caterpillar
PM	Porina moth
RG	Regeneration
RNA	Ribonucleic acid
Rnase	Ribonuclease
ROS	Reactive oxygen species
rpm	Revolutions per minute
RT-qPCR	Real time quantitative PCR
RTX	Repeats-in-toxin
SADN	Stem boring fly artificial diet no choice
SBF	Stem boring fly
SD	Secretion domain
SDS	Sodium dodecyl sulfate
SDTN	Stem boring fly detached tiller no choice
sec	Seconds
SM	Secondary metabolite
SNP	Single nucleotide polymorphism
SSR	Simple sequence repeat
ST	Sorbitol Tris
STC	Sorbitol Tris calcium chloride
SWPC	Stem boring fly whole plant choice
TB	Tris-boric
TBE	Tris-boric acid-EDTA
tBLASTn	BLAST search against a nucleotide database with a protein sequence
TE	Thioesterase domain

T _m	Melting temperature
TMD	Transmembrane domain
UV	Ultra violet
V	Volume
v/v	Volume/volume
w/v	Weight/volume
WA	Water agar
WPC	Whole plant choice
WT	Wild type
Δ	Gene deletion
μg	Microgram
μL	Microliter
μm	Micrometre

1.0 INTRODUCTION

1.1 *Epichloë* endophyte as a commercialised bioprotectant

The fungal genus *Epichloë* contains both sexual and asexual species and is classified as belonging to the family Clavicipitaceae within the phylum Ascomycota. This endophyte forms interactions with cool season grasses from the sub-family Pooideae within the family Poaceae (Johnson *et al.*, 2013a), which contains agriculturally important pasture species such as *Lolium perenne* (ryegrass), *Festuca arundinacea* (tall fescue), and *Festuca pratensis* (meadow fescue). In this interaction, the endophyte provides both abiotic (*e.g.* drought tolerance) and biotic (*e.g.* mammalian and insect bioactive compounds) benefits to the host plant, while the host plant in turn provides nutrients and a mode of transmission to the fungus (Schardl & Leuchtman, 2005). This symbiotic induced biotic activity has been commercialised in the agricultural industry as a bioprotectant agent.

1.1.1 Insect pests of *Lolium perenne*

Ryegrass is an economically important pasture crop in New Zealand as it provides nutrition for cattle raised for the dairy and meat industries (Ferguson *et al.*, 2018). Controlling insects that target ryegrass is therefore important, as reduction in palatable pasture reduces the nutritional intake of grazing cattle and in turn affects milk and meat production. In addition, money and time spent managing the insect populations and supplementary feed adds to production costs (Ferguson *et al.*, 2018). Insect population control strategies that do not use synthetic insecticides or chemicals are advantageous as they have reduced environmental impact, can be safer to use, may have lower economic cost, and are more specific with few if any non-target effects (Ferguson *et al.*, 2018).

There is a range of different insect species that damage ryegrass, although only a few species are key economic pests. While most of these species are endemic or native, some are accidental introductions from other countries. The insects typically cause damage when the larvae feed on either the root or tiller systems of the plant, though for a few species the adults also inflict damage. Some species complete their life cycle in a year (univoltine) with the adult insect present in winter and the larvae present

Chapter one: Introduction

during the summer breeding season, whereas others have 2 - 3 generations per year (Table 1.1).

Table 1.1: Comparison of economically important insect pests of ryegrass in New Zealand

Common name	Scientific name	Type	Distribution	Breeding season	Tissue effected	Economic impact	Control	Reference
Grass grub	<i>Costelytra zealandica</i>	Moth	New Zealand (endemic)	One cycle per 1-2 years (Adults Oct-Dec and pupa Jan-Sep)	Tillers and roots (pupa). Yellowing patches.	\$275M-\$706M on dairy farms and \$75M-\$205M on sheep and beef farms annually	None	(Ferguson et al., 2018)
Porina	<i>Wiseana cervinate</i>	Moth	New Zealand (endemic)	One cycle per year (Adults Oct-Mar and pupa Apr-Sep)	Tillers (pupa). Dead patches.	Up to \$84M on dairy farms and up to \$88M on sheep and beef farms annually	<i>Epichloe festucae</i> var <i>lolii</i> strain AR37 in ryegrass (bioactive= epoxy-janthitrems)	(Jense et al., 2004)(Ferguson et al., 2018)
Mealy bug	<i>Balanococcus poae</i>	Armored insect	Canterbury, Manawatu and Nelson NZ. (endemic)	All year round	Tillers (adult and pupa). Brown field.	N/A	None	(Ferguson et al., 2018)
Root aphid	<i>Aploneura lentisci</i>	Aphid	Mediterranean, Middle East region (endemic)	All year round	Tillers (nymphs) and roots (adult). Reduced plant growth.	N/A	<i>Epichloe festucae</i> var <i>lolii</i> strain AR37 in ryegrass (unknown)	(Popay et al., 2016) (Hume et al., 2007)(Ferguson et al., 2018)
Black field cricket	<i>Teleogryllus commodus</i>	Cricket	New Zealand, and Australia (native)	One generation per year (Adult Feb-May, and	Tillers (adult and pupa). Dead patches.	N/A	<i>Epichloe uncinata</i> in <i>Festuca pratensis</i> or a <i>festulolium</i>	(Becker et al., 2015)(Ferguson et al., 2018)
Argentine stem weevil	<i>Listronotus bonariensis</i>	Weevil	South America, New Zealand, and Australia (introduced)	Up to three generations between Sep-March	Tillers (pupa). Dead patches,	Up to \$200M on dairy farms and up to \$235M on sheep and beef farms annually	<i>Epichloe festucae</i> var <i>lolii</i> strain AR1 (bioactive= peramine). <i>Epichloe festucae</i> var <i>lolii</i> strain AR37 in ryegrass (unknown)	(Rowan, Dymock et al., 1990) (Popay et al., 1995)(Ferguson et al., 2018)
Black beetle	<i>Heteronychus arator</i>	Scarab	Africa, Upper North Island NZ, and Australia (introduced)	One generation per year (Adult Mar-Dec and pupa Jan-Mar)	Tillers and roots (adult and pupa). Yellowing patches	Up to \$223M on dairy farms and up to \$19M on sheep and beef farms annually	<i>Epichloe festucae</i> var <i>lolii</i> strain AR37 in ryegrass (unknown)	(Ball, Christensen et al., 1994)(Ferguson et al., 2018)

Chapter one: Introduction

There is currently no biological control for grass grub, and mealy bug. Porina, black beetle, Argentine stem weevil (ASW), and the root aphid are however, controlled by ryegrass infected with the *Epichloë festucae* var *lolii* strain AR37. The bioactive indole-diterpene (IDT) epoxy-janthitrem is known to deter feeding of porina larvae (Hennessy *et al.*, 2016). ASW is also controlled by ryegrass infected with *Epichloë festucae* var *lolii* AR1 (Rowan *et al.*, 1990). Finally, *E. uncinata* has bioactivity towards black field cricket (Table 1.1).

1.1.2 Commercialisation of *Epichloë* as an insect biocontrol agent

The discovery of the two *Epichloë* secondary metabolites (SMs), peramine (responsible for ASW deterrence) and lolitrem B (responsible for ryegrass staggers) prompted an investigation to identify *Epichloë* species which produced peramine but did not produce lolitrem B (Johnson *et al.*, 2013a). This investigation resulted in the commercialisation of Endosafe® by Department of Scientific and Industrial Research (DSIR) and later on AgResearch in 1991 (Johnson *et al.*, 2013a, Fletcher *et al.*, 2012, Milne, 2007). Unfortunately, summer slump and fescue foot were observed in cattle exposed to Endosafe, and further testing resulted in the identification of the mammalian toxin ergovaline, an endophyte produced ergot alkaloid in the grass (Table 1.2) (Fletcher *et al.*, 2012).

This prompted an investigation into identifying *Epichloë* species that produced peramine, but not lolitrem B or ergovaline (Popay *et al.*, 1999). This resulted in the identification and commercialisation of *E. festucae* var *lolii* AR1 strain in ryegrass in 2001 (Table 1.2) (Milne, 2007). Interestingly, cattle grazing on grass infected with AR1 produced 9% more milk than cattle grazing on grass infected with the common toxic strain (CT), defined as the lolB clade of *E. festucae* var *lolii* (Christensen *et al.*, 1993).

AR37, another *E. festucae* var *lolii* strain, which does not produce peramine, lolitrem B, or ergovaline, was also included in this investigation, and when *in planta* was shown to have bioactivity to a much wider range of insects than AR1 infected ryegrass. However, rare cases of staggers in grazing cattle were documented, although the symptoms were much milder than those caused by CT (Johnson *et al.*, 2013a). AR37 in ryegrass

Chapter one: Introduction

was commercialised in 2007, and trials have shown that grass infected with AR37 has greater advantages compared to grass infected with AR1, CT or grass that is endophyte free (Milne, 2007). Interestingly, the only bioactive molecules that have so far been detected in AR37 infected material are the *epoxy-janthitrems*, a group of IDTs (Table 1.2) (Jensen & Popay, 2004, Popay & Gerard, 2007, Finch *et al.*, 2010).

A parallel trial investigating *Epichloë* that did not produce ergovaline but did produce lolines was carried out on tall fescue (Johnson *et al.*, 2013a) and resulted in the identification and commercialisation of AR542 in tall fescue, *E. coenophiala*, in the USA in 2000 (MaxQ®) and AR542 in tall fescue, *E. coenophiala*, in New Zealand and Australia in 2003 (MaxP®) (Table 1.2) (Bouton, 2009, Johnson *et al.*, 2013a).

Finally, the highest ergovaline and lolitrem B producing endophyte species from both trials were commercialised in grasses in 2010 (Avanex®), *E. festucae* var *lolii* AR94/95 in ryegrass and *E. coenophiala* AR601 in tall fescue, and used in areas such as airports, sports fields, and recreational parks to deter birds (Table 1.2) (Pennell & Rolston, 2011).

Table 1.2: AgResearch commercialised insect biopesticide *Epichloë* species (Johnson *et al.*, 2013a)

Commercial or common name	Fungal species	Major alkaloids	Key traits	Hosts
Common-toxic	<i>E. festucae</i> var <i>lolii</i>	Lolitrems Peramine Ergovaline	Ryegrass staggers and deterrence against ASW and BB	Ryegrass in New Zealand
Endosafe	<i>E. festucae</i> var <i>lolii</i>	Peramine Ergovaline	Summer slump/fescue foot, and deterrence against ASW	Ryegrass in New Zealand
AR1	<i>E. festucae</i> var <i>lolii</i>	Peramine	Deterrence against ASW	Ryegrass in New Zealand, Australia, and South America
AR37	<i>E. festucae</i> var <i>lolii</i>	Epoxy-janthitrems	Broad insect deterrence	Ryegrass in New Zealand, and Australia
MaxP	<i>E. coenophiala</i> strain AR542 and AR584	Lolitrems Peramine	Broad insect deterrence	Tall fescue in New Zealand, and Australia
MaxQ	<i>E. coenophiala</i> strain AR542 and AR584	Lolitrems Peramine	Broad insect deterrence	Tall fescue in USA
Avanex	<i>E. festucae</i> var <i>lolii</i> strain AR94/95	Peramine Ergovaline Lolitrems B	Bird and wild life deterrence	Ryegrass in sports fields and recreational parks

ASW: Argentine stem weevil (*Listronotus bonariensis*). BB: Black beetle (*Heteronychus arator*)

1.1.3 Novel insect bioprotection of *Epichloë festucae* var *lolii* AR48 infected ryegrass

The asexual *Epichloë festucae* var *lolii* strain AR48 was isolated from *Lolium perenne* in Tuscany and has two new bioactivities towards *Ceradontha australis* (stem boring fly-SBF) and *Agrotis ipsilon* (cutworm moth caterpillars-CC) (Figure 1.1, 1.2, and 1.3). Both insects are ryegrass pests in New Zealand agricultural (refer to section 1.5).

SBF bioactivity of AR48 was identified during an ASW plot trial at Ruakura AgResearch New Zealand. This trial was set up to screen for ASW bioactivity in a range of endophyte infected ryegrasses, however during the trial there was a clear lack of SBF damage to AR48 and AR47 infected plants. The SBF damage was therefore assessed alongside the ASW damage. AR48 and AR47 did indeed have bioactivity against the SBF

(Figure 1.1). This bioactivity was then confirmed by subsequent SBF insect trials (Alison Popay, AgResearch; personal communication).

Two laboratory trials were conducted in Purdue University in the USA that assessed the CC bioactivity potential of a range of perennial ryegrass and endophyte combinations. For the first trial that was performed in 2008, the CC were individually assessed in petri dishes, which contained moist filter paper, and given detached tillers every 24 hours for 10 days. The settling response was measured after the first 24 hours and survival rate measured at 24-hour intervals. AR48 and AR47 had the lowest settling response (%) and lowest survival rate out of all treatments (Figure 1.2).

The second trial was performed in 2012, used the same method as the 2008 trial except that the CC were assessed for survival only on day 5 and day 10, and end CC biomass was measured. There was no difference in survival rates between the different treatments (data not presented) but AR48, AR47, and AR1 had the lowest end CC biomass (Figure 1.3).

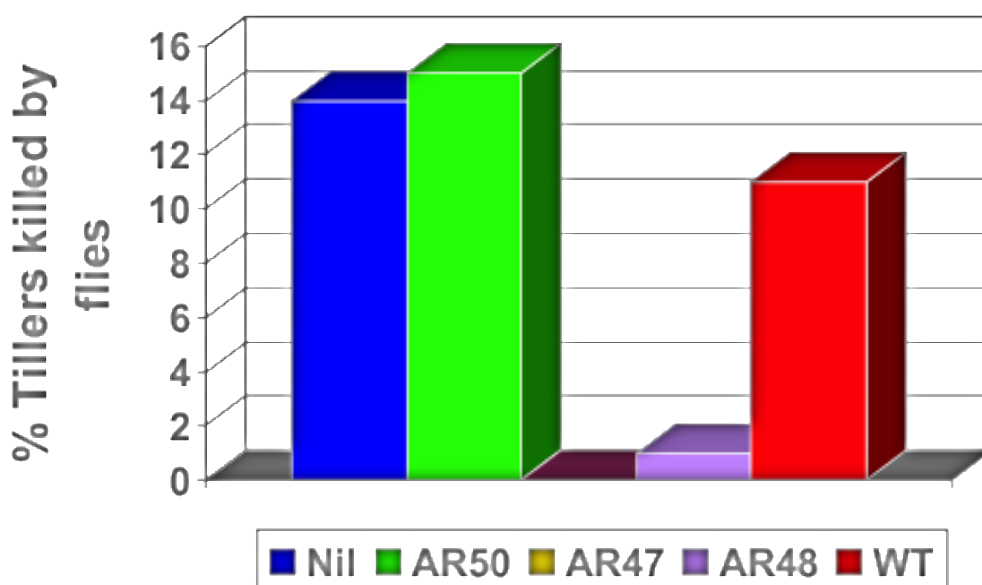


Figure 1.1: Stem boring fly (SBF-*Cerodontha australis*) bioactivity observed in an Argentine stem weevil (ASW- *Listronotus bonariensis*) plot trial, set up to screen for ASW bioactivity in a range of endophyte infected ryegrass, at Ruakura AgResearch New Zealand (unpublished data from David Hume, Grasslands AgResearch, New Zealand). Nil= no endophyte present. WT= wild type which is the common toxic strain found naturally occurring in ryegrass in New Zealand. AR= endophyte strain of interest.

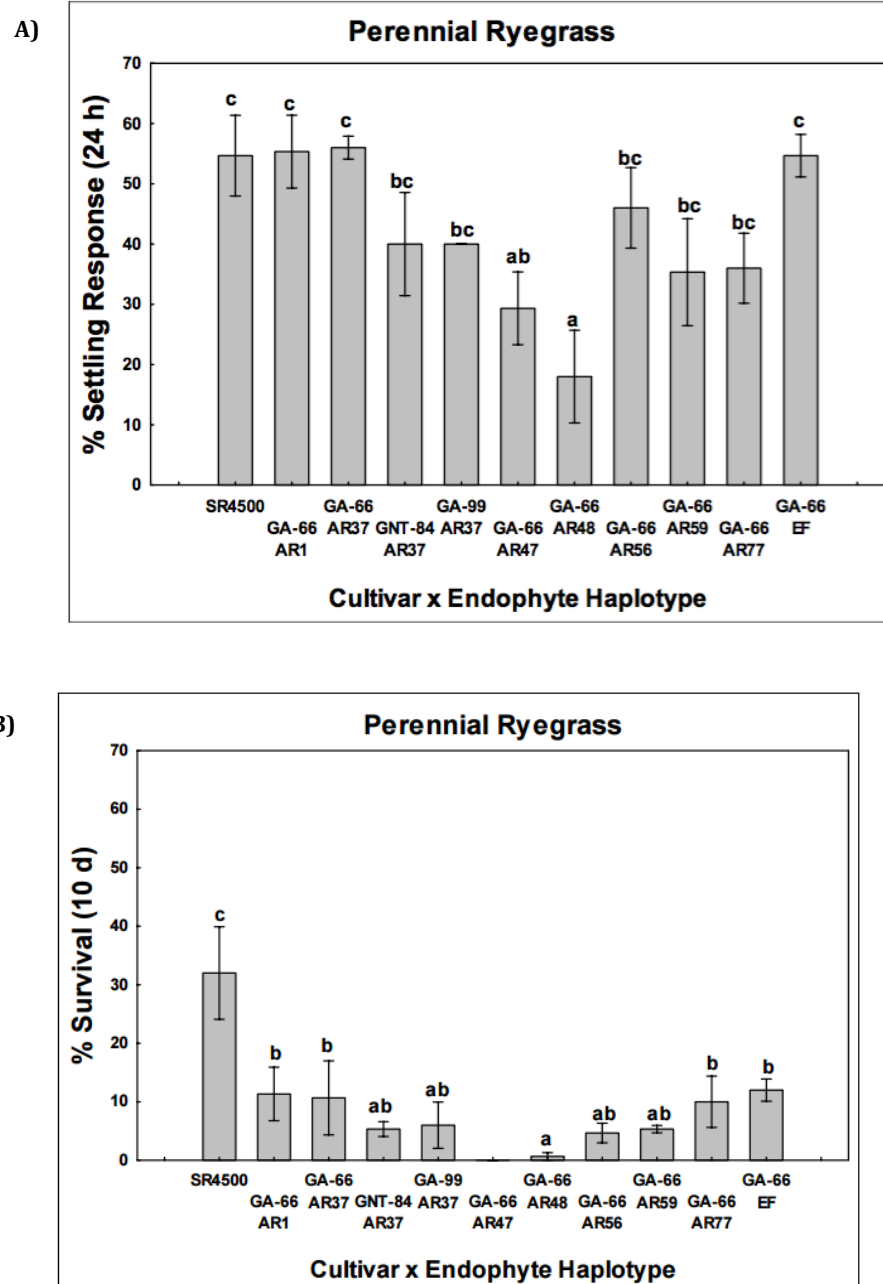


Figure 1.2: The detection of cutworm moth caterpillar (*CC-Agrotis ipsilon*) bioactivity in a range of perennial ryegrass (top label) and endophyte (bottom label) combinations under laboratory conditions 2008. CC contained in petri dishes with moist filter paper were given fresh detached tillers every 24 hours for 10 days. A) The settling response of CC after 24 hours exposure to different endophyte infected tiller combinations (data collected by Douglas S. Richmond, Purdue University, USA, and provided by David Humes, Grasslands AgResearch, New Zealand). B) Percentage of CC surviving on clippings of different endophyte infected tiller combinations after 10 days of laboratory feeding assay.

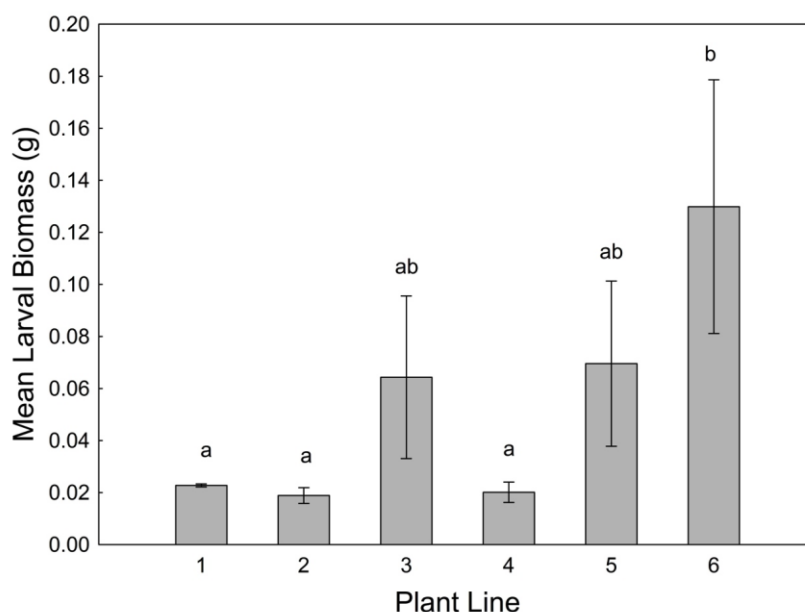


Figure 1.3: The detection of cutworm moth caterpillar (*Agrotis ipsilon*) bioactivity in a range of perennial ryegrass and endophyte combinations under laboratory conditions 2012. CC contained in Petri dishes with moist filter paper were given fresh detached tillers every 24 hours for 10 days, and end biomass measured (data collected by Stephanie Hathaway, Purdue University, USA, and provided by David Humes, Grasslands AgResearch, New Zealand). 1) AR1 in AGRLP-135. 2) AR1 in AGRLP-140. 3) AR47 in AGRLP-141. 4) AR48 in AGRLP-142. 5) HE toxic in FLp-322. 6) No endophyte in BG24T.

1.2 *Epichloë* endophyte molecular characterisation

1.2.1 *Epichloë* in culture and in planta morphologies

In planta, the endophyte is located in the aerial tissue within the intercellular space (apoplast) where in general single hyphae run parallel to the longitudinal axis of the leaf. These hyphae are physically attached to the plant cell walls, and while they are predominantly found at the base of the leaf, in some cases they form symbiotic relationships in the leaf blade as well (Figure 1.4) (Johnson *et al.*, 2013a, Clay, 1990).

Both endophyte and plant develop in parallel. In the cell division zone (CZ) of the plant leaf, endophyte hyphae are highly branched and grow from the hyphal tip. The plant cells, along with the attached hyphae, are then pushed out of the CZ by the dividing plant cells below into the expansion zone (EZ) of the plant leaf where the plant cells'

elongation and maturation occur. During this transition phase, the endophyte hyphae switch from tip to intercalary growth, allowing the hyphae to remain attached to the plant cell wall. Both plant and endophyte develop through intercalary growth in the EZ, but through different mechanisms *i.e.* the length of the plant cell compartments increase progressively during cell maturation, while endophyte hyphae compartments divide unevenly throughout the length of the hyphae (Figure 1.4) (Christensen *et al.*, 2008, Voisey, 2010, Schardl *et al.*, 2004).

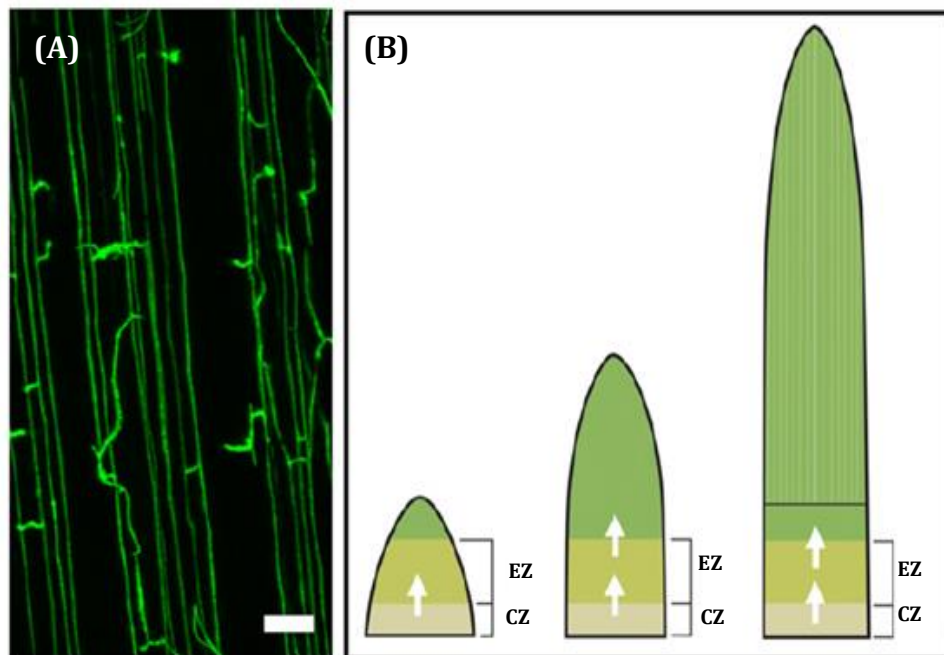


Figure 1.4: Fungal intercalary growth. (A) Morphology of hyphae in the grass leaf expansion zone using *E. festucae* strain FI1 expressing green fluorescent protein (GFP) in ryegrass. Scale bar = 50 μ m. (B) Diagram of the different growth zones within a grass leaf, cell division zone (CZ), and leaf expansion zone (EZ). Arrows indicate direction of growth. Taken from (Voisey, 2010) with permission from Elsevier.

1.2.2 *Epichloë* asexual and sexual life cycles

The symbiotic interaction between the host plant and endophyte can be placed anywhere on the continuum of mutualistic to antagonistic depending on the endophyte strain. The placement of a specific strain is dictated by the ratio of the rate of vertical/asexual (through the seed) transmission to horizontal/sexual (through ascospore production) transmission, with the mode regulated at each tiller and ratio fixed for each strain. Given that asexual strains of *Epichloë* cannot undergo horizontal transmission, all strains therefore form a mutualistic interaction *e.g.* *E. festucae* var

Chapter one: Introduction

lolii AR37. While sexual species of *Epichloë* can be placed anywhere on the continuum, e.g. *E. festucae* Fl1 rarely undergoes horizontal transmission and therefore forms a mutualistic interaction, *E. alumni* undergoes horizontal transmission frequently and therefore forms an intermediate mutualistic-antagonistic interaction (Schardl *et al.*, 2004), and *E. typhina* almost always undergoes horizontal transmission and therefore forms an antagonistic interaction (Chung & Schardl, 1997). Both the sexual and asexual reproductive processes coincide with the reproductive process of the host plant (Schardl *et al.*, 2004).

For asexual reproduction, the endophyte infects the ovary and ovules of each floret by growing from the vegetative apex into the inflorescence. Directly after fertilisation, the endophyte enters the embryonic sac, where during embryogenesis, it will infect both the embryo and surrounding structures. Finally, the endophyte colonises the shoot apex during germination, resulting in a systemic infection of the aerial tissue (Figure 1.5) (Philipson & Christey, 1986, Scott *et al.*, 2012).

For sexual reproduction to occur, a switch from restrictive growth to proliferative growth is required. This is dependent on the physiological state of both the grass and endophyte (Scott *et al.*, 2012). Sexual reproduction of the endophyte takes place during the development of the inflorescence. The immature inflorescence is initially covered by the leaf sheath. This leaf sheath is infected by the endophyte which results in the inflorescence failing to emerge, and instead, a stroma develops (Schardl *et al.*, 2004, Scott *et al.*, 2012, Johnson *et al.*, 2013a). For the development of ascospores from the stroma, cross-fertilisation between stroma of different mating types is required. This occurs *via* the female *Botanophila* fly that acts as a pollinator (Kohlmeyer & Kohlmeyer, 1974). Volatiles produced by the plant attract the fly to feed and oviposit. The fungal spores are then carried in the gut of the fly and fertilise the stroma of an opposite mating type upon excretion. This is a co-dependent relationship as the fly larva in turn requires the fertilised stroma as a food source. Once the stroma is fertilised, fruiting bodies (perithecia) develop with multiple sacs (asci) each containing 8 ascospores. These ascospores are then ejected into the air and infect neighbouring plants (Figure 1.5) (Schardl *et al.*, 2004, Chung & Schardl, 1997).

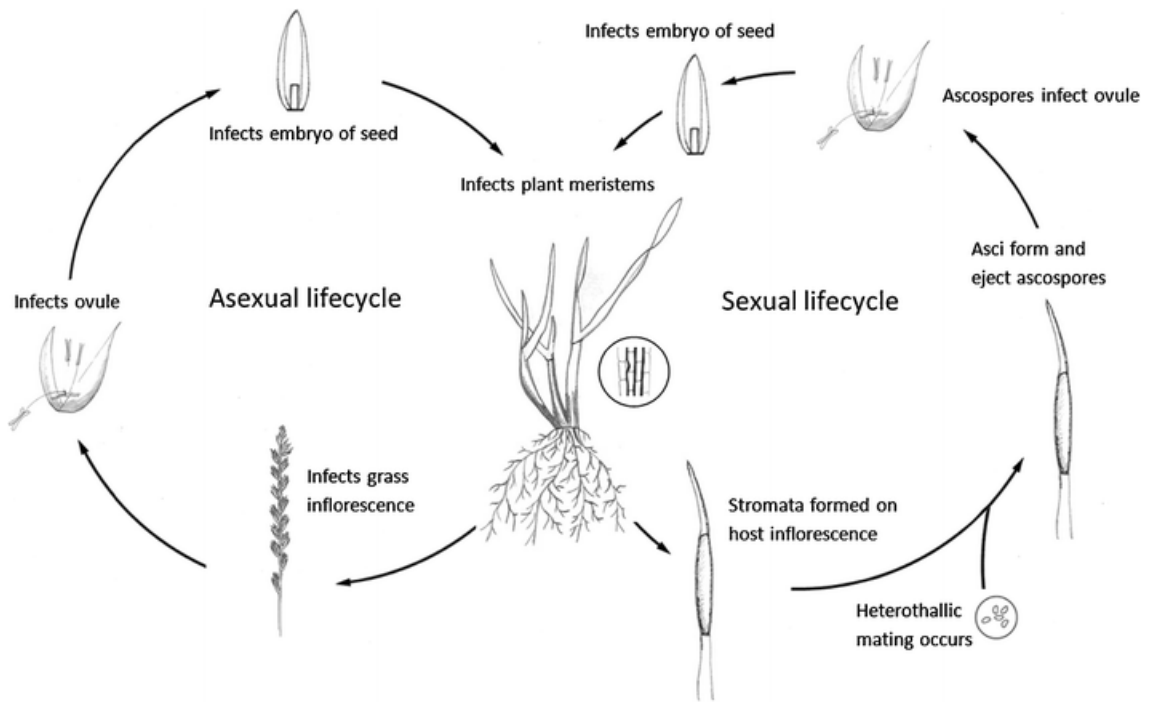


Figure 1.5: Diagram of both asexual and sexual life cycles of *Epichloë* species, taken from (Johnson, 2013a) with permission from Springer.

1.2.3 Establishment and maintenance of the *Epichloë*-host symbiosis

The evolutionary formation of the interaction that exists between endophytes and grasses is characterised by two key aspects: the ability of the endophyte to exist in harmony within the grass, and the evolutionary advantage that the endophyte provides to the grass. The use of both genetic and “omic” (transcriptomic and metabolomic) techniques, using *E. festucae* Fl1 and E2368 in ryegrass as a model system, has provided important insights into how this interaction is established and maintained (Scott *et al.*, 2012).

Through forward and reverse genetics, genes involved in the control of reactive oxygen species (ROS) (*noxA*, *noxR*, *bemA*, and *cdc24*) (Takemoto *et al.*, 2012, Scott *et al.*, 2012, Takemoto *et al.*, 2006, Tanaka *et al.*, 2006), iron up-take (*sidN*) (Johnson, 2008, Johnson *et al.*, 2007, Johnson *et al.*, 2013a, Johnson *et al.*, 2013b, Forester, 2014), hyphal anastomosis (*so*) (Charlton *et al.*, 2012), and response to environmental cues (*sakA* and *mpkA*) (Eaton *et al.*, 2010, Becker *et al.*, 2015, Eaton *et al.*, 2008, Qi & Elion, 2005, Scott & Eaton, 2008), have been identified as key components of this

interaction. Individual deletions of these genes resulted in *in planta* phenotypes associated with an antagonistic interaction *i.e.* the endophyte had increased hyphal branching, and hyphal proliferation, while the plant was stunted, had increased tillering, and underwent premature senescence.

The production of alkaloids by the endophyte provides a positive evolutionary selection pressure in favour of the interaction as these SMs provide bioprotection to the plant from both mammals and insects. These alkaloids were first identified by chromatography, and subsequently characterised by nuclear magnetic resonance (NMR) and mass spectrometry (MS) (Ball *et al.*, 1997, Casabueno & Pomilio, 1997, Gallagher *et al.*, 1984). The biosynthetic pathway for each alkaloid was then characterised by knocking out or expressing the genes of interest and observing resultant end and intermediate products using MS (Tanaka *et al.*, 2005, Young *et al.*, 2005, Young *et al.*, 2006, Fleetwood *et al.*, 2007, Schardl *et al.*, 2006, Spiering *et al.*, 2002). The distribution of genes associated with alkaloid production has been characterised in a range of *Epichloë* species through PCR amplification and genomic sequencing. In addition, the corresponding alkaloid products of each gene has been confirmed through detection of the alkaloid in endophyte infected plant material by liquid chromatography combined with mass spectrometry (LCMS) (Takach & Young, 2014, Young *et al.*, 2005, Young *et al.*, 2009).

1.2.4 Fungal secondary metabolite gene clusters

SMs are widely distributed throughout the kingdoms with diverse range of functionalities and can be defined in both the molecular and ecological perspective. SMs are low molecular weight compounds with restrictive taxonomic distribution that are dispensable to the host, and are produced at specific times during the organism's life cycle usually at low concentrations (Brakhage, 2013). However most importantly, SMs serve as survival functions for the producing organisms either by out-competing other organisms, scavenging for important nutrients, establishing and maintaining symbiotic associations, being sexual hormones or being differentiation effectors (Demain & Fang, 2000). This diverse range of functionalities of SMs makes these compounds of great interest to the scientific community especially in medicine and

Chapter one: Introduction

agriculture. For example, antibiotics *e.g.* penicillin (Fleming, 1943), immunosuppression drugs *e.g.* cyclosporine (Freed *et al.*, 1987), cholesterol reducing drugs *e.g.* lovastatin (Downs *et al.*, 1998) and anti-insect *e.g.* bassianolide (Xu *et al.*, 2009). However, not all SMs are beneficial for humans, for example some are toxins *e.g.* aflatoxin from *Aspergillus* (Mishra & Das, 2003), and fumonisins from *Fusarium* (Scott, 2012), while others cause contact dermatitis *e.g.* urushiols from *Toxicodendron radicans* (Kalish & Johnson, 1990).

The focus of in this study is to identify SMs produced by the endophyte *in planta* that either have insect deterrent or toxic bioactivity. This is because only endophyte infected plants gain the ability to protect the host from the insects of interest therefore the SMs of interest are endophyte rather than plant derived. Identifying insect bioactive SMs will allow for exploitation of the activity in agriculture.

Genes that are involved in the same SM pathway in fungi *e.g.* synthesis, post-translational modification, transportation, and regulation, are generally organised into gene clusters, with each gene under the control of its own promoter. The formation of these gene clusters makes synchronised regulation more effective due to the close proximity of the related genes. This arrangement is different to the arrangement of related genes in bacteria where the genes involved in the same pathway are controlled under one operon and are synthesised from a polysistronic mRNA (Keller *et al.*, 2005). These SM gene clusters are commonly located close to the telomeres *i.e.* sub-telomeric, where DNA is frequently manipulated, promoting the gain, loss or modification of the SM producing genes. This can result in the production of new bioactive compounds and/or bioactive combinations that may have either a positive, neutral, or negative impact on the host species.

1.2.5 Regulation of fungal secondary metabolites

SM synthesis requires the synchronised regulation of genes in the correct tissue at a specific stage of the organism's life cycle under a specific set of environmental conditions. This requires both general regulation mechanisms *e.g.* global transcription

Chapter one: Introduction

factors, and chromatin remodelling, as well as specific regulation mechanisms *e.g.* pathway specific transcription factors.

Global transcription factors are able to target genes either directly or indirectly upon activation by a specific stimulus. PacC is a fungal global transcription factor that targets a range of genes including SM genes. It is activated upon acidification *i.e.* pH stimuli causing multiple conformation changes which in turn result in activated PacC binding directly to target gene promoters (Luo *et al.*, 2017). AreA is another example of a fungal global transcription factor that binds directly to the target genes but in response to nitrogen levels (Mihlan *et al.*, 2003). CreA is a global transcription factor that targets a range of genes including those involved in the production of SMs but is specific to filamentous fungi. This global transcription factor is activated in response to carbon levels, and binds to regulatory elements at the promoters of target genes to repress transcription (Cepeda-García *et al.*, 2014). LaeA is a global transcription factor specifically for fungal SMs. In *Aspergillus nidulans*, LaeA connects light, sexual development, and SMs through the formation of a protein complex with VelB (expressed during sexual development) and VelA (up regulated in the dark) which in turn is proposed to block chromatin binding factors resulting in chromatin remodelling (Bayram *et al.*, 2008).

Some global regulators which also target SMs are species specific *e.g.* Tri6 is a global regulator of *Fusarium graminearum* (Nasmith *et al.*, 2011). For many SM gene clusters, the transcription factor which regulates the cluster is found within the cluster and is activated by a global transcription factor before binding to the promoters of each target gene *e.g.* aflR in the aflatoxin pathway (Yu *et al.*, 2004). However, in some cases, this transcription factor is not within the cluster *e.g.* PENR1 in the penicillin pathway (Litzka *et al.*, 1998).

Regulation of SM genes can also occur through chromatin remodelling either directly or indirectly. In the filamentous fungi *Fusarium fujikuroi* SM genes are directly regulated by the histone deacetylases, FfHda1 and FfHda2 (Studt *et al.*, 2013), while as mentioned earlier LaeA indirectly regulates histones through interaction with

chromatin binding factors (Bayram *et al.*, 2008). So far no global transcriptional factors or pathway specific transcription factors (within or outside the clusters) have been identified that target (positive or negative) the SM pathways currently linked to bioactivity in *Epichloë* (refer to section 1.2.6). A LaeA gene has been shown to be present in *Epichloë* but deletion of the gene has no effect on these pathways (Rahnama, 2016). However, histone modification has been directly linked to alkaloid regulation *in planta* (Chujo & Scott, 2014, Lukito, 2017).

1.2.6 *Epichloë in planta induced bioactive alkaloids*

The mammalian and insect bioactivities observed in *Epichloë* infected grasses has been linked to the presence of alkaloids produced by the endophyte such as lolitrem B (IDT alkaloid), ergovaline (ergot alkaloid), loline (1-aminopyrrolizidines), and peramine (pyrrolopyrazines) (Johnson *et al.*, 2013a). The biochemical pathways involved in the production of these key alkaloids have been proposed and annotated with the genes associated with each step (Figure 1.6).

Apart from lolines which have been detected at low levels in cultures of some *E. uncinata* strains (Blankenship *et al.*, 2001), these alkaloids are only produced *in planta* (Chujo & Scott, 2014), and are regulated by both the plant *e.g.* genotype (Faeth *et al.*, 2002) and hormones (Bastias *et al.*, 2017) as well as the environment *e.g.* light and temperature (Lane *et al.*, 2000, Hennessy *et al.*, 2016).

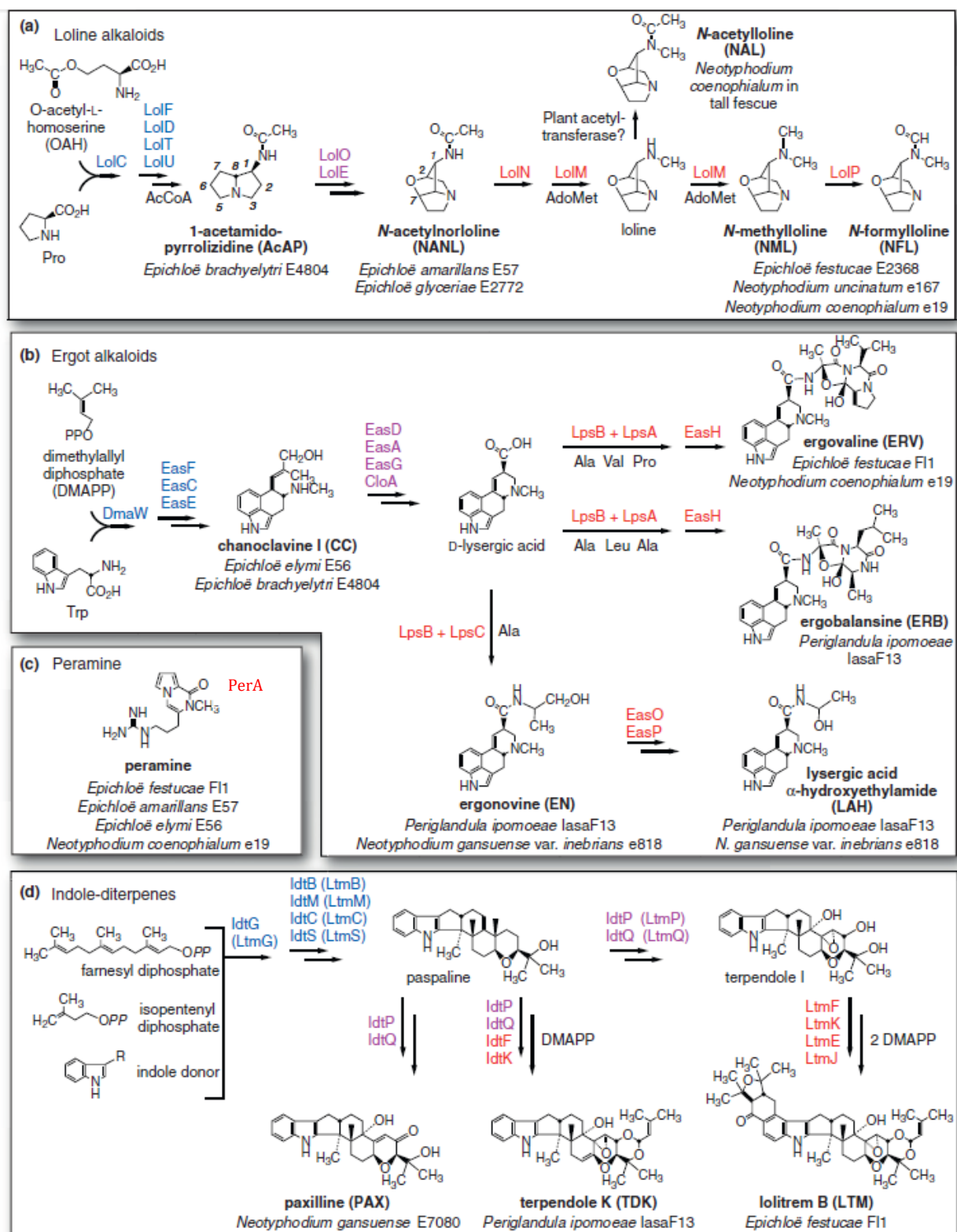


Figure 1.6: Simplified biochemical pathways that have been proposed for the production of secondary metabolites produced by *Epichloë* species. (A) Loline alkaloids. (B) Ergot alkaloids. (C) Peramine. (D) Indole-diterpenes. The corresponding gene(s) for each step in the pathway is highlighted in colour. Adapted from (Schardl et al., 2013a) with permission from Elsevier.

1.2.6.1 *Epichloë ergot alkaloids*

Ergot alkaloids are produced by several fungi in the orders Hypocreales and Eurotiales within the phylum Ascomycota and are discontinuously distributed (Panaccione, 2005). They are classified into three groups of increasing complexity: clavines, ergoamides, and ergopeptines (Schardl *et al.*, 2009), with all groups containing a core ergoline ring. Ergot alkaloids are toxic to bacteria, nematodes, insects, and mammals. In mammals, these compounds are able to interact with receptors in either an agonistic or antagonistic manner (Schardl *et al.*, 2012, Gerhards *et al.*, 2014).

In *Epichloë*, the ergopeptine ergovaline has been identified as the metabolite responsible for summer slump and fescue foot in cattle grazing on endophyte infected pastures (Blythe *et al.*, 2007). The toxicities of compounds produced earlier in the ergovaline pathway are unknown, but other ergopeptines as well as ergoamides and clavines have been linked to insect bioprotection in endophyte infected plants without causing mammalian toxicity (Tor-Agbidye *et al.*, 2001, Schardl *et al.*, 2006). Ergovaline is synthesised by enzymes encoded in the sub-telomeric EAS gene cluster, which is comprised of 11 genes organised into three clusters separated by transposon relics and miniature inverted-repeat transposable elements (MITEs) (Figure 1.7) (Fleetwood *et al.*, 2007, Fleetwood *et al.*, 2011, Tanaka *et al.*, 2012, Schardl *et al.*, 2013b).

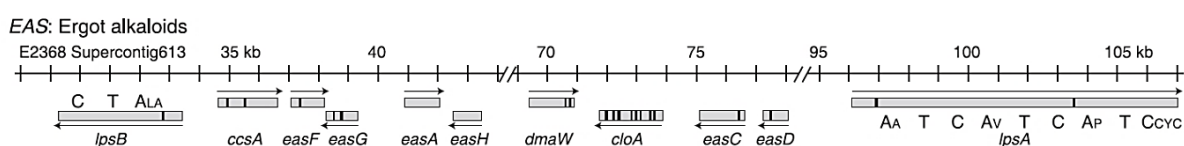


Figure 1.7: Ergot alkaloid (EAS) gene cluster in *Epichloë festucae* E2368. lpsA and lpsB ((A_{LA}) AMPylation domain binding lysergic acid, (A_A) AMPylation domain binding alanine, (A_V) AMPylation domain binding valine, (A_P) AMPylation domain binding proline, (T) thiolation domain, (C) condensation domain, and (C_{CYC}) cyclization condensation domain), adapted from (Schardl *et al.*, 2012) with permission from Elsevier.

1.2.6.2 *Epichloë 1-Aminopyrrolizidines*

1-Aminopyrrolizidines, commonly referred to as lolines, are a group of SM consisting of a saturated *exo*-1-amino pyrrolizidine with an unusual oxygen bridge between C(2) and

C(7), and variation of the R groups linked to N(1) (Schardl *et al.*, 2012). Lolines are produced by a small number of endophytes that infect some grasses in the Pooideae subfamily *i.e.* lolines are not generally produced by *Epichloë* species that infect ryegrass but there are a few exceptions *e.g.* *E. occultans*, but are produced by *Epichloë* species that infect fescue *e.g.* *E. coenophiala*, *E. festucae*, and *E. uncinata* (Popay *et al.*, 2009, Leuchtman *et al.*, 2000). These compounds have a broad range of insect deterrence and toxic activities, but are not toxic or tremorgenic to mammals (Schardl *et al.*, 2009). Some of the insect species affected by lolines are: aphids (*Rhopalosiphum padi*), Japanese beetle larvae (*Popillia japonica*), large milkweed (*Oncopeltus fasciatus*), army worm (*Spodoptera frugiperda*), and corn borer (*Ostrinia nubilalis*) (Schardl *et al.*, 2007). In *Epichloë*, lolines are produced by a series of enzymes encoded by genes in the *LOL* gene cluster, which contains 11 genes grouped into three clusters interspersed with MITEs (Figure 1.8) (Spiering *et al.*, 2005, Fleetwood *et al.*, 2011, Tanaka *et al.*, 2012).

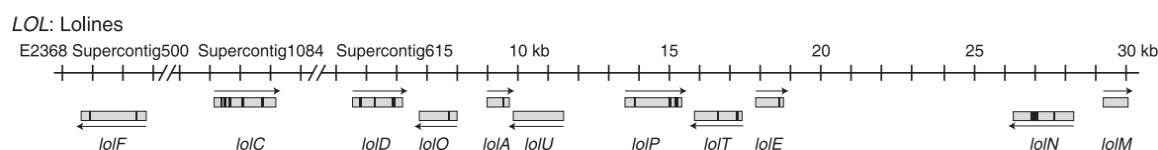


Figure 1.8: Loline (LOL) gene cluster in *Epichloë festucae* E2368, adapted from (Schardl *et al.*, 2012) with permission from Elsevier.

1.2.6.3 *Epichloë pyrrolopyrazines*

Peramine, the only known *Epichloë* produced pyrrolopyrazine, is responsible for deterring both larval and adult ASW from feeding on ryegrass. Peramine is synthesised by a single bimodular non-ribosomal peptide synthase (NRPS) encoded by the non subtelomeric gene *perA* (Tanaka *et al.*, 2005, Schardl *et al.*, 2012). The proposed amino acid substrates are 1-pyrroline-5-carboxylate, which binds to the first adenylation domain, and arginine, which binds to the second adenylation domain and is then methylated. There are no additional supporting genes associated with peramine synthesis *e.g.* transcription factors, post-transcriptional modifying enzymes, or transporters (Figure 1.9) (Berry *et al.*, 2015).

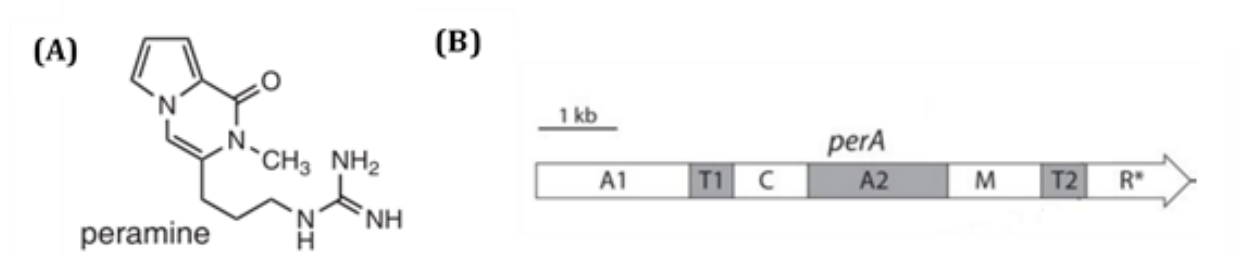


Figure 1.9: The structure of peramine (A) and the corresponding *perA* gene in *Epichloë festucae* FI1 (B), adapted from (Schardl *et al.*, 2012) and (Berry *et al.*, 2015) with permission from Elsevier and American Society for Microbiology.

1.2.6.4 *Epichloë* indole-diterpenes

Lolitrems are IDTs and the main metabolite responsible for ryegrass staggers (Gallagher *et al.*, 1981). It is synthesised through a complex metabolic network controlled by the *LTM/IDT* gene cluster which contains 11 genes split into three sub-telomeric clusters by transposon relics (Figure 1.10) (Young *et al.*, 2005, Young *et al.*, 2006, Schardl *et al.*, 2012). IDTs are reviewed comprehensively in section 1.3.

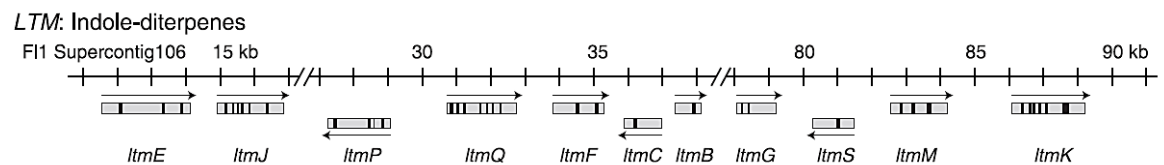


Figure 1.10: Indole diterpene (IDT/LTM) gene cluster in *Epichloë festucae* FI1, adapted from (Schardl *et al.*, 2012) with permission from Elsevier.

1.3 *Penicillium* and *Epichloë* indole-diterpene characterisation

IDTs are produced by *Penicillium*, *Aspergillus*, *Claviceps*, and *Epichloë* fungi from the phylum Ascomycota (Saikia *et al.*, 2008). Structural diversity is brought about through different patterns of prenylation, hydroxylation, epoxidation, methylation, and oxidation, as well as differences in the stereochemistry of the IDT ring. IDTs can be grouped into paxilline-like compounds or non-paxilline-like compounds (Parker & Scott, 2004). Many of these compounds have either anti-mammalian or anti-insect activity and act by inhibiting calcium activated potassium channels (maxi-K) (Knaus *et al.*, 1994), or activating glutamate-gated chloride channels (GluCl) (Smith *et al.*, 2000) respectively. *Penicillium paxilli* is commonly used as a model system for studying IDT

synthesis due to its rapid growth rate, production of large quantities of IDT compounds in culture, and easy genetic manipulation (Young *et al.*, 2001)

1.3.1 *Penicillium indole-diterpenes*

Synthesis of the IDT compound paxilline by *P. paxilli* was first investigated through the analysis of the chemical components of the pathway using, chromatography, MS, synthetic chemical synthesis, crystallography, and NMR (Smith III & Mewshaw, 1985, Munday-Finch *et al.*, 1996, Mantle & Weedon, 1994, Weedon & Mantle, 1987, Miles *et al.*, 1992). The genetic component of the paxilline pathway was then investigated using plasmid insertional mutagenesis, chromosomal walking, and bioinformatics. Paxilline biosynthesis was linked to a 50 kb region on chromosome Va that contained 21 putative genes. Genes of interest were: a GGPP synthase (*paxG*), two FAD-dependent monooxygenases (*paxM* and *paxN*), a prenyltransferase (*paxC*), two cytochrome P450 monooxygenases (*paxP* and *paxQ*), a dimethylallyltryptophan synthase (*paxD*), two transcription factors (*paxR* and *paxS*), a dehydrogenase (*paxH*), a metabolite transporter (*paxT*), and an oxidoreductase (*paxO*). Deletion of *paxG* resulted in abolishment of paxilline production. The detection of *paxG* expression in *P. paxilli* wild type (WT) cultures along with this deletion provided evidence for the involvement of this cluster in paxilline synthesis (Young *et al.*, 2001).

The first stable intermediate in the proposed paxilline pathway is paspaline which was successfully synthesised using a construct expressing *paxG*, *paxC*, *paxM*, and *paxB* in a *Pax⁻* *P. paxilli* strain (Saikia *et al.*, 2006). The roles of *paxP* and *paxQ* in the conversion of paspaline to paxilline were confirmed through individual gene deletions that resulted in the accumulation of paspaline and 13-desoxypaxalline respectively as well as intermediate compound feeding assays (McMillan *et al.*, 2003, Saikia *et al.*, 2007). The paxilline pathway therefore consists of the early pathway genes *paxG*, *paxC*, *paxM*, and *paxB* that together produce paspaline, which is then converted by the late pathway genes *paxP* and *paxQ* to 13-desoxypaxalline and paxilline respectively. Paxilline and associated intermediate compounds from the proposed biosynthetic scheme were successfully synthesised in *Aspergillus oryzae* by introducing different combinations of the above 6 genes into the host genome (Tagami *et al.*, 2013).

Chapter one: Introduction

The current paxilline pathway has PaxG synthesising geranylgeranyl pyrophosphate (GGPP) from isopentenyl diphosphate (IPP) and/or dimethylallyl pyrophosphate (DMAPP) and/or geranyl pyrophosphate (GPP) and/or farnesyl pyrophosphate (FPP). GGPP then undergoes a condensation reaction with indole-3-glycerol phosphate (IGP) by PaxC to produce 3-geranylgeranyl indole (3-GGI). This compound is then converted to pasapaline through two consecutive rounds of epoxidation by PaxM and cyclisation by PaxB. Pasapaline is then converted to 13-desoxypaxilline by PaxP, through multiple oxidation steps, and finally to paxilline through multiple oxidation steps by PaxQ (Figure 1.11).

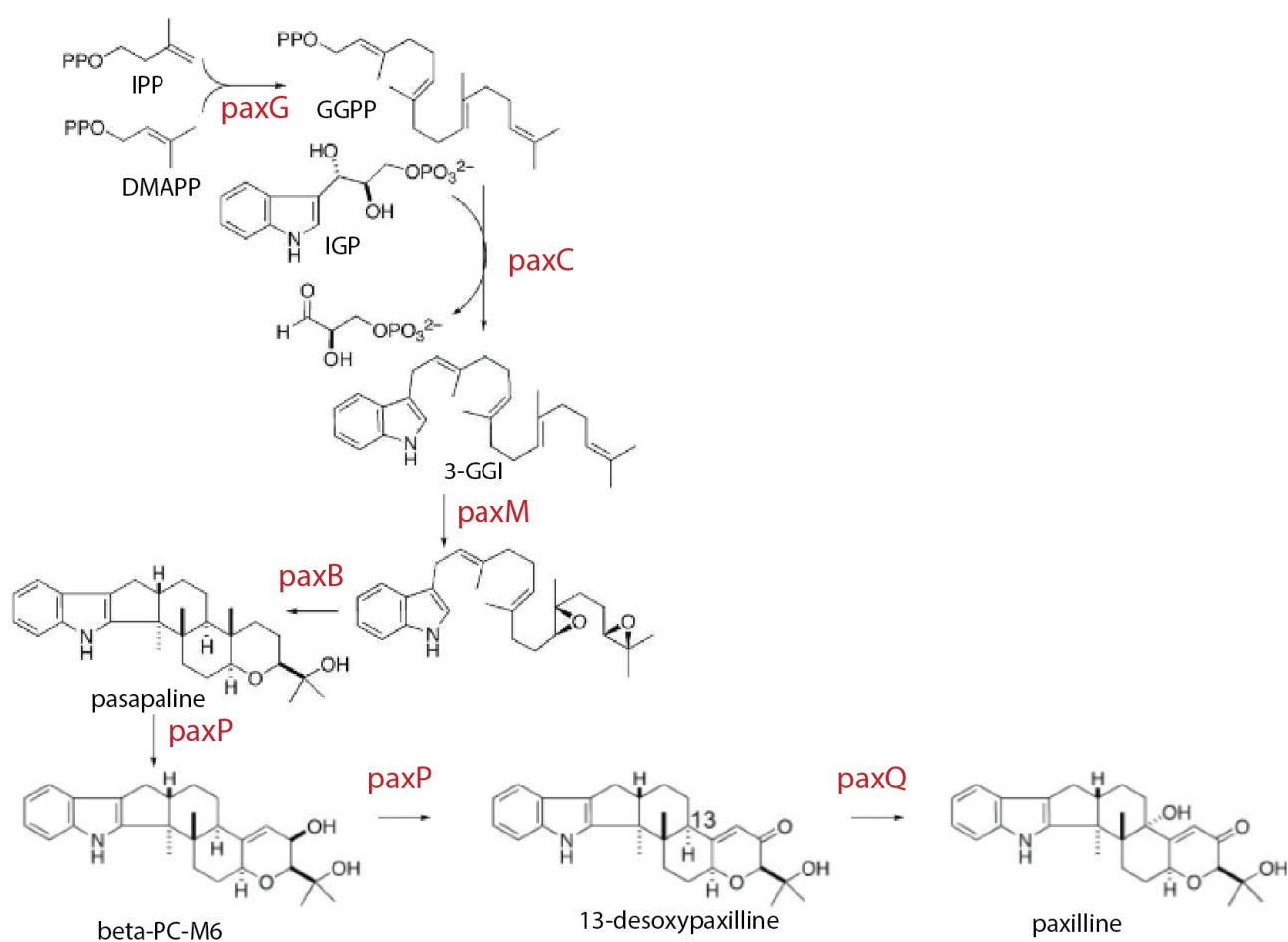


Figure 1.11: Simplified proposed paxilline biosynthetic pathway in *Penicillium paxilli* adapted from (Saikia *et al.*, 2006, Saikia *et al.*, 2007) with permission from John Wiley and Sons. The compounds are labelled below the corresponding chemical structure with genes responsible for the synthesis in red above the corresponding arrow. Isopentenyl diphosphate (IPP). Dimethylallyl pyrophosphate (DMAPP). Geranylgeranyl pyrophosphate (GGPP). Indole-3-glycerol phosphate (IGP). 3-geranylgeranyl indole (3-GGI).

1.3.2 *Epichloë indole-diterpenes*

Epichloë can synthesise the paxilline-like compounds lolitrems, terpendoles, and janthitrems. Lolitrem B/A/C/F, lolitriol, janthitrems, paspaline, paxilline and terpendole C/M have been linked to mammalian tremorgenicity, through the inhibition of calcium activated potassium channels (Parker & Scott, 2004, Saikia *et al.*, 2008, Imlach *et al.*, 2011) while *epoxy*-janthitrems have been linked to insect deterrence (Jensen & Popay, 2004, Popay & Gerard, 2007). Initially the *Epichloë* IDT gene naming convention was *ltm* for lolitrem B synthesis genes given lolitrem B is the final product of the pathway. But the current naming convention is now *idt* for indole-diterpene given that a range of IDT compounds can be produced dependent on the functional gene combination.

One IDT of agricultural importance is lolitrem B, a transient mammalian neurotoxin, which has been linked to ryegrass staggers (Gallagher *et al.*, 1981). The biosynthetic pathway of lolitrem B was first modelled using the paxilline biosynthetic pathway from *P. paxilli*. PCR amplification of two conserved regions of the gene *paxG* followed by chromosomal walking identified *paxG* and *paxM* homologues in *Epichloë* (*idtG* and *idtM*), as well as an *Epichloë* specific P450 monooxygenase *idtK*. The genes were linked to lolitrem synthesis through deletion of *idtM* which abolished production and detection of both mRNA and proteins from *idtM*, *idtG*, and *idtK* genes in *Epichloë* WT infected ryegrass (Young *et al.*, 2005).

Due to the large AT-rich regions either side of this cluster suppression subtraction hybridization libraries followed by Southern blotting and sequencing rather than chromosome walking was used to identify other possible lolitrem genes.

Bioinformatics analysis of this region identified homologous genes to *paxP*, *paxQ*, *paxB*, and *paxC* in *Epichloë* (*idtP*, *idtQ*, *idtB*, and *idtC*) along with the *Epichloë* specific prenyl transferase genes *idtF* and *idtE*, and another P450 monooxygenase *idtJ*. These genes are organized into 3 clusters with cluster 1 containing *idtG*, *idtM*, and *idtK*, cluster 2 containing *idtP*, *idtQ*, *idtF*, *idtC*, and *idtB*, and cluster 3 containing *idtE* and *idtJ*. RT-qPCR showed that all 10 genes are all up-regulated *in planta* but not expressed in culture suggesting that the genes are symbiotically regulated. No conserved consensus sequence was identified across all 10 genes that might explain universal up-

Chapter one: Introduction

regulation through a transcription factor. Finally *idtC* and *idtM* were identified as *paxC* and *paxM* homologues through complementation into the respective *P. paxilli* $\Delta paxC$ and $\Delta paxM$ strains that restored paxilline synthesis (Figure 1.12) (Young *et al.*, 2006).

Genome sequencing of sexual, asexual, and hybrid strains identified that this SM gene cluster is sub-telomeric, and that the three clusters are separated by non-conserved AT-rich retro-transposable elements and MITE's (Young *et al.*, 2009). A novel gene, *idtS*, was identified through genome sequencing and is most similar to *paxA*. Both genes have unknown functions but are linked to IDT synthesis (Figure 1.12) (Schardl *et al.*, 2012, Schardl *et al.*, 2013c).

The lolitrem gene profile of 44 *Epichloë* isolates through PCR and Southern blotting identified three distinct groups; strains with all 10 genes, strains missing *idtE* and *idtJ*, and strains either missing at least one of the core genes (*idtG*, *idtM*, *idtB*, and *idtC*) or all of the genes. These profiles along with the corresponding chemical profiles were used to propose a biosynthetic pathway for lolitrem B production (Young *et al.*, 2009). This pathway was further investigated through individual gene deletions (*idtP*, *idtQ*, *idtF*, *idtK*, *idtE*, and *idtJ*) as well as recombinant gene expression (*idtP* and *idtQ*) followed by feeding assays and complementation of *paxP* and *paxQ* with *idtP* and *idtQ*, respectively (Saikia *et al.*, 2012).

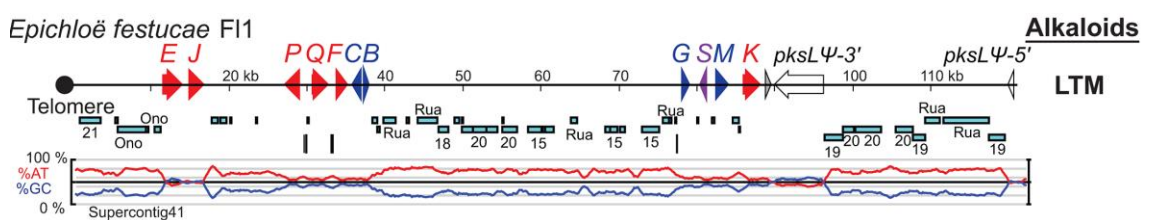


Figure 1.12: Indole diterpene (IDT/LTM) gene cluster in *Epichloë festucae* FI1 strain adapted from (Schardl *et al.*, 2013c) with permission from PLOS. IDT genes as red/blue/purple arrows, transposable elements in blue boxes with corresponding name or size, and GC content below

The pathway is that IdtG, IdtC, IdtM, and IdtB catalyse the same steps as their corresponding Pax enzymes to produce paspaline (Introduction 1.3.1). Both IdtP and IdtQ are then able to bind paspaline creating a fork in the pathway. Typically, IdtQ will act first thereby directing the pathway down the main branch into lolitrem B synthesis,

but in some situations *IdtP* will act first and shunt the pathway down the minor branch into paxilline synthesis. Both pathways involve multiple oxidation steps catalysed by first *IdtQ* then *IdtP* for lolitrem B synthesis or first *IdtP* and then *IdtQ* for paxilline synthesis (the exact pathway is unknown). For lolitrem synthesis, terpendole I is then modified by *IdtK* and *IdtF*, which form the I ring structure, and/or *IdtE* and *IdtJ*, which form the A and B ring structures. These two pairs act independently. This results in a grid like biosynthetic pathway rather than a linear pathway resulting in a wide range of IDT produced through different terpendole I modifications. If any of these later pathway genes (*idtK*, *idtF*, *idtE*, and *idtJ*) are absent or non-functional then the minor branch towards paxilline synthesis is enhanced (Figure 1.13) (Saikia *et al.*, 2012).

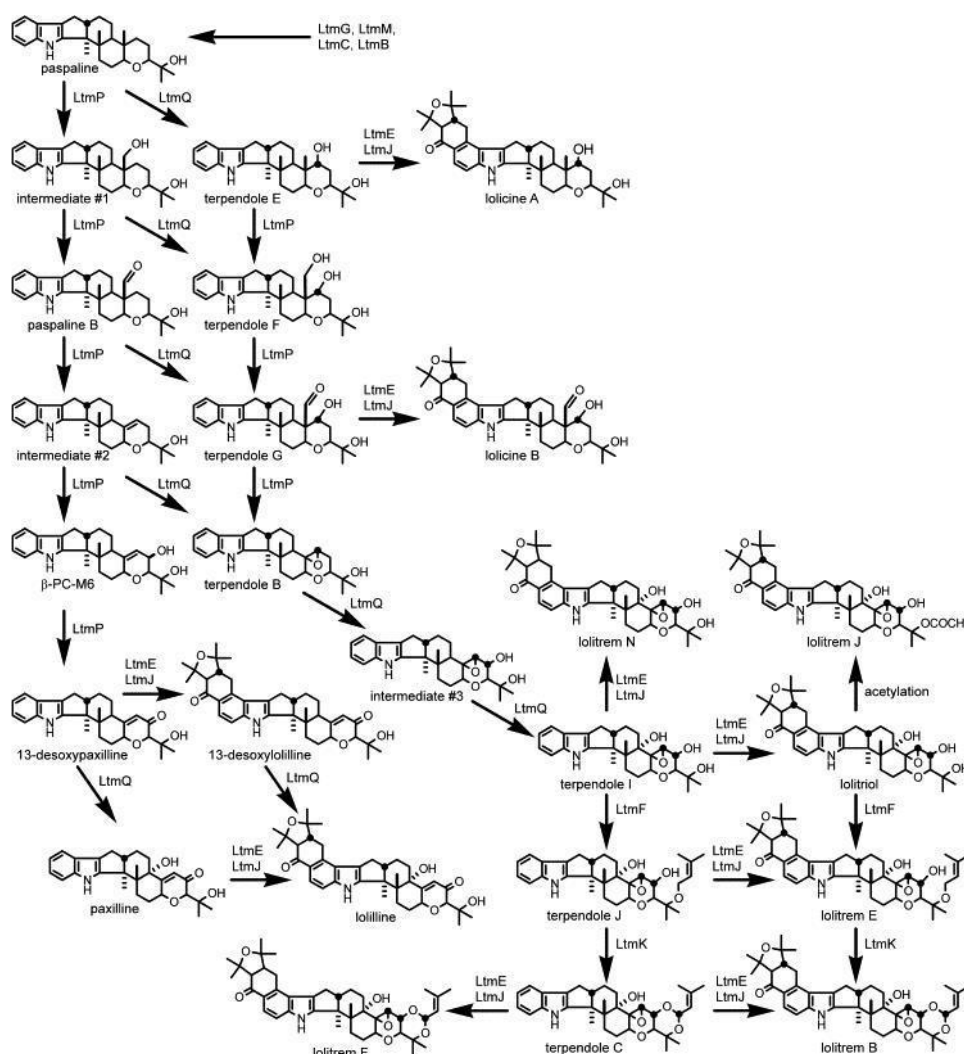


Figure 1.13: Proposed lolitrem B biosynthetic pathway in *Epichloë festucae* Fl1 strain from (Saikia *et al.*, 2012) with permission from John Wiley and Sons. The compounds are labelled below the corresponding chemical structure with genes responsible for the synthesis above the corresponding arrow. To note: *ltm* genes are the old nomenclature and are now referred to as *idt* genes *e.g.* *ltmP* is the same gene as *idtP*.

1.4 Makes caterpillars floppy (Mcf) as a possible *Epichloë* insect bioactive

The development of commercialised *Epichloë* strains has successfully arisen from understanding the biosynthesis, bioactivity, and distribution of the four SM pathways discussed above (Introduction 1.1 and 1.2). However, these pathways can only account for a proportion of the observed bioactivities. Research is therefore now focusing on the identification of new sources of bioactive molecules to explain new insect bioactivities. One newly identified gene of interest is a gene in the *Epichloë* genome called “makes caterpillars floppy” (*mcf*) identified by Ambrose in 2014. This gene is homologous to a bacterial gene that confers insecticidal activity and therefore has the potential to explain AR48 new bioactivity (Figure 1.14).

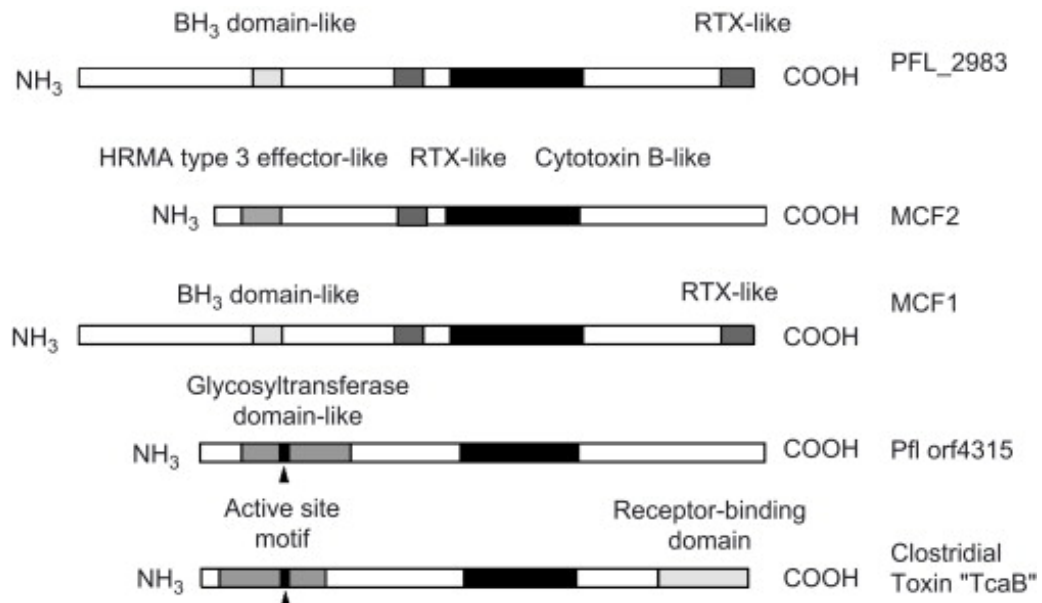


Figure 1.14: Comparison of makes caterpillars floppy (Mcf)-like proteins adapted from (Dowling & Waterfield, 2007), with permission from Elsevier. PFL_2983 (*fitD* from *Pseudomonas fluorescens*). Mcf2 (*mcf2* from *Photorhabdus luminescens*). Mcf1 (*mcf1* from *Photorhabdus luminescens*). Pfl orf4315 (*P. fluorescens* insect toxin (*fitD*) from *Pseudomonas fluorescens*). Toxin “TcdB” (*tcdB* from *Clostridium difficile*).

1.4.1 *Photorhabdus luminescens* Mcf

Photorhabdus luminescens is a Gram-negative Enterobacteriaceae bacterium that is both a symbiont of entomopathogenic nematodes from the Heterorhabditidae genus and a pathogen to the nematode’s target insects. *P. luminescens* lives in the gut of the nematode, and upon infection of the target insect by the nematode, is released from the gut into the midgut of the insect. *P. luminescens* then secretes both

Chapter one: Introduction

immunosuppressing compounds as well as toxins resulting in persistence of infection and death of the insect allowing both the nematode and bacteria to use the insect as a reservoir for breeding. The juvenile nematodes are reinfected with the bacterium before emerging from the insect corpse. This three-way interaction is used to study the switch between symbiotic and pathogenic life stages, and is regularly compared to *E. coli* which has a single symbiotic life stage (Forst *et al.*, 1997).

One of the many toxin genes identified from *P. luminescens* is one *mcf*. This gene was identified through screening a *P. luminescens* cosmid library using the tobacco hornworm caterpillar (*Manduca sexta*) as a model insect system. Normally, *E. coli* when injected into *M. sexta* is rapidly cleared from the insect, but when *E. coli* is expressing the correct toxin from the cosmid library, the bacteria persists in the insect and kills it. Using this screening method, a 33 kb cosmid was identified, and insertional mutagenesis showed that an 8.8 kb gene (*mcf*) within the cosmid was responsible for both the persistence and toxicity activities. The 324 kDa protein product from this gene is predicted to contain a N-terminal BH3 (Bcl2 homology domain 3) domain which is found in pro-apoptotic Bcl-2 (B-cell lymphoma 2) proteins, a central transmembrane domain (TMD) from *Clostridium difficile* TcdA/TcdB, a RTX-like (Repeat-in-toxin) toxin repetitive region from *Actinobacillus pleuropneumoniae*, and a C-terminal RTX-like toxin repetitive region (Figure 1.14) (Daborn *et al.*, 2002).

E. coli expressing *mcf* has been shown to cause apoptosis in mammalian cell lines, haemocytes, and insect midgut through characteristic membrane blebbing, chromatin condensation, DNA fragmentation, and changes in biomarkers (Dowling *et al.*, 2004). Finally, the BH3 domain was shown to be important for this insect activity as mutations in this domain dramatically reduced bioactivity. Cells exposed to the Mcf BH3 domain have changes in mitochondrial membrane potential and release cytochrome c into the cytoplasm, showing that the toxin works by activating apoptosis *via* the mitochondrial pathway (Dowling *et al.*, 2007).

Further screening of the cosmid library identified a *mcf* gene allelic variant to *mcf*(1) called *mcf*2. This gene when expressed by *E. coli* and injected into *M. sexta* also results

in insect death. The 262 kDa protein product is predicted to contain the same central TMD and RTX-like toxin repetitive region. However, rather than a BH3 domain, it has an N-terminal HrmA domain, which is a type-III secreted effector from the plant pathogen *Pseudomonas syringae* and no C-terminal domain (Dowling *et al.*, 2004). All *Photorhabdus* strains studied, contain both *mcf* genes with *mcf1* in different genomic regions and sometimes next to a type IV exporter, and *mcf2* in the same genomic region and always next to a type I exporter (Figure 1.14) (Dowling & Waterfield, 2007).

1.4.2 *Pseudomonas fluorescens* FitD

A *mcf* class protein was identified in *Pseudomonas fluorescens*, a Gram-negative bacterial species that forms a beneficial relationship with plants by colonizing the root system and producing bioactive compounds. Bioinformatics analysis of the genome sequence identified a *mcf* class gene, which is part of a cluster comprised of eight genes labelled *fitA* to *fitH*, with the *mcf* gene labelled *fitD*. The *fitD* gene is present as two allelic variants with a N-terminal glycosyltransferase-like domain or a BH3 domain, a central TMD, and no RTX-like domains. The genes that cluster around *fitD* are involved in the transport (*fitA*, *fitB*, and *fitC*) and regulation (*fitE*, *fitF*, and *fitG*) of the toxin. This cluster is not present in all *Pseudomonas* strains and there is syntony within but not outside the cluster. When *P. fluorescens* strains containing the Fit (*Pseudomonas* Insect Toxin) cluster were injected into *Galleria mellonella* (wax moth) or *M. sexta* (tobacco hornworm moth) caterpillars the insects died in a similar manner and rate as *P. luminescens mcf* treated insects, while *P. fluorescens* strains without the cluster had minimal deaths. In addition, *E. coli* expressing *fitD* injected into the two above insect models resulted in death, and *P. fluorescens* infection of *Drosophila melanogaster* also results in death (Figure 1.14) (Dowling *et al.*, 2007, Péchy - Tarr *et al.*, 2008, Olcott *et al.*, 2010).

1.4.3 *Epichloë* Mcf

In 2014, a paper published by Ambrose *et al* (2014) suggested that *mcf* had been horizontally transferred (HGT) from *P. luminescens* into the *Epichloë* genus. At that time, the gene had only been identified in bacterial species from the *Photorhabdus* and *Pseudomonas* genera, and in the fungal genus *Epichloë*. However, a subsequent

paper in 2017 (Dupont & Cox) identified *mcf* in other fungal species; *Aspergillus flavus* (*Eurotiomycetes*), *Metarhizium* species (*Sordariomycetes*), *Neonectria ditissima* (*Sordariomycetes*) and *Phlebiopsis gigantea* so the HGT event of *mcf* into *Epichloë* has been retracted (Tian *et al.*, 2017).

Annotation of all 13 *Epichloë* species analysed identified two conserved introns (a variably present 5' intron and a conserved 3' intron). The *mcf* mRNA from *E. typhina* subsp. *Poa* *Ps1* was extracted and sequenced. This confirmed the presence and location of both annotated introns. This cDNA sequence was then expressed in *E. coli*, and the transgenic *E. coli* injected into CC. This resulted in death of the caterpillar within 24 to 48 hours, while caterpillars injected with *E. coli* expressing empty vector or just water survived (Ambrose *et al.*, 2014).

1.5 AR48 infected *Lolium perenne* insect bioactivity

Ryegrass infected with *Epichloë festucae* var *lolii* AR48 confers new bioactivity towards the SBF (*Cerodontha australis*) and CC (*Agrotis ipsilon*) (Introduction 1.1.3). Currently, both these insects are minor pests to New Zealand agriculture however, identification of the bioactive/s responsible for these bioactivities will future proof the industry when or if these species become major pests. Also, the identified bioactive/s could possibly be applied on other agricultural insect pests depending on the bioactive/s insect target range.

1.5.1 Agromyzidae characterisation

The Agromyzidae family is within the true or two-winged fly order Diptera, and contains flies of 0.9 mm to 6.0 mm in length that are morphologically similar. These flies differ mainly in varying colour combinations of black and yellow, and occasionally green, grey, and blue as well. Worldwide approximately 2,500 species have been identified which are usually restricted to a single geographical location (Spencer, 2012). The Agromyzidae target a large range of dicots and monocot plants, in particular ornamentals, fruit, vegetables, and cereals, with most species restricted to a single family or genera, though true polyphagia has been identified in 13 species. The majority of the Agromyzidae target the leaf, which is why the flies are commonly

Chapter one: Introduction

referred to as leaf mining flies despite approximately 25% of species feeding on alternative structures such as the root, stem, seed head, pod, twig, or flower (Spencer, 1973).

1.5.1.1 *Agromyzidae* life cycle

The life cycle for each *Agromyzidae* species varies with the length being host as well as temperature dependent. In general, the complete life cycle takes 21-28 days under favourable conditions, although it can as much as double that under unfavourable conditions. There are multiple cycles per season, with the number dependent on the temperature *i.e.* the hotter the summer the shorter the cycle and the more cycles per season. The female ovipositor punctures the plant tissue creating wound sites for both feeding (80%) as well as for laying eggs (20%). A single female will lay approximately 500 eggs just under the tissue surface, one egg per wound, over its two-week long life span. The egg, which is initially clear, will become creamy white over time and hatch 3 days later. The emerging 1 mm long transparent larva will start to burrow into the plant tissue creating an enclosed transparent “mine” scattered with black excrement, avoiding any dead or potentially hazardous regions along the way. The larva will undergo three instars and grow to 1.9 mm over the next 4-6 days, finally forming a pupa containing the third instar. Pupation may occur either inside the plant tissue at the base of the mine or the larva will emerge from the tissue and develop just outside the plant or just below the soil surface. The pupa is initially yellow and will become brown over time with black pupa normally indicating parasitism. The adult fly will emerge approximately 9 days later and as SBF are considered “moderate” fliers the flies usually remain near the hatched location, although wind can aid in long distance dispersal. Outside the breeding season, there are few flies present and most *Agromyzidae* enter diapause over winter in the pupal stage (Jovicich, 2009, Georgia, 2018, Blancard, 2012).

1.5.1.2 *Distribution of Agromyzidae New Zealand*

Three extensive studies on *Agromyzidae* population composition and distribution have been conducted in New Zealand: Watt (1924) identified 12 new species, Harrison (1976) identified a further 4 species, and Spencer (1976) discovered a further 21 new

Chapter one: Introduction

species. Currently 41 species of Agromyzidae have been identified in New Zealand and other sub-Antarctic Islands, of which 34 species are endemic and are thought to have arrived *via* 16 immigration events from Australia and 1 from South America. These species are from the following genera; *Melanagromyza* (1 spp.), *Hexomyza* (1 spp.), *Cerodontha* (sub-genera *Ictermiza* (1 spp.)), *Cerodontha* (3 spp.), *Liriomyza* (22 spp.), *Phytoliriomyza* (7 spp.), and *Phytomyza* (6 spp.) (Spencer, 1976).

The establishment of these particular species is most likely due to wind dispersal of flies from neighbouring countries or human introduction, alongside the establishment of the corresponding specific host plant. Australia has twice as many genera and three times as many species compared to New Zealand, and the two countries have only 7 Agromyzidae species in common. Distribution of this family within New Zealand is uneven but is wide spread throughout the North and South Islands. Plant hosts have been confirmed for 26/41 species as well as an additional 3 species with reasonable certainty. Other Agromyzidae hosts are present in New Zealand but the corresponding Agromyzidae are absent, supporting the randomness of the immigration events (Spencer, 1976).

1.5.1.3 *Cerodontha australis* characterisation

The most common and widely distributed Agromyzidae species in New Zealand is *Cerodontha australis*, also known as the wheat sheath miner or SBF. This species is identified by a grey thorax, yellow legs, yellow frons, and the shape of the third antennal segment. New Zealand also has three other less common *Cerodontha* species, *C. sylvesterensis* (yellow notoplural, darker femur, and different aedeagus *i.e.* male sex organs), *C. angustipennis* (black thorax, and yellow notopleural), and *Ictermiza triplicate* (extended yellow lunule, and wide rounded antenna) (Figure 1.15 and 1.16). *C. australis* is present in meadows and the road side of both the North Island, South Island, and some sub-Antarctic Islands. Sydney Australia is the only location outside New Zealand that has been reported to have *C. australis*. *Cerodontha* species target cereal and pasture grasses such as *Hordeum vulgare* (Barley), *Lolium perenne* (Ryegrass), *Triticum aestivum* (Wheat), *Dactylus glomerata* (Cocksfoot), and the endemic New Zealand grass *Poa anceps* (Spencer, 1976). In New Zealand, the

breeding season peaks between December to January and slows down between February to March.

1.5.1.4 Economic impact and control management of Agromyzidae

Apart from the damage caused by the genus *Liriomyza*, which contains the top three Agromyzidae pests (globally invasive polyphagous leaf miners *i.e.* *L. huidobrensis*, *L. sativa*, and *L. trifolii*) all of which are not present in New Zealand (Spencer, 1973), damage to host plants from Agromyzidae insects most of the time remains just below the economic threshold. Damage from Agromyzidae depends on the host range, the host type, how the larvae feed, what part of the plant is affected, the stage of plant growth, and the size of the insect population. The presence of the mine can result in a loss of tissue function *i.e.* reduced photosynthetic capacity of the plant, and the puncture wounds are thought to increase secondary bacterial and fungal infections (Spencer, 1973).

However, these flies do have the potential to become pests under some conditions. In nature the Agromyzidae are controlled by very host specific parasitoid wasps from the Eulophidae and Braconidae families (Jovicich, 2009). This control can occasionally be lost due to an unsynchronised emergence of wasps and flies or a reduced number of wasps due to disease or climate change. This type of outbreak is, however, short lasting and minor. More serious and long term outbreaks occur due to direct or indirect long term extensive and misused insecticide application, which in some cases targets the Agromyzidae but more commonly the associated parasitoid (Spencer, 1973). This has led to varying degrees of resistant populations of Agromyzidae and/or the associated parasitoid compounding the detrimental effect of these species on the economy. Alternative control methods are other Agromyzidae targeting insects, border control, trapping, resistant crops cultivars, and dynamic environments have worked to varying degrees (Weintraub *et al.*, 2017, Hondo *et al.*, 2006, Huang *et al.*, 2009).

Chapter one: Introduction

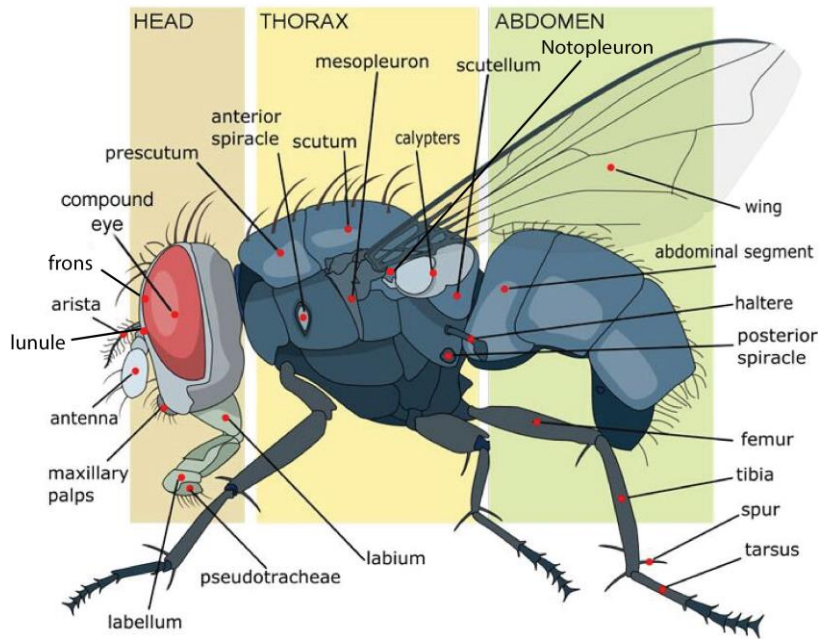


Figure 1.15: Schematic diagram of the morphology of Diptera, with key areas and structures labelled, adapted from (Wikipedia, 2018).

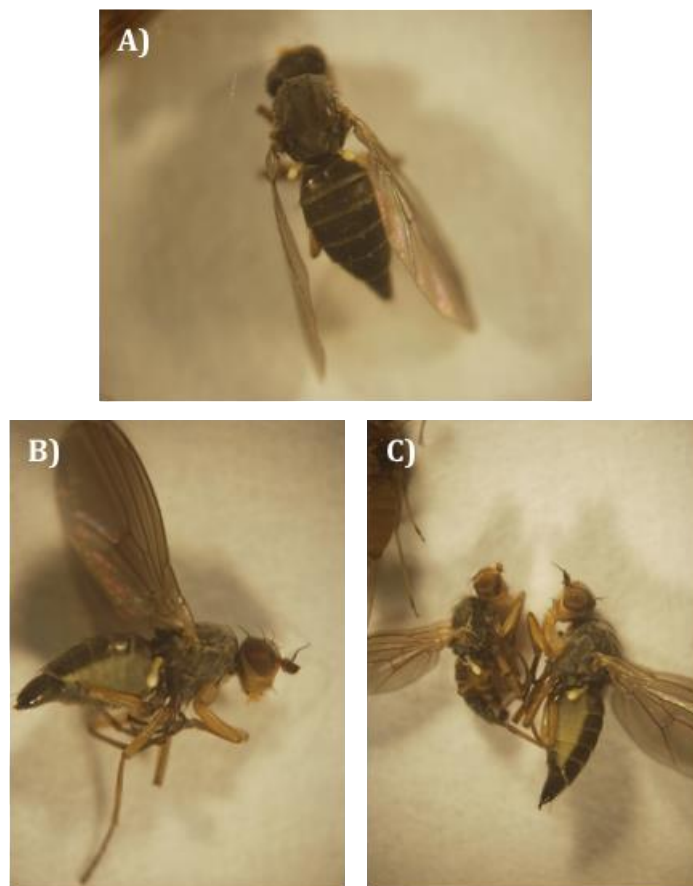


Figure 1.16: *Ceradontha australis* (stem boring fly-SBF). A) Top view. B). Side view C) Male (left) and female (right)

1.5.2 Noctuidae characterisation

The Noctuidae family “owlet moths”, within the Lepidoptera order (moths and butterflies), contains moths that have “owl-like eye” patterns on the top of the forewings that reflect light. Currently, Noctuidae is the largest Lepidoptera family containing over 20,000 species, however this family is commonly re-classified due to the diverse range of characteristics. In general, the moths are nocturnal ranging from 10 mm to 170 mm in length, are brown with lighter and/or darker patches, and have wings that are held upright to form a “roof” at rest. Many exceptions are found with some species being diurnal, and/or colourful, and/or having flat rested wings. Noctuidae are found worldwide with the exception of Antarctic regions. The moths feed on nectar and are important pollinators, while the larva feed on the leaves, flowers, fruits, and stems of the plant, inflicting enough damage to cause significant economic loss. The target plants and distribution of each species can range from broad to very specific (CSIRO, 2018, BAMONA, 2018). New Zealand has approximately 160 Noctuidae species, which is a relatively low number given the size of family, of which 139 are species endemic to New Zealand. Although the family has been identified as being important, it is not well studied in New Zealand, and many species have either not yet been discovered or correctly identified. Furthermore the corresponding host plants are commonly unknown (Landcare, 2018).

1.5.2.1 Agrotis ipsilon characterisation

Agrotis ipsilon (previously known *Agrotis ypsilon*), commonly known as the black cutworm or greasy cutworm or dark sword moth or CC, is classified as belonging to the Noctuidae family. Although this moth is found worldwide, it is absent in some tropical and cold regions, and is more prevalent in the northern compared to the southern hemisphere. In America, *A. ipsilon* has been observed to migrate north in the spring and south in the fall to evade undesirable temperatures (Capinera, 2015).

Adult *A. ipsilon* are between 35 mm to 50 mm long with long thin forewings that are a mottled dark-brown colour, and at rest the wings sit flat and rectangular. The first two thirds of the forewing is dark-brown and the remaining third pale-brown to grey, with black ‘dagger’ shaped markings along the outer edge. The hind wing is white to light

grey but the veins stand out as dark markings. There is a distinct “Y” pattern on the forewings that gives the moth the name “ippsilon” (the Greek symbol for Y). The females are darker than the males, and have filiform rather than feathered antenna (Figure 1.17) (CABI, 2018, Taranaki Educational Resource: Research, 2018).

A. ipsilon larvae target approximately 50 plant species including but not limited to vegetables, maize, sweet corn, cereals, grasses, lucerne, white clover, plantain, and weeds such as dock (Khattab & Azazy, 2013). New Zealand currently has five *Agrotis* species; *A. admirationis*, *A. infusa*, *A. innominate*, *A. ipsilon*, and *A. munda*, with *A. ipsilon* being endemic and distributed throughout the country (Landcare, 2018).

1.5.2.2 *Agrotis ipsilon* life cycle

The breeding season for *A. ipsilon* in New Zealand is October to April and peaks between February to March, with 2-3 life cycles occurring each summer depending on the temperature. The complete life cycle takes between 7 to 12 weeks. The female moth can lay between 600-800 eggs over its lifetime, with eggs ovideposited on to the surface of low lying leaves or leaf debris as a single egg or clusters of up to 3 eggs. The egg is 0.45 mm in diameter and changes from white to brown upon maturing, with the larva emerging 3-5 days later to reside on the soil surface. The emerging larva is light-grey with stripes and dark spots along the sides and head. The larva will darken to light-brown/almost black over 5-8 instars over the next 4-6 weeks. Upon moulting to the fourth instar, the larva will build a burrow in the soil where it will hide during the day and emerge at night to feed on plant material brought into the burrow. At maturity the larva will be approximately 50 mm long and weigh about 150 mg, and will then form a 17 mm to 25 mm long red-brown pupa under the soil, which will darken over the 2-3 weeks before the adult moth emerges. Females are able to lay fertile eggs 3-5 days after emerging. *A. ipsilon* are found as either a late stage larva or pupa during the winter months, with only a few moths in existence (Allan, 1984, Agpest, 2018, CABI, 2018, Capinera, 2015, Harris *et al.*, 1962).

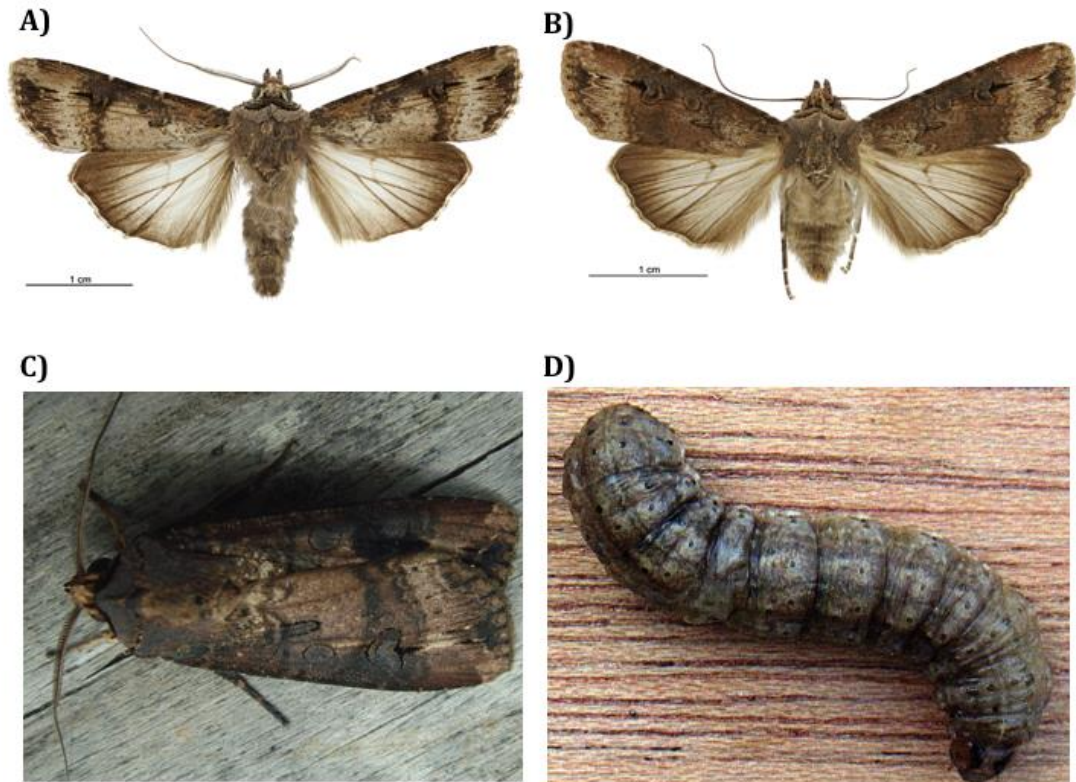


Figure 1.17: *Agrotis ipsilon* (cutworm moth (CM) and cutworm moth caterpillar (CC)). A) Male. B) Female. C) Top view resting male. D) Larva, adapted from (Landcare, 2018) and (Taranaki Educational Resource: Research, 2018).

1.5.2.3 Economic impact and control management of *Agrotis ipsilon*

Damage inflicted by *A. ipsilon* only occurs during the larval stage of the life cycle. Each larva on average consumes a total of 400 cm² of foliage during development; 10% during the second to last instar and 80% during the last instar. This is due to the quantity of plant material required to sustain the larvae as well as the technique of feeding, which involves severing the tiller at the base killing the whole leaf, even if the detached tiller is not completely consumed by the larva (Capinera, 2015).

Alternatively, the larva may only damage the meristematic tissue rather than severing the stem, but this also results in leaf death. Damage tends to be observed in patches, as the larva will kill off one plant before moving to neighbouring plants. This means younger plants that have few leaves are more susceptible to infestation by this pest than mature plants (Jackson, 2013).

A. ipsilon outbreaks tend to occur after floods as moist conditions promote breeding. Outbreaks also occur if there is a large weed infestation in or near young crops as the

Chapter one: Introduction

weeds act as reservoir for larvae that can then migrate to the crop. In general, yield loss ranges from 20%-80%, of plants before the two leaf stage with populations of 3 caterpillars/100 plants. When plants are at the two to four leaf stage an infestation of 6 caterpillars/100 plants results in a loss of 10,000 plants/ha (Agpest, 2018). The likelihood of an outbreak is hard to predict as it depends on the dynamic interaction between the crop (type, size, and stage of development), the *A. ipsilon* population (size and stage of development), and the environmental conditions (humidity, temperature, and wind).

Populations of *A. ipsilon* are controlled by crop management, insecticides and natural predators. Crop management techniques include not planting in or near fields previously infested with *A. ipsilon*, eliminating weeds or other host plants within and around the crop site, keeping the crop site well drained, monitoring for presence of larva, using light or pheromone trapping of moths, and burning/burying plant waste. Natural predators of *A. ipsilon* are viruses, bacteria, fungi, protozoa, nematodes, birds, mammals, and insects. Mixing *A. ipsilon* resistant Kentucky bluegrass with endophyte infected ryegrass was shown to reduce the insect population (*Richmond & Shetlar, 2001*)

1.6 Aims

The overall aim of this project is to identify the bioactive compound or compounds present in *E. festucae* var *lolii* strain AR48 infected ryegrass that have stem boring fly (*Cerodontha australis*) and cutworm moth caterpillar (*Agrotis ipsilon*) bioactivity. This is to be achieved by bioinformatics to identify the candidate genes followed by an analysis for bioactivity using reverse genetics in the model *E. festucae* strain Fg1 experimental system followed by insect bioactivity trials.

Aim 1: Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1.

Objective 1.1: Sequence the genome of in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1.

Objective 1.2: Analyse the functionality and presence of the bioactive secondary metabolite genes in the genome of in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1 through bioinformatics.

Objective 1.3: Detect the presence of the bioactive secondary metabolite compounds in in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1 infected ryegrass through mass spectrometry.

Objective 1.4: Analyse the structure of any newly identified compounds through mass spectrometry.

Aim 2: Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass.

Objective 2.1: Analyse the distribution and functionality of the *mcf* gene in the *Epichloë* using bioinformatics.

Objective 2.2: Analyse the potential bioactivity of Mcf through reverse genetics.

Aim 3: Test the insect bioactivity capabilities of *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1 infected ryegrass.

Objective 3.1: Design and perform a stem boring fly (*Cerodontha australis*) bioactivity trial on a range of wild type and a Δmcf mutant *Epichloë*-infected ryegrass.

Objective 3.2: Design and perform a cutworm moth caterpillar (*Agrotis ipsilon*) bioactivity trial on a range of wild type and a Δmcf mutant *Epichloë*-infected ryegrass.

Objective 3.3: Design and perform a porina caterpillar (*Wiseana* spp) bioactivity trial on a range of wild type and a Δmcf mutant *Epichloë* infected ryegrass.

Objective 3.4: Design and perform a light brown apple moth caterpillar (*Epiphyas postvittana*) bioactivity trial on a range of wild type and a Δmcf mutant *Epichloë*-infected ryegrass.

2.0 MATERIALS AND METHODS

2.1 Molecular and biological materials

2.1.1 Details of strains used in this study

Strain	Relevant characteristics	Source or reference	Comment
<i>E. festucae</i>			
AR48	AR48 Wild type	AgResearch	Wild type
AR1	AR1 Wild type	AgResearch	Wild type
AR37	AR37 Wild type	AgResearch	Wild type
PN3203	Fg1 Wild type	Massey University	Wild type
PN2278	Fl1 Wild type	Massey University	Wild type
Fg1 #117	Fg1/pTM05	This study	Δmcf mutant
<i>P. paxilli</i>			
PN2013	Wild type	Itoh (1994)	Complete paxilline pathway
PN2258	PN2031/pLM12	Massey University McMillan (2003)	$\Delta paxP$
PN2259	PN2031/pRC3	Massey University McMillan (2003)	$\Delta paxQ$
P.P-T1	PN2258/TM06	This study	$\Delta paxP$ AR48 <i>idtP</i> complementation
P.P-T2	PN2258/TM06	This study	$\Delta paxP$ AR48 <i>idtP</i> complementation
P.P-T3	PN2258/TM06	This study	$\Delta paxP$ AR48 <i>idtP</i> complementation
P.P-T4	PN2258/TM06	This study	$\Delta paxP$ AR48 <i>idtP</i> complementation
P.P-T5	PN2258/TM06	This study	$\Delta paxP$ AR48 <i>idtP</i> complementation
P.Q-T1	PN2259/TM07	This study	$\Delta paxQ$ AR48 <i>idtQ</i> complementation
P.Q-T2	PN2259/TM07	This study	$\Delta paxQ$ AR48 <i>idtQ</i> complementation
P.Q-T3	PN2259/TM07	This study	$\Delta paxQ$ AR48 <i>idtQ</i> complementation
P.Q-T4	PN2259/TM07	This study	$\Delta paxQ$ AR48 <i>idtQ</i> complementation
P.Q-T5	PN2259/TM07	This study	$\Delta paxQ$ AR48 <i>idtQ</i> complementation
P.P-T6	PN2258/SS1	This study	$\Delta paxP$ <i>P. paxilli</i> <i>paxP</i> complementation
P.P-T7	PN2258/SS1	This study	$\Delta paxP$ <i>P. paxilli</i> <i>paxP</i> complementation

Chapter two: Materials and Methods

P.P-T8	PN2258/pSS1	This study	$\Delta paxP$ <i>P. paxilli</i> <i>paxP</i> complementation
P.P-T9	PN2258/pSS1	This study	$\Delta paxP$ <i>P. paxilli</i> <i>paxP</i> complementation
P.P-T10	PN2258/pSS1	This study	$\Delta paxP$ <i>P. paxilli</i> <i>paxP</i> complementation
P.Q-T6	PN2259/pSS2	This study	$\Delta paxQ$ <i>P. paxilli</i> <i>paxQ</i> complementation
P.Q-T7	PN2259/pSS2	This study	$\Delta paxQ$ <i>P. paxilli</i> <i>paxQ</i> complementation
P.Q-T8	PN2259/pSS2	This study	$\Delta paxQ$ <i>P. paxilli</i> <i>paxQ</i> complementation
P.Q-T9	PN2259/pSS2	This study	$\Delta paxQ$ <i>P. paxilli</i> <i>paxQ</i> complementation
P.Q-T10	PN2259/pSS2	This study	$\Delta paxQ$ <i>P. paxilli</i> <i>paxQ</i> complementation
P.P-T11	PN2258/pSS56	This study	$\Delta paxP$ Fl1 <i>idtP</i> complementation
P.P-T12	PN2258/pSS56	This study	$\Delta paxP$ Fl1 <i>idtP</i> complementation
P.P-T13	PN2258/pSS56	This study	$\Delta paxP$ Fl1 <i>idtP</i> complementation
P.P-T14	PN2258/pSS56	This study	$\Delta paxP$ Fl1 <i>idtP</i> complementation
P.P-T15	PN2258/pSS56	This study	$\Delta paxP$ Fl1 <i>idtP</i> complementation
P.Q-T11	PN2259/pSS58	This study	$\Delta paxQ$ Fl1 <i>idtQ</i> complementation
P.Q-T12	PN2259/pSS58	This study	$\Delta paxQ$ Fl1 <i>idtQ</i> complementation
P.Q-T13	PN2259/pSS58	This study	$\Delta paxQ$ Fl1 <i>idtQ</i> complementation
P.Q-T14	PN2259/pSS58	This study	$\Delta paxQ$ Fl1 <i>idtQ</i> complementation
P.Q-T15	PN2259/pSS58	This study	$\Delta paxQ$ Fl1 <i>idtQ</i> complementation
<i>E. coli</i>			
DH5 α	F- Φ 80/ <i>lacZ</i> Δ M15 Δ (<i>lacZ</i> YA- <i>argF</i>) U169 <i>recA1 endA1 hsdR16</i> (rk-, mk+) <i>phoA</i> supE44 λ -thi-1 <i>gyrA96 relA1</i>	ThermoFisher Scientific	Cell line
XL 1-Blue	<i>recA1 endA1 gyrA96 thi-1 hsdR17 supE44 relA1 lac</i> [F' <i>proAB</i>	ThermoFisher Scientific	Cell line

Chapter two: Materials and Methods

	<i>lacIq/lacZΔM15 Tn10</i> (Tet ^R)		
TM03	DH5α/pTM03	This study	Fg1 <i>mcf</i> whole gene KO
TM04	DH5α/pTM04	This study	AR48 <i>mcf</i> complementation
TM05	DH5α/pTM05	This study	Fg1 <i>mcf</i> 5' gene KO
TM06	DH5α/pTM06	This study	AR48 <i>idtP</i> COMP
TM07	DH5α/pTM07	This study	AR48 <i>idtQ</i> COMP
PN1375	XL-1/pAN7-1	Massey University	Backbone
DB05	DH5α/pDB05	Massey University Berry (2016)	<i>P.paxilli</i> heterologous expression Fl1 <i>perA</i>
PN4299	DH5α/pDB48	Massey University Berry (2016)	Hyg resistant
DB49	DH5α/pDB49	Massey University Berry (2016)	Gen resistant
PN1994	XL 1-Blue/pSS1	Massey University Saikia (2007)	<i>paxP</i> COMP
PN1995	XL 1-Blue/pSS2	Massey University Saikia (2007)	<i>paxQ</i> COMP
PN4078	DH5α/pSS56	Massey University Saikia (2007)	Fl1 <i>idtP</i> COMP
PN4079	DH5α/pSS58	Massey University Saikia (2007)	Fl1 <i>idtQ</i> COMP
<i>L. perenne</i>			
A13520	AR48 wild type/ Samson ryegrass	Margo Forde Germplasm centre	Seeds
A11751	AR47 wild type/ Samson ryegrass	Margo Forde Germplasm centre	Seeds
A16825	AR1 wild type/ Samson ryegrass	Margo Forde Germplasm centre	Seeds
A17345	AR37 wild type/ Samson ryegrass	Margo Forde Germplasm centre	Seeds
A25872	Common toxic/ Samson ryegrass	Margo Forde Germplasm centre	Seeds
A11104	Endophyte negative/ Samson ryegrass	Margo Forde Germplasm centre	Seeds

2.1.2 Details of plasmids used in this study

Plasmids	Relevant characteristics	Source or reference	Comment
pTM03	<i>mcf</i> RB-PtrpC- <i>hph</i> -TtrpC- <i>mcf</i> LB; Hyg ^R /Amp ^R	This study	Fg1 <i>mcf</i> whole gene knock-out (KO)
pTM04	<i>mcf</i> promoter- <i>mcf</i> ORF- <i>mcf</i> terminator;Amp ^R	This study	AR48 <i>mcf</i> whole gene complementation (COMP)
pTM05	<i>mcf</i> RB-PtrpC- <i>hph</i> -TtrpC- <i>mcf</i> LB; Hyg ^R /Amp ^R	This study	Fg1 <i>mcf</i> 5' gene KO
pTM06	<i>nptII</i> -P <i>paxM</i> -AR48 <i>idtP</i> -T <i>paxM</i> ; Gen ^R /Amp ^R	This study	AR48 <i>idtP</i> COMP
pTM07	<i>nptII</i> -P <i>paxM</i> -AR48 <i>idtQ</i> -T <i>paxM</i> ; Gen ^R /Amp ^R	This study	AR48 <i>idtQ</i> COMP
pAN7-1	PtrpC- <i>hph</i> -TtrpC; Hyg ^R /Amp ^R	Massey University	Backbone
pDB05	P <i>paxM</i> - <i>perA</i> -T <i>paxM</i> ; Amp ^R	Massey University Berry (2016)	<i>P. paxilli</i> heterologous expression Fl1 <i>perA</i>
pDB48	PtrpC- <i>hph</i> -TtrpC; Hyg ^R /Amp ^R	Massey University Berry (2016)	Hyg resistant
pDB49	PtrpC- <i>nptII</i> -TtrpC; Gen ^R /Amp ^R	Massey University Berry (2016)	Gen resistant
pSS1	<i>paxP</i> -PtrpC- <i>nptII</i> -TtrpC; Gen ^R /Amp ^R	Massey University Saikia (2007)	<i>paxP</i> COMP
pSS2	<i>paxQ</i> -PtrpC- <i>nptII</i> -TtrpC; Gen ^R /Amp ^R	Massey University Saikia (2007)	<i>paxQ</i> COMP
pSS56	<i>nptII</i> -P <i>paxM</i> -Fl1 <i>idtP</i> -T <i>paxM</i> ; Gen ^R /Amp ^R	Massey University Saikia (2007)	Fl1 <i>idtP</i> COMP
pSS58	<i>nptII</i> -P <i>paxM</i> -Fl1 <i>idtQ</i> -T <i>paxM</i> ; Gen ^R /Amp ^R	Massey University Saikia (2007)	Fl1 <i>idtQ</i> COMP

2.1.3 Details of primers used in this study

Primers	Sequence 5' to 3'	Comments	Product size bp
pTM03			
Hyg_F	AGCTTGGAAGTATATTGAA GG	Hygromycin F/ sequencing	2185
pDB33.7	CAGGTCGAGTGGAGATGTG G	Hygromycin R	
pRS425_F	GCTGTTTCCTGTGTGAAATTG	pAN7.1 F/ sequencing	2591
pRS425_R	GTCGTGACTGGGAAAACCC	pAN7.1 R/ sequencing	
TM49	GTAACGCCAGGGTTTTCCCA GTCACGACCCGGGCAAAGGT CTCTTCTCGTGGC	TM03 LB F/ TM04 F/ sequencing	1428
TM50	CCACTCCACATCTCCACTCGA CCTGGCAACCCGAGAGAGA ACC	TM03 LB R	
TM51	ATGCTCCTTCAATATCAGTTC CAAGCTGGTTATGCTCGGCT ATTGAC	TM03 RB F	1394
TM52	GCGGATAACAATTTACACA GGAAACAGCCCGGGCGGAG TTGGGGGGCATTAT	TM03 RB R/ TM04 R/ sequencing	
TM55	CGTCTTTGGCACACAGTTGG	TM03 <i>mcf</i> screening F	1743
TM56	TATCGCCGCATCGATATCGG	TM03 <i>mcf</i> screening R	
pTM04			
TM115	AGACGCATTGGGTCAACAGT	TM04 Screening LB F	1237
TM116	GTTGAAGACGAGGTGCGGT A	TM04 Screening LB R	
TM117	CGGCTTTGCGAAGTGATAGC	TM04 Screening RB F	1049
TM118	TTGGAGCGAACGACCTACAC	TM04 Screening RB R	
pTM05			
TM70	GTAACGCCAGGGTTTTCCCA GTCACGACCCGGGCACCATT TCGCAGTCGTAGC	TM05 LB F	1911
TM71	CCACTCCACATCTCCACTCGA CCTGAGCAAAGGACTAGGCC AACC	TM05 LB R	
TM72	ATGCTCCTTCAATATCAGTTC CAAGCTCTTCGTCGCATTGAC TTGGC	TM05 RB F	2095
TM73	GCGGATAACAATTTACACA GGAAACAGCCCGGGATGTC GGCCTGTACAGAACG	TM05 RB R	

Chapter two: Materials and Methods

TM86	ATGTAGCGCTTCTCTGCAGG	TM05 <i>hph</i> screening F	2669
TM87	ATGGGTCTTGAAGCCTCTGC	TM05 <i>hph</i> screening R	
TM109	TACCGGGTTGATCGTGATGC	TM05 LB screen F	2528
TM89	ACTGAGGAATCCGCTCTTGG	TM05 LB screen R	
TM90	ATGTCCTCGTTCCTGTCTGC	TM05 RB screen F	2674
TM110	CGTTGGGTTTGCAGATGAGC	TM05 RB screen R	
TM111	TTTGGCTGCTCAGACTTGGG	TM05 Deleted region screen 1# F	1099
TM112	CACGGTTCGCCTAACAAACC	TM05 Deleted region screen 1# R	
TM113	GGCCTAATCCTTTGCTTCCG	TM05 Deleted region screen 2# F	1442
TM114	AGTGACACCAACTCCTGTGC	TM05 Deleted region screen 2# R	
pTM06			
TM74	GATCGCCCTTCCCAACAGTT GCGCAGTTGTTGGCATGGGA GTAGG	TM06 pDB49- <i>PpaxM</i> (pDB05) F	1278
TM75	TAAGACAGCATGCAACATAA ACATGGTTTCTGAATCTTAAA GATACATG	TM06 <i>idtP</i> - <i>PpaxM</i> (pDB05) R	
TM76	TGTATCTTTAAGATTCAGAAA CCATGTTTATGTTGCATGCTG TCTTAGC	TM06 <i>PpaxM</i> (pDB05)- <i>idtP</i> F/Screening	1907
TM77	GAAAACCAAAAATTGCTCCA ATGGTTCATGTCCTATCACTC CTGTGC	TM06 <i>TpaxM</i> (pDB05)- <i>idtP</i> R/Screening	
TM78	AAACGACAGGAGTGATAGG ACATGAACCATTGGAGCAAT TTTTGG	TM06 <i>idtP</i> - <i>TpaxM</i> (pDB05) F	1322
TM79	GCGTCGCGCCATTCGCCATT CAGGCCGAATTGAGAAGCTG ATTTGC	TM06 pDB49- <i>TpaxM</i> (pDB05) R	
TM80	GACAGCAAATCAGCTTCTCA ATTCGGCCTGAATGGCGAAT GGCGC	TM06 <i>TpaxM</i> (pDB05)-pDB49 F	7508
TM81	TCCATCCTACTCCCATGCCAA CAACTGCGCAACTGTTGGGA AGGG	TM06 <i>PpaxM</i> (pDB05)-pDB49 R	
pTM07			
TM74	GATCGCCCTTCCCAACAGTT GCGCAGTTGTTGGCATGGGA GTAGG	TM06 pDB49- <i>PpaxM</i> F	1278

Chapter two: Materials and Methods

TM82	AAAGTCAAAACGCTCTGTTA ACATGGTTTCTGAATCTTAAA GATACATG	TM07 <i>idtQ</i> - <i>PpaxM</i> R	
TM83	ATGTATCTTTAAGATTGAGAA ACCATGTTAACAGAGCGTTT TGACTTTC	TM07 <i>PpaxM</i> - <i>idtQ</i> F/Screening	2060
TM84	GAAAACCAAAAATTGCTCCA ATGGTTCACAGATCCTTCATC CTAGCTC	TM07 <i>TpaxM</i> - <i>idtQ</i> R/Screening	
TM85	AAGAGCTAGGATGAAGGAT CTGTGAACCATTGGAGCAAT TTTTGGT	TM07 <i>idtQ</i> - <i>TpaxM</i> F/Screening	1322
TM79	GCGTCGCGCCATTGCGCATT CAGGCCGAATTGAGAAGCTG ATTTGC	TM06 <i>pDB49</i> - <i>TpaxM</i> R	
TM80	GACAGCAAATCAGCTTCTCA ATTCGGCCTGAATGGCGAAT GGCGC	TM06 <i>TpaxM</i> - <i>pDB49</i> F	7508
TM81	TCCATCCTACTCCCATGCCAA CAACTGCGCAACTGTTGGGA AGGG	TM06 <i>PpaxM</i> - <i>pDB49</i> R	
<i>P. paxilli</i> transformation screening			
TM92	TTGATGAGGATGGGCGTTGC	<i>P. paxilli paxP</i> screen F (pSS1)	1871
TM93	CCGATTTCACATCTCAACAC C	<i>P. paxilli paxP</i> screen R (pSS1)	
TM94	AACCACAGCTTTCATGTCAG G	<i>P. paxilli paxQ</i> screen F (pSS2)	2037
TM95	AGCCTTACAGAGAGATTCGT GG	<i>P. paxilli paxQ</i> screen R (pSS2)	
TM125	TAATGTTGCACGCTGTCCCA	Fl1 <i>idtP</i> screen F (pSS56)	1826
TM126	TTCAACATACGGTAACTGTCT TCTCC	Fl1 <i>idtP</i> screen R (pSS56)	
TM127	GGAGATGTTAACAGAGCATT TTGACT	Fl1 <i>idtQ</i> screen F (pSS58)	2012
TM128	TCACAGATTCTTCTCCCCAGC	Fl1 <i>idtQ</i> screen R (pSS58)	

2.2 Sterile conditions

Unless stated otherwise, all media and reagents were prepared using Mill-Q (MQ) water (Barnstead NANOpure water purification system-Thermo Scientific™ Barnstead™) and sterilised by autoclaving (20 mins at 121°C). All equipment involved with *E. coli* and *Epichloë* were sterilised by autoclaving, and all experiments were carried out under sterile conditions within a UV sterilised laminar flow hood. All equipment involved with *P. paxilli* were sterilised by autoclaving, and all experiments were carried out under sterile conditions within a UV sterilised biohazard hood.

2.3 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1

2.3.1 *Epichloë festucae* growth conditions

Colonies were maintained on Potato dextrose (PD) (2.4% (w/v) PD at pH 6.5) as a liquid medium or on media solidified using 1.5% (w/v) agar, with or without selection, at 22°C for 5-7 days for *E. festucae* strains, and for 14-30 days for *E. festucae* var *lolii* strains.

2.3.2 *Penicillium paxilli* growth conditions

Colonies were maintained on Czapek Dox Yeast extract (CDYE) (3.34% (w/v) CD, 0.5% (w/v) YE, and 5% (v/v) of trace element mix) as a liquid medium or with 1.5 % (w/v) agar, with or without selection, at 22°C for 7 days. The trace element mix contained 1.7 mM FeSO₄·7H₂O, 1.73 mM ZnSO₄·7H₂O, 0.59 mM MnSO₄·H₂O, 0.2 mM CuSO₄·5H₂O, and 0.17 mM CoCl₂·6H₂O.

2.3.3 *Epichloë festucae* genomic DNA extraction

Mycelia from 50 mL of liquid culture (Method 2.3.1) grown for 4 days was filtered through a nappy liner and washed with 250 mL of MQ water. The mycelia were frozen at -80°C for at least 2 hours, lyophilised overnight, and then ground to a fine powder under liquid nitrogen using a mortar and pestle. The macerated mycelia were then transferred into 2 mL Eppendorf tubes in 15-20 mg aliquots, with excess mycelia stored in Nunc tubes at -20°C. 800 µL of extraction buffer (150 mM EDTA, 50 mM Tris-

Chapter two: Materials and Methods

HCl, at pH 8.0) was added to the tubes and mixed before addition of DNase-free RNase (final concentration of 10 mg/mL). The samples were incubated for 30 mins at 37°C after which proteinase K (final concentration of 2 mg/mL) was added and samples incubated for a further 30 mins at 37°C. Insoluble material was removed by centrifugation at 17,000 g for 15 mins and the top transparent aqueous solution transferred into a fresh Eppendorf tube containing a ½ volume of phenol and a ½ volume of chloroform, the tube was then mixed, and centrifuged at 17,000 g for 15 mins. This phenol and chloroform step was repeated 2 more times. The final transparent aqueous solution was then transferred into a fresh Eppendorf containing 1 volume of chloroform and centrifuged at 17,000 g for 15 mins. The transparent aqueous layer was then transferred into a fresh Eppendorf containing 1 volume of isopropanol and precipitated overnight at -20°C. DNA was then pelleted by centrifugation at 17,000 g for 15 mins after which the aqueous solution discarded. If a polysaccharide pellet was visible, 800 µL of 1M NaCl was added to the tube, and the mixture incubated at room temperature for 10 mins before centrifuging at 17,000 g for 10 mins. The aqueous solution was then transferred into a fresh Eppendorf containing 1 volume of isopropanol and precipitated for 10 mins at room temperature before the DNA was pelleted by centrifugation at 17,000 g for 10 mins. After the supernatant was removed, the pellet was washed with 70% (v/v) ethanol, before being left to air-dry. The DNA was then resuspended in MQ and stored at 4°C (Byrd *et al.*, 1990).

2.3.4 *Epichloë festucae* crude DNA extraction

Approximately 1 cm² of mycelia from a 5-7 day old solid culture (Method 2.3.1) was macerated in a 1.5 mL Eppendorf tube using a pestle. 150 µL of lysis buffer (100 mM Tris-HCL, 100 mM EDTA, 1% SDS at pH 8.0) was added to the Eppendorf tube, mixed, and the sample incubated at 70°C for 30 mins. Next, 150 µL of 5 M CH₃CO₂K was added to the tube, which was then incubated on ice for 10 mins and then centrifuged for 20 mins at 17,000 g. The supernatant was transferred to a new Eppendorf tube containing 140 µL of isopropanol and incubated at -20°C overnight to precipitate the DNA. The sample was then centrifuged for 20 mins at 17,000 g, and the isopropanol removed, and the pellet washed with 70% (v/v) ethanol. The DNA was repelleted by centrifugation 17,000 g for a further 5 mins, the ethanol removed, and the pellet air-

Chapter two: Materials and Methods

dried at 37°C. The pellet was then resuspended in 50 µL of MQ, heated at 70°C for 10 mins, and centrifuged for 10 mins at 17,000 g to remove any insoluble material. The supernatant was carefully removed, then aliquoted in to a 96 well plate, and stored at -20°C until required.

2.3.5 *Penicillium paxilli* crude DNA extraction

In a 2 mL screw cap tube 200 µL of spore stock (Method 2.3.10) was added to approximately 50 µL of 0.5 mm glass beads. A Fastprep machine (ThermoSavant FP120) set at 20 secs at 4 m/s was then used to disrupt the spores, which were then placed on ice. Next, the samples were centrifuged for 20 mins at 30,000 g at 4°C and placed back on ice. The top 50 µL of the supernatant was removed, and transferred to a 96 well plate, and used immediately or kept at -20°C.

2.3.6 *Epichloë festucae* glycerol stocks

Into a Nunc tube, 2 mL of PD liquid culture containing 5-day-old mycelia (with or without selection) (Method 2.3.1) was mixed with 2.5 mL 30% (v/v) glycerol and stored at -80°C.

2.3.7 *Penicillium paxilli* glycerol stocks

Into a Nunc tube, 800 µL of spore stock (Method 2.3.10) was mixed with 200 µL of 50% (v/v) glycerol and stored at -80°C.

2.3.8 *Penicillium paxilli* protoplast preparation

For each strain, 25 mL 30 hour old liquid culture (Method 2.3.2) was filtered through a sterile funnel containing a nappy liner. The collected mycelia were initially washed with 200-300 mL of MQ water, then equilibrated using 50-100 mL of OM buffer (1.2 M MgSO₄ and 10 mM NaHPO₄ at pH 5.8 using NaH₂PO₄) and dried with paper towels. Into pre-weight flasks, 4 g lots of wet mycelia were added along with 40 mL of twice syringe filtered (0.2 µm Ahlstrom Relia Perp) lysing enzyme (10 g/ml, *Trichoderma harzianum*, Sigma L1412), and incubated at 30°C overnight with shaking at 80 rpm. The next day, the presence of the protoplasts were checked under the microscope using a haemocytometer. The protoplasts from identical flasks were then collectively filtered

Chapter two: Materials and Methods

through a funnel containing a nappy liner and collected in a 200 mL Schott bottle. Next, 5 mL aliquots of the protoplast solution were transferred into 15 mL Falcon tubes, and carefully overlayed with 2 mL of ST buffer (0.6 M sorbitol, and 100 mM Tris-HCL, at pH 8.0). The tubes were then centrifuged at 20,000 g for 5 mins at 4°C. The protoplasts (white layer) were removed from the interface along with the top colourless layer and transferred to 15 mL Falcon tubes containing 5 mL STC buffer (1 M sorbitol, 50 mM Tris-HCL, and 50 mM CaCl₂, at pH 8.0). The two solutions were mixed, and centrifuged for 5 mins at 20,000 g at 4 °C. The STC buffer rinse step was repeated 3 more times with tubes pooled until the protoplasts were in a single tube. The protoplasts were then resuspended in 500 µL of STC buffer, and the concentration calculated using a haemocytometer. To make stocks, the protoplasts were diluted to 1.25×10^8 protoplasts/mL in STC buffer, and 80 µL of this protoplast solution was added to 20 µL 40% (v/v) PEG aliquots, which were stored at -80°C.

2.3.9 *Penicillium paxilli* protoplast transformation

For each transformation, 50 µL of the appropriate protoplast (Method 2.3.8) was defrosted on ice. To the protoplasts, 2 µL of spermidine (7.11 mg/mL) and 5 µL of heparin (5 mg/mL) were added alongside 1.0–2.5 µg of DNA (in no more than 30 µL), mixed by pipetting, and incubated on ice for 30 mins. To the mixture, 900 µL of 40% (v/v) PEG was added, mixed by pipetting, and incubated back on ice for 20 mins. Then, 300 µL of this mixture was added to 3 mL of 0.8% (w/v) RG (2.4% PD (w/v), 0.8 M sucrose, and 0.8% (w/v) agar, at pH 6.5) previously heated to 50°C, mixed by pipetting, and poured onto plates containing 1.5% (w/v) RG (2.4% PD (w/v), 0.8 M sucrose, and 1.5% (w/v) agar, at pH 6.5). The plates were incubated overnight at 22°C, and then overlayed with 5 mL of 0.8% (w/v) RG containing the antibiotic of choice. For this project, hygromycin at 150 µg/mL and geneticin at 100 µg/mL. The plates were then incubated for a further 4-6 days at 22°C, and 20 transformants picked and streaked out onto individual CDYE plates containing the antibiotic of choice. A single spore colony was then picked from each transformant and re-plated out onto individual CDYE plates containing the antibiotic of choice, with four identical colonies per plate. These were then incubated at 22°C for 7 days.

2.3.10 *Penicillium paxilli* spore stocks

P. paxilli was grown on CDYE plates (with or without selection) as 4 separate colonies for 5-7 days (Method 2.3.2). Using a scalpel, 1 cm² sections of each centre of the 4 colonies were cut out of the plate and placed into a universal glass bottle containing 3 mL of 0.01% (v/v) triton X-100. The spores were then washed off the colonies by gently shaking the bottle. This solution was then transferred into 2 mL Eppendorf tubes, and stored at 4°C for up to 6 months.

2.3.11 Bioinformatics analysis of *Epichloë festucae* insect bioactive genes

FASTA formatted genome sequences (AR48, Fg1, AR1, AR37, AR5, and E2368) were imported into Geneious as individual BLAST databases. Fl1 gene models for ergot alkaloid, peramine, and indole-diterpene (IDTs) biosynthetic genes together with E2368 gene models for loline biosynthetic genes were used as queries to interrogate each of the genome databases using BLASTn. Gene homologues were manually annotated, spliced, and virtually translated to generate encoded protein products. Pairwise and multiple sequence alignments of gene or protein sequences were generated using the global alignment tool within Geneious allowing for free end gaps and 65% similarity. IdtP and IdtQ substrate binding site and catalytic amino acids were predicted using Phyre2 advanced analysis.

2.3.12 *Lolium perenne* seed accession

The plants required for the insect assay trials were grown from seeds sourced from the Margot Forde Germplasm Centre (Palmerston North, New Zealand) where each seed harvest is associated with a seed accession number. AR48 in Samson ryegrass (A13520), AR47 in Samson ryegrass (A11751), AR1 in Samson ryegrass (A16825), AR37 in Samson ryegrass (A17345), CT in Samson ryegrass (A25872), and nil in Samson ryegrass (A11104).

2.3.13 *Lolium perenne* seed DNA extraction

For each extraction, 0.1 g of seed (Method 2.3.12) was distributed into 6 seeds (maximum) per 2 mL micro tube (Sestet) containing one ceramic bead. The seeds were disrupted using FastPrep-24 tissue homogenizer for 20 secs at speed 6.5. The tubes

Chapter two: Materials and Methods

were then centrifuged for 30 secs at 20,000 g, and the beads removed. Next, 160 μ L of NaOH (0.133 mM) was added to each tube, and the un-capped tubes microwaved at low power (10% of 1100W) for 1 min, alongside a small beaker of water. Then, 600 μ L of 1x TE (1M Tris-HCL, 0.1M EDTA, pH 8.0) solution was added, and mixed by vortexing. The tubes were incubated at 4°C overnight, then centrifuge at 20,000 g for 5 mins, and supernatant transferred to a 96 well plate.

2.3.14 Simple sequence repeat (SSR) polymerase chain reaction (PCR)

Each SSR PCR reaction contained 10 μ L PCR reaction (1x TE buffer (1M Tris-HCL, 0.1M EDTA, pH 8.0), 1.5 mM $MgCl_2$, 50 μ M dNTPS, 1 U Taq polymerase, 0.2 μ M of each primer (B11 or ans014), 4 μ L of 30 fold diluted seed extract (Method 2.3.13), and 4 μ L MQ), with the following conditions used: 1 cycle at 94°C for 4 min, 35 cycles at 94°C for 30 secs, 60°C for 30 secs, 72°C for 30 secs, and a final extension of 72°C for 7 min.

2.3.15 SSR genotyping

Into each well of a PCR 96 well plate, 2 μ L of SSR PCR product (Method 2.3.14) was added to 9 μ L of Hi-Di containing 1.5% (v/v) Genes (500LIZ) as a size marker, and denatured under the following conditions: 1 cycle of 94°C for 5 min, and 1 cycle of 4°C for 5 min. The PCR products were then analysed on an ABI 3100 Genetic Analyser (Applied Biosystems), with the resultant electropherograms analysed using ABI Prism GeneScan (v 3.7, Applied Biosystems).

2.3.16 DNA sequencing

PCR (Method 2.4.21), plasmid (Method 2.4.3), and genomic DNA (Method 2.3.3) were sequenced by New Zealand Genomics Limited (NZGL) as instructed by the company. Genomic DNA was sequenced in a single lane of 250 bp paired-end generated on an Illumina MiSeq run by NZGL to give 14.8 million high quality reads (200x genome coverage). The reads were dynamically trimmed using the SolexaQA package to their longest fragment such that the base call error rates did not exceed a P value of 0.05, and paired end reads of less than 100 bp discarded. *De novo* assembly was performed using ABySS version 2.0.0 with default parameters and a *k*-mer length of 95 bp.

2.3.17 Indole-diterpene extraction from *Epichloë festucae* herbage and seed

50 mg of milled freeze-dried pseudostem tissue (Method 2.3.1) or milled seed (Method 2.3.12) was mixed with 1 mL of extraction buffer 1 (80% (v/v) acetonitrile, 1% (v/v) acetic acid, and 0.99 µg/mL of N-benzyl-1, 8-naphthaleneimide as internal standard) and mixed by end-over-end rotation in the dark for 1 hour. Samples were centrifuged at 21,000 g for 5 mins, and the supernatant collected. 600 µL of this supernatant was then diluted with 4.6 mL of 1% (v/v) acetic acid before loading onto an Isolute C18 spin column, which was previously prepared by washing with 2 mL of 50% (v/v) methanol, and then 2 mL of 1% (v/v) acetic acid. The column was then washed with 2 mL of 1% (v/v) acetic acid, and then 1 mL of 50% (v/v) methanol. The IDT fraction was eluted from the column using by washing with 1 ml of methanol containing 1% (v/v) ammonia and syringe filtered.

2.3.18 Indole-diterpene extraction from *Penicillium paxilli* cultures

Approximately 50 mg of milled freeze-dried culture (Method 2.3.2) was mixed by end-over-end rotation in the dark for 1 hour with 1 mL of extraction buffer 1 (80% (v/v) acetonitrile, 1% (v/v) acetic acid, and 0.99 µg/mL of N-benzyl-1, 8-naphthaleneimide as internal standard). Samples were centrifuged at 21,000 g for 5 mins, the supernatant collected and syringe filtered.

2.3.19 Chromatography of indole-diterpene extracts for triple quadrupole (TSQ) analyses

IDT compounds in the extracts (Method 2.3.17 and 2.3.19) were separated by high performance liquid chromatography (HPLC) prior to mass spectrometry (MS) analysis using an Accela 1250 pump and a Kinetix C18 2.6µ; 150x2.1 mm column set to a flow rate of 0.3 mL/min. For each sample the liner gradient was as follows using eluent A (100% water with 0.1% formic acid) and eluent B (100% acetonitrile, 0.1% formic acid): T₀ 90% A, T₆ 40% A, T₁₇ 0% A, T₁₉ 0% A, T₂₀ 50% A, T₂₅ 90% A.

2.3.20 Chromatography of indole-diterpene extracts for triple quadrupole (TSQ) analyses

IDT compounds extracts (Method 2.3.17 and 2.3.18) were separated by HPLC prior to MS analysis using an Accela 1250 pump and a Gemini-NX 3u C18 110A; 150x2.0 mm column set to a flow rate of 0.2 mL/min. For each sample the liner gradient was as follows using eluent A (100% water with 0.1% formic acid) and eluent B (100% acetonitrile, 0.1% formic acid): T₀ 50% A, T₂₀ 30% A, T₄₀ 0% A, T₄₃ 0% A, T₄₄ 50% A, T₅₀ 50% A.

2.3.21 Mass spectrometry analysis TSQ of indole-diterpenes from *Epichloë festucae*

HPLC separated IDT compounds (Method 2.3.19) were then analysed using a Thermo TSQ Quantum mass spectrometer. The mass spectrometer was set to scan selected MRMs with Q1 and Q3 isolation widths of 0.7 amu (Table 2.1). The data was processed using LCQuan software for quantification.

2.3.22 Mass spectrometry analysis LTQxl of indole-diterpenes from *Epichloë festucae*

HPLC separated IDT compounds (Method 2.3.20) were then analysed using a Thermo LTQ XL mass spectrometer. The mass spectrometer was set to scan MS¹ (180 – 800 *m/z*) and collect MS² of selected parent ions in each of the four method segments, with the isolation width for MS² precursor ions set to ±1 amu (Table 2.2). The data was processed using LCQuan software for quantification

Table 2.1: Indole-diterpenes analysis by triple quadrupole (TSQ) selected reaction monitoring the following chromatogram segments

Parent ion	Fragment ion	Collision energy	Tube lens
420.3	130.1	20	80
	402.2	5	80
422.3	130.1	20	80
	404.2	5	80
436.3	130.1	20	83
	418.2	5	83
438.3	130.1	20	85
	420.2	5	85
454.3	130.1	20	80
	436.2	5	80

Table 2.2: Indole-diterpenes analysis by linear ion trap (LTQxl) selected reaction monitoring the following chromatogram segments.

Segment 1 (Time 0–13.5 min)			
Analyte Retention	MS1 precursor ion (m/z)	MS2 filter ions (m/z)	time (min)
lolitrem N	620.4	562.4	9.0
lolitriol	620.4	562.4	10.8
Segment 2 (Time 13.5–22.0 min)			
Analyte Retention	MS1 precursor ion (m/z)	MS2 filter ions (m/z)	time (min)
Paxitriol	438.3	420.3	13.0
Paspaline B	436.3	420.3	15.4
Paxilline	436.3	420.2	16.2
Terpendole E	438.3	422.2	16.7
Lolitrem K	602.3	544.4	16.8
Lolitrem M	604.3	546.4	15.5
Lollicine	604.3	546.4	18.6
Lolitrem J	662.4	604.4	15.0
Segment 3 (Time 22.0–28.6 min)			
Analyte Retention	MS1 precursor ion (m/z)	MS2 filter ions (m/z)	time (min)
13-desoxypaxilline	420.3	402.2, 405.2	22.8
Lolitrem A	702.4	644.3	25.7
Segment 4 (Time 28.6–40.0 min)			
Analyte Retention	MS1 precursor ion (m/z)	MS2 filter ions (m/z)	time (min)
Paspalline	422.3	130.2, 406.3	33.9
Terpendole C	520.3	504.3	28.4
Lolitrem B	686.4	628.3	29.8
Lolitrem E	688.4	630.3	31.3

2.3.23 Mass spectrometry analysis LTQxl of indole-diterpenes from *Penicillium paxilli*

HPLC separated IDT (Method 2.3.20) were then analysed using a Thermo LTQ XL mass spectrometer with an insolation width of 2.00 m/z , normalised collision energy of 35.00%, and an isolation window of 400 m/z to 600 m/z . The MS² was collected in a data dependent manner by selecting the most intense ion from the parent list of 406.20 m/z , 418.20 m/z , 420.20 m/z , 422.20 m/z , 438.20 m/z , 452.20 m/z , 454.20 m/z , 474.30 m/z , 488.30 m/z , 490.30 m/z , 504.30 m/z , 506.30 m/z , 522.30 m/z , 542.30 m/z , 554.30 m/z , 556.30 m/z , 572.30 m/z , 574.30 m/z , 588.30 m/z , and 590.30 m/z , using dynamic exclusion of repeat count 3, repeat duration of 10 secs, exclusion list size of 50 masses, and exclusion duration of 10 secs. Where a parent ion was not detected, the most dominant peak in the MS¹ spectrum was fragmented.

2.3.24 Fragmentation in tree generation for *Epichloë festucae* indole-diterpenes

HPLC separated IDT compounds (Method 2.3.20) were then analysed using a Thermo LTQ XL mass spectrometer with an insolation width of 2.00 m/z , normalised collision energy of 35.00%, and an isolation window of 400 m/z to 600 m/z . Spectra collected were (MS^1 420.30 m/z -> MS^2 404.30 m/z), (MS^1 422.30 m/z -> MS^2 406.30 m/z), (MS^1 436.30 m/z -> MS^2 418.30 m/z -> MS^3 346.30 m/z), (MS^1 438.30 m/z -> MS^2 420.30 m/z), (MS^1 436.30 m/z -> MS^2 418.30 m/z -> MS^3 400.30 m/z) and (MS^1 436.30 m/z -> MS^2 360.30 m/z).

2.4 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass

2.4.1 Bioinformatics analysis of makes caterpillars floppy (mcf)

FASTA formatted genome sequences (AR48, Fl1, Fg1, AR1, AR37, AR5, and E2368) were imported to Geneious as individual BLAST databases. The *E. typhina* subsp *Poa* *Ps1 mcf* gene (Ambrose *et al.*, 2014) was used as a query sequence to interrogate each of the genome databases using BLASTn. Pairwise and multiple sequence alignments were generated using the global alignment tool within Geneious allowing for free end gaps and 65% similarity. Additional genomes from the Kentucky Endophyte Genome database (Schardl *et al.*, 2013c) were searched, using the BLASTn search engine provided, with the same *E. typhina* subsp *Poa* *Ps1mcf* gene. All gene homologues were manually annotated, spliced, and virtually translated to generate encoded protein products. Domains were annotated from a selection of these manually annotated Mcf protein sequences as well as literature Mcf protein sequences (Dowling & Waterfield, 2007) using a range of online tools: BLASTp, InterPro Scan, Phyre2, and Hhpred. The *Epichloë mcf* gene location was annotated using the completely assembled *E. festucae* Fl1 genome sequence (Winter *et al.*, 2018) annotated with E2368 gene models (EfM3.0) and RNA sequencing data (Schardl *et al.*, 2013c). The selected genes were then either searched in other *Epichloë* genomes using the BLASTn search engine provided by the Kentucky Endophyte Genome database or the FASTA

formatted genome sequence (AR48, Fg1, AR1, and AR37) databases on Geneious using the BLASTn function.

2.4.2 *Escherichia coli* growth conditions

Colonies were maintained on Luria Broth (LB) (1% (w/v) tryptone, 0.5% (w/v) yeast extract, and 86 mM NaCl) as a liquid medium or with 1.5% (w/v) agar, with or without selection, at 22°C overnight.

2.4.3 *Escherichia coli* plasmid extraction

Plasmids from 1 day old liquid cultures (Method 2.4.2) were extracted using the High Pure Plasmid Isolation Kit (Roch) as instructed by the manufacturer.

2.4.4 Chemically competent *Escherichia coli* DH5α cells

A 24-hour-old streaked plate (Method 2.4.2) was used to inoculate a single colony into 50 mL of SOB medium (2% tryptone, 0.5% yeast extract, 10 mM NaCl, and 2.5 mM KCl) in a 500 mL flask. The culture was grown at 18°C at 150-250 rpm for 19-50 hours until the A_{600} was between 0.4-0.8. The flask was immediately put on ice and incubated for 10 mins. The culture was then transferred into GSA bottles, centrifuged at 10,000 g for 15 mins at 4°C, and supernatant discarded. The pellet was resuspended in 17 mL (1/3 volume of the SOB medium) of ice-chilled transformation buffer (TB) (10 mM PIPES, 15 mM $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, and 250 mM KCl) and incubated on ice for 10 mins. Next, the solution was centrifuged at 10,000 g for 15 mins at 4°C, and the supernatant discarded. The pellet was then resuspended in 4 mL (1/12.5 volume of the SOB medium) of ice-chilled TB, 300 μL of DMSO (final concentration 7% (v/v)) added and incubated on ice for 10 mins. The chemically competent *E. coli* cells were then transferred into 1.5 mL Eppendorf tubes in 0.1 mL aliquots, flash frozen in liquid nitrogen, and stored at -80°C.

2.4.5 *Escherichia coli* DH5α cell transformation

For each transformation, 50 μL of chemically competent *E. coli* cells (Method 2.4.4) were thawed on ice. To the cells, 5 μL of Gibson assembly mixture (Method 2.4.23) or 1 ng DNA (Method 2.4.3) was added and incubated back on ice for 30 mins. The cells were then heat shocked for 30 secs at 42°C and placed back on ice for 2 mins. To the

Chapter two: Materials and Methods

cells, 900 μL of SOC stock (2% tryptone, 0.5% yeast extract, 10 mM NaCl, 2.5 mM KCl, 10mM MgCl_2 , 10 mM $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, and 20 mM Glucose) was added, and incubated at 37°C with shaking at 225 rpm for 1 hour. Typically, the cells were plated out as 30 μL and 270 μL aliquots onto LB with 150 $\mu\text{g}/\text{mL}$ ampicillin or kanamycin (Method 2.4.2).

2.4.6 *Escherichia coli* glycerol stocks

A single colony was spread out across a LB plate (with or without antibiotic selection) so that a lawn of bacterial growth can establish (Method 2.4.2). To the plate, 5 mL of 50% (v/v) glycerol was added, and colonies scrapped off the plate surface using a glass rod. The glycerol solution containing the suspended cells was then collected using a pipette, transferred into Nunc tubes, and stored at -80°C.

2.4.7 *Escherichia coli* plasmid design

Plasmids were designed in silico using the MacVector software system, with primers designed using the in-software application (Length: 18-25 bp, GC%: 45-55 %, and T_m : 55-80°C, 2 bp GC clamp, and maximum T_m difference between primers of 4°C)

2.4.8 *Epichloë festucae* protoplast preparation

For each strain, 50 mL of a 4-6 day old mycelia in liquid culture (Method 2.3.1) was filtered through a funnel containing a nappy liner. The collected mycelia was initially washed with 200-300 mL of MQ water, then equilibrated using 50-100 mL of OM buffer (1.2 M MgSO_4 and 10 mM NaH_2PO_4 , at pH 5.8 using NaH_2PO_4), and dried with paper towels. Into pre-weighed flasks, 4 g lots of wet mycelia was added along with 40 mL of twice syringe filtered (0.2 μm Ahlstrom Relia Perp) lysing enzyme (10 mg/mL, *Trichoderma harzianum*, Sigma L1412), and incubated at 22°C overnight with shaking at 80 rpm. The next day, the presence of the protoplasts were checked under the microscope using a haemocytometer. The protoplasts from identical flasks were then collectively filtered through a funnel containing a nappy liner and collected in a 200 mL Schott bottle. Next, 5 mL aliquots of the protoplast solution were transferred into 15 mL Falcon tubes, and carefully overlaid with 2 mL of ST buffer (0.6 M sorbitol, and 100 mM Tris-HCL, at pH 8.0). The tubes were then centrifuged at 20,000 g for 5 mins at 4°C. The protoplasts (white layer) were removed from the interface along with the top

transparent layer, and transferred to 15 mL Falcon tubes containing 5 mL STC buffer (1 M sorbitol, 50 mM Tris-HCL, and 50 mM CaCl₂, at pH 8.0). The two solutions were mixed, and centrifuged for 5 mins at 20,000 g at 4°C. The STC buffer rinse step was repeated 3 more times with tubes pooled until the protoplasts were in a single tube. The protoplasts were then resuspended in 500 µL of STC buffer, and the concentration calculated using a haemocytometer. To make stocks, the protoplasts were diluted to 1.25×10^8 protoplast/mL in STC buffer, and 80 µL of this protoplast solution was added to 20 µL 40% (v/v) PEG aliquots, which were kept at -80°C.

2.4.9 *Epichloë festucae* protoplast transformation

For each transformation, 50 µL of the appropriate protoplasts (Method 2.4.8) were defrosted on ice. To the protoplasts, 2 µL of spermidine (7.11 mg/mL) and 5 µL of heparin (5 mg/mL) were added along with 1.0-2.5 µg of DNA (in no more than 30 µL), mixed by pipetting, and incubated on ice for 30 mins. To the mixture, 900 µL of 40% (v/v) PEG was added, mixed by pipetting, and incubated back on ice for 20 mins. Then, 50 µL of this mixture was added to 3 mL of 0.8% (w/v) regeneration medium (RG) (2.4% PD (w/v), 0.8 M sucrose, and 0.8% (w/v) agar, at pH 6.5) previously heated to 50°C, mixed by pipetting, and poured on to plates containing 1.5% (w/v) RG (2.4% PD (w/v), 0.8 M sucrose, and 1.5% (w/v) agar, at pH 6.5). The plates were incubated overnight at 22°C, and then overlaid with 5 mL of 0.8% (w/v) RG containing the antibiotic of choice. Transformants were selected on final concentrations of hygromycin at 150 µg/mL and geneticin at 100 µg/mL. The plates were then incubated for a further 7-14 days at 22°C, with 100-200 transformants picked onto PD agar plates containing the antibiotic over this time period. Each transformant was nuclear purified three times.

2.4.10 *Epichloë festucae* spore isolation

E. festucae was subcultured onto PD plates, with each plate containing 5 colonies, and grown until the colonies were 1.5-2 cm in diameter *i.e.* approximately 10 days (Method 2.3.1). Next, 2 mL of PD broth was added to the plate and scrubbed with a glass rod. This PD spore suspension was washed over the colonies, and scrubbed several times to increase the spore concentration, before being removed, and filtered through a 1 mL

Chapter two: Materials and Methods

tip containing glass wool into a 1.5 mL Eppendorf tube. The spore stock was then plated out on to PD plates to obtain single spore purified colonies (Method 2.3.1).

2.4.11 *Lolium perenne* growth conditions

Wild type (WT) endophyte infected ryegrass seeds (Method 2.3.12) were germinated in seedling trays containing non-fungicidal soil (provided by AgResearch) in a PC1 glasshouse. Ryegrass seedlings infected with mutant endophyte strains (Method 2.4.13) were planted to root trainers containing non-fungicidal soil (provided by AgResearch) in a PC2 glasshouse. All seedlings were top watered until a root system was established and then bottom watered. The presence of the endophyte was detected by immunoblotting (Method 2.4.14).

2.4.12 *Lolium perenne* seed sterilisation

Uninfected Samson *L. perenne* seeds (Method 2.3.12) were soaked in 50% (v/v) H₂SO₄ for 30 mins and rinsed 3 times with MQ water. The seeds were then soaked in 50% (v/v) chlorine bleach for 30 mins and rinsed 3 times with MQ water. The seeds were then spread onto filter paper lined petri dishes and air-dried in a laminar flow cabinet. The seeds were then kept in these containers at 4°C until require for plant inoculations (Method 2.4.13).

2.4.13 *Lolium perenne* seedling inoculation

Sterilised uninfected Samson *L. perenne* seeds (Method 2.4.12) were placed right side up and with the shoot end of the seed pointing upwards onto 3% (w/v) WA plates. The plates were placed in a light tight container and positioned so that the seed shoot end was upwards and incubated in the dark at 22°C for 7 days. The meristems of the seedlings were then inoculated with 7-day old endophyte mycelia from PD agar plates (without selection) (Method 2.4.11), by making an incision into the meristem with a staple blade under a dissection microscope and inserting mycelia into the cut. The seedlings were then placed back into the light tight container and incubated for a further 7 days, again with the seeds positioned with shoot upright. The seedlings were then exposed to light for a further 7 days before being planted into root trainers (Method 2.4.11).

2.4.14 *Epichloë festucae* infected *Lolium perenne* plant immunoblotting

Immunoblotting (Simpson *et al.*, 2012) was performed on plants from inoculated seedlings (Method 2.4.13) or plants from endophyte infected seeds (Method 2.3.12 and 2.4.11). Each tiller was cut with a scalpel horizontally at the base, as close to the soil as possible without contaminating the newly exposed surface. The freshly cut detached tiller end was then blotted onto a nitrocellulose membrane (0.45 µm). The membrane was then incubated in milk protein blocking solution (BS) (20 mM Tris (hydroxymethyl) methylamine, 50 mM NaCl, 0.5% (w/v) non-fat milk powder, pH 7.5) to coat any non-protein bound areas, for at least 2 hours on an orbital shaker at room temperature. The BS was then removed, and the membrane was rinsed twice with fresh BS. Primary antibody (polyclonal rabbit anti-endophyte produced at AgResearch in conjunction with Massey University's Small Animal Production Unit) (25 ml in 25 ml BS) was then incubated with the membrane on an orbital shaker overnight at 4°C. The antibody solution was removed, and the membrane washed twice with BS. Secondary antibody (goat anti-rabbit IgG-AP, sc-2034, Santa Cruz Biotechnology, USA) (6.25 mL in 25 ml BS) was then incubated with the membrane on an orbital shaker for at least 2 hours at room temperature. The antibody solution was removed, and the membrane washed twice with BS. Chromogens were prepared as manufacturer's instructions (SIGMAFAST™ Fast Red TR/Naphthol AS-MX). The chromogen solution was then incubated with the membrane on an orbital shaker for 15 mins or until red colour developed on control positive blot, at room temperature. Development was then stopped by rinsing the membrane three times in MQ water.

2.4.15 *Epichloë festucae* infected *Lolium perenne* plant macroscopy

Mycelia plugs were grown on PD plates next to each other at 22°C for 7 days (Method 2.3.1), with colony morphology compared in size, shape, colour, and texture.

2.4.16 *Epichloë festucae* infected *Lolium perenne* plant microscopy

Microscopy slides were placed onto 1.5% (w/v) water agar (WA) plates and then overlaid with 1.5% (w/v) WA. Mycelia plugs of *E. festucae* grown on 3% (w/v) WA plates for 5-7 days at 22°C were placed on these pre-prepared plates so that the mycelia were on the surface of the agar directly above the edge of the embedded

Chapter two: Materials and Methods

slide, and grown for 5-7 days at 22°C. A block of the newly formed mycelia was cut and place on a new slide, stained with 4-5 µL of Calcofluor white (3 mg/mL) (fluorescent Brighter 28; Sigma), and covered with a cover slip. The slide was imaged using an Epi-fluorescence microscopy (Olympus IX83) under 40× oil immersion objective lens, NA=0.075, outfitted with U-MWUS filter tubes for Calcofluor white. Images were captured with Retiga 600M (QImaging) camera using a Bin2X2. Images were produced with ImageJ software (NIH).

2.4.17 DNA gel extraction

DNA was extracted from agarose gel electrophoresis (Method 2.4.22) using the Wizard SV Gel and PCR Clean-up System (Promega) as instructed by the manufacturer.

2.4.18 DNA column purification

DNA was purified from PCR solutions (Method 2.4.21) using the QIAquick PCR Purification Kit (Qiagen) as instructed by the manufacturer

2.4.19 DNA Qubit

DNA was quantified using the Qubit 2.0 Fluorometer (Thermo Fisher Scientific). For each sample, 199 µL or 190 µL of working solution (1 µL broad range double stranded DNA reagent and 199 µL of corresponding buffer) was added to 1 µL of DNA solution or 10 µL of either standard 1 or 2 (used for calibration) respectively, and incubated at room temperature for 2 minutes, before being measured on the Qubit using the correct settings for the chosen reagent.

2.4.20 DNA Nanophotometer

For each DNA sample, 3.5 µL of DNA solution was analysed using lid factor 10 (for concentrations between 15-800 ng/µL) and factor 50 (for double stranded DNA). Readings of 260/280 and 260/230 were taken along with the concentration (ng/µL).

2.4.21 PCR

Taq DNA polymerase (Roch) or Q5[®] DNA polymerase (New England Biolabs, inc.) reaction mixture were used as instructed by the manufacturer, with the addition of 2% (v/v) DMSO when required.

2.4.22 DNA agarose gel electrophoresis

Gels were prepared using 0.8% or 1.5% (w/v) agarose in 1x TBE buffer (89 mM Tris, 89 mM boric acid, 2 mM Na₂EDTA) were loaded with DNA samples pre-mixed with 5:1 of DNA loading dye (20% (w/v) sucrose, 5 mM EDTA, 1% (w/v) SDS, and 2% (w/v) bromophenol blue) alongside 1 Kb plus ladder (Thermo Fisher Scientific). The samples were then run using a Molecular Imager[®] Gel Doc[™] XR + System, stained in ethidium bromide (1 µg/mL) solution for 15-30 mins, and de-stained in MQ for 10-15 mins before imaging using a UV transilluminator Gel Documentation System (Bio-Rad).

2.4.23 Gibson assembly

For each assembly, 10 µL 2x Gibson assembly master mix (4 µL of 5x Isothermal buffer, 0.08 µL of T5 exonuclease, 0.25 µL of Phusion polymerase, 2 µL Taq ligase, and 3.67 µL MQ water) was thawed on ice. To this, 50-100 ng of linear vector backbone along with 3-fold excess of each insert fragment, using the relative molar concentrations, was added, and made up to 20 µL with MQ water. The fragments were designed to have a 15 bp overlap between neighbouring fragments with 100% bp matching and were generated using PCR (Method 2.4.21) followed by column purification (Method 2.4.18). This mixture was incubated at 50°C for 60 mins in a thermo cycler. The mixture can be used straight away or stored at 4°C. The Gibson assembly mixture is then transformed into *E. coli* (Method 2.4.5)

2.4.24 Clone checker

Single colonies from the Gibson assembly mixture transformed *E. coli* plates (Method 2.4.5) were picked, and resuspended in individual PCR tubes containing 6 µL of LB. Next, 3 µL of this suspension was transferred to PCR tubes containing 8 µL of green clone checker solution and heated to 100°C for 30 secs using a thermo cycler. Once the tube had cooled, 1 µL of the restriction enzyme, chosen based on the plasmid *in silico*

restriction map (Method 2.4.7), and 1 μL of the corresponding restriction enzyme buffer was added to the tube, and incubated at the appropriate restriction enzyme temperature for 30 mins. The samples were then analysed using gel electrophoresis (Method 2.4.22). The remaining 3 μL of LB suspension can be used to start cultures (Method 2.4.2) for plasmid extractions (Method 2.4.3).

2.4.25 Restriction analysis

The amount of enzyme used depended on the amount of DNA digested and was calculated based on the assumption that 1 enzyme unit can digest 1 μg of DNA in 1 hour in 50 μL therefore. The enzyme was chosen based on the restriction map (Method 2.4.7) with the buffer type and temperature recommended by manufacturer.

2.4.26 *Epichloë festucae* Fg1 *mcf* whole gene replacement construct

For the generation (Method 2.4.7) of *mcf* whole gene replacement construct (pTM03, appendix 23), *mcf* left-boarder (LB) (TM40/TM50) and *mcf* right-boarder (RB) (TM51/TM52) were amplified (Method 2.4.21) from Fg1 WT genomic DNA (Method 2.3.3), and the hph cassette (hph_F/DB33.7) and backbone (pRS426_F/pRS426-R) amplified from pAN7-1 (Appendix 25 and Method 2.4.3). All the products (RB 1428 bp, LB 1394 bp, hph 2185 bp, and backbone 2591 bp) were purified (Method 2.4.17), assembled using Gibson assembly (Method 2.4.23), and sequenced (Method 2.3.16).

2.4.27 *Epichloë festucae* Fg1 *mcf* 5' gene replacement construct

For the generation (Method 2.4.7) of *mcf* 5' gene replacement construct (pTM05, appendix 24), *mcf* LB (TM70/TM71) and *mcf* RB (TM72/TM73) were amplified (Method 2.4.21) from Fg1 WT genomic DNA (Method 2.3.3), and the hph cassette (hph_F/DB33.7) and backbone (pRS426_F/pRS426-R) amplified from pAN7-1 (Appendix 25 and Method 2.4.3). All the products (RB 1911 bp, LB 2095 bp, hph 2185 bp, and backbone 2591 bp) were purified (Method 2.4.17), assembled using Gibson assembly (Method 2.4.23), and sequenced (Method 2.3.16).

2.4.28 *Epichloë festucae* var *lolii* AR48 *mcf* gene complementation construct

For the generation (Method 2.4.7) of *mcf* gene complementation construct (pTM04, appendix 27), AR48 *mcf* open reading frame (ORF) (TM49/TM52) was amplified (Method 2.4.21) from AR48 WT genomic DNA (Method 2.3.3), and backbone (pRS426_F/pRS426-R) amplified from pAN7-1 (Appendix 25 and Method 2.4.3). All the products (AR49 *mcf* ORF 11786 bp and backbone 2591 bp) were purified (Method 2.4.17), assembled using Gibson assembly (Method 2.4.23), and sequenced (Method 2.3.16).

2.4.29 *Epichloë festucae* var *lolii* AR48 *idtP* gene complementation construct

For the generation (Method 2.4.7) of *idtP* gene complementation construct (pTM06, appendix 10); *idtP* (TM76/TM77) was amplified (Method 2.4.21) from AR48 WT genomic DNA (Method 2.3.3), *PpaxM* (TM74/TM75) and *TpaxM* (TM78/TM79) from pDB05 (Appendix 16 and Method 2.4.3) and backbone (TM80/TM81) from pDB49 (Appendix 12 and Method 2.4.3). All the products (*idtP* 1907 bp, *PpaxM* 1278 bp, *TpaxM* 1322 bp, and backbone 7508 bp) were purified (Method 2.4.17), assembled using Gibson assembly (Method 2.4.23), and sequenced (Method 2.3.16).

2.4.30 *Epichloë festucae* var *lolii* AR48 *idtQ* gene complementation construct

For the generation (Method 2.4.7) of *idtQ* gene complementation construct (pTM07, appendix 14); *idtQ* (TM83/TM84) was amplified (Method 2.4.21) from AR48 WT genomic DNA (Method 2.3.3), *PpaxM* (TM74/TM82) and *TpaxM* (TM85/TM79) from pDB05 (Appendix 16 and Method 2.4.3) and backbone (TM80/TM81) from pDB49 (Appendix 12 and Method 2.4.3). All the products (*idtQ* 2060 bp, *PpaxM* 1278 bp, *TpaxM* 1322 bp, and backbone 7508 bp) were purified (Method 2.4.17), assembled using Gibson assembly (Method 2.4.23), and sequenced (Method 2.3.16).

2.4.31 DIG probe preparation for Southern blotting

DNA was prepared by purifying 1 µg of linearized DNA produced either by PCR (Method 2.4.21 and 2.4.18) or restriction digest of a plasmid (Method 2.4.25, 2.4.22, and 2.4.17). The volume was adjusted to 16 µL with MQ water and the DNA denatured by heating at 100°C for 5 mins and cooled on ice. Then, 4 µL of DIG-High Prime (DIG

Chapter two: Materials and Methods

High Prime DNA Labelling and Detection Starter Kit-Roch) was added, and the mixture incubated overnight at 37°C. The reaction was stopped by adding EDTA (final concentration 20 mM pH 8.0) and heated at 65°C for 10 mins. This resulted in approximately 100 ng/μL of DIG labelled DNA probe.

2.4.32 Genomic DNA preparation for Southern blotting

Genomic DNA was extracted from *E. festucae* mycelia using the small scale Byrd method (Method 2.3.3), and the concentration quantified using the Qubit (Method 2.4.19). For each restriction digest of each sample, 1 μg of this genomic DNA was added to a 1.5 mL Eppendorf tube along with 20 U restriction enzyme (chosen based on the plasmid and gene *in silico* restriction map (Method 2.4.7)), 1x restriction buffer (recommended by the manufacturer), 10 μg of Rnase A, and MQ water up to 100 μL. The tube was then incubated at the appropriate temperature for the chosen restriction enzyme (recommended by the manufacturer) overnight. Before stopping the reaction, 5 μL of the reaction was analysed using gel electrophoresis (Method 2.4.22) to check the extent of the DNA digestion. Once satisfied the reaction was complete, the restriction reaction was stopped by adding 0.3 mM NaOAc (pH 5.2) and 2.5% (v/v) of 100%(v/v) ethanol and incubated at 25°C for at least 3 hours or overnight. The DNA was pelleted by centrifuging at 17,000 g for 15 mins at 4°C, and supernatant discarded. The DNA was then washed with 300 μL 70% (v/v) ethanol, centrifuging at 17,000 g for 5 mins, air dried, and re-suspended in a mixture of 16 μL of MQ water and 4 μL SDS loading dye.

2.4.33 Gel electrophoresis for Southern blotting

A 0.8% (w/v) agarose gel was loaded with prepared DNA (Method 2.4.32) alongside 20 μL of 1 Kb plus ladder (Thermo Fisher Scientific). The gel was then run at 80 V for 3-5 mins or until the samples had entered the gel, and then 30 V overnight. With the gel kept in the cast, the gel was stained with ethidium bromide, washed in MQ water, and image taken with and without a ruler as a sizing reference (Method 2.4.22).

2.4.34 DNA blotting for Southern blotting

The gel (Method 2.4.33) was washed by agitation in solution 1 (0.25 M HCl) for 15 mins, and the solution removed. Then the gel was washed in solution 2 (0.5 NaOH and 0.5 M NaCl) by agitation for 45 mins, and the solution removed. Next, the gel was washed in solution 3 (0.5 M Tris pH 7.4, and 2 M NaCl) with agitation for 60 mins, and solution removed. Finally, the gel was washed in 2x SSC (0.3 M NaCl, and 30 mM Na citrate) with agitation for 2 mins. The blot was then set up as follows: into the gel stand 20x SSC (3 M NaCl, and 0.3 mM Na citrate) buffer was placed into the two side wells, a 3MM Whatman (MM) sheets placed on top (cut slightly larger than the blotting stand so that the MM sides dipped into each well), and gladwrap added over the wells but not the gel blotting stand. The gel was then placed onto the blotting stand, 2x SSC wetted nylon membrane (cut to gel size and marked for orientation) placed on top, then 2 sheets of 2x SSC wetted MM sheets (cut to gel size) on top of the membrane, then 2 dry MM sheets (cut to gel size) on top of the two wetted MM sheets, and lastly a stack of paper towels weighted down with 1 L bottle filled with water. This was left at room temperature overnight to transfer that DNA from the gel to membrane through capillary action. The membrane was then dried between MM sheets, and DNA linked to the nylon membrane by UV irradiation for 2 min using CEX-800 UV cross-linker.

2.4.35 Hybridization of the probe for Southern blotting

The DIG Easy Hyb machine was pre-heated to the appropriate temperature, calculated by $T_m = 49.82 + 0.41 \times (\% G + C) - (600 / l)$ with l = length of probe in bp. $T_{opt} = T_m - 25$. The probe (Method 2.4.31) was denatured by heating at 100°C for 5 mins and cooled on ice. The membrane (Method 2.4.34), washed in 10 mL prehybridisation solution (3 fold dilution of DIG Easy Hyb Granules at 37°C-DIG High Prime DNA Labelling and Detection Starter Kit-Roch) for 1 hour with gentle agitation in a PYRX™ hybridization tube in the DIG Easy Hyb machine, and solution removed. To the PYRX™ hybridisation tube containing the membrane, 0.06% (v/v) denatured probe (prehybridisation solution DIG High Prime DNA Labelling and Detection Starter Kit-Roch) was added and incubated overnight with gentle agitation in the DIG Easy Hyb machine.

2.4.36 Stringency washes for Southern blotting

The membrane (Method 2.4.35) was incubated in 250 mL of 2x SSC (50 mL 20x SCC (3 M NaCl, and 0.3 mM Na citrate), 5 mL 10% (w/v) SDS, and 445 mL MQ water) for 5 mins with gentle agitation. This step was repeated. The membrane was then incubated in 250 mL of 0.5x SSC (12.5 mL 20x SCC (3 M NaCl, and 0.3 mM Na citrate), 5 mL 10% (w/v) SDS, and 482.5 mL MQ water pre-heated to 70°C) for 15 mins with gentle agitation. This step was repeated.

2.4.37 Immunological detection for Southern blotting

The membrane (Method 24.36) was incubated in 100 mL washing buffer (100 mL maleic acid buffer (0.1 M maleic acid, and 0.15 M NaCl, pH 7.5), and 1.5 mL Tween 20) with agitation for 5 mins, and solution removed. Then the membrane was incubated in 50 mL blocking solution (5 mL blocking solution, and 45 mL maleic acid buffer) with agitation for 30 mins, and solution removed. Next, the membrane was incubated in 10 mL antibody solution (2 µL Anti-Digoxigenin-AP (DIG High Prime DNA Labelling and Detection Starter Kit-Roch), and 10 mL blocking solution) with agitation for 30 mins, and solution removed. Finally, the membrane was incubated in 200 mL washing buffer solution with agitation for 15 mins two times, followed by 100 mL of detection buffer (0.1 M Tris, and 0.1 NaCl, pH 9.5) with agitation for 5 mins. The membrane is then developed without agitation using 10 mL colour substrate solution (100 µL NBT/BCIP stock solution (DIG High Prime DNA Labelling and Detection Starter Kit-Roch), and 5 mL detection buffer) in the dark. Typically, bands can be seen within 6 hours, and stopped using 100 mL MQ water. The membrane was air dried and stored in a dry dark place.

2.5 Test the insect bioactivity capabilities of *Epichloë festucae* var *lolii*

AR48 and *Epichloë festucae* Fg1 infected ryegrass

2.5.1 Stem boring fly whole plant choice trial plant preparation

Seeds from the Margot Forde Germplasm Centre (Method 2.3.12) infected with a range of endophyte strains were germinated (Method 2.4.11) and then at 6 weeks immunoblotted to check for the presence of endophytes (Method 2.4.14). In preparation for the insect trial, 20 replications worth of plants were selected, with

Chapter two: Materials and Methods

each replication containing one ryegrass plant infected with AR48, AR47, AR1, AR37, CT, or nil endophytes, and tillers trimmed to a maximum height of 15 cm. Both the position of each plant in each replication and the position of each replication within the glasshouse were randomised.

2.5.2 Stem boring fly preparation

Stem boring fly preparation (SBF-*Cerodontha australis*) were collected from ryegrass fields at Grasslands AgResearch by sweeping the grass surface with a net and transferring the insects into containers. At Massey University Palmerston North, CO₂ gas was used to sedate the insects and, using a dissection microscope, the SBF were sorted out. SBF were identified by their grey thorax, yellow legs, yellow frons, black notopleura, and 3rd antennae segment (Introduction 1.5.1). The SBF were re-sedated and sorted into groups of 20 females (x 20) and 20 males (x 20) SBF and transferred into Eppendorf tubes. Females SBF were identified by the lower abdomen being larger, pointier, and black (Figure 1.15 and 1.16).

2.5.3 Stem boring fly whole plant choice trial

Two Eppendorf tubes (one containing female SBF and one containing male SBF) (Method 2.5.2) were added to the plants (now covered by a fine nylon mesh bag) (Method 2.5.1), tubes open, and bags tied closed. The adult SBF are therefore not naïve, though most likely exposed to ryegrass as a major food source, but the eggs, larva, and, pupa are naïve and only exposed to ryegrass. The plants were then bottom watered for 6 weeks. At the end of the trial the number of mines, presence of a pupa, and resultant fly emergence was recorded for each plant. One-way analysis of variance (ANOVA) was carried out on average mines per tiller (%), average pupa per mine (%), and average fly per pupa (%) to examine the significance of endophyte differences. The analyses were conducted using GenStat 17th edition (VSN International).

2.5.4 Cutworm moth caterpillar whole plant choice trial plant preparation

Seeds from the Margot Forde Germplasm Centre (Method 2.3.12) infected with a range of endophyte strains were germinated (Method 2.4.11) and then at 6 weeks immunoblotted to check for the presence of endophytes (Method 2.4.14).

Chapter two: Materials and Methods

Alternatively, endophytes were inoculated in to ryegrass seedlings (Method 2.4.13), which were then planted (Method 2.4.11), and at 6 weeks plant tissue was analysed by immunoblot to check for the presence of endophytes (Method 2.4.14). In preparation for the insect trial, 20 replications worth of plants were selected, with each replication containing one ryegrass plant infected with AR48, AR47, AR1, AR37, Fl1, Fg1, CT, or nil endophytes, and tillers trimmed to a maximum height of 15 cm and tillers counted. Both the position of each plant in each replication and the position of each replication within the glasshouse were randomised

2.5.5 Cutworm moth caterpillar preparation

Cutworm moth (CM-*Agrotis ipsilon*) were caught using a light trap, placed in a container containing dock leaves and moist paper towels, and left to lay eggs over 1-2 weeks. Once hatched, the cutworm moth caterpillar (CC-*Agrotis ipsilon*) were kept in these containers, and the detached dock leaves were replaced every 2-3 days or when needed. After 1 week, the caterpillars were moved to new containers containing detached dock leaves and bark and fed on detached dock leaves for 2-3 weeks or until the start of the CWPC trial. The containers were kept in a shaded area in the same glasshouse as the ryegrass plants at AgResearch.

2.5.6 Cutworm moth caterpillar whole plant choice trial

In to each replication, 40 caterpillars (Method 2.5.5) were added to the plants (Method 2.5.4) and covered by a fine nylon bag. The CC are therefore not naïve as the initial food source was dock leaves (Method 3.5.5) rather than the tested plant source which was ryegrass. The plants were then bottom watered for 2 weeks. At the end period the number of tillers, and score (5= No damage, 4= 25% damage, 3= 50% damage, 2= 75% damage, and 1= Dead) was recorded for each plant. One-way analysis of variance (ANOVA) was carried out on average difference in tiller number and average plant visual score using GenStat 17th edition (VSN International) to examine the significance of endophyte differences.

2.5.7 Cutworm moth or porina caterpillar detached tiller no choice trial plant preparation

Seeds from the Margot Forde Germplasm Centre (Method 2.3.12) infected with a range of endophyte strains were germinated (Method 2.4.11) and then at 6 weeks immunoblotted to check for the presence of endophytes (Method 2.4.14).

Alternatively, endophytes were inoculated in to ryegrass seedlings (Method 2.4.13), which were then planted (Method 2.4.11), and at 6 weeks plant tissue was analysed by immunoblot to check for the presence of endophytes (Method 2.4.14).

2.5.8 Porina caterpillar preparation

Porina moths (PM-*Wiseana* spp) were caught using a light trap, placed in a container containing artificial diet (2.5% (w/v) agar, and 1% (w/v) freeze-dried endophyte free ryegrass up to 1 L carrot juice) and moist paper towels, and left to lay eggs over 1-2 weeks. Once hatched, the porina caterpillars (PC-*Wiseana* spp) were kept in these containers, and the artificial diet was replaced every 2-3 days or when needed. After 1 week, the caterpillars were moved to new containers containing artificial diet and bark, where the caterpillars remained for 2-3 weeks or until the start of the PDTN trial. The artificial diet was made fresh every week and stored at 4 °C during the week. The containers were kept in a temperature controlled cabinet at 18°C. The CC (Method 2.5.5) or PC were weighed before being placed into separate yellow screw top containers that were filled $\frac{3}{4}$ of the way with bark. After being ranked by weight, the caterpillars to be used for the trial were selected so that there was the smallest weight difference between the lightest and heaviest. Selected caterpillars were then assigned an endophyte strain in a repeating order so that each endophyte was assigned caterpillars from each weight range. These were then randomly distributed based on endophyte label in an air-conditioned laboratory (with light) for the CDTN or an 18°C incubator (without light) for the PDTN and starved overnight.

2.5.9 Cutworm moth or porina caterpillar detached tiller no choice trial

The CC are not naïve as the initial food source was dock leaves (Method 3.5.5) rather than the tested plant source which was ryegrass. The PC are also not naïve as the initial food source though contained ryegrass also contained agar and carrot juice

Chapter two: Materials and Methods

(Method 3.5.8) rather than the tested plant source which was only ryegrass. Each day, the caterpillars were weighed, and fed the pre-weighed ryegrass tiller. Any uneaten tillers were removed and weighed. This was done until 8 tillers (CC) or 10 tillers (PC) had been added and removed from the containers. One-way analysis of variance (ANOVA) and repeated measurements linear mixed model was carried out on CC/PC survival and CC/PC weight using GenStat 17th edition (VSN International) to examine the significance of endophyte differences.

2.5.10 Light brown apple moth caterpillar artificial diet no choice trial plant preparation

Seeds from the Margot Forde Germplasm Centre (Method 2.3.12) infected with a range of endophyte strains were germinated (Method 2.4.11) and then at 6 weeks immunoblotted to check for the presence of endophytes (Method 2.4.14). Alternatively, endophytes were inoculated in to ryegrass seedlings (Method 2.4.13), which were then planted (Method 2.4.11), and at 6 weeks plant tissue was analysed by immunoblot to check for the presence of endophytes (Method 2.4.14). The grass was then harvested, freeze-dried, and milled before being added to the artificial diet (2.5% (w/v) agar, and 1% (w/v) freeze-dried endophyte infected or free ryegrass up to 1 L carrot juice).

2.5.11 Light brown apple moth caterpillar preparation

The light brown apple moth caterpillars (LBAM- *Epiphyas postvittana*) were ordered from Plant and Food New Zealand a week before the start of the trial. Day old LBAM were added to separate yellow screw top containers and assigned an endophyte strain. The caterpillars were then randomly distributed based on endophyte label in an 18°C incubator (without light).

2.5.12 Light brown apple moth caterpillar artificial diet no choice trial

On day one of each week, artificial diet (2.5% (w/v) agar, and 1% (w/v) freeze-dried endophyte infected or free ryegrass up to 1 L carrot juice) was added to the containers (Method 2.5.11) and on day 4 of each week the diet was replaced. The LBAM are therefore naïve as they are only exposed to the tested food source. At the start of each

Chapter two: Materials and Methods

week the artificial diet was made fresh and stored at 4°C during the week. LBMA establishment (production of silk cocoon), and moulting times (head colour and size change) were recorded over this time period. One-way analysis of variance (ANOVA) was carried out on caterpillar establishment times and moulting times using GenStat 17th edition (VSN International) to examine the significance of endophyte differences

3.0 RESULTS

3.1 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1

Secondary metabolites (SMs) are the main source of bioprotective compounds produced by fungi. In *Epichloë*, four SM pathways have been identified as producing bioactive compounds that target insects; lolitrem B, ergovaline, loline, and peramine (Introduction 1.2.6). These pathways were analysed in the *E. festucae* var *lolii* asexual strain AR48 that has two new insect bioactivities against the stem boring fly (SBF-*Cerodontha australis*) and cutworm moth caterpillar (CC-*Agrotis ipsilon*) (Introduction 1.1.3). During this analysis the *E. festucae* strain Fg1 was identified as being AR48-like, and important as a model system for genetic manipulation, therefore this strain was also analysed

3.1.1 Analysing the functionality and presence of the bioactive secondary metabolite genes in the genome of AR48 and Fg1 through bioinformatics.

The genome of AR48 was sequenced (Method 2.3.16) to gain an insight into which known bioactive SM pathways were present. The final assembly consisted of 1580 scaffolds containing 36 million bp with a GC content of 43%. The average scaffold length was 22,900 bp, with the largest scaffold 238,100 bp, and a scaffold N_{50} of 46,100 bp (Table 3.1).

Table 3.1: Genome assemble statistics of AR48 and Fg1

Statistics	AR48	Fg1
Number of reads	21 million	14 million
Genome assembly size	36 Mbp	35 Mbp
Fold coverage of sequence	127 fold	250 fold
Scaffold number	1580	3769
Scaffold N_{50} *	46,100 bp	70,535 bp
Contig number	4,618	11,141
Contig N_{50} *	15,710 bp	19,839 bp
GC%	43%	44%

* The contig/scaffold length at which 50% of the contig lengths are longer

Chapter three: Results

An analysis of the genome sequence of AR48 identified all eleven indole-diterpene (IDT) genes involved in lolitrem B synthesis (Figure 3.1 and Method 2.3.11). However, both *idtF* and *idtK* each had single base deletions that would result in premature translational termination of the transcripts thereby rendering the genes non-functional (Figure 3.2). For the remaining known alkaloid pathways, no genes were identified from either the ergovaline or loline pathways, though the single gene responsible for peramine production *perA* was identified. Analysis of this gene showed that it contained a 230 bp deletion identical to the *perA* allele in the *E. festucae* sexual strain Fg1 (Figure 3.3). The presence of the same null allele suggests that AR48 and Fg1 have a close ancestry.

To further investigate this ancestry the genome of Fg1 was sequenced (Method 2.3.16). The final assembly consisted of 3769 scaffolds containing 35 million bp with a GC content of 44%. The average scaffold length was 9458 bp, with the largest scaffold 400,034 bp, and a scaffold N_{50} of 70,535 bp (Table 3.1).

The genome of Fg1 was also analysed for the presence of known bioactive SM genes (Method 2.3.11). As expected, no genes involved in ergovaline synthesis or loline synthesis were identified, but all eleven IDT genes involved in lolitrem B synthesis were present (Figure 3.1). Again *idtF* and *idtK* each had single base deletions, with *idtF* sharing an identical change to AR48, and *idtK* having an alternative deletion closer to the 5' end of the gene (Figure 3.2). The phylogenetic relationship between AR48 and Fg1 was investigated through simple sequence repeat (SSR) analysis using 23 loci (Method 2.3.15). Fg1 and AR48 share a common ancestor that is unique to the AR48 clade, which supports the alkaloid bioinformatics analysis that these strains are closely related (Figure 3.4).

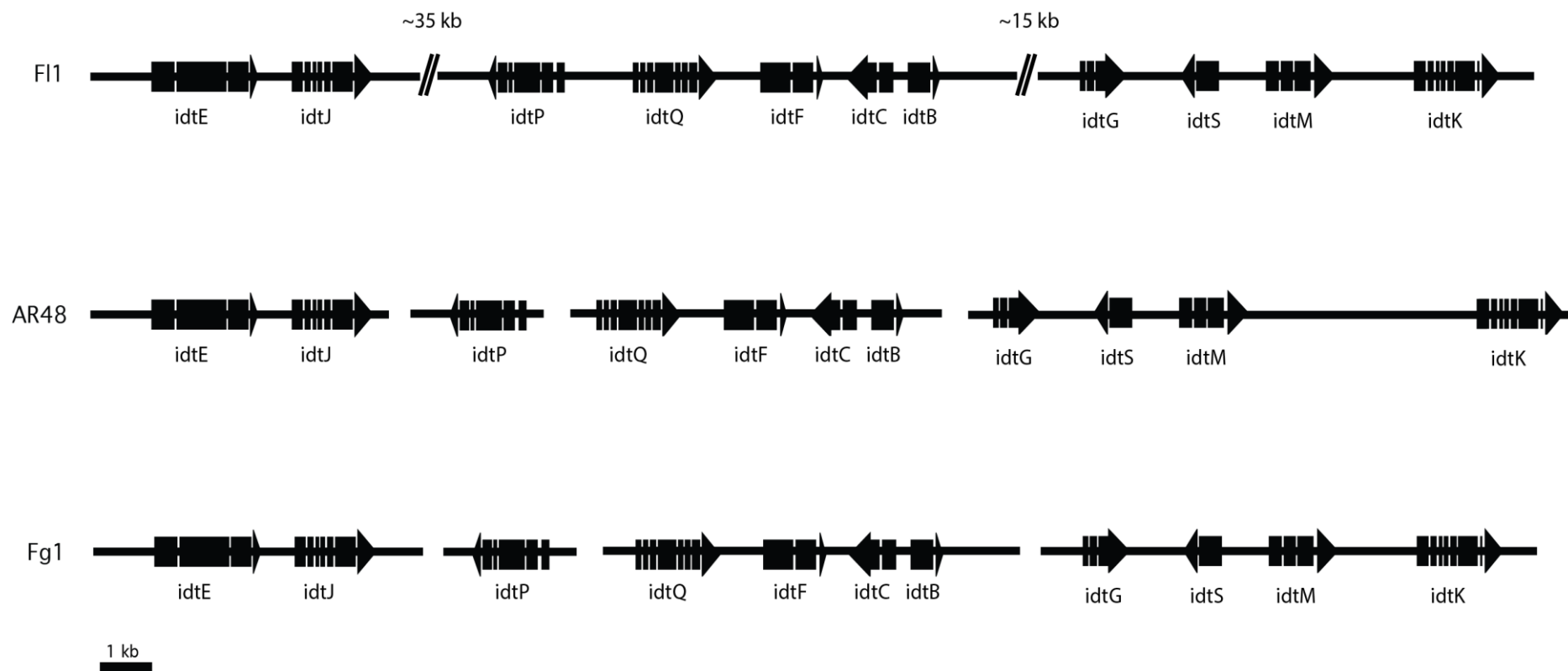


Figure 3.1: Organisation of indole-diterpene (IDT) genes in different *Epichloë festucae* strains. Contigs from strains FI1, AR48, and Fg1 were annotated in Geneious for genes involved in indole-diterpenes synthesis: cluster 1 contains *idtG*, *idtS*, *idtM*, and *idtK*, cluster 2 contains *idtQ*, *idtF*, *idtC*, and *idtB*, and cluster 3 contains *idtE*, and *idtJ*. While *idtP* was on a separate contig it is likely to be linked to cluster 2 based on the known organization of these genes in strain FI1. Contigs are represented by horizontal black lines. Genes are represented by black arrows, introns as white boxes and the gene name directly below. Double slashed lines represent large genomic regions of repetitive DNA sequence, with the approximate size of the region shown above.

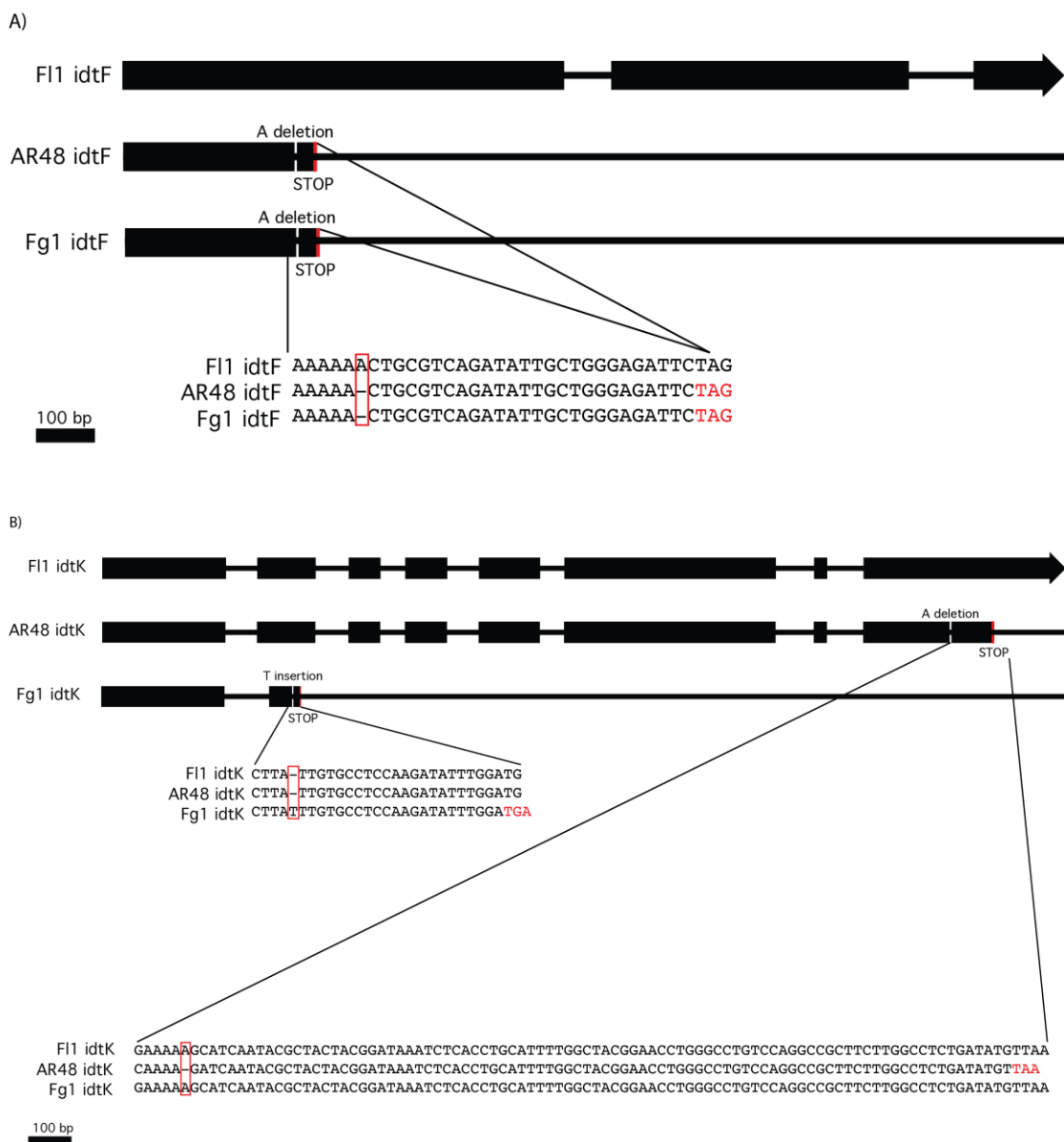


Figure 3.2: Indole-diterpene (IDT) *IdtF* and *idtK* gene alignment in different *Epichloë festucae* strains. Gene sequences of *idtF* (A) or *idtK* (B) from Fl1, AR48, and Fg1 were aligned using Geneious global alignment tool with free end gaps and 65% similarity. Genes are represented by thin black horizontal lines. The transcripts are represented by black arrows, with introns as gaps. The region around the deletion is enlarged, with the missing base represented by a dash, and the deletion highlighted by a red box and the premature stop codon highlighted in red text.

Chapter three: Results

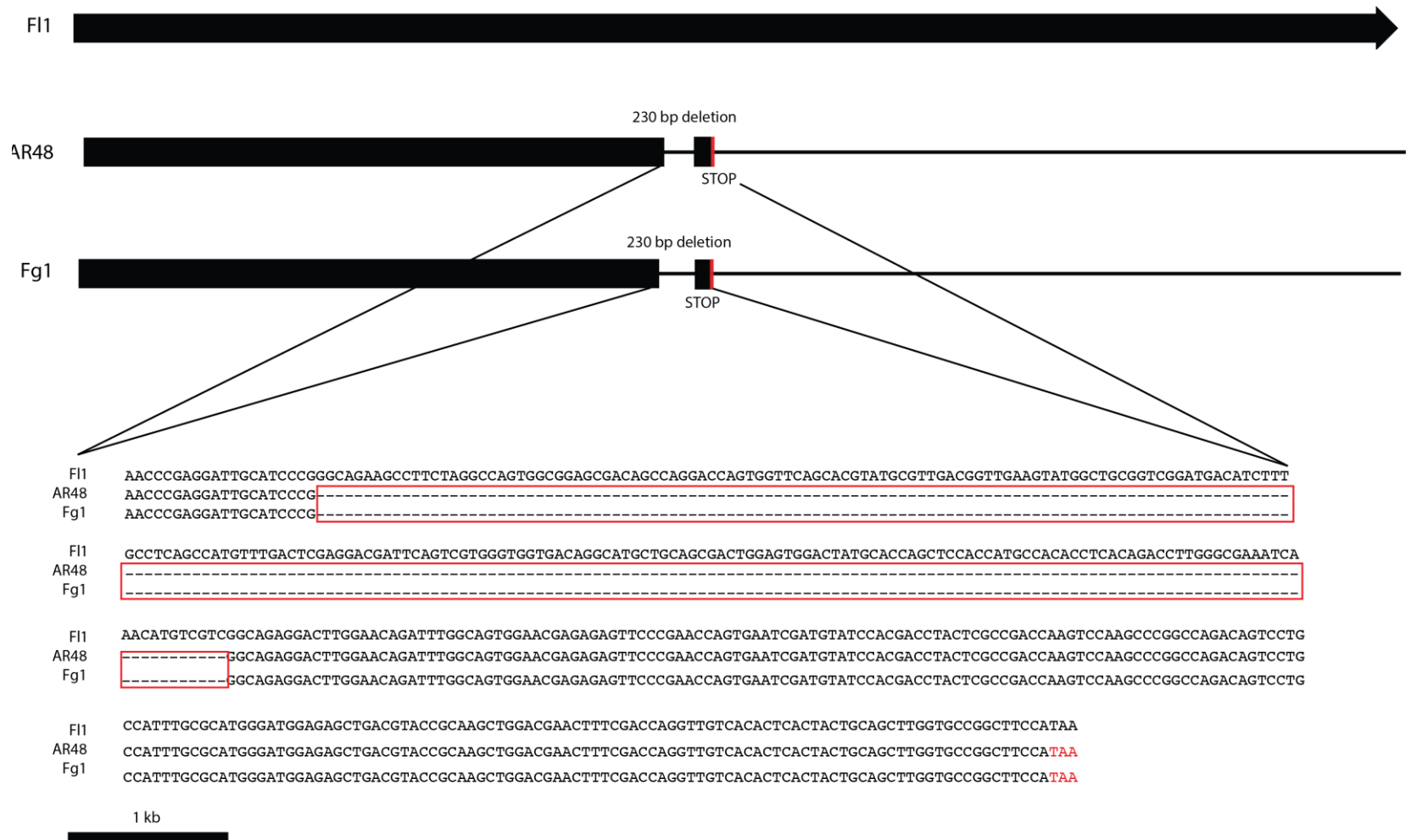


Figure 3.3: *PerA* gene alignment for different *Epichloë festucae* strains. Gene sequences of *perA* from FI1, AR48, and Fg1 where aligned and translated using Geneious global alignment tool with free end gaps and 65% similarity. Genes are represented by thin black horizontal lines. Transcripts are represented by black arrows, with introns as gaps. The deleted region is enlarged, with missing bases represented by a dash, the deleted region highlighted by a red box and the premature stop codon highlighted in red text

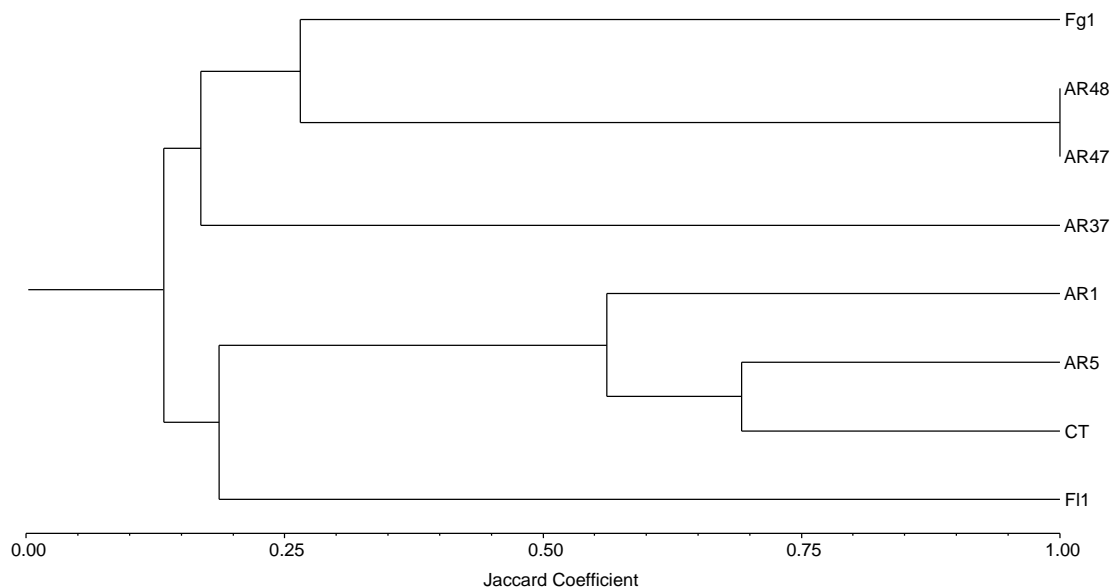


Figure 3.4: Simple sequence repeat (SSR) dendrogram of *Epichloë festucae* strains using 23 loci. Only the key strains used in this study are shown.

The genomes from the *E. festucae* strains E2368, AR1, AR37, and AR5 also contain *idt* genes but are missing *idtE* and *idtJ*, and in addition E2368 does not contain *idtG*, *idtS*, *idtM*, and *idtK* (Method 2.3.11). The encoded Idt proteins from these genomes when aligned to the corresponding proteins from AR48 and Fg1 all had high sequence identity ranging from 99.1%-100%, with the exception of IdtP and IdtQ which dropped to 92.6% and 90.3% respectively. However, the protein sequences of IdtP and IdtQ from AR48 and Fg1 share sequence identity of 99.8% and 99.1% respectively (Figures 3.5, 3.6, and Appendix 1).

The amino acid changes for IdtP and IdtQ for both AR48 and Fg1 sequences were compared to the remaining *E. festucae* corresponding genes (Method 2.3.11). For IdtP there were 34 changes in total, with one non-conservative change specific to Fg1 *i.e.* S226P. Of these shared changes 14/34 (41%) were identified as being non-conservative, and of these non-conservative changes 10/14 (71%) were from polar or charged amino acids to hydrophobic or uncharged amino acids. One of the changes removes a cysteine (C12W), which could affect the tertiary structure of the protein.

Chapter three: Results

E2368 was the only other strain that shared changes with AR48 and Fg1, with 3 of the changes conservative and 3 other changes non-conservative. Many of the changes are located in or near P450 predicted pockets *e.g.* I191H, S208F, and K395I, with most of these changes to more hydrophobic amino acids (Figure 3.5, Appendix 2 and 3, and Method 2.3.11).

For IdtQ, there were 53 changes in total, with two specific to Fg1 *i.e.* S162F (non-conservative) and R532M (conservative) and two specific to AR48 *i.e.* I177S (non-conservative) and T217I (non-conservative). Of these shared changes 27/49 (55%) were identified as being non-conservative, and of these non-conservative changes 8/27 (29%) were from polar or charged amino acids to hydrophobic or uncharged amino acids, however 8/27 (22%) were from hydrophobic or uncharged to polar or charged amino acids. In contrast to IdtP, one of the changes adds a cysteine *i.e.* C306R, which could affect the tertiary structure of the protein. There was some variability between the remaining *E. festucae* strains but all are conservative amino acid substitutions. E2368 again shared some changes with AR48 and Fg1, with three of the changes conservative and one change non-conservative. Again, many of the changes are located in or near P450 predicted pockets *e.g.* H62Y, T470I, and E484A, with approximately equal balance of polar/charged and hydrophobic/aromatic changes (Figure 3.6, Appendix 2 and 4, and Method 2.3.11).

For both AR48 and Fg1 IdtP and IdtQ the haem binding site that is required for catalytic activity has no amino acid changes in the key positions. Also, the key amino acids in Helices I, J, and K are conserved (Figure 3.5 and 3.6) (McMillan *et al.*, 2003).

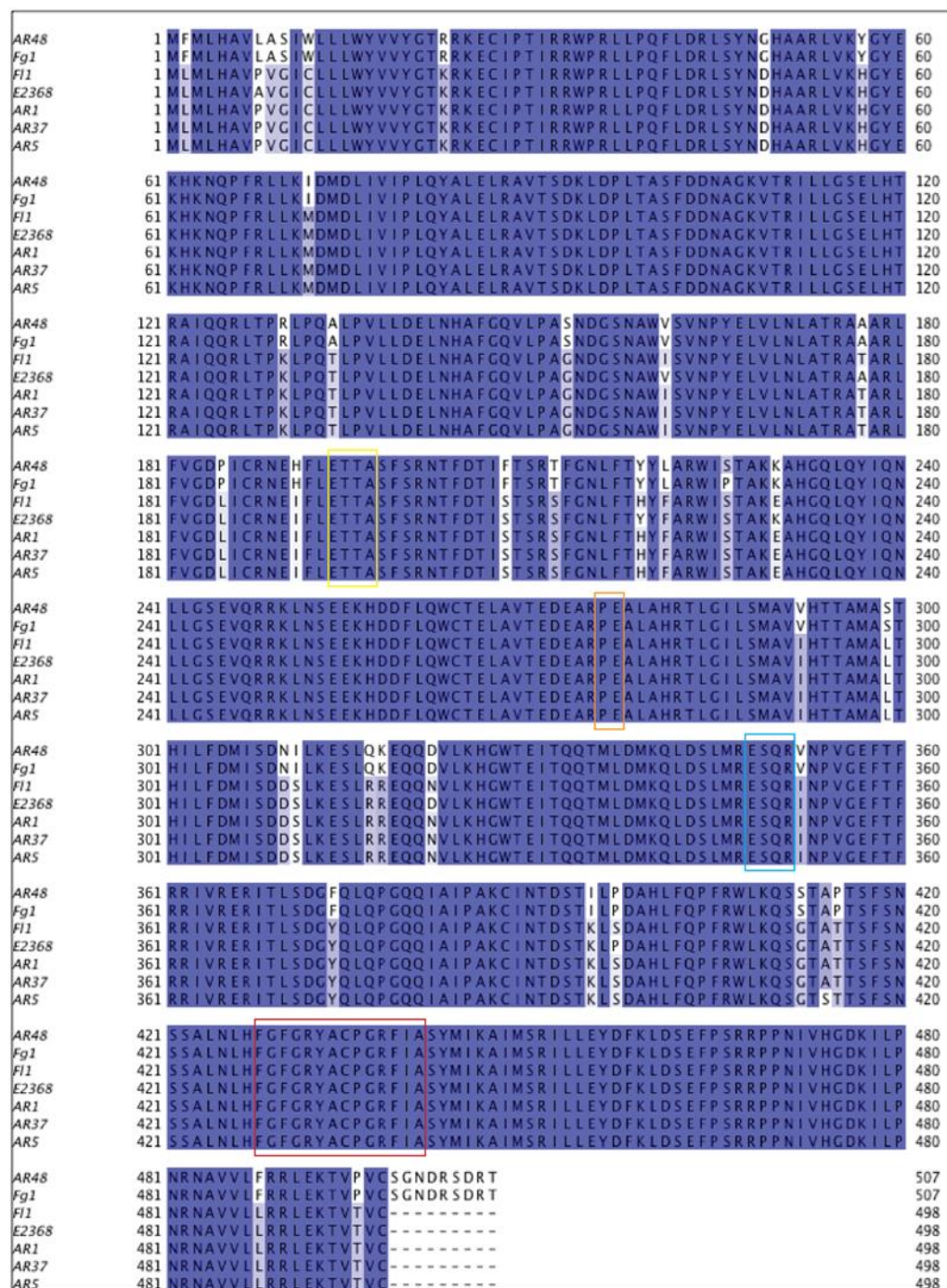


Figure 3.5: Amino acid sequence alignment of indole-diterpene (IDT) IdtP in *Epichloë festucae* strains AR48, Fg1, Fl1, E2368, AR1, AR37, and AR5 using Geneious. The amino acids are colour coded by similarity to the amino acid in the corresponding position in the remaining sequences, with dark purple as most similar and white as least similar. The amino acid number is labelled either side of the sequence. The sequences within the yellow box are a conserved motif found in Helix I (E/H(T/S)(T/S)(S/T/A)). The sequences within the orange box are conserved amino acids found in Helix J (PE). The cyan box contains conserved sequence motifs found in Helix K (ExxR). The red box contains sequences comprising the haem-binding site (F(G/S)xGx(H/Y)xCxGxx(I/L/F)A) where x represents any amino acid.

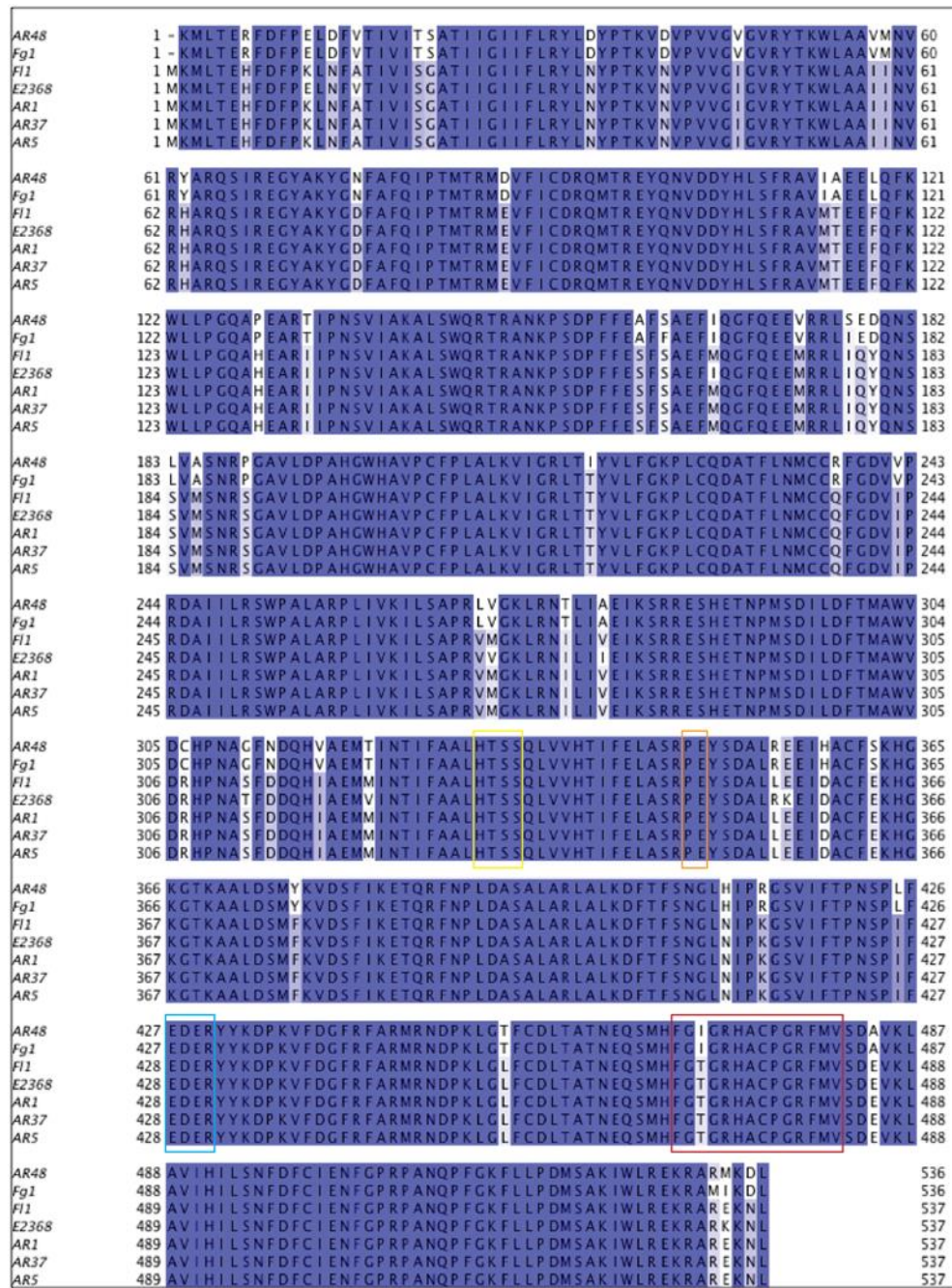


Figure 3.6: Amino acid sequence alignment of indole-diterpene (IDT) ldtQ in *Epichloë festucae* strains AR48, Fg1, FI1, E2368, AR1, AR37, and AR5 using Geneious. The amino acids are colour coded by similarity to the amino acid in the corresponding position in the remaining sequences, with dark purple as most similar and white as least similar. The amino acid number is labelled either side of the sequence. The sequences within the yellow box are a conserved motif found in Helix I (E/H(T/S)(T/S)(S/T/A)). The sequences within the orange box are conserved amino acids found in Helix J (PE). The cyan box contains conserved sequence motifs found in Helix K (ExxR). The red box contains sequences comprising the haem-binding site (F(G/S)xGx(H/Y)xCxGxx(I/L/F)A) where x represents any amino acid.

3.1.2 Detection of the bioactive secondary metabolite compounds in AR48 and Fg1 infected ryegrass through mass spectrometry

IDT compounds were extracted from pseudostem of ryegrass infected with AR48, Fg1, AR1, AR37, and FI1, and analysed by mass spectrometry (MS) (Method 2.3.17, 2.3.20 and 2.3.22). The control strain FI1 in ryegrass contained all IDT compounds normally observed in the lolitrem B synthetic pathway when using this protocol. This IDT profile was mirrored in the common toxic (CT) infected plant material as expected from previous analysis (unpublished data. Plant material infected with AR1 contained all early- and mid- pathway compounds, *e.g.* paspaline B, terpendole E, terpendole F, 13-desoxypaxilline, and paxitriol, but did not contain any IdtE and IdtJ derived late-pathway IDT compounds *e.g.* lolitriol, lolitrem K, lolitrem J, and lolitrem B. This is due to the absence of *idtE* and *idtJ* genes in the genome of AR1. However, IdtK, and IdtF derived late-pathway IDT compounds were identified as expected due to the presence of *idtK* and *idtJ* genes which are predicted to be functional *e.g.* terpendole M and terpendole C. AR37 and AR1 infected plant materials have a very similar IDT profile due to the absence of *idtE* and *idtJ*, and presence of functional *idtK* and *idtF* genes. However, the presence of the additional functional *janD* gene enables AR37 to produce *epoxy-janthitrem* IDT compounds (data not shown) (Table 3.2, Figure 3.11, and Appendix 1). The gene *janD* (given the *epoxy-janthitrem* product) is orthologous to *paxD* (prenyl transferase) and is located close to the known IDT cluster in AR37. Additional genes hypothesized to be involved in *epoxy-janthitrem* synthesis have been identified (Richard Johnson, AgResearch; personal communication).

Both AR48 and Fg1 infected material contained all early- and mid- pathway compounds confirming that the early- to mid- pathway enzymes IdtG, IdtM, IdtC, IdtB, IdtP, and IdtQ are functional supporting the bioinformatics analyses. Fg1 infected plant material contains terpendole K and lolitriol indicating that the late-pathway proteins IdtE, and IdtJ, are functional as predicted by bioinformatics. However, AR48 infected plant material, which also has *idtE* and *idtJ* genes predicted to be functional, does not contain either these compounds or any other IdtE/IdtJ derived IDT. Both Fg1 and AR48 infected plant materials do not contain IdtK and IdtF derived IDT as predicted by the bioinformatics analysis, which indicated that the genes responsible for the production

of terpendole C, lolitrem E, and lolitrem B were non-functional. In addition, no *epoxy-janthitrem* IDT compounds were identified as expected due to the absence of *janD* from both genomes (data not shown) (Table 3.2, Figure 3.11, and Appendix 1.1).

3.1.3 Analysing the structure of any newly identified compounds through mass spectrometry

During the routine IDT analysis (Method 2.3.20 and 2.3.22) four new IDT compound peaks were identified only in extracts from the AR48 and Fg1 infected plant material; new IDT compound one which is terpendole E-like (438 m/z and 10.3 mins), new IDT compound two which is 13-desoxypaxilline-like (420 m/z and 11.8 mins), new IDT compound three which is paxitriol-like (438 m/z and 19.4 min), and new IDT compound four which is terpendole I-like (454 m/z and 8.7 min). The new IDT compound peaks one, two, and four have marginally different retention times than the corresponding known IDT with the same m/z ratio *i.e.* no more than 0.3 min, while the new IDT compound peak three has a large retention time difference than the corresponding known IDT with the same m/z ratio *i.e.* 1 minute. Each peak showed the characteristic MS² fragments of early- and mid-pathway IDTs (Table 3.5, and Appendix 5).

The new IDT compound three was further investigated (Method 2.3.19 and 2.3.21). This analysis produced characteristic 130 m/z , 420 m/z , and 402 m/z daughter ions confirming this peak was an IDT compound. By comparing the fragmentation patterns of paxitriol and terpendole E whose structures are known and have the same multiple reaction monitoring (MRMs) a tentative structure for this new IDT compound three peak was proposed. The new IDT compound three is not a stereoisomer of either paxitriol and terpendole E as though the MRMs is the same and retention times differ (a characteristic of some stereoisomers) the fragmentation pattern differs (a characteristic of a constitutional isomer) (Figure 3.8, 3.9, 3.10, and Appendix 6, 7, and 8)

3.1.4 New indole-diterpene compound three synthesis through *Penicillium paxilli* complementation

Bioinformatics analysis suggested that the genes *idtP* and *idtQ* from AR48 and Fg1 encode the proteins that are most likely to be responsible for the synthesis of the new IDT compound three (Results 3.1.1). To understand this synthetic pathway, *Penicillium paxilli* single gene knock-out strains $\Delta paxP$ and $\Delta paxQ$ (Saikia *et al.*, 2007) were transformed with either *idtP* from *P. paxilli* (pSS1) (Saikia *et al.*, 2007), AR48 (pTM06), and Fl1 (pSS56/pDB49) (Saikia *et al.*, 2012) or *P. paxilli* (pSS2) (Saikia *et al.*, 2007), *idtQ* from AR48 (pTM07), and Fl1 (pSS58/pDB49) (Saikia *et al.*, 2012) (Method 2.3.9, and Appendix 9 to 15). Spore stocks of a representative number of these hygromycin or geneticin transformants were prepared, and PCR screened for the presence of the transformed gene for IDT analysis using MS (Method 2.3.5, 2.3.10, 2.3.18, 2.3.20, 2.3.22, 4.2.21, and 2.4.22, and Appendix 17).

The IDT profiles of all the controls were as expected. For the *P. paxilli* WT control paspaline, post paspaline products (paspaline B, paxitriol, PC-M6, and 13-desoxypaxilline) and paxilline were detected. This IDT profile was mirrored for both the *paxP* and *paxQ* complementation controls. For the AR48 *idtP* or Fl1 *idtP* complementations into *P. paxilli* $\Delta paxP$, paspaline accumulated therefore the paxilline biosynthesis pathway was not restored. For the AR48 *idtQ* or Fl1 *idtQ* complementations into *P. paxilli* $\Delta paxQ$, 13-desoxypaxilline accumulated therefore the paxilline biosynthesis pathway as not restored. In addition, no new IDT compound three or other new IDT compounds were detected in extracts of only the AR48 *idtP* and *idtQ* complementations (Table 3.3 and 3.4, Figure 3.11, and Appendix 17).

Chapter three: Results

Table 3.2: Mass spectrometry indole-diterpene (IDT) compound profiles of extracts from ryegrass pseudostem infected with different *Epichloë festucae* strains (ppm).

Sample Name	Retention Time (min)	F11	CT	AR1	AR37	AR48	Fg1
Paspaline		108	63	157	39	1179	192
Terpendole F		7	3	8	2	1	0
One <u>Terpendole E-like</u>	10.3	0	0	0	0	5	1
Terpendole E	10.5	11	9	20	12	0	0
Paspaline B		3	2	3	2	99	9
Two <u>13-Desoxypaxilline-like</u>	11.8	0	0	0	0	23	23
13-Desoxypaxilline	12.1	9	5	15	2	130	30
Paxilline		2	2	9	2	91	31
Three <u>Paxitriol-like</u>	11.9	NA	NA	NA	NA	NA	NA
Paxitriol	10.0	7	7	12	11	2	1
Terpendole I	8.6	32	20	79	41	2	1
Four <u>Terpendole G-like</u>	8.7	0	1	2	1	27	2
Terpendole G		4	4	4	2	0	0
Terpendole C		13	36	39	2	0	0
Terpendole K		31	85	90	1	0	0
Terpendole M (?)		74	85	106	9	0	0
Terpendole A (?)		23	25	31	9	0	0
Terpendole N		186	276	521	5	0	0
Lolilline		312	17	0	0	0	0
Lolicine A	11.1	117	36	0	0	0	0
Lolitrem M	10.25	348	89	0	0	0	0
Lolitriol		3856	365	0	0	0	18
Lolitrem K		160	50	0	0	0	410
Lolitrem E		211	75	0	0	0	0
Lolitrem B		901	1000	0	0	0	0
Lolitrem A		194	83	0	0	0	0
Lolitrem N		0	0	0	0	0	0
Lolitrem F		43	50	0	0	0	0
Epoxy-Janthitriol		0	0	0	1704	0	0
Epoxy-Janthitrem I		0	0	0	3	0	0
Epoxy-Janthitrem II		0	0	0	429	0	0
Epoxy-Janthitrem III		0	0	0	170	0	0
Epoxy-Janthitrem IV		0	0	0	169	0	0

Underlined name: unknown peak with different retention time but same m/s as known IDT. (?): compound without standard. NA: not assessed. The stereochemistry of the compounds and standards are unknown.

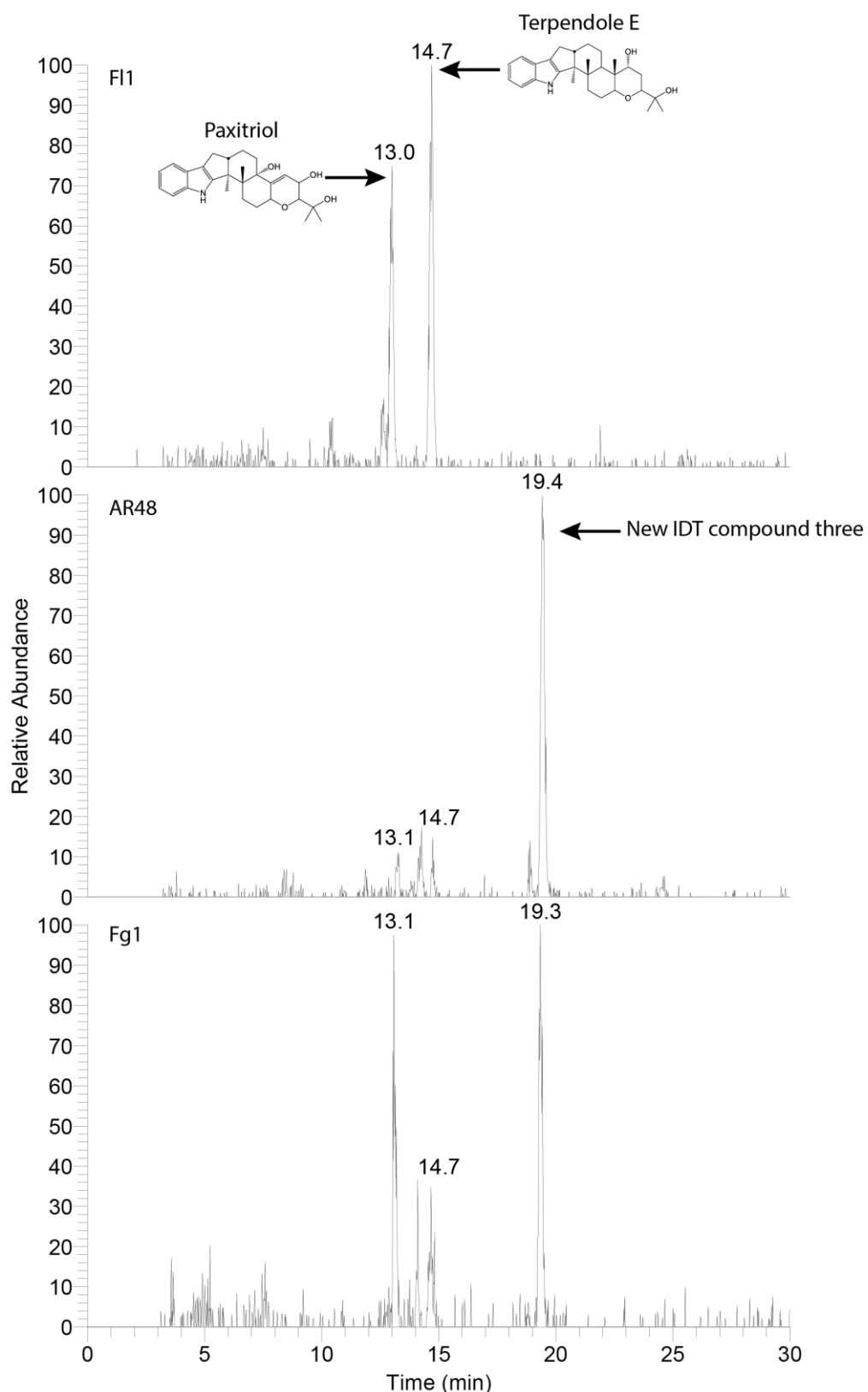


Figure 3.7: Liquid chromatography mass spectrometry (LC-MS) analysis of indole-diterpenes (IDTs) from *Epichloë festucae* infected ryegrass. Single ion extracted (438 m/z) chromatograms of FI1, AR48, and Fg1. Key ions are paxitriol (13.1 mins), terpendole E (14.7 mins), and new IDT compound three (19.3 mins), with the compound structure and name where known placed beside the corresponding peak. The stereochemistry of the compounds and standards are unknown.

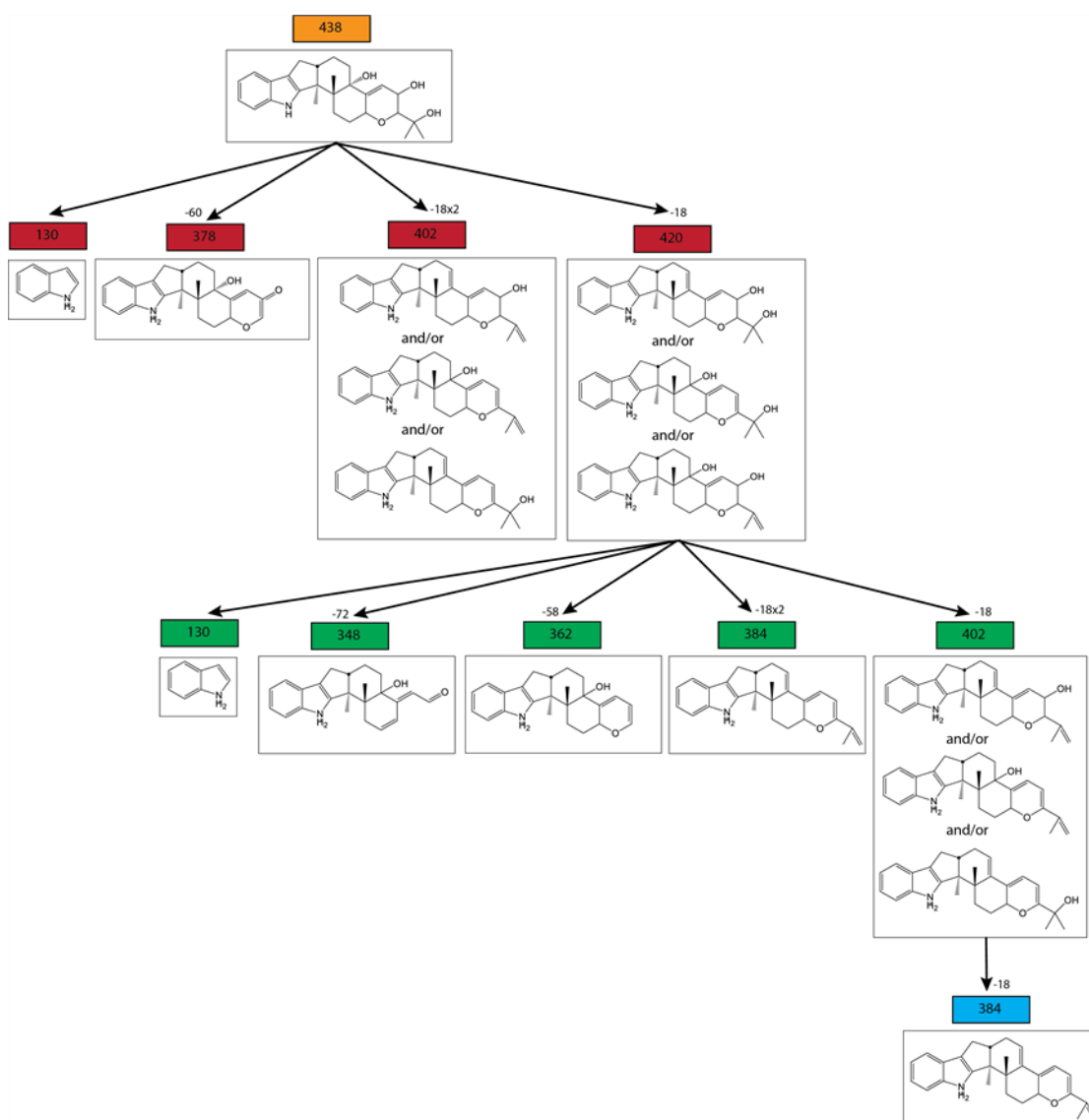


Figure 3.8: Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of paxitriol from *Epichloë festucae* FI1 infected ryegrass. Collision-induced fragmentation of the 438 m/z parent ion results in key ions 420 m/z (loss of H_2O), 402 m/z (loss of two H_2O), 378 m/z (loss of $\text{C}_3\text{H}_8\text{O}$) and 130 m/z (core fragment for early- and mid-pathway IDTs). Collision-induced fragmentation of the 420 m/z MS^2 daughter ion results in key ions 402 m/z (loss of second H_2O), 384 m/z (loss of second and third H_2O), 362 m/z (loss of $\text{C}_3\text{H}_6\text{O}$), 348 m/z (loss of $\text{C}_4\text{H}_8\text{O}$) and 130 m/z (core fragment). Collision-induced fragmentation of the 402 m/z MS^3 daughter ion results in a third H_2O loss to afford the 384 m/z ion. The stereochemistry of the compounds and standards are unknown.

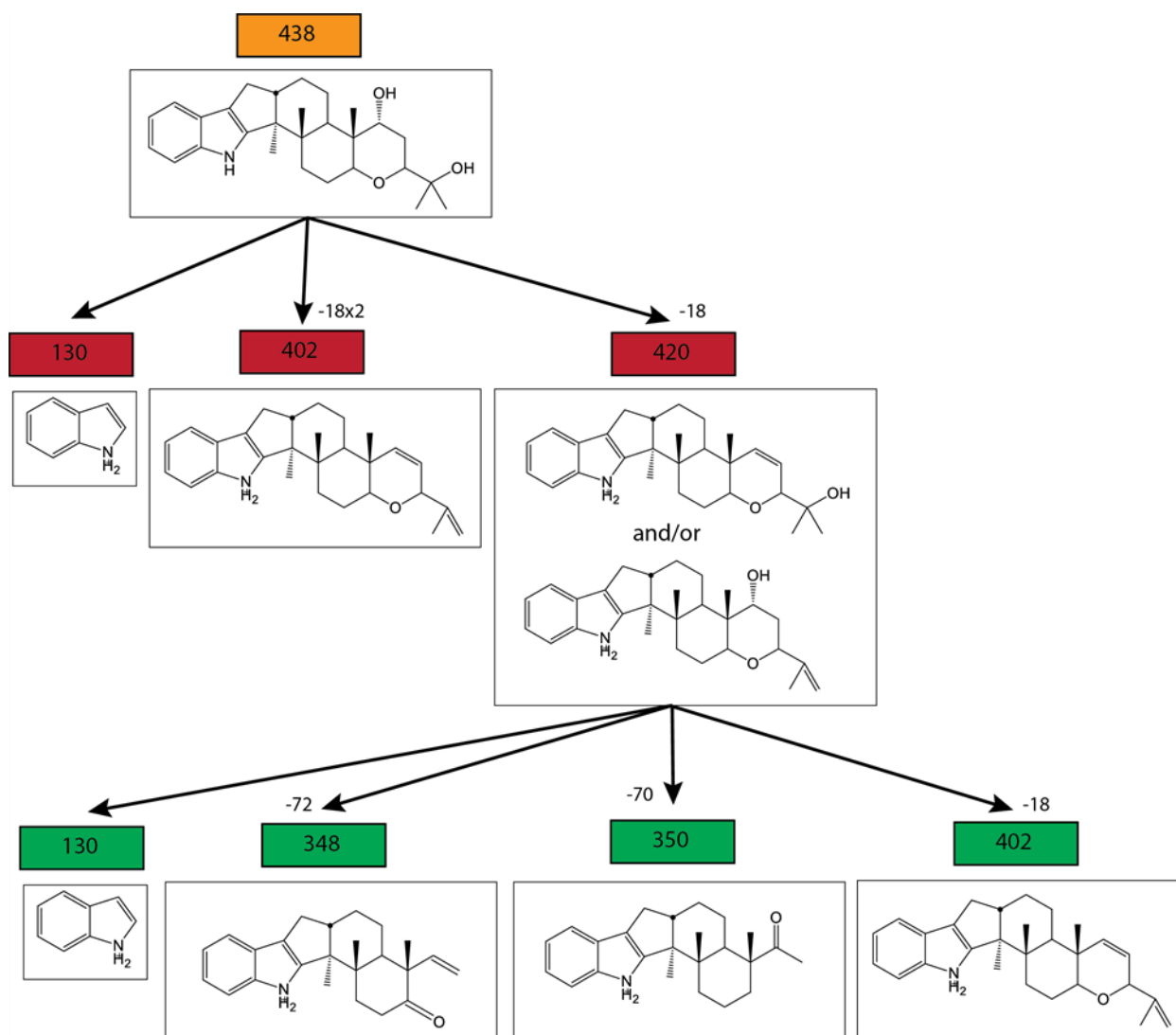


Figure 3.9: Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of terpendole E from *Epichloë festucae* FI1 infected ryegrass. Collision-induced fragmentation of the 438 m/z parent ion results in key ions 420 m/z (loss of H_2O), 402 m/z (loss of two H_2O) and 130 m/z (core fragment for early- and mid-pathway IDTs). Collision-induced fragmentation of the 420 m/z MS² daughter ion results in key ions 402 m/z (loss of second H_2O), 350 m/z (loss of C_4H_6O), 348 m/z (loss of C_4H_8O) and 130 m/z (core fragment). The stereochemistry of the compounds and standards are unknown.

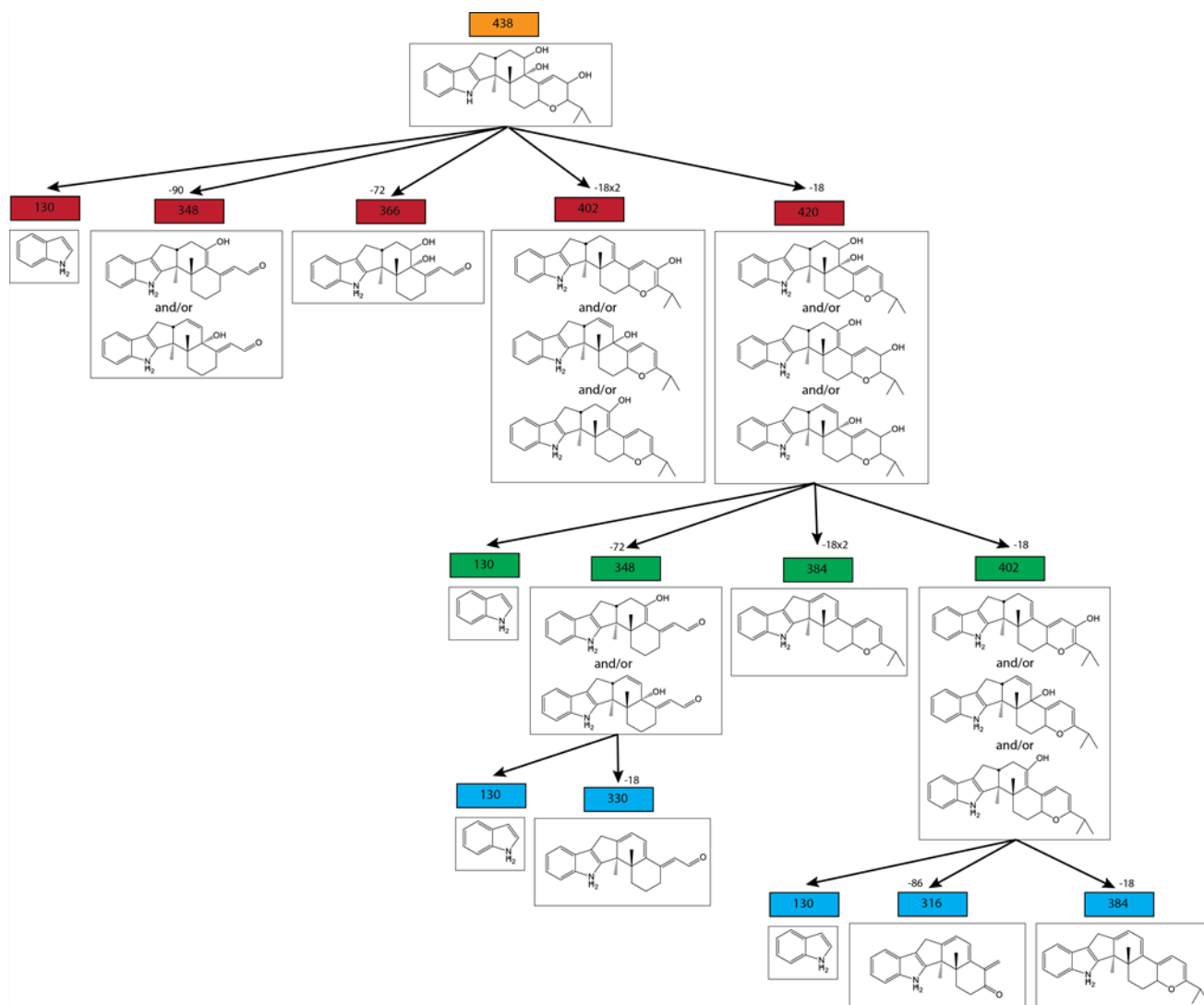


Figure 3.10: Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of new indole-diterpene compound three from *Epichloë festucae* AR48 and Fg1 infected ryegrass. Collision-induced fragmentation of the 438 m/z parent ion results in key ions 420 m/z (loss of H_2O), 402 m/z (loss of two H_2O), 366 m/z (loss of $\text{C}_4\text{H}_8\text{O}$), 348 m/z (loss of H_2O and $\text{C}_4\text{H}_8\text{O}$) and 130 m/z (core fragment for early- and mid-pathway IDTs). Collision-induced fragmentation of the 420 m/z MS^2 daughter results in key ions 402 m/z (loss of second H_2O), 384 m/z (loss of second and third H_2O), 348 m/z (loss of $\text{C}_4\text{H}_8\text{O}$) and 130 m/z (core fragment). Collision-induced fragmentation spectrum of the 348 m/z MS^3 daughter ion results in key ions of 330 m/z (loss of second H_2O) and 130 m/z (core fragment). Collision-induced fragmentation spectrum of the 402 m/z MS^3 daughter ion results in key ions 384 m/z (loss of third H_2O), 316 m/z (loss of $\text{C}_5\text{H}_{10}\text{O}$) and 130 m/z (core fragment). The stereochemistry of the compounds and standards are unknown.

Chapter three: Results

Table 3.3: Average intensity of indole-diterpene (IDT) compounds identified in *Penicillium paxilli* wild type, $\Delta paxP$ (KO-knock-out), and $\Delta paxP$ complemented with *paxP* from *Penicillium paxilli* or *idtP* from *Epichloë festucae* strains AR48 or FI1 (ppm). The stereochemistry of the compounds and standards are unknown.

IDT	Emindole SB	Paspaline	Paspaline B	Paxitriol	PC-M6	13-Desoxypaxilline	Paxilline	Prenyl-Paxilline
WT	18	38	8	3	33	10	26	1
$\Delta paxP$ KO	3	91	0	0	0	0	0	0
<i>Pax paxP</i>	1 7	105	1	1	64	1	19	2
	2 1	59	1	0	19	0	19	1
	3 17	135	1	1	55	2	20	1
	4 14	123	0	1	68	2	18	0
	5 13	103	1	1	46	6	24	1
AR48 <i>idtP</i>	1 2	108	0	1	1	3	0	0
	2 2	127	0	0	4	0	1	0
	3 1	93	0	0	1	0	0	0
	4 1	78	0	0	1	0	0	0
	5 0	102	0	1	4	0	1	0
FI1 <i>idtP</i>	1 0	0	0	0	0	0	1	0
	2 9	3	2	0	2	17	0	0
	3 0	2	0	0	0	0	0	0
	4 2	38	0	0	1	0	0	0
	5 0	59	0	0	2	0	0	0

Chapter three: Results

Table 3.4: Average intensity of indole-diterpene (IDT) compounds identified in *Penicillium paxilli* wild type, $\Delta paxQ$ (KO-knock-out), and $\Delta paxQ$ complemented with *paxQ* from *P. paxilli* or *idtQ* from *Epichloë festucae* strains AR48 or FI1 (ppm). The stereochemistry of the compounds and standards are unknown.

IDT	Emindole SB	Paspaline	Paspaline B	Paxitriol	PC-M6	13-Desoxypaxilline	Paxilline	Prenyl-Paxilline
WT	18	38	8	3	33	10	26	1
<i>paxQ</i> KO	13	18	2	1	10	22	0	0
<i>Pax paxQ</i>	1 2	4	0	0	3	0	19	0
	2 1	2	0	0	3	0	16	0
	3 1	3	0	0	3	0	15	0
	4 5	17	1	1	11	1	23	1
	5 1	2	0	0	0	0	4	0
AR48 <i>idtQ</i>	1 24	28	0	1	19	18	1	0
	2 17	20	2	1	15	20	1	0
	3 13	11	2	0	9	20	1	0
	4 8	6	2	0	7	19	1	0
	5 0	1	2	0	1	14	1	0
FI1 <i>idtQ</i>	1 1	3	1	0	4	12	1	0
	2 0	0	0	0	0	0	0	0
	3 3	14	1	1	7	18	1	0
	4 5	8	0	1	14	16	0	0
	5 23	35	2	0	20	26	1	0

Chapter three: Results

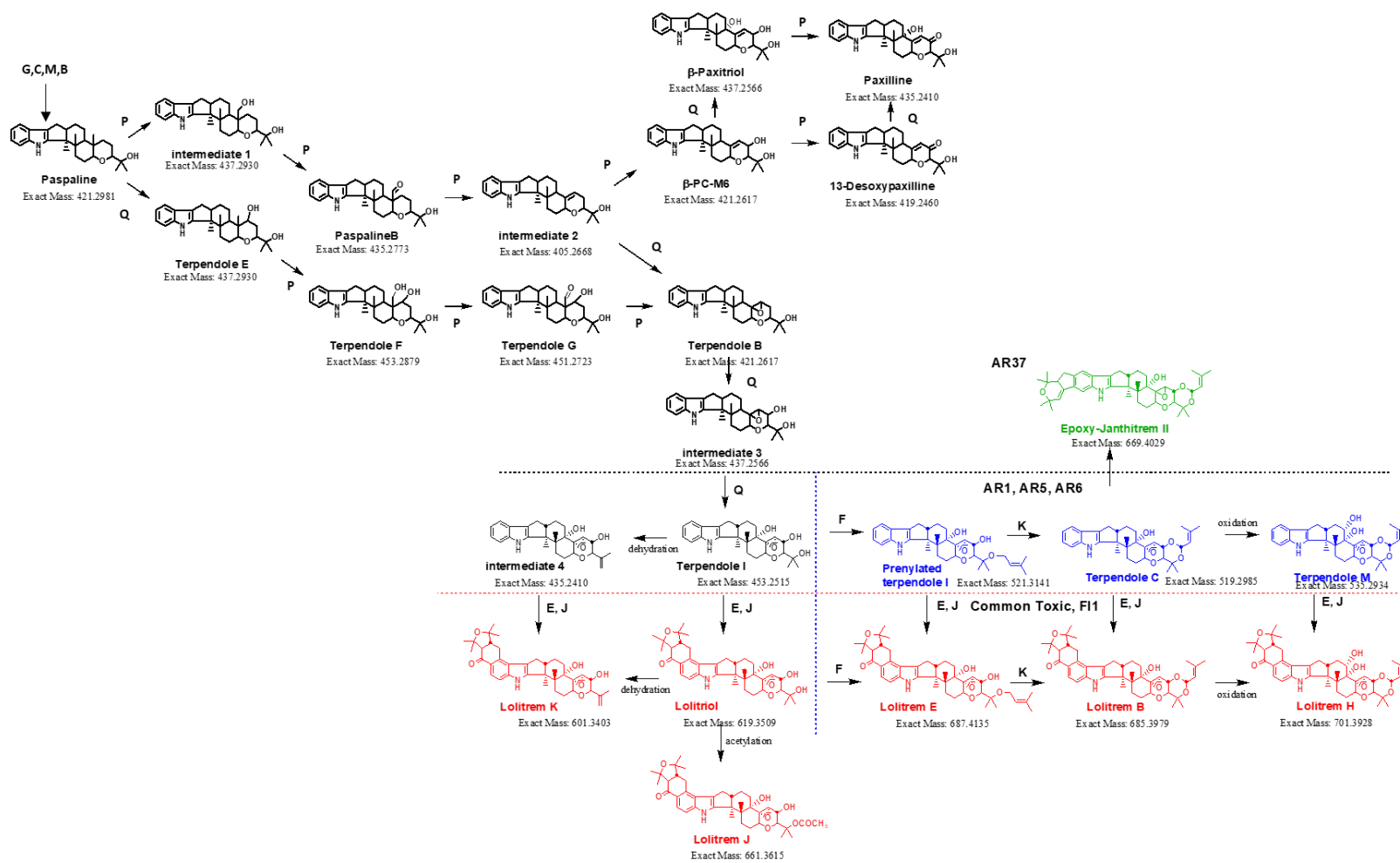


Figure 3.11: Simplified lolitrem B pathway in *Epichloë*. Genes (single letter *e.g.* indole-diterpene (IDT) = *idtP* = P) next to associated reaction. The section containing the end products of a strain is indicated. P/Q derived IDTs (black). E/J derived IDTs (red). F/K derived IDTs (blue/red). Epoxy-janthitrem IDT (green).

3.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass

Only a set number of compounds from the known bioactive second metabolite (SM) pathways currently identified in *Epichloë* (indole-diterpenes (IDTs), lolines, ergot alkaloids and peramine) can explain the wide range of insect bioactivities observed in infected plant material (Introduction 1.1 and 1.2). Understanding the genetic basis of all these bioactivities *i.e.* new gene and/or compound identification is crucial for development of the *Epichloë* commercialisation programme.

Ambrose *et al.* (2014) linked the presence of the makes caterpillars floppy (*mcf*) gene to cutworm moth caterpillars (CC-*Agrotis ipsilon*) bioactivity by injecting *E. coli* expressing the *mcf* gene from the sexual *E. typhina* subsp *Poa* *Ps1* strain into CC which resulted in death, most likely through activation of apoptosis via the mitochondrial pathway (Introduction 1.4). The product of this gene is therefore a good candidate for CC bioactivity observed in AR48 Infected ryegrass, which of the known bioactive SM pathways only produces intermediate IDT from the lolitrem B pathway (Results 3.1). The bioactivity of *mcf* might extend to stem boring fly (SBF-*Cerodontha australis*) bioactivity depending on the host bioactivity range of the protein (Introduction 1.1.3).

3.2.1 Analysing the distribution and functionality of the *mcf* gene within the *Epichloë festucae* species through bioinformatics

A comparative analysis of the *mcf* gene across *Epichloë* was performed using bioinformatics to understand both the distribution and functionality of the gene, and how this might relate to CC bioactivity (Method 2.4.1). If the presence of a functional *mcf* gene is found only in strains with CC bioactivity, and conversely the presence of a non-functional gene or absence of the gene is found only in strains with no CC bioactivity, this will provide further supporting evidence that Mcf could be responsible for this insect bioactivity. The *E. typhina* subsp *Poa* *Ps1* *mcf*, referred to as “*E. typhina* *mcf* model”, from Ambrose *et al.* (2014) was used as the gene model and

corresponding protein model as there is experimental evidence supporting both the gene's structure *e.g.* DNA and cDNA sequencing, as well as resultant protein bioactivity, *e.g.* expression levels and artificial CC insect assay (Ambrose *et al.*, 2014).

The initial analysis focused on strains from the species *E. festucae* as the CC bioactivity status of most of these strains was known and the genomes had been sequenced (Introduction 1.1.3). All strains analysed contained a single *mcf* gene. Only AR48 and Fg1 contained *mcf* genes with both the *E. typhina mcf* model gene introns as well as the start and stop codons conserved. The remaining strains have either lost the *E. typhina mcf* model gene start codon along with the first intron but have an in frame start codon soon afterwards (F11, E2368, and AR37) or contain an out of frame premature stop codon due to acquisition of a mutation, *e.g.* 23-nucleotide deletion (AR1). An alignment of all these genes identified that most of the variation in sequence occurred at the 5' end (Figure 3.12, and Appendix 18).

These gene annotations, identified through the bioinformatics analyses, were used to predict the corresponding protein products (Method 2.4.1). Only AR48 and Fg1 are predicted to produce a protein product that is similar to the *E. typhina* Mcf model protein. F11, E2368, and AR37 are predicted to produce proteins without the N-terminal region of the *E. typhina* Mcf model protein, and AR1 is predicted to produce a protein without the C-terminal region of the *E. typhina* Mcf model protein. An alignment of all these proteins identified that most of the variation in sequence occurred at the C-terminal end (Figure 3.12, and Appendix 19).

3.2.2 Analysing the distribution and functionality of the *mcf* gene within the *Epichloë* genus through bioinformatics

If *mcf* is responsible for CC bioactivity then understanding the distribution and functionality of this gene not just within *E. festucae* species, but also within the *Epichloë* genera could identify other strains of commercial interest. These newly identified strains may have other bioactivities of interest that are not present in AR48, therefore these strains could be more ideal for commercialisation and/or for the commercialization of products with variable bioactivity ranges.

Chapter three: Results

In total, an additional 14 *Epichloë* strains were analysed from 11 *Epichloë* species (Method 2.4.1). No hybrid strains were analysed. Again all strains contained a single *mcf* gene. Both *E. amarillans* strains, *E. aotearoae*, *E. brachyelytri*, one *E. bromicola* AL04262 strain, *E. glyceriae*, and *E. mollis*, had *mcf* genes with both introns of the *E. typhina mcf* model gene as well as the start and stop codons conserved, *i.e.* 50% of the strains. The remaining strains had either an out of frame premature stop codon due to acquisition of a mutation (*E. bromicola* AL0434, *E. elymi*, *E. gansuensis*, and *E. typhina* subsp. *Poa* E5819), had lost the *E. typhina mcf* model gene stop codon but had an in frame stop codon soon afterwards (*E. baconii*) or lost the start codon corresponding to the *E. typhina mcf* model gene along with the first intron but had an in frame start codon soon afterwards (*E. typhina* ATC 200736). An alignment of all these genes identified variation in sequence throughout the gene (Figure 3.13, and Appendix 20).

E. amarillans strains, *E. aotearoae*, *E. brachyelytri*, *E. bromicola* AL04262 strain, *E. glyceriae*, and *E. mollis*, all contain genes annotated like the *E. typhina mcf* model gene and therefore are predicted to produce proteins that are similar to the *E. typhina* Mcf model protein. *E. bromicola* AL0434, *E. elymi*, *E. gansuensis*, and *E. typhina* subsp. *Poa* E5819, are predicted to produce protein products with the N-terminal region of the *E. typhina* Mcf model protein present but with varying degrees of the central and C-terminal regions of the *E. typhina* Mcf model protein present. *E. baconii* is predicted to produce a protein product that is very similar to the *E. typhina* Mcf model protein but with a slight extension at the C-terminal end. Finally, *E. typhina* ATC 200736 is predicted to produce a protein product without the N-terminal region of the *E. typhina* Mcf model protein. Alignment of all these proteins identified that most of the variation in sequence occurred at both the N- and C- terminal ends (Figure 3.13, and Appendix 21).

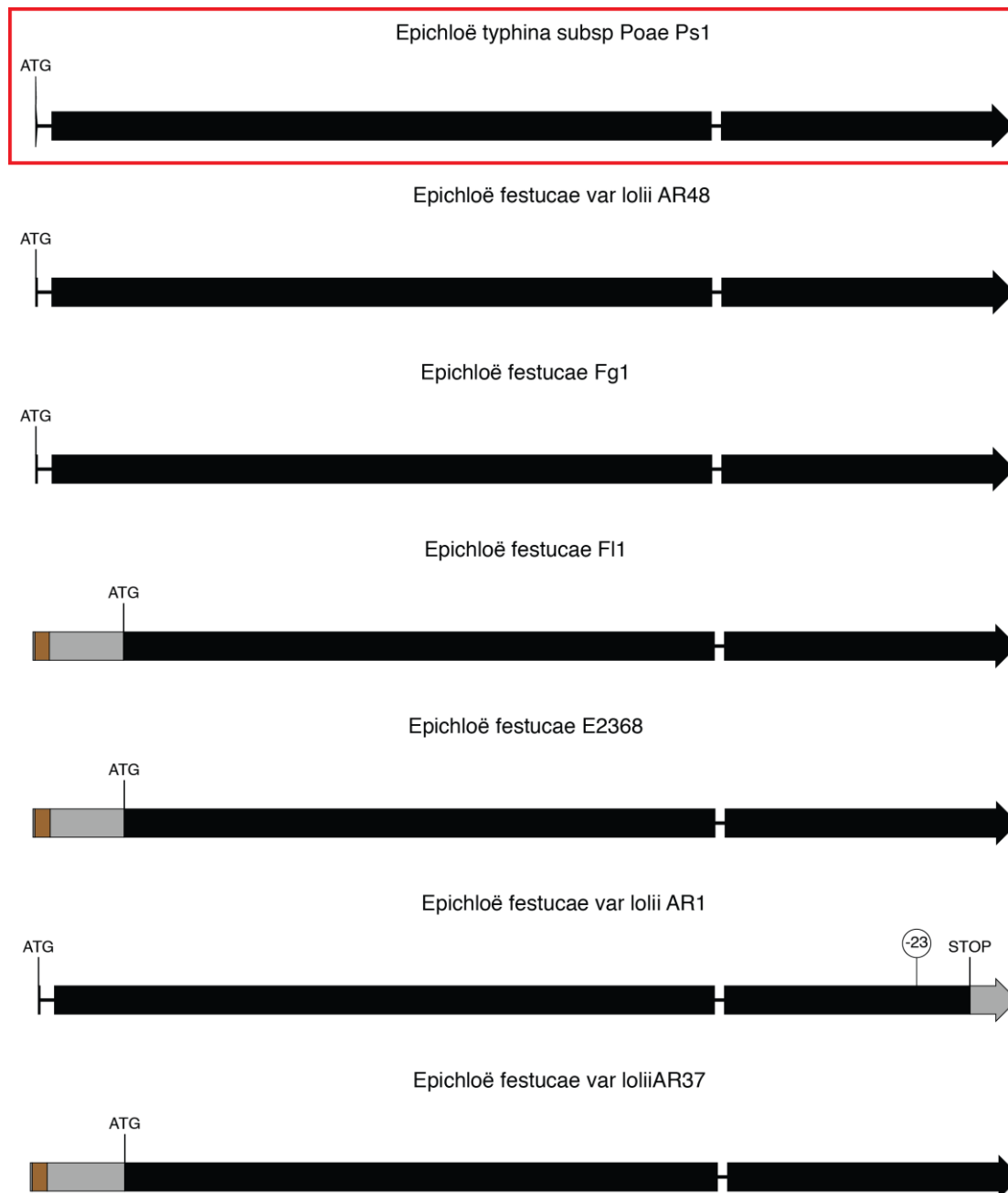
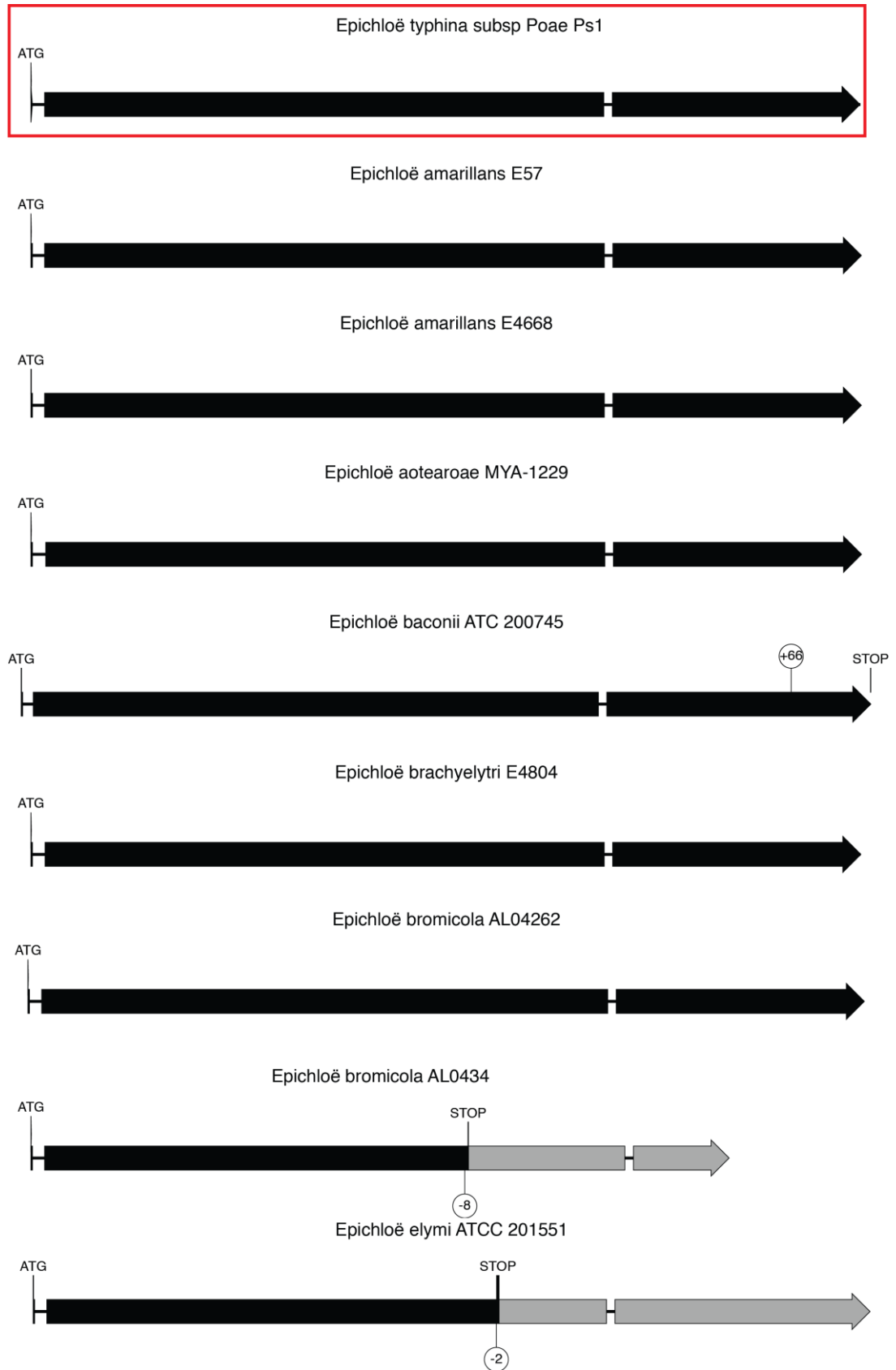


Figure 3.12: Analysis of the predicted makes caterpillars floppy (*mcf*) gene structure in a range of *Epichloë festucae* strains. The *E. typhina* gene model is highlighted in a red box (Ambrose *et al.*, 2014). The gene is represented by a solid line, with transcript overlaid as an arrow with gaps as introns, black sections as translated regions and grey sections as not translated regions. The brown boxes highlight sequences conserved with intron 1 in *E. typhina* model gene but no longer function as an intron due to mutations. Nucleotide changes are represented by circles, with the number as well as insertion (+) or deletions (-) inside the shape. The start codons are annotated.

Chapter three: Results



Chapter three: Results

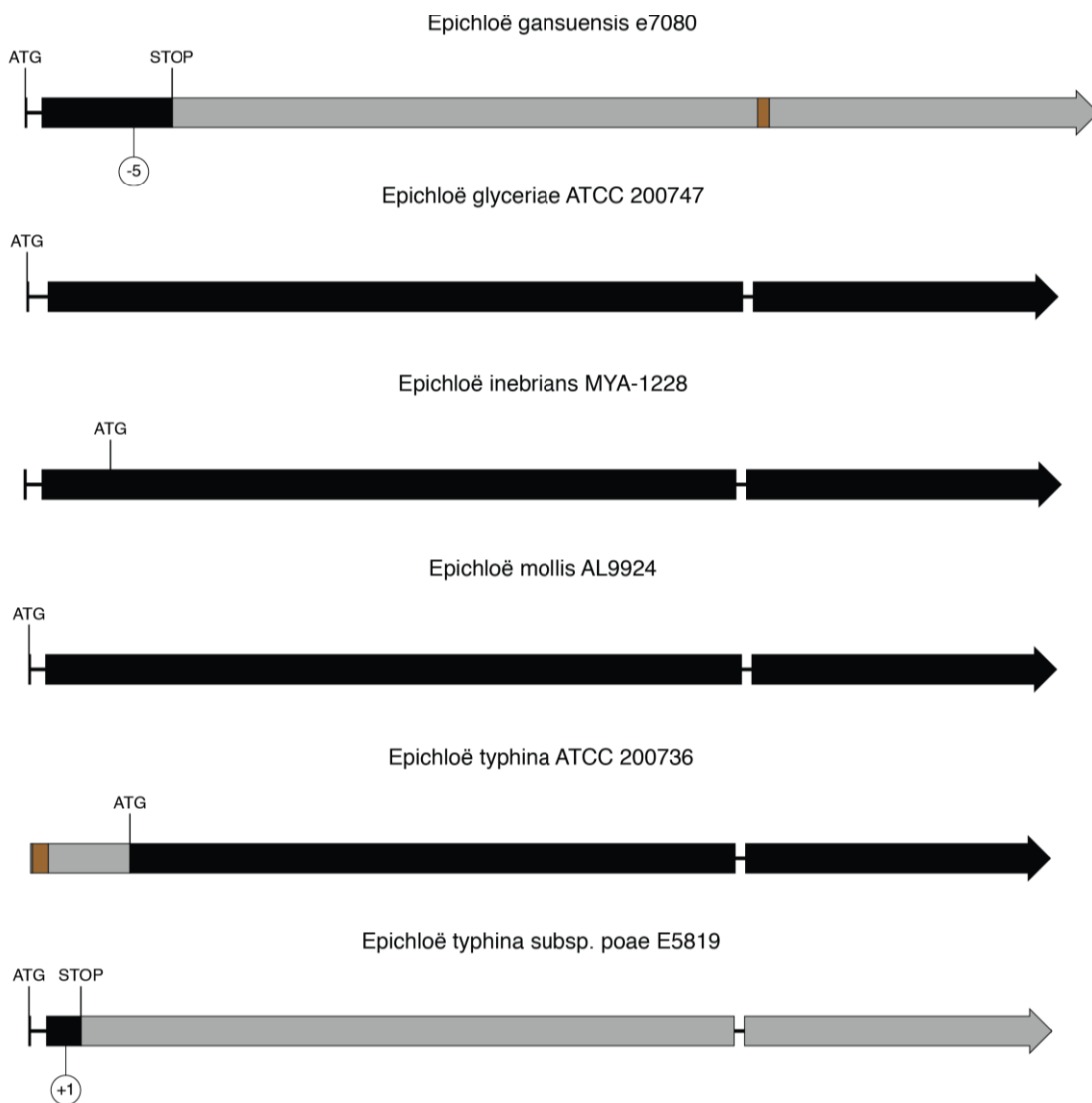


Figure 3.13: Analysis of the predicted makes caterpillars floppy (*mcf*) gene structure in a range of *Epichloë* species. The *E. typhina* gene model is highlighted in a red box (Ambrose *et al.*, 2014). The gene is represented by a solid line, with transcript overlaid as an arrow with gaps as introns, black sections as translated regions and grey sections as not translated regions. The brown boxes highlight sequences conserved with the intron in *E. typhina* model gene but no longer functional as an intron due to mutations. Nucleotide changes are represented by circles, with the number as well as insertion (+) or deletions (-) inside the shape. The start codons are annotated.

3.2.3 Analysing the location of the *mcf* gene within the *Epichloë* genus through bioinformatics

The expression of only the *E. typhina mcf* model gene under an inducible promoter in *E. coli* successfully established CC bioactivity (Ambrose *et al.*, 2014). The bioactive is therefore produced by a single gene *i.e.* does not require additional genes for synthesis and/or is not modified by additional genes. This is also observed for the bacterial Mcf proteins however these genes are associated/cluster with other genes involved in transportation and/or transcription regulation (Daborn *et al.*, 2002, Péchy - Tarr *et al.*, 2008, Waterfield *et al.*, 2003). Bioinformatics analysis of the *mcf* gene genomic location was therefore performed on all strains analysed in this study to investigate whether the *Epichloë mcf* gene is within a cluster or associated with other important genes (Method 2.4.1)

The completely assembled FI1 genome, which has been annotated using the E2368 version 3 gene models (EfM3.0) as well as RNA sequencing data from a range of wild type (WT) and mutant strains, was used as the genome reference (Winter *et al.*, 2018, Schardl *et al.*, 2013c). The BLASTx analysis provided by the online database (Schardl *et al.*, 2013c) was used to identify the genes surrounding *mcf* as encoding for a cytokinesis inhibitor, tRNA methyltransferase, extracellular protein, cell wall protein, tRNA release factor, and hypothetical protein respectively (Figure 3.14).

The location of these FI1 *mcf* surrounding genes was then analysed in the *Epichloë* strains used in this study (Results 3.2.1 and 3.2.2). All strains contained all of the surrounding genes, although in some genomes the genes were spread across up to three scaffolds. This is due to fragmentation of the genome assemblies. Within each scaffold the orientation and order was conserved. The predicted functionality of each individual gene was not analysed (Figure 3.15).

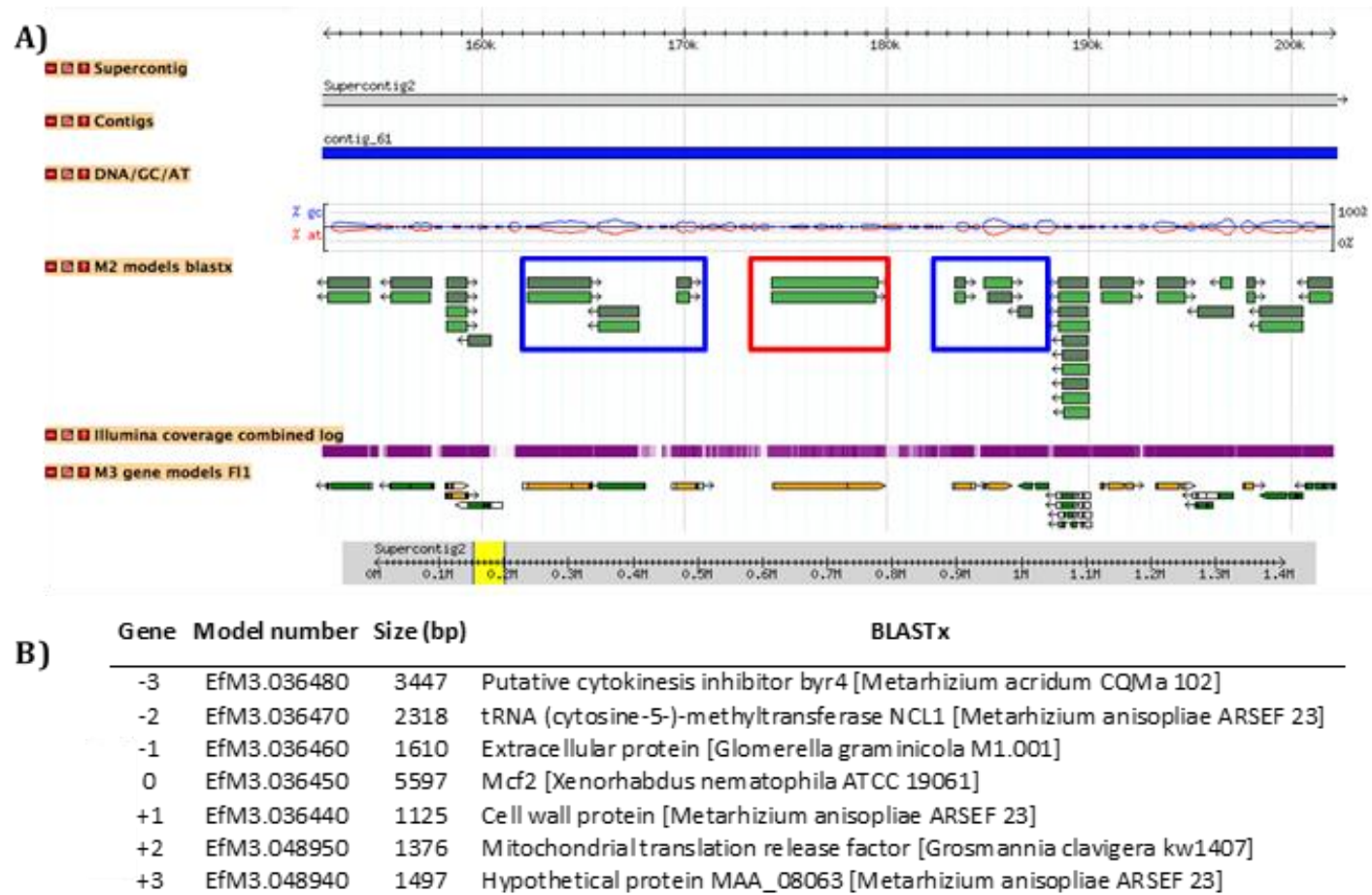


Figure 3.14: Identification of genes surrounding makes caterpillars floppy (*mcf*) within the *Epichloë festucae* FI1 genome of chromosome 7. A) Screenshot of a 50 kb genomic area around *mcf* EfM3.036450 (red box) with the following characteristics highlighted; GC content, BLASTx genes, Illumina RNAseq reads, and M3 models. The genes selected for further analysis are -3 EfM3.036480, -2 EfM3.036470, -1 EfM3.036460, +1 EfM3.036440, +2 EfM3.048950, and +3 EfM3.048940 (blue boxes). B) Table of the BLASTx hits and gene sizes of the selected genes in (A).

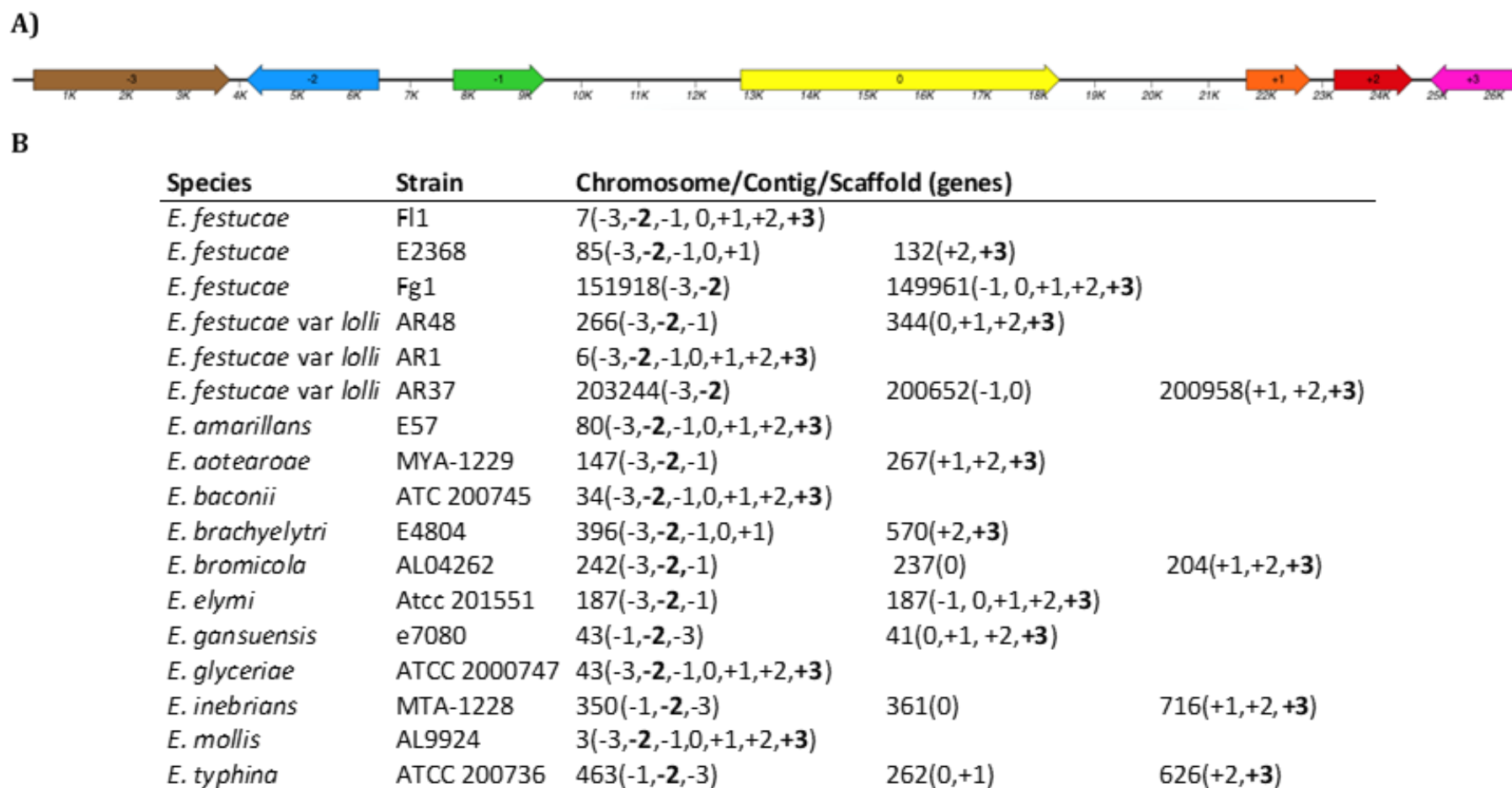


Figure 3.15: Analysis of makes caterpillars floppy (*mcf*) syntony in *Epichloë*. A) Schematic of the gene structure around *mcf* in *Epichloë festucae* FI1 genome of chromosome 7. B) Analysis of syntony from a range of *Epichloë* strains with chromosome/contig/scaffold indicated followed by gene present and order in brackets with orientation indicated by bold genes being on the reverse strand. Genes (-3 EfM3.036480, -2 EfM3.036470, -1 EfM 3.036460, 0 EfM3.036450 (*mcf*), +1 EfM3.036440, +2 EfM3.048950, and +3 EfM3.048940)

3.2.4 Analysing the distribution, functionality, and location of the *mcf* gene outside the *Epichloë* genus through bioinformatics

Outside *Epichloë*, *mcf*/*P. fluorescens* insect toxin (*fitD*) is commonly identified in bacterial species such as *Photorhabdus*, *Xenorhabdus*, and *Pseudomonas* (Ruffner *et al.*, 2015). To understand the full extent of the *mcf* gene distribution and functionality, bioinformatics was used to identify and then predict the functionality of *mcf* gene/s outside the *Epichloë* genus but within the fungal kingdom (Method 2.4.1).

NCBI searches using the model *E. typhina mcf* model gene and protein sequences did not identify any *mcf* genes in fungal genomes apart from *Epichloë*. However, Dupont (2017) identified four other fungal species with *mcf* genes: *Aspergillus flavus*, *Metarhizium* species, *Neonectria ditissima*, and *Phlebiopsis gigantea*. Unfortunately, the paper did not provide gene or genome reference identifiers and so the genes were identified by repeating their methodology *i.e.* the listed species were searched against the JGI MycoCom database to identify available strains, and then the *E. typhina* Mcf model protein sequence was analysed by tBLASTn against these strains. Only *N. ditissima* R0905 (NCBI accession KPM41439.1), and *P. gigantea* 11061_1 CR5-6 (NCBI accession KIP08609.1) genomes had *mcf* gene hits while *A. flavus* NRRL3357, *M. robertsii* ARSEF 23 and *M. acridum* CQMa 102 searches did not result in an obvious *mcf* gene hits (Figure 3.16).

These *mcf* genes from *N. ditissima* and *P. gigantea* were then annotated and corresponding proteins predicted (Method 2.4.1). The *N. ditissima mcf* gene is slightly larger than the *E. typhina mcf* model gene (6,145 bp) at 6,334 bp with one intron, which is not conserved in *E. typhina mcf* model gene, and produces a 2,090 aa protein. The *P. gigantea mcf* gene is also slightly larger than *E. typhina mcf* model gene (6,145 bp), though smaller than *N. ditissima mcf* gene (2,090 bp), at 6,264 bp with two introns, which are both conserved in *E. typhina mcf* model gene, and produces a 2,048 aa protein. When the two *mcf* genes and predicted proteins were aligned to the *E. typhina mcf* model gene and Mcf model protein sequences, *P. gigantea* and *E. typhina* model had the highest gene and protein sequence identities (55.3% and 39.5% respectively) then *N. ditissima* and *E. typhina* model (52.0% and 28.8% respectively).

Chapter three: Results

The *N. ditissima* gene and protein sequence was more similar to *E. typhina* model gene than *P. gigantea* (Figure 3.16, and Appendix 22).

The same bioinformatics analysis was performed using the six genes that have been identified surrounding *mcf* in the *Epichloë* to indicate if syntony has been conserved outside *Epichloë* genus (Method 2.4.1, and Results 3.2.3). *A. flavus* and *M. robertsii* both contained genes -3, -2, +2, and +3, with *M. robertsii* containing +1 in addition. The coverage (%) and identity (%) for all of these identified genes were at least 94% for both parameters, except for +2 *A. flavus* at 74% coverage and an E values of 0.0. For *N. ditissima* and *P. gigantean*, searches did not result in any obvious gene hits (Table 3.5).

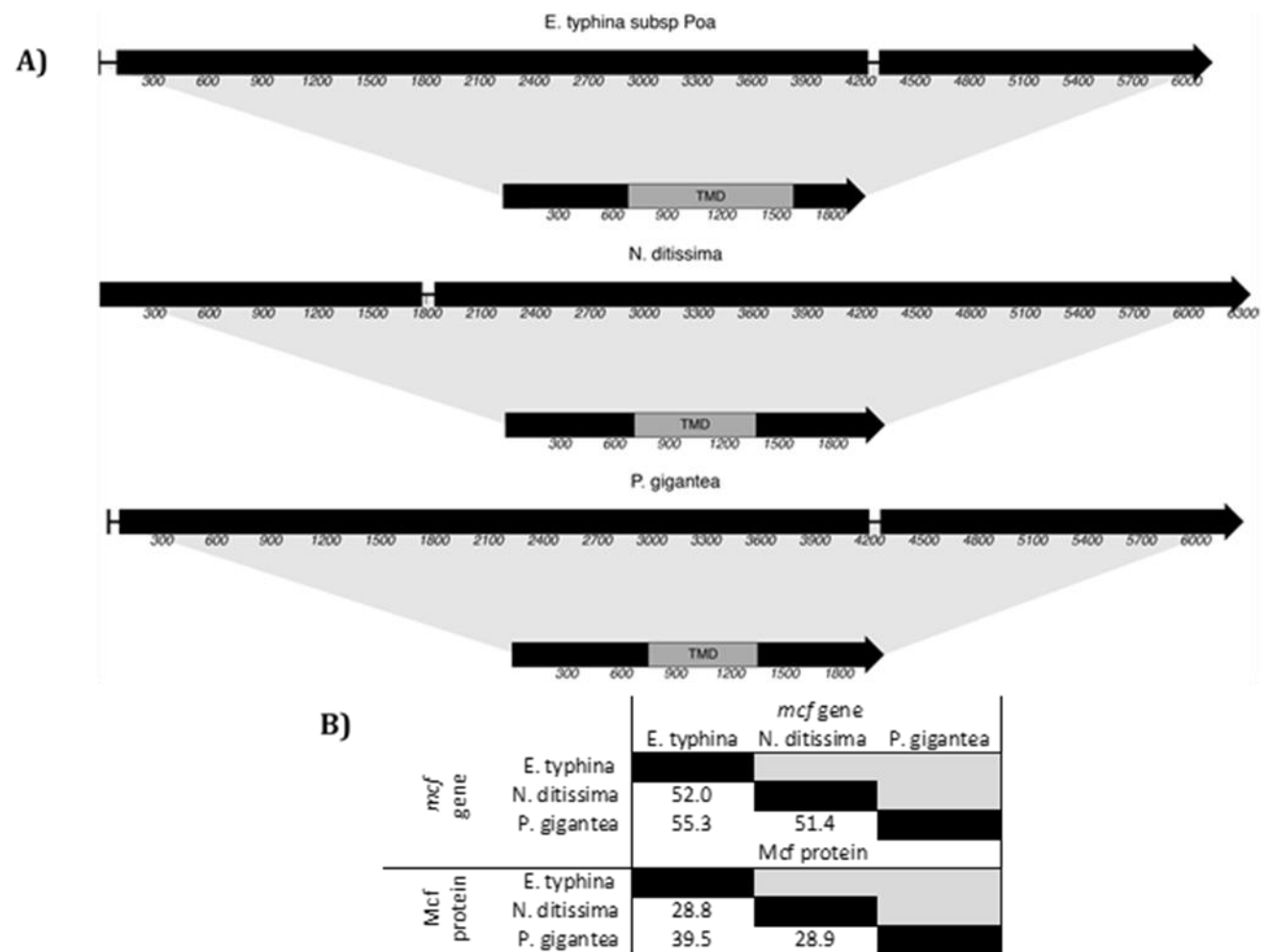


Figure 3.16: Identification of other fungal makes caterpillars floppy (*mcf*) genes outside *Epichloë*. A) Gene annotated for exons (black arrow) and introns (gaps) and translated protein (below) with domains predicted by InterPro scan (grey box). B) Pair wise alignments between *mcf* and Mcf like sequences with identity (%). Black box is an alignment between the same gene and grey box is a repeat alignment.

Chapter three: Results

Table 3.5: Location of makes caterpillars floppy (*mcf*) in the genomes of fungi outside the *Epichloë* genus using reference genes as location markers

Strain	Gene	Size (bp)	Location	Orientation	BLASTn(^)/BLASTp(*)	Coverage	Identity	E value
						(%)	(%)	
A. flavus ^	-3	3,004	AAIH02000400.1	N/A	Aspergillus flavus NRRL3357 cytokinesis regulator (Byr4), putative (AFLA_007210), partial mRNA	98	100	0.0
	-2	2,256	AAIH02000035.1	N/A	Aspergillus flavus NRRL3357 5-adenosylmethionine-dependent methyltransferase superfamily domain-containing protein (AFLA_024870), partial mRNA	100	100	0.0
	+2	1,597	AAIH02000334.1	N/A	Aspergillus bombycis peptide chain release factor 1 (ABOM_011014), partial mRNA	74	93	0.0
	+3	1,197	AAIH02000344.1	N/A	Aspergillus bombycis hypothetical protein (ABOM_009699), partial mRNA	91	94	0.0
M. anisopliae ^	-3	3,096	ADNJ02000001.1	+ve	Metarhizium robertsii ARSEF 23 cytokinesis regulator mRNA	100	100	0.0
	-2	1,980	ADNJ02000001.1	-ve	Metarhizium brunneum ARSEF 3297 tRNA (cytosine-5-)-methyltransferase NCL1 partial mRNA	100	99	0.0
	+1	885	ADNJ02000002.1	N/A	Metarhizium robertsii ARSEF 23 cell wall galactomannoprotein Mp2/allergen F17-like protein mRNA	100	100	0.0
	+2	1,253	ADNJ02000004.1	+ve	Metarhizium robertsii ARSEF 23 Peptide chain release factor class I/class II mRNA	96	100	0.0
	+3	1,413	ADNJ02000004.1	-ve	Metarhizium robertsii ARSEF 23 hypothetical protein mRNA	94	100	0.0
N. ditissima *	0	2,090	-	N/A	Makes caterpillars floppy protein [Epichloe typhina subsp. poae]	89	31	0.0
P. gigantea *	0	2,048	-	N/A	Makes caterpillars floppy protein [Epichloe typhina subsp. poae]	97	40	0.0

Note: Genes (-3 efM3.036480, -2 efM3.036470, -1 efM 3.036460, 0 efM3.036450 (*mcf*), +1 efM3.036440, +2 efM3.048950, and +3 efM3.048940)

3.2.5 Analysing domain composition of Mcf/FitD proteins through bioinformatics

The *mcf* gene is present in all strains analysed throughout the *Epichloë* genera and in two other fungal species *N. ditissima* and *P. gigantean* as well as the bacterial species *Photorhabdus*, *Xenorhabdus*, and *Pseudomonas* (Results 3.2.1, 3.2.2, and 3.2.4) (Dowling & Waterfield, 2007). However, there are slight variations in gene annotations and therefore corresponding predicted protein products. To understand the functionality of these Mcf proteins, the domain composition from a selection of *Epichloë* strains as well as *N. ditissima* and *P. gigantean* were analysed using online tools that utilize either the primary (Pfam or InterPro Scan) or secondary (Phyre2 or Hhpred) protein structure (Method 2.4.1). In addition, a range of Mcf/FitD proteins from literature were included in this analysis as controls (Table 3.6).

Table 3.6: Characteristics of published Mcf/FitD proteins

Species	Bacteria (B)/ Fungus (F)	Protein	Size (a.a)	Domains	Reference
<i>Fungi</i>					
<i>Epichloë festucae</i> var <i>lolii</i> AR48	F	Mcf	1,992	CPD1/CPD2 /TMD	This study
<i>Epichloë festucae</i> Fl1	F	Mcf	1,844	CPD1/CPD2 /TMD	This study
<i>Neonectria ditissima</i>	F	Mcf	2,090	CPD1/CPD2 /TMD	This study
<i>Phlebiopsis gigantea</i>	F	Mcf	2,048	CPD1/CPD2 /TMD	This study
<i>Epichloë typhina</i> subsp <i>Poa</i> Ps1	F	Mcf	1,996	TMD	(Ambrose, Koppenhöfer et al. 2014)
<i>Bacteria</i>					
<i>Photorhabdus luminescens</i>	B	Mcf1	2,929	BH3/TMD/ RTX	(Dowling, Waterfield et al. 2007)
<i>Photorhabdus luminescens</i>	B	Mcf2	2,388	HRM/TMD/ RTX	(Waterfield, Daborn et al. 2003)
<i>Pseudomonas fluorescens</i>	B	FitD	3,003	GT/TMD	(Péchy-Tarr, Bruck et al. 2008)
<i>Vibrio vulnificus</i>	B	MCF-like domain	367	CPD/TMD	(Agarwal, Agarwal et al. 2015)

GT: Glycosyltransferase domain; CPD1/2: Cysteine protease domain 1 or 2; TMD:

Transmembrane domain, Mcf: makes caterpillars floppy, and fitD; *P. fluorescens* insect toxin

Chapter three: Results

Pfam and InterPro scan both predicted the presence of a central transmembrane domain (TMD) similar to the *Clostridium difficile* TcdA and TcdB TMD (pfam12920 and IPR024769) for all Mcf/FitD protein sequences, and at similar locations between each sequence and between tools. No other domains were predicted using either tool (Table 3.7 and Figure 3.17).

Table 3.7: Makes caterpillars floppy (Mcf)/ *P. fluorescens* insect toxin (FitD) protein domain predictions using online tools that predicts using primary protein structure.

Endophyte	Protein	Domain	Range (a.a)	Accession	E value
<i>Pfam</i>					
<i>E. festucae</i> var <i>lolii</i> AR48	Mcf	TcdA_TcdB_pore	703-1324	pfam12920	1.22E-174
<i>E. festucae</i> Fl1	Mcf	TcdA_TcdB_pore	555-1176	pfam12920	2.24E-173
<i>E. typhina</i> subsp <i>Poa</i> Ps1	Mcf	TcdA_TcdB_pore	701-1319	pfam12920	5.44E-151
<i>N. ditissima</i>	Mcf	TcdA_TcdB_pore	707-1328	pfam12920	2.46E-179
<i>P. gigantea</i>	Mcf	TcdA_TcdB_pore	706-1346	pfam12920	1.56E-120
<i>P. luminescens</i>	Mcf 1	TcdA_TcdB_pore	1616-2249	pfam12920	0.00E+00
<i>P. luminescens</i>	Mcf 2	TcdA_TcdB_pore	1011-1648	pfam12920	0.00E+00
<i>P. fluorescens</i>	FitD	TcdA_TcdB_pore	1618-2250	pfam12920	0.00E+00
<i>Interpro</i>					
<i>E. festucae</i> var <i>lolii</i> AR48	Mcf	TcdA_TcdB_pore	702-1353	IPR024769	N/A
<i>E. festucae</i> Fl1	Mcf	TcdA_TcdB_pore	554-1205	IPR024769	N/A
<i>E. typhina</i> subsp <i>Poa</i> Ps1	Mcf	TcdA_TcdB_pore	706-1357	IPR024769	N/A
<i>N. ditissima</i>	Mcf	TcdA_TcdB_pore	710-1383	IPR024769	N/A
<i>P. gigantea</i>	Mcf	TcdA_TcdB_pore	705-1354	IPR024769	N/A
<i>P. luminescens</i>	Mcf 1	TcdA_TcdB_pore	1617-2276	IPR024769	N/A
<i>P. luminescens</i>	Mcf 2	TcdA_TcdB_pore	1012-1675	IPR024769	N/A
<i>P. fluorescens</i>	FitD	TcdA_TcdB_pore	1619-2277	IPR024769	N/A

Both Phyre2 and Hhpred predicted the presence of the same central TMD as Pfam and InterPro Scan (c4r04A/4r04A) in all Mcf/FitD proteins, and at similar locations between each sequence and between tools. In addition, Phyre2 also predicted the presence of two N-terminal cysteine protease domains (CPD1 and CPD2) (d1hq0a and d1ukfa respectively) for all proteins, except for *E. festucae* Fl1 Mcf and *P. fluorescens* FitD which did not have a CPD1 predicted to be present. These domains are in similar

Chapter three: Results

locations between each protein sequence. The only other domain predicted to be present was a signalling domain (SD) (*Epichloë*: c3ilaG and *Photorhabdus*: c4rswB) that was identified at the C-terminus for *E. festucae* AR48 Mcf, at the C-terminus for *E. typhina* Mcf model, and at the N-terminus for *P. luminescens* Mcf2 (Table 3.8 and Figure 3.17).

Only the TMD was predicted for the control strains; *E. typhina* Mcf model, *P. fluorescens*, and *P. luminescens*. Literature also predicts BH3 (Bcl-2 domain three) domain, HrmA domain, RTX-like domains (Repeat-in-toxin), and glycosyltransferase domain for these proteins (Dowling & Waterfield, 2007). None of these domains were predicted during this bioinformatics analysis. However, the CPD1 and CPD2 were predicted to be present for these proteins and at a similar position as the literature predicted domains, except for *P. fluorescens* which did not have the CPD1 predicted to be present (Table 3.6, and 3.8, and Figure 3.17).

Chapter three: Results

Table 3.8: Makes caterpillars floppy (Mcf) and *P. fluorescens* insect toxin (FitD) protein domain predictions using online tools that predicts using secondary protein structure.

Endophyte	Protein	Domain	Range (a.a)	Model number	Confidence (%)	Coverage(%)	E value
<i>Phyre2</i>							
<i>E. festucae</i> var <i>lolii</i> AR48	Mcf	Clostridium difficile toxin a (tcda)	690-1597	c4r04A_	100	N/A	N/A
		Cysteine proteinases	546-632	d1ukfa_	96.9	N/A	N/A
		CNF1/YfiH-like putative cysteine hydrolases	14-137	d1hq0a_	85.1	N/A	N/A
		Signaling protein	1945-1966	c3ilaG_	48.6	N/A	N/A
<i>E. festucae</i> Fl1	Mcf	Clostridium difficile toxin a (tcda)	542-1449	c4r04A_	100	N/A	N/A
		Cysteine proteinases	399-484	d1ukfa_	96.8	N/A	N/A
<i>E. typhina</i> subsp <i>Poa</i> Ps1	Mcf	Clostridium difficile toxin a (tcda)	688-1601	c4r04A_	100	N/A	N/A
		Cysteine proteinases	551-643	d1ukfa_	96.4	N/A	N/A
		CNF1/YfiH-like putative cysteine hydrolases	34-136	d1hq0a_	93.2	N/A	N/A
		Signaling protein	1949-1968	c3ilaG_	56.7	N/A	N/A
<i>N. ditissima</i>	Mcf	Clostridium difficile toxin a (tcda)	675-1642	c4r04A_	100	N/A	N/A
		Cysteine proteinases	598-647	d1ukfa_	95.6	N/A	N/A
		CNF1/YfiH-like putative cysteine hydrolases	137-173	d1hq0a_	66.9	N/A	N/A
<i>P. gigantea</i>	Mcf	Clostridium difficile toxin a (tcda)	694-1598	c4r04A_	100	N/A	N/A
		Cysteine proteinases	560-623	d1ukfa_	96.3	N/A	N/A
		CNF1/YfiH-like putative cysteine hydrolases	103-142	d1hq0a_	89.2	N/A	N/A
<i>P. luminescens</i>	Mcf 1	Clostridium difficile toxin a (tcda)	1609-2532	c4r04A_	100	N/A	N/A
		Cysteine proteinases	1407-1551	d1ukfa_	91	N/A	N/A
		CNF1/YfiH-like putative cysteine hydrolases	1011-1050	d1hq0a_	67.3	N/A	N/A
<i>P. luminescens</i>	Mcf 2	Clostridium difficile toxin a (tcda)	1004-1931	c4r04A_	100	N/A	N/A
		Signaling protein	44-294	c4rswB_	100	N/A	N/A
		Cysteine proteinases	801-946	d1ukfa_	95.9	N/A	N/A
		CNF1/YfiH-like putative cysteine hydrolases	405-444	d1hq0a_	65.1	N/A	N/A
<i>P. fluorescens</i>	FitD	Clostridium difficile toxin a (tcda)	1611-2537	c4r04A_	100	N/A	N/A
		Cysteine proteinases	1465-1560	d1ukfa_	100	N/A	N/A
<i>Hhpred</i>							
<i>E. festucae</i> var <i>lolii</i> AR48	Mcf	Toxin A; Glucosyltransferase	438-1425	4R04_A	N/A	100	1.10E-103
<i>E. festucae</i> Fl1	Mcf	Toxin A; Glucosyltransferase	290-1277	4R04_A	N/A	100	1.60E-107
<i>E. typhina</i> subsp <i>Poa</i> Ps1	Mcf	Toxin A; Glucosyltransferase	442-1429	4R04_A	N/A	100	2.30E-107
<i>N. ditissima</i>	Mcf	Toxin A; Glucosyltransferase	470-1459	4R04_A	N/A	100	3.80E-114
<i>P. gigantea</i>	Mcf	Toxin A; Glucosyltransferase	439-1429	4R04_A	N/A	100	1.30E-107
<i>P. luminescens</i>	Mcf 1	Toxin A; Glucosyltransferase	1285-2344	4R04_A	N/A	100	6.30E-135
<i>P. luminescens</i>	Mcf 2	Toxin A; Glucosyltransferase	679-1743	4R04_A	N/A	100	4.90E-110
		HopA1; signaling protein	31-291	4RSW_A		99.9	5.30E-27
<i>P. fluorescens</i>	FitD	Toxin A; Glucosyltransferase	1287-2348	4R04_A	N/A	100	2.10E-135

Chapter three: Results

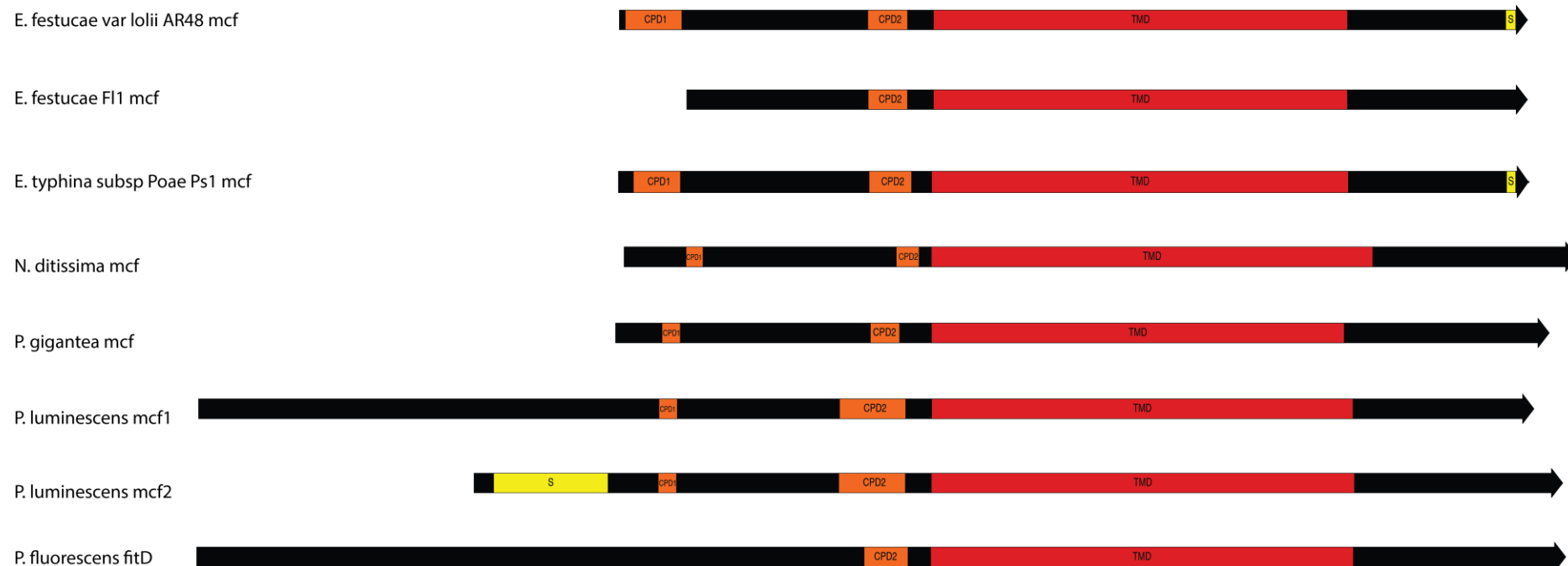


Figure 3.17: Domain analysis of makes caterpillars floppy (Mcf) and *P. fluoresces* insect toxin (FitD) proteins using online tools (Pfam, InterPro Scan, Phyre2 or Hhpred) in a range of species. Black arrow is the protein. Red box is domain/s predictions identified by all online tools. Orange box is domain/s predictions identified by some of the online tools. Yellow box is domain/s predictions identified by one online tool. CPD1/2: Cysteine protease domain 1 or 2, TMD: transmembrane domain, S: Secretion signal.

3.2.6 Analysing the potential bioactivity of Mcf through reverse genetics of *Epichloë festucae* Fg1

From the bioinformatics analysis, both AR48 and Fg1 appear to be the only *E. festucae* strains analysed in this study that contain an equivalent *E. typhina* *mcf* model gene and therefore produce an equivalent *E. typhina* Mcf model protein. This *Epichloë* allele will be referred to as AR48 allele. The remaining analysed *E. festucae* strains have either an allelic variant, this *Epichloë* allele will be referred to as F11 allele, and/or a non-functional *mcf* gene therefore the bioactivity potential of the produced Mcf protein is unknown (Results 3.2.1). In addition, AR48 has confirmed presence of CC bioactivity, while AR1 and AR37 have confirmed absence of CC bioactivity; these strains have AR48 possibly non-functional allele or F11 possibly non-functional respectively (Introduction 1.1.3). There is therefore a correlation between the presence of a functional AR48 *mcf* gene/Mcf protein and CC bioactivity. In addition, Mcf has been directly linked to CC bioactivity through an artificial CC trial (Ambrose *et al.*, 2014).

Biological activity is typically linked to specific genes by first deleting the gene of interest (gene deletion, Δ), which should result in abolishment of bioactivity, and then reintroducing the gene back into the Δ (complementation, COMP), which should result in re-establishment of bioactivity (Scott *et al.*, 2012). Although AR48 is the logical strain of choice because of the demonstrated bioactivity against CC it is very slow growing and intractable to genetic manipulation (Introduction 1.1.3). Therefore the fast growing strain Fg1, which shares a close common ancestor to AR48 and has the same alkaloid profile as AR48 was used (Results 3.1).

Two different plasmids were used in an attempt to delete the *mcf* gene in Fg1 through homologous recombination (Method 2.4.26 and 2.4.27). pTM03 was designed to delete the whole Fg1 *mcf* gene *i.e.* approximately 6 kb. However mis-annotation of AR48/Fg1 *mcf* meant that the start of the gene was still present in the Fg1 genome after the recombination event *i.e.* the first few amino acids either side of the first intron (Appendix 23). pTM05 was designed to delete approximately 2 kb from the start of the Fg1 *mcf* gene removing the start of translation. This second plasmid was designed as deletions of smaller regions typically occur at higher rates. In this second

Chapter three: Results

construct both the mis-annotated and gene model start sites will be deleted (Figure 3.19, and Appendix 24). Plasmid pTM03 or pTM05 was linearized with the restriction enzyme *Sma*I and gel purified before being transformed in WT Fg1 fungal protoplast. Transformants were selected by plating the transformed protoplast mixture on hygromycin. Hygromycin resistant colonies were subsequently nuclear purified to generate homokaryons for molecular analysis. Gene deletions were identified from ectopic integrations through PCR screening across the deleted region, which results in difference in product size, typically a smaller WT ectopic band and a larger Δmcf band. Putative Δmcf are then confirmed using Southern analysis (Method 2.3.4, 2.4.9, 2.4.17, 2.4.21, 2.4.22, 2.4.25, and 2.4.31 to 2.4.37).

For the pTM03 transformation 86 transformants were screened using multiplex PCR as the deleted region is much larger than the replacement resistance gene (Method 2.4.21). The first set of primers amplified outside and across the hygromycin resistance gene and the second set of primers amplified within the deleted region. All transformants produced both products indicating that the resistance gene was ectopically integrated. For the pTM05 transformation 323 transformants were screened using PCR. This time the deleted region was small enough to distinguish Δmcf strains through amplification outside and across the hygromycin resistance gene (Figure 3.18 and 3.19).

One heterokaryon transformant (Fg1 TM05 #117) was identified *i.e.* both smaller Δmcf and larger WT products produced. This transformant was purified through spore purification (Method 2.4.10). PCR products were successfully amplified outside and across both borders and no product was produced when amplified within the deleted region. Finally, the transformant was confirmed as a knock-out (KO) through Southern blotting. When the Fg1 WT genomic DNA was digested using *Bam*H1 and probed with the digoxigenin (DIG)-11-dUTP labelled linearized pTM05, a 6 kb band was observed. The creation of the gene deletion adds a *Bam*H1 cut site as well as increases the size of this region. The #117 transformant is therefore a “true” Δmcf strain as 5.2 kb and 1.1 kb bands were present as a result of the added cut site. The 6.3 kb band was present as a result of incomplete digestion, however this could occur for both WT and Δmcf

digests. The 3.4 kb band was universal for both WT and Δmcf as this region is not affected by the homologous recombination event. The two additional bands between sizes 2.7 kb and 2.8 kb are most likely ectopic integrations as the bands are not present in the WT and are not larger than the inserted site *e.g.* 6.3 kb, which would result from tandem integration (Figure 19 and 20, and Appendix 26).

The in culture morphologies were analysed for the Fg1 Δmcf at both the macroscopic and microscopic (Method 2.4.15 and 2.4.16) level. The Fg1 WT strain was used as the control. For in culture macroscopic morphology, Fg1 WT and Fg1 Δmcf strains size and morphology was comparable, with both strains forming rough white fluffy filamentous colonies. For in culture microscopic morphology, Fg1 WT and Fg1 Δmcf strains again were comparable with both strains forming normal hyphal tips, forming branch points, bundles, coils, and conidia (Figure 21).

3.2.7 Analysing the potential bioactivity of *Mcf* through reverse genetics in *Epichloë festucae* var *lolii* AR1 and *Epichloë festucae* var *lolii* AR37

As an alternative approach, due to the complications in initially making an Fg1 Δmcf strain, AR1 and AR37 were both transformed with a functional AR48 *mcf* gene (Method 2.4.9, and Results 3.2.6). AR1 has an AR48 possibly non-functional allele while AR37 has a Fl1 possibly non-functional allele, and both have confirmed absence of CC bioactivity (Introduction 1.1.3, and Results 3.2.1). The advantage of complementation is that the plasmid integrates ectopically through non-homologous recombination that occurs at a much higher rate than homologous recombination. However, the plasmid integrates at random loci and multiple times. This affects the overall transformed gene expression level and can cause disruption of other important genomic regions.

Protoplasts of AR1 and AR37 were transformed with pTM04 using the same method used to create gene deletions (Results 3.2.6). pTM04 was designed to contain the AR48 *mcf* coding region as well as 2 kb extensions at both the 5' and 3' ends as promoter and terminator respectively. As this plasmid did not encode for a selectable maker, the protoplasts were co-transformed with pDB48 that contains the hygromycin resistance gene. The AR1 and AR37 transformants were screened using PCR. To target the

Chapter three: Results

introduced AR48 *mcf* gene, and not the AR1/AR37 WT gene that was still present, primers were designed to amplify across the borders between the backbone and gene of the ectopically integrated pTM04. (Method 2.3.4, 2.4.21, 2.4.22, and 2.4.28, and Appendix 23, 27, and 28).

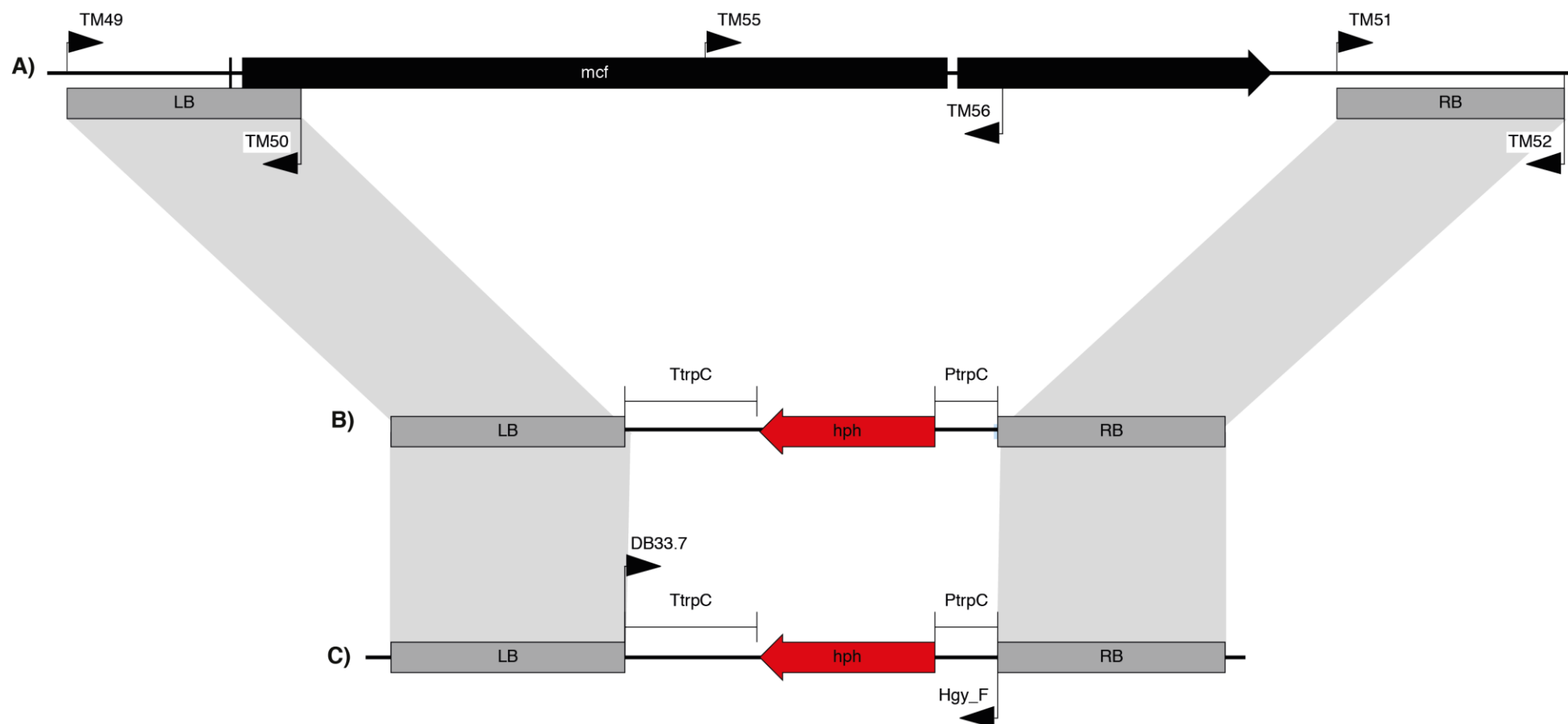


Figure 3.18: Strategy for deletion of the whole *Epichloë festucae* Fg1 makes caterpillars floppy (*mcf*) gene. (A) Physical map of wild type *mcf* genomic locus. (B) Physical map of the linear insert of the *mcf* replacement construct pTM03. (C) Physical map of the Δmcf deletion mutant locus. The black box is *mcf* with introns as gaps. The homologous regions are in light grey boxes. The red box is the hygromycin (*hph*) selectable marker, and the promoter/terminator are in brackets.

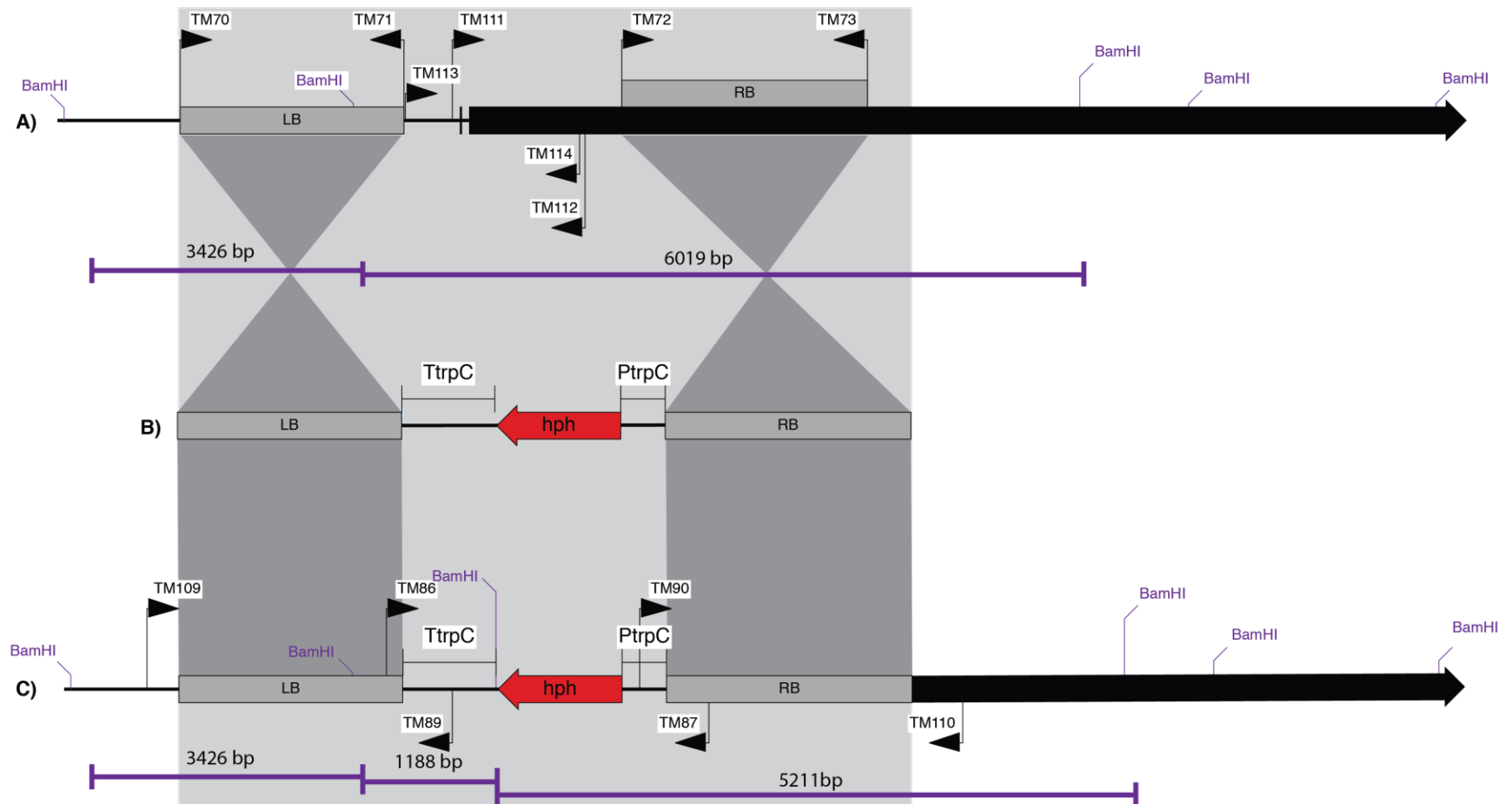


Figure 3.19: Strategy for deletion of the 5' end of the *Epichloë festucae* Fg1 makes caterpillars floppy (*mcf*) gene. (A) Physical map of wild type *mcf* genomic locus. (B) Physical map of the linear insert of *mcf* replacement construct pTM05. (C) Physical map of the Δmcf deletion mutant locus. The black box is *mcf* with introns as gaps. The homologous regions are in dark grey boxes. The regions where the digoxigenin (DIG)-11-dUTP labelled linear pTM05 insert probe binds are in light grey boxes. The red box is the hygromycin (*hph*) selectable marker, and the promoter/terminator are in brackets. The restriction cut sites for the *Bam*HI, used for the Southern blot, are indicated in purple with corresponding fragments with sizes in purple lines below.

Chapter three: Results

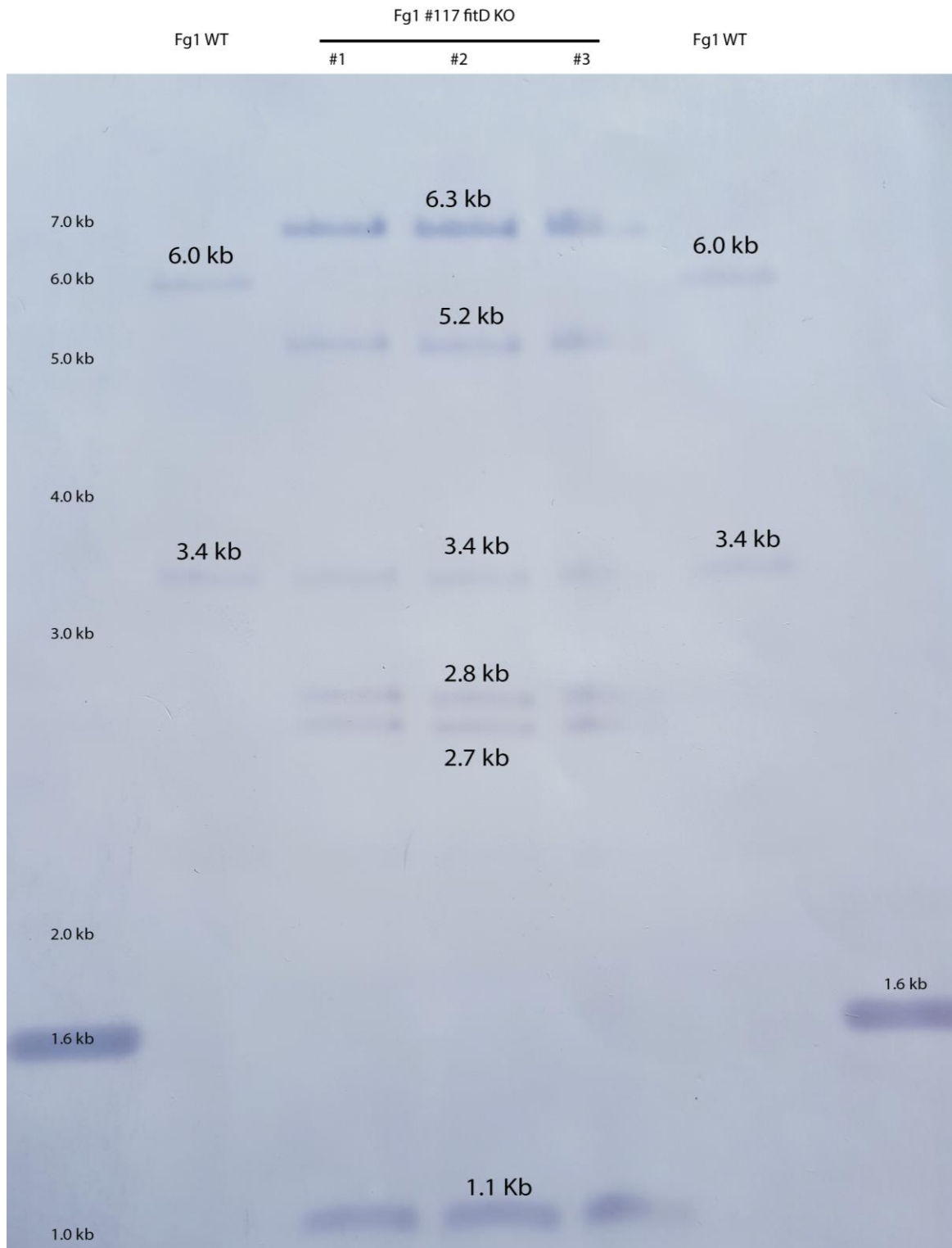


Figure 3.20: NBT/BCIP strained Southern blot of *Bam*H1 genomic digest (1 μ g) of *Epichloë festucae* Fg1 wild type (WT) and makes caterpillars floppy (*mcf*) gene deletion (Δmcf)(#117) strains probed with digoxigenin (DIG)-11-dUTP linear pTM05 insert probe. The ladder is 1 kb plus with the 1.6 kb band as a reference. 1#, 2#, and 3# refer to three spores isolated from the same transformant (#117). WT complete digest with *Bam*H1: 6.0 kb and 3.4 kb. Δmcf complete digest with *Bam*H1: 5.2 kb, 3.4 kb, and 1.1 kb.

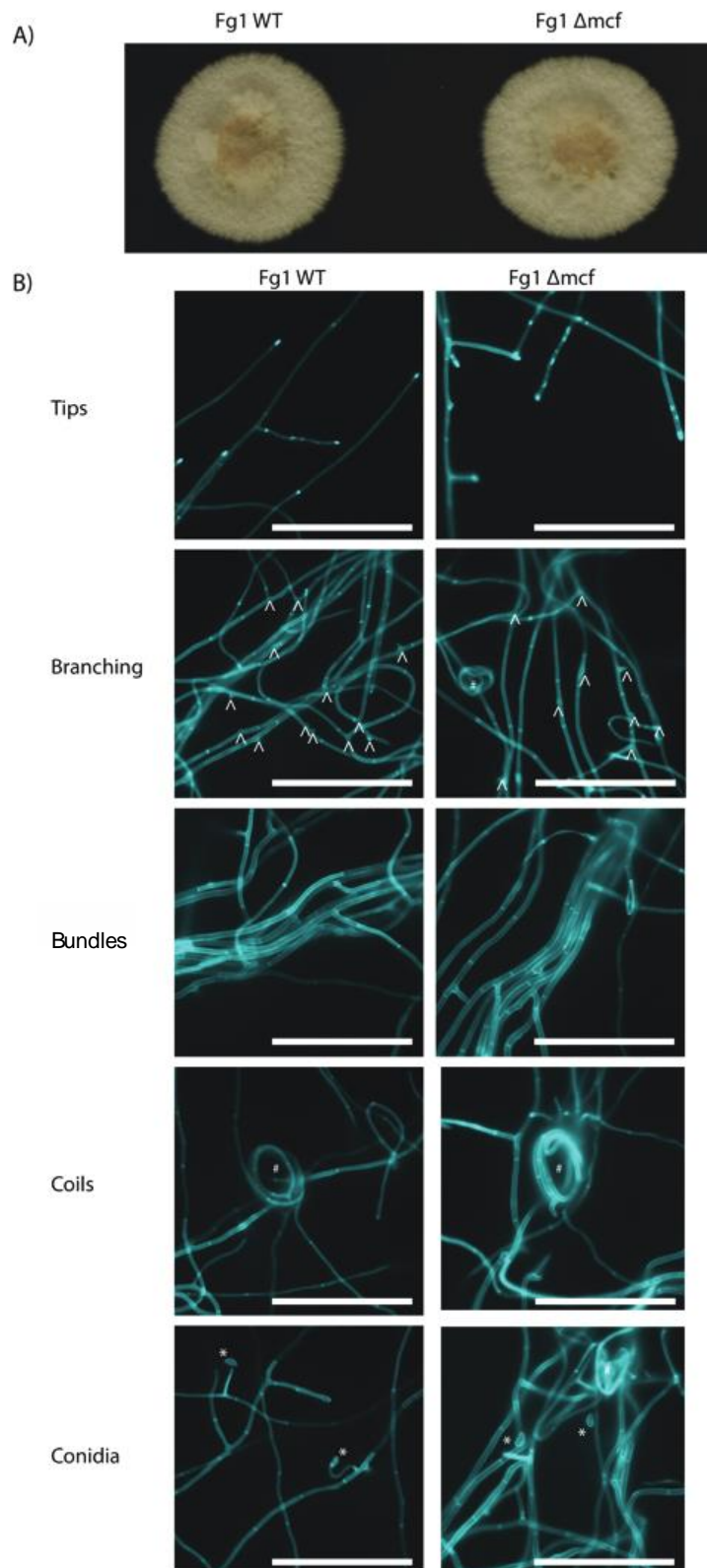


Figure 3.21: Culture phenotype of *Epichloë festucae* Fg1 wild type (WT) and makes caterpillars floppy (*mcf*) gene deletion (Δmcf) strains. A) Colony morphology of Fg1 WT and Δmcf strains grown on 2.5% PD agar at 22°C for 7 days. B) Fluorescent images captured by inverted microscopy of hyphae grown for 7 days on 2% water agar plates and stained with Calcofluor white. Bar= 20 μm . Arrows indicate branch points, stars indicate conidia and hash-tags indicate coils.

3.3 Test the insect bioactivity capabilities of *Epichloë festucae* var *lolii*

AR48 and *Epichloë festucae* Fg1 infected ryegrass

A comprehensive analysis of the alkaloid profile of both AR48 and Fg1 identified two compounds that might be the bioactives responsible for stem boring fly (SBF-*Cerodontha australis*) and/or cutworm moth caterpillar (CC-*Agrotis ipsilon*) bioactivity observed in AR48 infected plants (Introduction 1.1.3). The first compound is the new indole-diterpene (IDT) compound three that is unique to AR48 and Fg1 and was identified from an analysis of IDTs in grass samples infected with these strains (Results 3.1). The second product is an endotoxin encoded makes caterpillars floppy (*mcf*), which was previously identified by Ambrose *et al* (2014) to be present in *Epichloë* and shown to have CC bioactivity. Out of the *E. festucae* strains analysed in this study, only AR48 and Fg1 genomes contained functional *mcf* gene that were the same *mcf* allele as Ambrose *et al* (2014) bioactive *mcf* gene. Both products are therefore unique to AR48 and Fg1, in relation to the *E. festucae* strains analysed, and therefore good candidates for the unique insect bioactivity. Insect trials involving endophyte infected ryegrass material and insects captured from the New Zealand environment were carried out to investigate the bioactive potential of these two products.

3.3.1 Design and perform a stem boring fly (*Cerodontha australis*) whole plant choice bioactivity trial on a range of wild type *Epichloë*-infected ryegrass

During an Argentine stem weevil (ASW-*Listronotus bonariensis*) field trial in New Zealand, which involved a range of *Epichloë* infected ryegrass plants, SBF protection was observed only in ryegrass plants infected with AR48 or AR47 that presented with fewer insect damaged tillers and/or insect killed tillers than the other endophyte infected plants (Introduction 1.1.3). This SBF bioactivity was confirmed in subsequent SBF trials (Alison Popay, AgResearch; personal communication). A SBF whole plant choice (SWPC) trial was set up at Grasslands AgResearch Palmerston North to confirm these results (Method 2.5.3). The strains tested in this SBF whole plant choice (SWPC) trial were AR48 and the closest related strain (by simple sequence repeat (SSR) analysis) AR47, the two commercial strains AR1 and AR37, and the control strain common toxic (CT) and endophyte-free (nil) (Results 3.1.1). In preparation for the

Chapter three: Results

SWPC trial, 20 infected plants of each endophyte strain were trimmed to a length of approx. 15 cm, and grouped into replications with one endophyte strain infected plant per replication. The replications were then randomised, and covered with a netted bag. At the start of the trial, SBF adults were captured from surrounding AgResearch Grasslands (Palmerston North) fields using a net, sorted and sexed at Massey University Drosophila Laboratory, and then added to the netted plants with 20 male and 20 female flies per replication. The plants were then bottom watered for 6 weeks over one breeding cycle to give time for eggs to be laid in the tillers, hatch, and the emerging larva to feed on the inner tissue before pupating at the base. The plants were then uncovered and assessed for damage based on the presence of mines (tiller damage), presence of pupae, and pupae collected to assess fly emergence (Figure 3.22).

Both the control strains CT and nil plants had the presence of mines and pupae, with pupa successfully emerging when collected into Eppendorf tubes. For both strains approximately 40% of the tillers per plant had insect damage in the form of a mine with typically one mine per tiller. Again for both strains, nearly 100% of the mines contained a pupa, and approximately 80% of the collected pupae emerged. Both commercial strains AR1 and AR37 infected plants sustained insect damage at similar levels as the CT and nil plants, and the remaining parameters tested were also at similar levels as the CT and nil plants. AR48 and AR47 infected plants sustained little to no insect damage *i.e.* approximately 2% of tillers per plant had insect damage. This difference was statistically significant. For AR47 the tillers with mines did have pupae present at similar levels to CT, nil, AR1 and AR37, and the pupae present did emerge at similar levels to CT, nil, AR1 and AR37. AR48 had statistically fewer pupae per mine than all other strains and statistically fewer emerging pupae per mine than all other strains apart from AR47 (Figure 3.23).



Figure 3.22: Stem boring fly (SBF-*Cerodontha australis*) whole plant choice trial (SWPC) set up. A) One replication containing 6 plants covered with netting that is supported by a wire. B) All 20 replications in the glasshouse. C) Side view of a SBF. D) Male SBF (Left) and SBF fly (Right). E) Larva/caterpillar in ryegrass tiller with surrounding leaf damage (mine).

Chapter three: Results

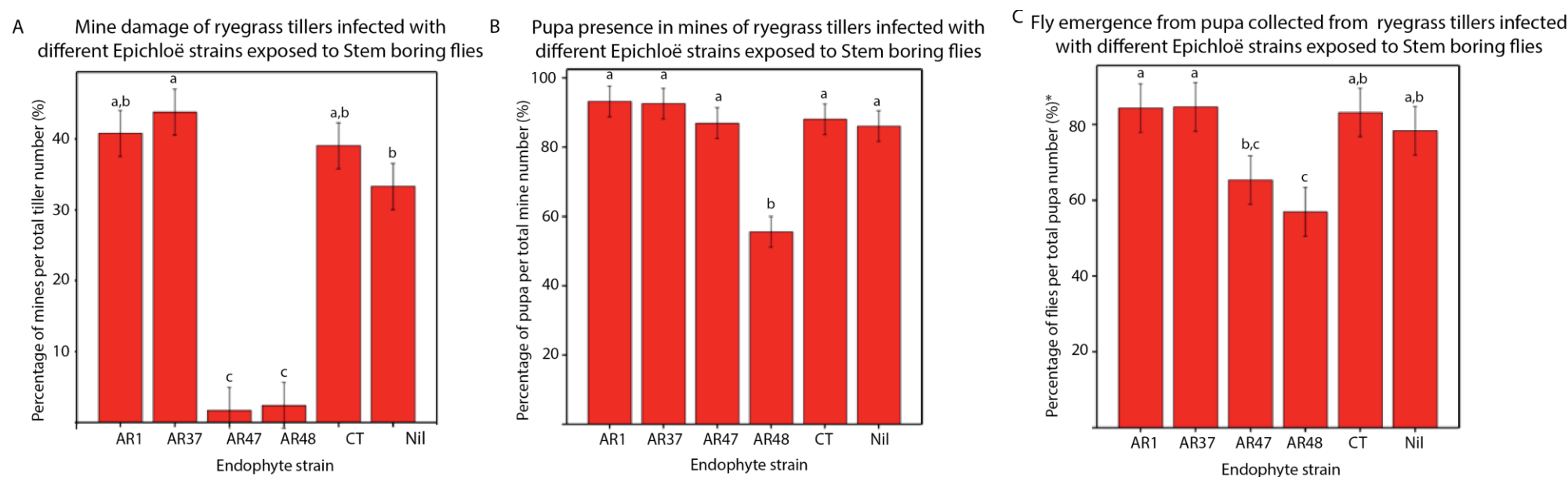


Figure 3.23: Stem boring fly (SBF-*Cerodontha australis*) whole plant choice trial (SWPC) results. A range of *E. festucae* strains infected into ryegrass were assessed for bioactivity by exposing the 20 plants of each endophyte type, one plant of each endophyte per replication with 20 male and 20 female SBF added to each replication, over the breeding season for 6 weeks in a glasshouse. A) Tiller damage inflicted by feeding larvae that form mines. B) The presence of pupae at the base of each mine. C) The ability of the adult fly to hatch from the pupae, assessed by collecting the pupae in Eppendorf tubes (*only the first 10 replications were assessed). Statistics were done by one-way analysis of variance (ANOVA) using GenStat 17th edition (VSN International). All results presented are averages of 20 replications. CT= Common toxic. Nil= no endophyte present.

3.3.2 Design and perform a cutworm moth caterpillar (*Agrotis ipsilon*) whole plant choice bioactivity trial on a range of wild type *Epichloë*-infected ryegrass

Two separate laboratory CC trials both conducted at Purdue University in the USA, also identified CC bioactivity in only AR48 and AR47 infected ryegrass (Introduction 1.1.3). Again, a whole plant choice trial was set up at Grasslands AgResearch in an attempt to replicate this CC bioactivity (CWPC) (Method 2.5.6). The same experimental design used for the SWPC trial was used in CWPC trial, but with the addition of *E. festucae* strains Fl1 and Fg1; both of these strains are predicted to have functional copies of *mcf* but with Fg1 containing a AR48 *mcf* allele and Fl1 containing a Fl1 *mcf* allele. In addition, only Fg1 infected ryegrass contains the new IDT compound three (Results 3.1). CC were obtained by catching cutworm moths (CM) using a light trap with hatched caterpillars raised on detached dock leaves. As for SBF, 20 replications were set up with plants prepared in the same manner but with the addition of counting the number of tillers per plant before the start of the trial. To each replication, 40 CC were added and plants bottom watered for 2 weeks to allow for insect damage to occur by the feeding CC. The plants were then assessed for difference in tiller number, and overall plant damage using a visual score system (Figure 3.24).

When the plants were assessed for changes in tiller numbers after CC exposure, the strains clustered into three groups; group 1 which contains strains not statistically significantly different to nil *e.g.* nil, Fg1, AR47, and AR48; group 2 which contains strains statistically significantly different to nil and some but not all of the other *E. festucae* strains *e.g.* CT, AR37, and AR1, and group 3 which contains strains statistically significantly different to all other strains *e.g.* Fl1. Group 1 had the largest tiller loss, and group 3 had the smallest tiller loss or largest tiller gain. This same clustering pattern was observed when the plants were visually scored for damage, however the least damaged plants were group 3 and the most damaged plants were group 1 (Figure 3.25).

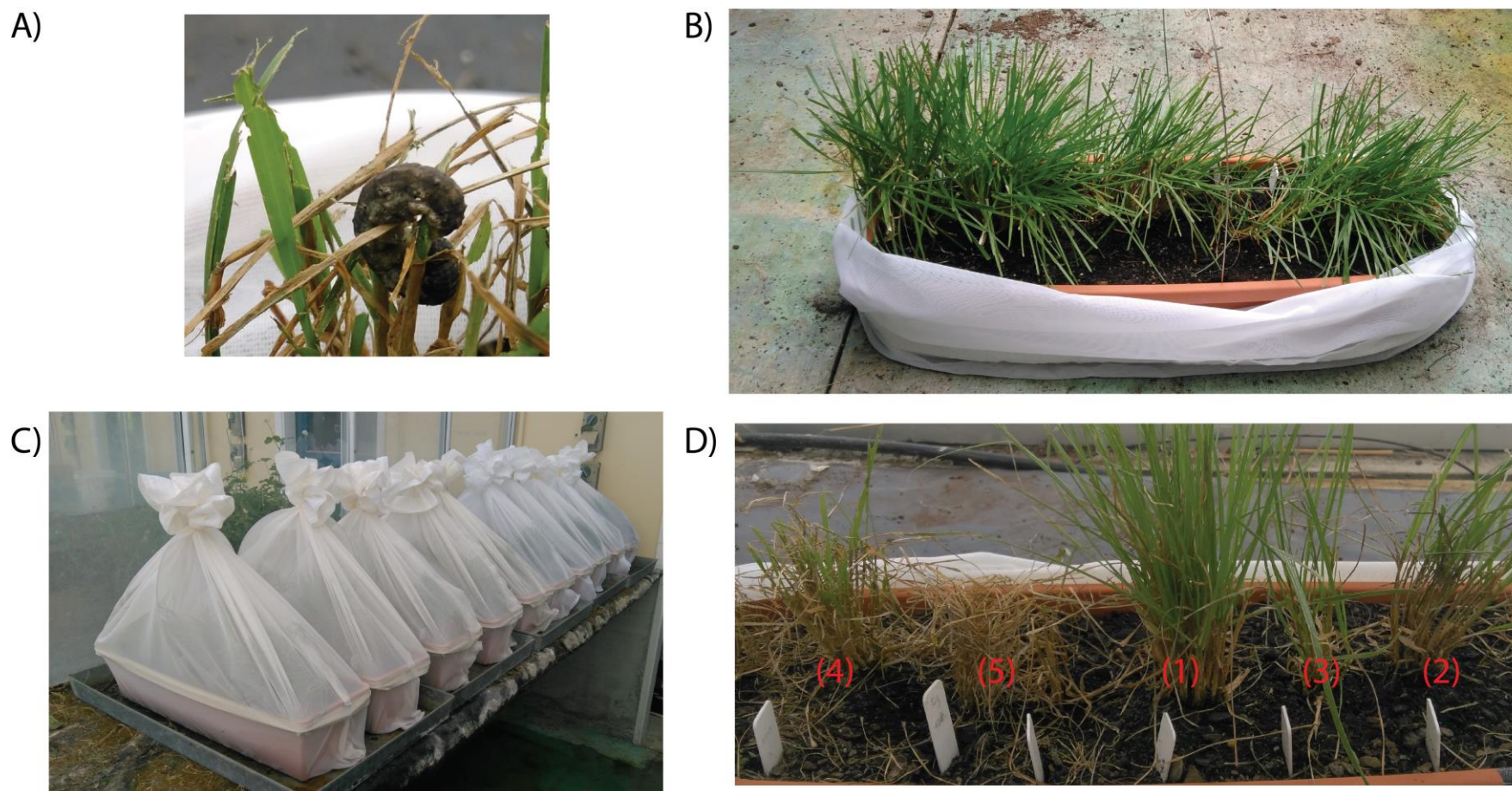
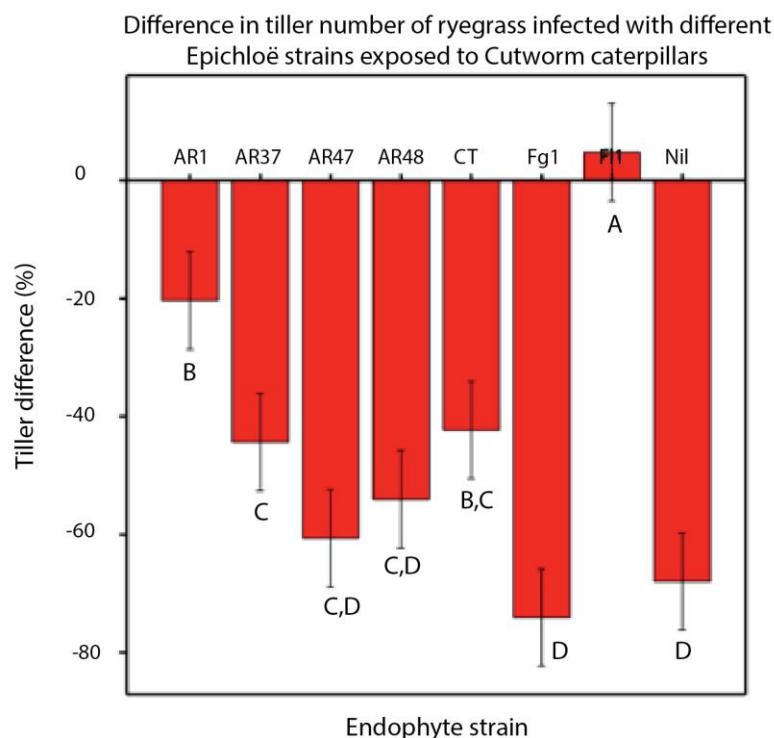


Figure 3.24: Cutworm moth caterpillar (CC-*Agrotis ipsilon*) whole plant choice trial (CWPC) set up. A) CC on a ryegrass tiller. B) One replication before the start of the insect trial containing 6 plants covered with netting that is supported by a wire. C) All 10/20 replications in the glasshouse, with the remaining 10 replication mirrored on other side of glasshouse. D) One replication at the end of the insect trial with example of each visual score value (1= No damage. 2= 10% damage. 3= 50% damage. 4= 80% damage. 5= Dead).

A)



B)

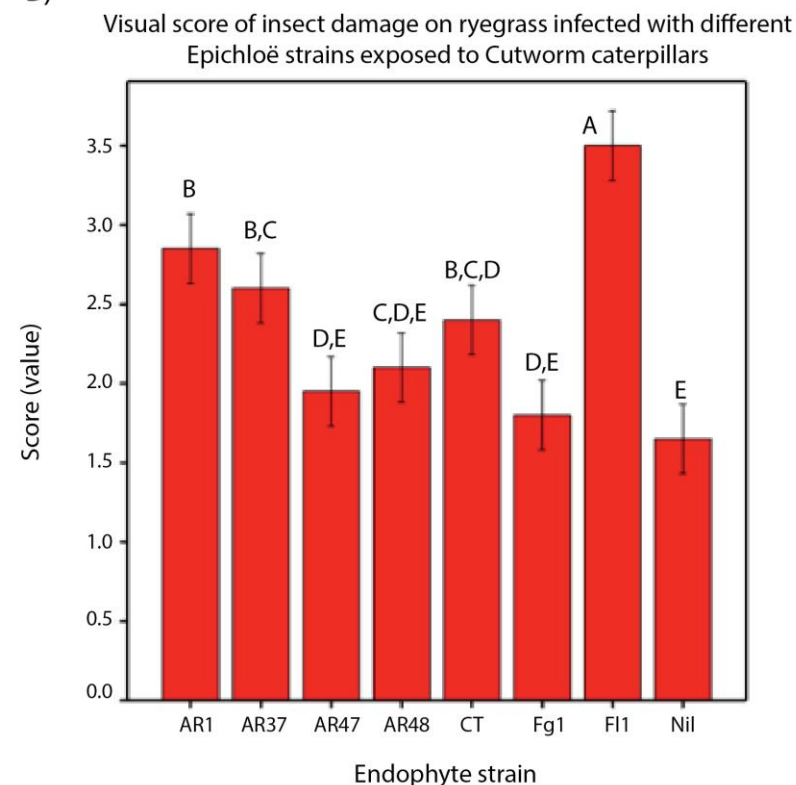


Figure 3.25: Cutworm moth caterpillar (*CC-Agrotis ipsilon*) whole plant choice trial (CWPC) results. A range of *E. festucae* strains infected into ryegrass were assessed for bioactivity by exposing the 20 plants of each endophyte type, one plant of each endophyte per replication with 40 CC added to each replication, for 2 weeks in a glasshouse. A) Tiller difference before and after CC exposure. B) Visual score value given to each plant where 1= Dead. 2= 80% damage. 3= 50% damage. 4= 20% damage. 5= No damage. Statistics were done by one-way analysis of variance (ANOVA) using GenStat 17th edition (VSN International). All results presented are averages of 20 replications. CT= common toxic. Nil= no endophyte present.

3.3.3 Design and perform a cutworm moth caterpillar (*Agrotis ipsilon*) detached tiller no choice bioactivity trial on a range of wild type and *mcf* deletion *Epichloë*-infected ryegrass

The trials conducted in Purdue both demonstrated AR48 and AR47 infected ryegrass has bioactivity towards CC (Introduction 1.1.3). However, ryegrass infected with both these strains showed no statistically significant difference to nil ryegrass in the Grasslands CWPC trial (Results 3.3.2). As the USA CC trials were detached tillers, a second experimental design, CC detached tiller no choice (CDTN) trial, was designed based upon the USA trials methodologies (Method 2.5.9). This CDTN trial was therefore set up in an attempt to replicate this bioactivity at Grasslands AgResearch.

For the CDTN trial, the same endophyte strains were used as for the CWPC trial with the exception of AR47 which was removed and Fg1 Δmcf (Results 3.2.6) which was included. The plants used in this trial were located in two different glasshouses. A PC1 glasshouse that contained 5 plants each of the following endophyte strains: AR48 wild type (WT), Fg1 WT, AR37 WT, Fl1 WT, CT WT, and nil. A PC2 glasshouse that contained 3 plants each of the following endophyte strains: Fg1 WT and Fg1 Δmcf . For the PC1 glasshouse plants, the bioactivity of each endophyte strain was assessed using 5 biological replications *i.e.* 5 different plants labelled 1, 2, 3, 4, and 5, as well as 3 technical replications *i.e.* 3 caterpillars per plant with plant 5 having 4 caterpillars labelled A, B, C, and D, so that a total of 16 caterpillars were used for each endophyte strain *e.g.* 1A, 1B, 1C etc. For the PC2 glasshouse plants, the bioactivity of each endophyte strain was assessed using 3 biological replications *i.e.* 3 different plants, as well as 3 technical replications *i.e.* with 3 caterpillars per plant, so that a total of 9 caterpillars were used for each endophyte strain (Method 2.5.9).

In preparation for the trial, CC were obtained from eggs laid by captured cutworm moths (CM), and then weighed and ranked by weight. From this population, 114 CC were selected with the smallest weight variability between them and endophyte strains were assigned throughout the weight range *e.g.* AR48 plant 1 caterpillar A, Fg1 plant 1 caterpillar A etc. then AR48 plant 1 caterpillar B, Fg1 plant 1 caterpillar B etc. The CDTN trial was performed in an air-conditioned laboratory with CC kept in

Chapter three: Results

containers filled with bark (Figure 3.26). Each day, CC were weighed, the old detached tiller removed and weighed, and new detached tiller weighed and added. At the end of the 8 day trial, the change in CC weight, change in tiller weight, and CC survival rate was then calculated and statistically analysed (Method 2.5.9).

The nil endophyte ryegrass treatment was statistically significantly higher than the none (no ryegrass) treatment, being 75% survival versus 0% survival respectively. For the PC1 glasshouse plants, all strains apart from Fg1 had statistically significantly lower survival rates than nil. While there was large variability in the survival rates between endophyte strains, *i.e.* 15% to 80%, none of the strains were statistically significantly different to each other. For the plants maintained in the PC2 glasshouse, the survival rate of Fg1 and Fg1 Δmcf was not statistically significantly different to one another. The survival rate range of the PC2 plant material fed CWPC was much narrower and higher than the PC1 plant material fed CWPC at 80% to 100% in contrast to 15% to 80% respectively (Figure 3.27).

In addition to survival rate, the daily weight change of the CC was assessed. Again, the artificial environment was able to sustain the CC as all CC, apart from the none (no ryegrass) treatment, had a positive weight change trend over the assessed period. This difference between none and the remaining samples was statistically significant. For the plants maintained in the PC1 glasshouse, FI1 was the only strain that had a gain in weight that was statistically significantly lower in rate than the remaining plant material, *e.g.* nil, AR48, Fg1, AR37, and CT, with FI1 at 4.5 mg in contrast to 4.75 mg to 5.25 mg (log weight scale) for the remaining strains, on the final day. All other strains did not have statistically significant different daily weight changes compared to nil across the assessed time period. For the plants maintained in the PC2 glasshouse, there was no statistically significant difference in daily weight change for Fg1 and Fg1 Δmcf samples. The PC2 CC had a higher daily weight change than the PC1 CC over the assessed time period (Figure 3.28).

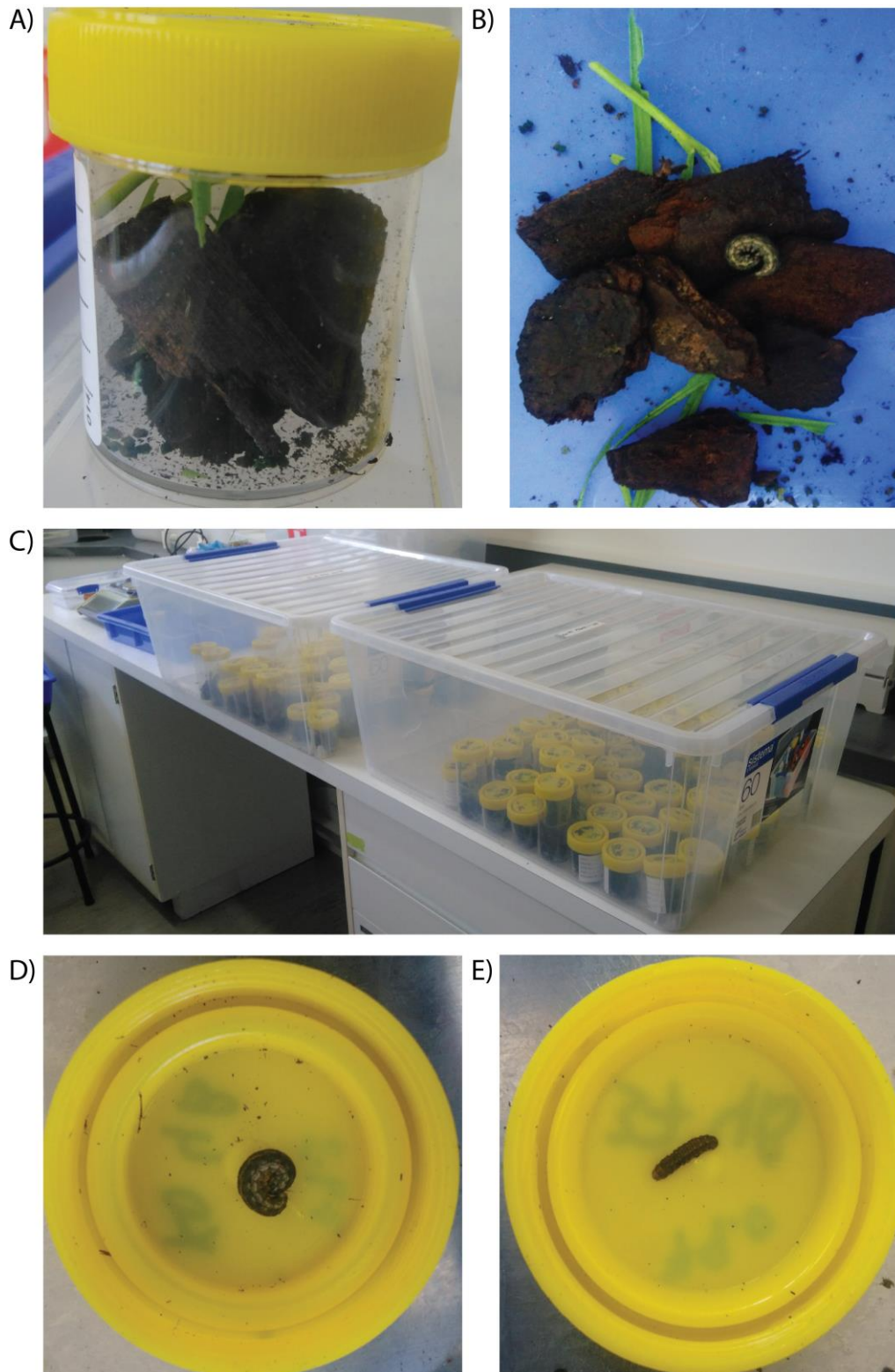


Figure 3.26: Cutworm moth caterpillar (CC-*Agrotis ipsilon*) detached tiller no choice trial (CDTN) set up. A) and B) A single sample containing bark, caterpillar, and detached tiller. C) Layout of trial on laboratory bench. D) Healthy alive CC. E) Dead CC.

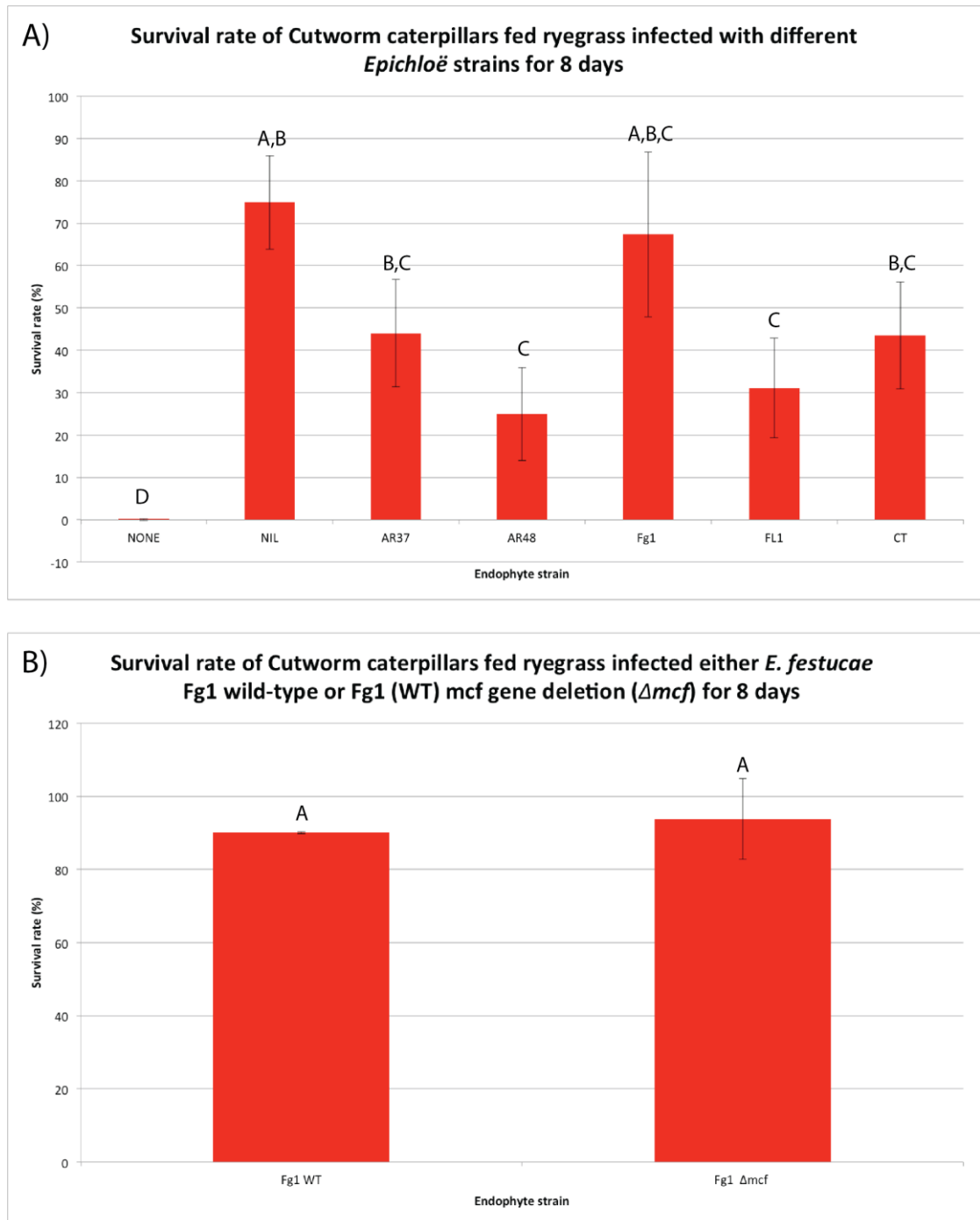


Figure 3.27: Cutworm moth caterpillar (CC-*Agrotis ipsilon*) detached tiller no choice trial (CDTN) survival rate (%) results. CC, kept in containers in an air-conditioned laboratory, and were fed detached tillers of ryegrass infected with a range of *E. festucae* strains every 24 hours over 8 days. A) Survival rate of caterpillars fed plants maintained in a PC1 Glasshouse containing a range of *Epichloë* strains. All values are averages of 16 replications. B) Survival rate of CC fed plants maintained in a PC2 glasshouse containing WT and delta-mcf FG1. Statistics were done by one-way analysis of variance (ANOVA) using GenStat 17th edition (VSN International). All PC1 data presented as an average of 16 replications and PC2 data presented as an average of 9 replications. CT= common toxic. WT= wild type. Nil= no endophyte. None= no ryegrass.

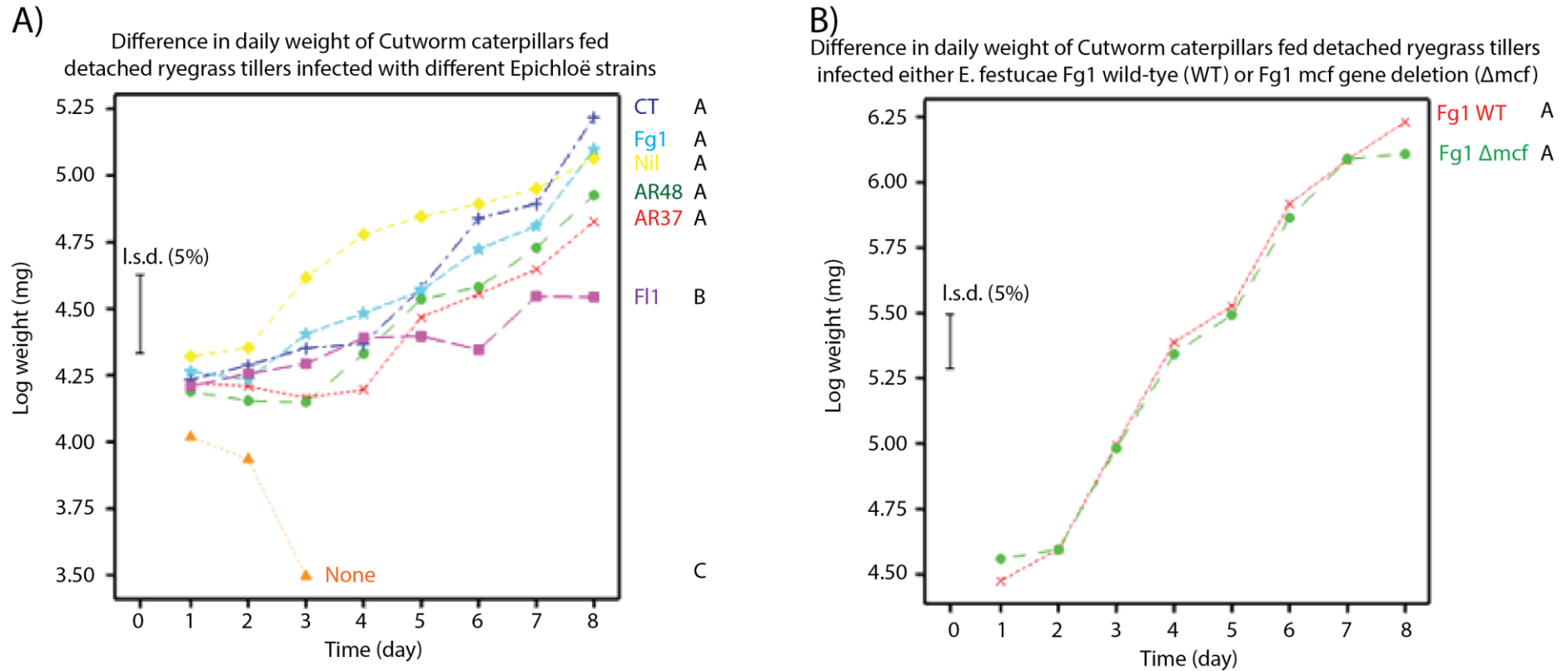


Figure 3.28: Cutworm moth caterpillar (CC-*Agrotis ipsilon*) detached tiller no choice trial (CDTN) daily weight change results. CC, kept in containers in an air-conditioned laboratory, and were fed detached tillers of ryegrass infected with a range of *E. festucae* strains every 24 hours over 8 days. A) Daily weight change of CC fed plants kept at a PC1 glasshouse. B) Daily weight change of CC fed plants kept at a PC2 glasshouse. Statistics were done by repeated measurements linear mixed model using GenStat 17th edition (VSN International). All PC1 data presented as an average of 16 replications and PC2 data presented as an average of 9 replications. CT= common toxic. WT= wild type. Nil= no endophyte. None= no ryegrass.

3.3.4 Design and perform a porina caterpillar (*Wiseana* spp) detached tiller no choice bioactivity trial on a range of wild type *Epichloë*-infected ryegrass

Porina (*Wiseana* spp) is a major ryegrass pest in New Zealand, and *Epichloë* infected ryegrass is known to be bioactive against the porina caterpillar (PC) most likely through the IDT class *epoxy-janthitrems* that are produced by a set of *idt* genes including *janD* (Hennessy *et al.*, 2016) (Sarah Finch, AgResearch; personal communication). The absence of *janD* in both genomes of AR48 and Fg1 suggest that these strains cannot synthesise *epoxy-janthitrems* and this was validated by mass spectrometry (MS) analysis of AR48 and Fg1 infected ryegrass (Results 3.1). An overseas trial has shown AR48 to have bioactivity against the CC, which is yet to be repeated in New Zealand. It is therefore possible that the bioactive that targets CC is also able to target other species of Lepidoptera such as the PC (Introduction 1.1.3, and Results 3.3.2 and 3.3.3).

A porina caterpillar detached tiller no choice (PDTN) trial was therefore set up to test this bioactivity at Grasslands. The same method used for the CDTN trial was used for the PDTN trial, except the PC obtained from porina moths (PM) caught using a light trap, were raised on an artificial diet instead of dock leaves. The strains tested for this trial were AR48, Fg1, FI1, AR37, and nil, and all the endophyte infected plants were maintained in the same PC1 glasshouse prior to detachment of tiller. Each endophyte strain had 9 replications; 3 plants and 3 caterpillars per plant. The PDTN trial was conducted in a temperature controlled growth chamber at 18°C (Method 2.5.9).

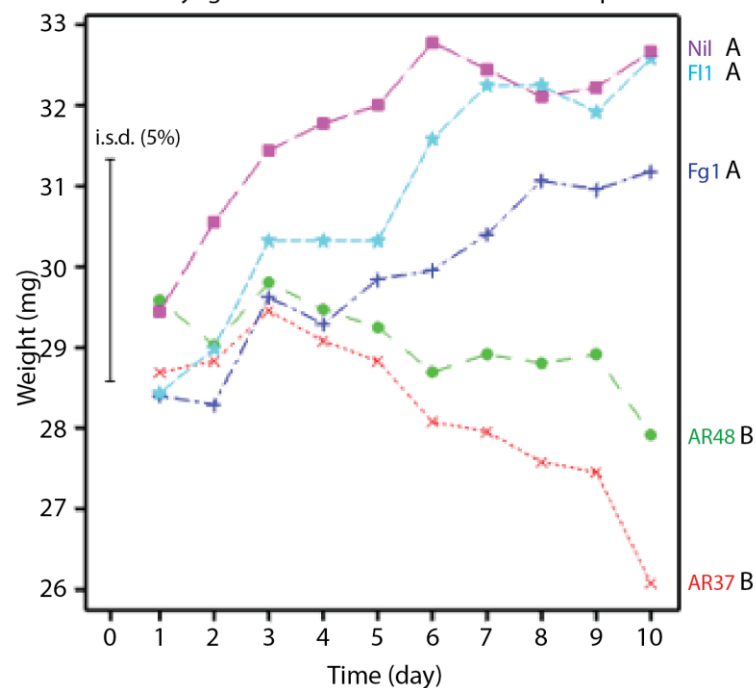
The PDTN trial was successful as the PC fed on the nil treatment had a positive weight gain trend over the entire trial ending at approximately 32.5 mg, while the PC fed AR37 (which is known to affect PC) had a negative weight loss trend ending at approximately 26.0 mg. This difference was statistically significant. Of the remaining strains, AR48 was the only strain that was statistically significantly different to nil, being not statistically significantly different to AR37. The amount of detached tiller consumed over the entire trial was also analysed for each strain. All endophyte-infected detached tillers were statistically significantly different to nil, with less detached tiller consumed, *e.g.* approximately 0.5 mg to 1.20 mg for endophyte infected in comparison to 1.60 mg for endophyte free, respectively. FI1 was statistically significantly different to AR37 but

Chapter three: Results

not AR48 and Fg1, and AR37 was statistically significantly different to FI1 but not AR48 and Fg1 (Figure 3.29).

Chapter three: Results

A) Daily caterpillar weight of *Porina* caterpillars fed artificial diet containing freeze-dried ryegrass tillers infected with different *Epichloë* strains



B) Total amount of diet consumed by *Porina* caterpillars fed artificial diet containing freeze-dried ryegrass tillers infected with different *Epichloë* strains for 10 days

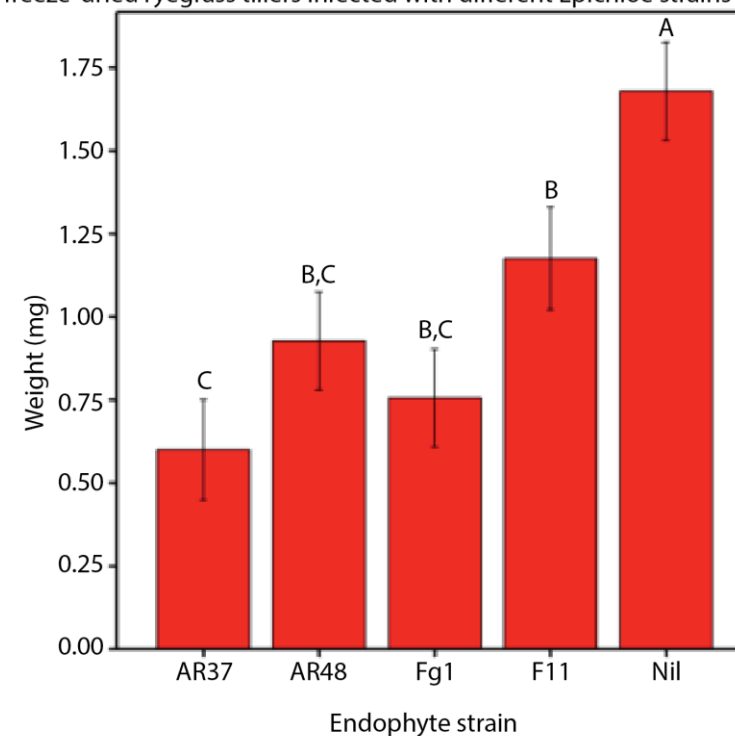


Figure 3.29: *Porina* caterpillar (*PC-Wiseana* spp) detached tiller no choice trial (PDTN) results. PC, kept in containers in a temperature-controlled chamber, were fed a detached tillers infected with different *E. festucae* strains over 10 days. A) Daily caterpillar weight. B) Total detached tiller weight consumed over 10 days. All values are averages of 9 replications. Statistics were done by either repeated measurements linear mixed model (A) or One-way analysis of variance (ANOVA) (B) using GenStat 17th edition (VSN International). Nil- no endophyte present.

3.3.5 Design and perform a light brown apple moth caterpillar (*Epiphyas postvittana*) bioactivity trial on a range of wild type *Epichloë*-infected ryegrass

The light brown apple moth caterpillar (LBAM-*Epiphyas postvittana*) is not a pest of ryegrass but is currently being developed at AgResearch as a “universal” insect bioactivity indicator in a LBAM artificial diet no choice (LADN) trial. The LBAM, provided by Plant and Food New Zealand, can be easily and quickly bred under laboratory conditions in large numbers throughout the year, making the insect an ideal model system (Alison Popay, AgResearch; personal communication). The LBMA were raised on an artificial diet in clear screw top containers filled 2/3 with bark in a temperature-controlled room and fed artificial diet containing different endophyte infected ryegrass. One restriction of the artificial diet is that the caterpillars can only be raised up to the final moult and therefore do not form pupae and emerge into moths *i.e.* approximately 2 to 3 weeks before naturally dying off. Over this time period, the caterpillars are observed for the timing of establishment, identified when the caterpillars produce a silk cocoon, as well as the timing of the first, second, and third moults, identified by size change and lighting of the head. The testing agent can be deemed as being/containing an insect bioactive when the caterpillars do not establish or do not moult, have reduced establishment and/or moulting times, and/or die prematurely. All times are in relation to a blank control *i.e.* nil endophyte infected ryegrass or the suspension reagent of the purified compound (Method 2.5.12).

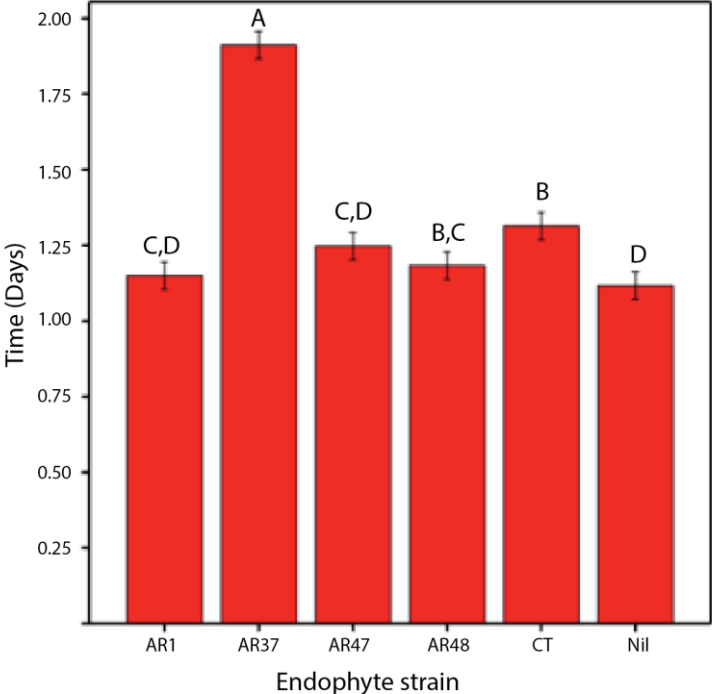
This trial was performed with freeze-dried ryegrass containing: AR48 and AR47 to test the robustness of the “universal” insect bioactivity indicator as well as whether AR48/AR47 have bioactivity against other Lepidoptera species outside grass pests. AR37 was included as a positive control as previous trials with this strain have shown large increases in both the time taken to establish and moulting. Nil was included as a negative control as there is no effect on establishment or moulting of LBAM (Alison Popay, AgResearch; personal communication).

For establishment time, only AR37 had a statistically significant increased time at approximately 1.90 days in relation to all the other strains at approximately 1.25 days. For the remaining strains, AR48, AR47, AR1, CT, and nil, only AR48 and CT were

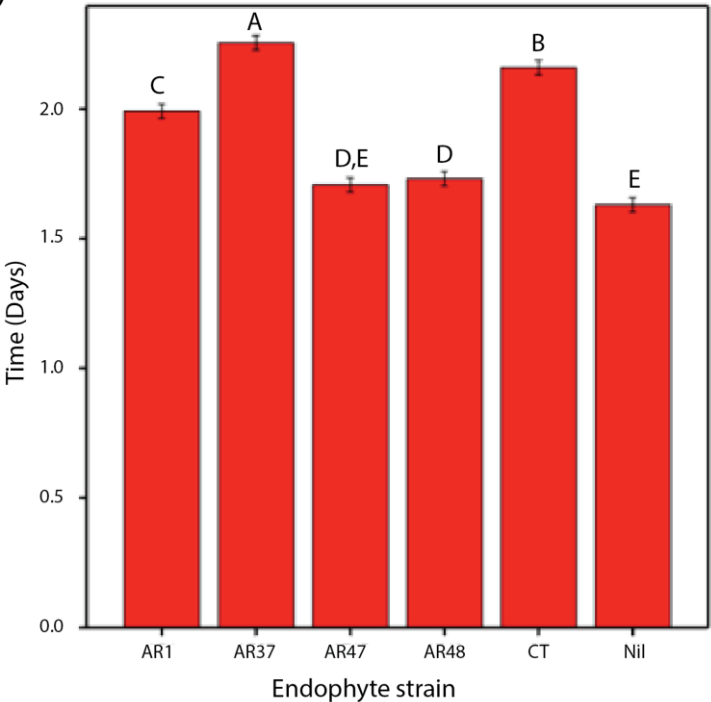
Chapter three: Results

statistically significantly different to nil. However, AR48 was not statistically significantly different to both AR47 and AR1. For the timing of the first moult, AR37, CT, and AR1 were statistically significantly different in relation to each other at approximately 2.25 days, 2.20 days and 2.00 days respectively, as well as to the remaining strains AR47, AR48, and nil which were at approximately 1.75 days). For the remaining strains, only AR48 was statistically significantly different to nil but not to AR47. For the timing of the second moult, AR37 and CT were both statistically significantly different to all other strains but not to each other at 2.25 days. AR1 was statistically significantly different to all strains at 2.20 days. For the remaining strains at approximately 2.15 days, again only AR48 was statistically significantly different to nil but not to AR47. Finally for the timing of the third moult, only AR48, AR47, and AR1 underwent a third moult within the assessed period of 16 days. This timing was not statistically significantly different between these strains (Figure 3.30).

A) Establishment time of Light brown apple moth caterpillars on artificial diet containing ryegrass infected with different *Epichloë* strains

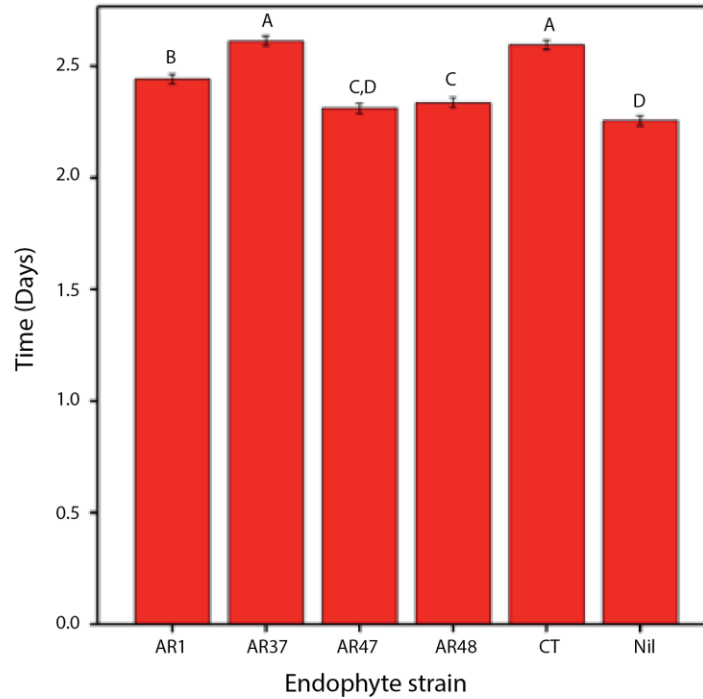


B) Timing of the first moult of Light brown apple moth caterpillars on artificial diet containing ryegrass infected with different *Epichloë* strains



Chapter three: Results

- C) Timing of the second moult of Light brown apple moth caterpillars on artificial diet containing ryegrass infected with different *Epichloë* strains



- D) Timing of the third moult of Light brown apple moth caterpillars on artificial diet containing ryegrass infected with different *Epichloë* strains

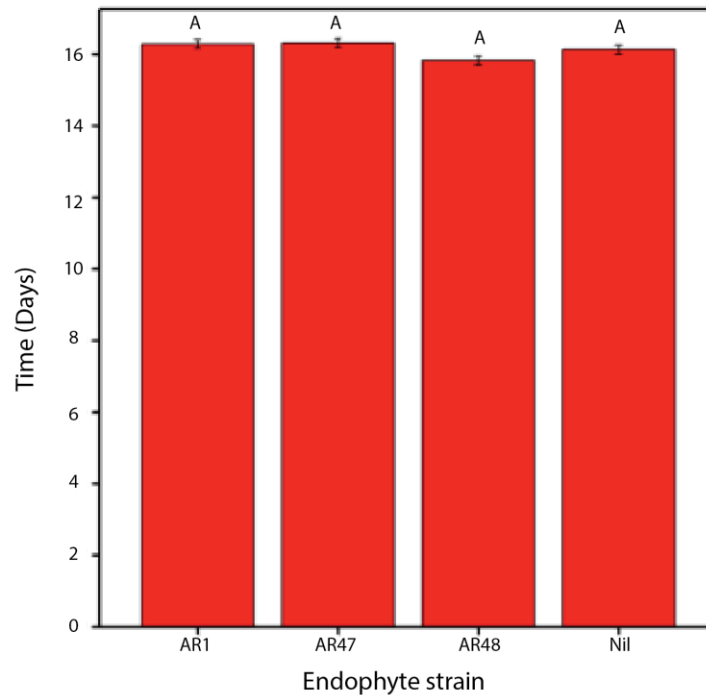


Figure 3.30: Light brown apple moth caterpillar (LBAM-*Epiphyas postvittana*) artificial diet no choice trial (LADN) results. LBAM, kept in containers in a temperature controlled room, were fed an artificial diet containing carrot juice, agar, and freeze-dried ryegrass infected with different strains of *E. festucae* strains over 16 days. A) Time taken to establish a silk cocoon. B) Time taken to undergo first moult. C) Time taken to undergo second moult. D) Time taken to undergo third moult. All values are averages of 25 replications. Statistics were done by one-way analysis of variance (ANOVA) using GenStat 17th edition (VSN International). Nil= no endophyte present.

4.0 DISCUSSION

4.1 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1

4.1.1 Fg1 as a model AR48 strain

For *Epichloë*, a common technique used to assess the role of a candidate gene in a specific process is through targeted gene deletion and resultant phenotype assessment *i.e.* reverse genetics, *e.g.* *noxA* deletion in *E. festucae* Fl1 strain, when inoculated into ryegrass seedlings, results in loss of the maintenance of the plant symbiotic interaction (Tanaka *et al.*, 2008). The sexual *E. festucae* strains in general are easier to create targeted gene deletions than the asexual *Epichloë festucae* var *lolii* strains. The reason for this is currently unknown but attempts to generate targeted gene deletions in *E. festucae* var *lolii* AR37 have to date been unsuccessful (Richard Johnson, AgResearch; personal communication), whilst a range of targeted gene deletions in *E. festucae* Fl1 have been successful (Scott *et al.*, 2012, Tanaka *et al.*, 2008, Charlton *et al.*, 2012, Becker *et al.*, 2015, Johnson *et al.*, 2013b). In addition, the sexual strains have a faster growth rate than the asexual strains, making an already lengthy process manageable, *e.g.* 5-7 days for sexual and 2-3 weeks for asexual, for regeneration of colonies.

The potential stem boring fly (SBF-*Cerodontha australis*) and cutworm moth caterpillar (CC-*Agrotis ipsilon*) bioactivity of makes caterpillars floppy (*mcf*) was investigated using reverse genetics. However AR48 is an asexual strain and therefore before target gene deletion could be performed an appropriate sexual model strain needed to be identified. Fg1 has an identical deletion in *perA* as AR48 (Young *et al.*, 2005) suggesting a close evolutionary relationship, which was then supported through simple sequence repeat (SSR) analysis that showed AR48 and Fg1 were in the same clade.

Bioinformatics analysis followed by mass spectrometry (MS) identified that AR48 and Fg1 have identical profiles for both known *Epichloë* bioactive secondary metabolite (SM) pathways *i.e.* no ergot alkaloid or loline genes, a non-functional peramine gene, and all indole-diterpene (IDT) genes but non-functional *idtK* and *idtI* and sequence diverged *idtP* and *idtQ*, as well as functional *mcf* gene. However, Fg1 in ryegrass does not have CC bioactivity, and the SBF bioactivity has currently not been assessed. Fg1 is

therefore not an entirely equivalent AR48 model system. The lack of observed bioactivity in Fg1 could be due to the strain being present in a non-native host, which is known to affect endophyte gene expression levels (Leuchtman *et al.*, 2000, Christensen *et al.*, 1997). The expression levels of the *mcf* gene (or Mcf protein) were not measured, and so additional experiments are required to assess this hypothesis.

The sexual model FI1 strain does have CC bioactivity whereas the SBF bioactivity is unknown. However, both the known *Epichloë* bioactive SM pathways and the *mcf* gene differ between FI1 and AR48, making FI1 a poor model for AR48. It is possible that FI1 infected ryegrass has a different CC bioactive present that is not present in AR48 infected ryegrass, which could lead to misinterpretation of *mcf* reverse genetic analysis, *e.g.* ergot alkaloids are suggested to have CC bioactivity and FI1 has a complete ergot alkaloid pathway (Potter *et al.*, 2008, Schardl *et al.*, 2013a).

4.1.2 AR48 and Fg1 in planta insect bioactivity potential predicted through bioinformatics

At the start of the study, the complete profiles of the known bioactive SM pathways in AR48 and Fg1 were unknown. The most effective method for assessing the potential capabilities of AR48 and Fg1 infected plants for the associated bioactivities of these pathways is to perform a bioinformatics analysis of the genes present in these pathways, followed by MS analysis of the corresponding compounds produced by these pathway genes. Although this does not directly assess AR48 and Fg1 in planta bioactivity towards these target insects, it does provide strong evidence for potential bioactivity, *i.e.* if the gene *perA* is predicted by bioinformatics analysis to be absent or non-functional and peramine is not detected in endophyte infected material by MS, then that endophyte infected plant most likely does not have Argentine stem weevil (ASW-*Listronotus bonariensis*) bioprotection. Of course the bioactivity can only be confirmed with an insect trial, but these types of experiments take a lot of time and can only be performed at certain times of the year.

The bioinformatics analysis of AR48 and Fg1 genomes identified the presence of all the peramine and lolitrem B pathway genes, and the absence of all the loline and ergot

alkaloid pathway genes. The *perA* gene, although present, was non-functional and although all IDT genes were present only a partial lolitrem B pathway was detected in AR48 and Fg1 plant material, which agrees with the bioinformatics *idt* gene predictions (Young *et al.*, 2009). In addition, the AR48 and Fg1 *idt* genes coincide with *idt* gene clusters in other IDT producing *Epichloë* strains, *i.e.* diversity is present in the presence and absence as well as functionality of the genes, but with the cluster order and gene order within each cluster generally well conserved (Young *et al.*, 2009). However, *idtP* is isolated on a short single contig in the genome of AR48, but this is most likely a result of the fragmented AR48 genome assembly. Therefore *idtP* is expected to group with *idtQ*, *idtF*, *idtC*, and *idtB* in cluster 2 (Young *et al.*, 2009). Also due to the fragmented genome assemblies for both AR48 and Fg1, the order between each cluster as well as the distance between the clusters is unknown. AR48 does have an additional 5920 bp between *idtM* and *idtK* in cluster 1 in comparison to Fl1 and Fg1 (Young *et al.*, 2009), but this region does not contain additional genes. The only discrepancy in the IDT MS profile was that the Fg1 infected plant material contained late-pathway compounds in the lolitrem B pathway derived from *IdtE* and *IdtJ*, *e.g.* lolitrem K and lolitriol (Young *et al.*, 2009) and these compounds were not identified in AR48 infected material. Given that both AR48 *idtE* and AR48 *idtJ* genes are 100% identical to the Fg1 *idtE* and Fg1 *idtJ* genes, it is assumed that these compounds are present in AR48 infected material but at levels below the limit of detection.

Based on the absence of the ergot alkaloid pathway and an inability to synthesise lolitrem B, AR48 and Fg1 infected plant material would be unlikely to have the mammalian bioactivity associated with the presence of ergovaline and lolitrem B, *e.g.* summer slump and fescue foot, and ryegrass staggers (Tor-Agbidye *et al.*, 2001), respectively. Conversely based upon a non-functional *perA* gene (peramine), and an inability to synthesise epoxy-janthitrems, these strains would not be expected to have the insect bioactivity associated with these compounds, *e.g.* ASW (Rowan *et al.*, 1990) and PC (Hennessy *et al.*, 2016) protection, respectively. In contradiction to this, AR48 infected ryegrass appears to have PC bioactivity, so this is therefore likely to be due to the presence of another bioactive compound with activity towards PC, possibly Mcf that is known to target a range of Lepidoptera caterpillars (Daborn *et al.*, 2002,

Waterfield *et al.*, 2003, Péchy - Tarr *et al.*, 2008). This highlights the limitation of the above screening method.

4.1.3 AR48 and Fg1 new indole-diterpene compound three structure predicted through mass spectrometry

During routine IDT MS analysis using targeted multiple reaction monitoring (MRMs) four novel IDT peaks, which are not normally present in the FI1 model IDT profile (Wade Mace, AgResearch; personal communication), were identified only in AR48 and Fg1 infected plant material. These peaks had characteristic IDT fragments and the same MRMs compared to known IDT compounds, but different retention times, and for some of the compound's different overall fragmentation patterns. The new IDT compounds with the same overall fragmentation patterns are most likely stereoisomers of known IDT compounds, *i.e.* the change in retention time is due to differences in the spatial arrangement of the same atom arrangement. This could be confirmed by comparing these new IDT compounds with stereoisomer standards of the corresponding known IDT compound and/or nuclear magnetic resonance (NMR) structure confirmation. While the new IDT compounds with different overall fragmentation patterns are most likely constitutional isomers, *i.e.* the change in retention time is due to differences in the arrangement of the same atoms. This could only be confirmed by NMR structure confirmation. Note that that stereochemistry of the standards used is not known.

The new IDT compound one has the same MRMs ratio as terpendole E but comes off the column 0.2 mins earlier and has a different fragmentation pattern than terpendole E. This peak is most likely intermediate 1 that is slightly less hydrophobic than terpendole E, though commonly not observed in the FI1 IDT profile (Wade Mace, AgResearch; personal communication). This would be confirmed by comparing the new IDT compound one's fragmentation pattern and retention time with an intermediate 1 standard and/or intermediate 1 detectable strain. The new IDT compound two has the same MRMs as 13-desoxypaxilline but comes off the column 0.3 mins earlier and has a different fragmentation pattern. This peak is a true new IDT peak as there is no known IDT compound with this profile. The new IDT compound

Chapter four: Discussion

three has the same MRMs as paxitriol but comes off the column 1 min later and has a different fragmentation pattern. This peak is also a new IDT peak as there is no known IDT compound with this profile. Finally, the new IDT compound four has the same MRMs and fragmentation pattern as terpendole I but comes off the column 0.1 mins earlier. This peak is most likely a stereoisomer of terpendole I around the hydroxyl groups, resulting in a change in retention time.

The structure of the new IDT compound three (paxitriol-like peak) was further investigated due to the large change in retention time and fragmentation pattern in comparison to paxitriol and terpendole E, which both have the same MRMs. This new IDT compound three contains three OH groups on the 6-ring IDT core structure, as supported by fragmentation of both the new compound three and paxitriol into 420 m/z , 402 m/z , and 384 m/z ions, in contrast to the fragmentation of terpendole E where a 384 m/z ion is not observed. The new IDT compound three therefore has the same chemical formula as paxitriol of $C_{27}H_{35}NO_4$ but appears to be rearranged to form a more hydrophobic structure.

Where the new IDT compound three differs to paxitriol is in the placement of these three OH groups. While paxitriol fragments to generate a 378 (MS^2) ion, due to the loss of $(CH_3)_2CO$, this ion is absent for the new IDT compound three. Instead the new IDT compound fragments to generate a 366 (MS^2) ion due to the loss of C_4H_8O . Given these differences in fragmentation, OH group present on carbon 27 in paxitriol is suspected to be absent in the new IDT compound three. To generate the analogous fragmentation from paxitriol, first the OH group on carbon 27 needs to be removed, at the MS^2 fragmentation level, so that subsequent fragmentation at the MS^3 level generates loss of C_4H_8O . These differences support that the new IDT compound three is a constitutional isomer and not a stereoisomer of paxitriol.

The placement of the three OH groups can be inferred through the comparison of paxitriol and terpendole E fragmentation patterns. Terpendole E fragments to generate the unique 350 m/z ion because of the presence of a methyl group on carbon 12. In contrast, paxitriol does not have the methyl group on carbon 12 as it has been

reduced to a double bond between carbons 11 and 12 and does not generate the 350 m/z fragment ion. As the new IDT compound three does not generate the 350 m/z fragment ion, the new IDT compound must therefore have a double bond between carbons 11 and 12, and so the only logical places for the three OH groups are on carbons 10, 13, and 14, given that these sites have been observed to be hydroxylated in other *E. festucae* produced IDT compounds (Figure 4.2).

The results from the MS analysis suggest the new IDT compound three has the chemical formula of $C_{27}H_{35}NO_4$. The new IDT compound three has three sites of hydroxylation at carbons 10, 13, and 14, and a double bond between carbons 11 and 12. The absence of the OH group on carbon 27 would result in the formation of a hydrophobic appendage on the new IDT compound three that would explain the longer retention time observed in relation to paxitriol and terpendole E.

4.1.4 AR48 and Fg1 new indole-diterpene compound three synthesis predicted through bioinformatics

All IDT producing fungi contain four core genes which are involved in the first four steps of each pathway; *idtG* encoding a geranylgeranyl pyrophosphate synthase, *idtC* encoding a geranylgeranyl transferase, *idtM* encoding a FAD dependent epoxidase, and *idtB* encodes a cyclase. IdtG converts isopentenyl diphosphate (IPP) and/or dimethylallyl pyrophosphate (DMAPP) and/or geranyl pyrophosphate (GPP) and/or farnesyl pyrophosphate (FPP) into geranylgeranyl pyrophosphate (GGPP). GGPP then undergoes indole condensation by IdtC with indole-3-glycerol phosphate (IGP) to produce 3-geranylgeranyl indole (3-GGI). Finally, 3-GGI then undergoes single or double epoxidation by IdtM depending on the pathway. These epoxidated compounds are then cyclized by IdtB by either Markovnikov or anti-Markovnikov mechanisms (Van de Bittner *et al.*, 2018). Diversity is then achieved through regio- and stereo-specific decorations of these cyclized products. *Epichloë* strains that contain functional *idtG*, *idtC*, *idtM*, and *idtB*, IdtM perform either single or double epoxidation/s and IdtB performs anti-Markovnikov cyclisation (Saikia *et al.*, 2006). Single epoxidation with anti-Markovnikov cyclisation leads to emindole SB formation, while double epoxidation with anti-Markovnikov cyclisation leads to paspaline formation (Van de

Bittner *et al.*, 2018). However, for both lolitrem and paxilline synthesis, paspaline is the major intermediate of the pathways not emindole SB (Saikia *et al.*, 2006, Young *et al.*, 2009). Diversity is then achieved through multiple oxidation steps, by the P450 monooxygenases IdtP and IdtQ, from the intermediate paspaline (Figure 4.1) (McMillan *et al.*, 2003, Saikia *et al.*, 2012).

The tentative structure for the new IDT compound three identified from AR48 indicates that the novelty is due to differences in the location of the hydroxyl groups decorated onto the paspaline backbone. IdtP is known to hydroxylate at carbons 10 and 12 while IdtQ is known to hydroxylate at carbons 11 and 13 (Saikia *et al.*, 2012). The synthesis of the new compound would therefore involve the previously documented functions of IdtP and IdtQ, *i.e.* IdtP would hydroxylate carbon 10 and 12, and IdtQ would hydroxylate carbon 13, with the hydroxylation at carbon 14 performed by an unknown mechanism (Saikia *et al.*, 2012). The new IDT compound three is therefore the result of a new OH location combination as well as an OH and backbone combination not previously observed. All IDT compounds synthesised from paspaline in both the paxilline and lolitrem B pathways have a hydroxyl group on carbon 27 (McMillan *et al.*, 2003, Saikia *et al.*, 2012), however this is absent in the predicted structure of the new IDT compound three. This would suggest that the new IDT compound is derived from a precursor without the hydroxylated carbon 27 such as emindole SB, which is present in AR48 and Fg1 infected plant material at a level detectable by MS. However, ring I cannot form without this hydroxyl group. The predicted structure of the new IDT compound three therefore cannot be resolved from our current understanding of the lolitrem B pathway. Finally, the new IDT compound two (13-desoxypaxilline-like peak) might be part of the pathway which involves the new IDT compound three (paxitriol-like peak) given that the known IDT equivalent compounds, *i.e.* 13-desoxypaxilline and paxitriol, can both be modified into paxilline. The role of IdtP and IdtQ in the synthesis of the new IDT compound three was investigated using heterologous *idt* gene expression in different *P. paxilli* *pax* deletion (Δ) backgrounds. The presence of either AR48 *idtP* or *idtQ*, in a *P. paxilli* Δ *paxQ* or Δ *paxP* background respectively did not result in the synthesis of the new IDT compound three or other AR48 IdtP or IdtQ complementation specific IDT compounds.

Chapter four: Discussion

This mirrors the previous findings using *idtP* and *idtQ* genes from FI1 heterologously expressed in *P. paxilli* $\Delta paxQ$ or $\Delta paxP$ backgrounds, respectively (Saikia *et al.*, 2012). The failure to complement may be due to the first step post-paspaline in *Epichloë* spp. involves IdtQ, rather than IdtP as found in *P. paxilli*. This hypothesis would explain the absence of IDT products in the AR48 *idtP* complemented $\Delta paxP$ background. However, one might expect to find some post paspaline products such as terpendole E in a AR48 *idtQ* complemented $\Delta paxQ$ background but the competition for substrate from the *P. paxilli* PaxP in this background may result in very low levels of other IDTs (Figure 4.2) (Motoyama *et al.*, 2012).

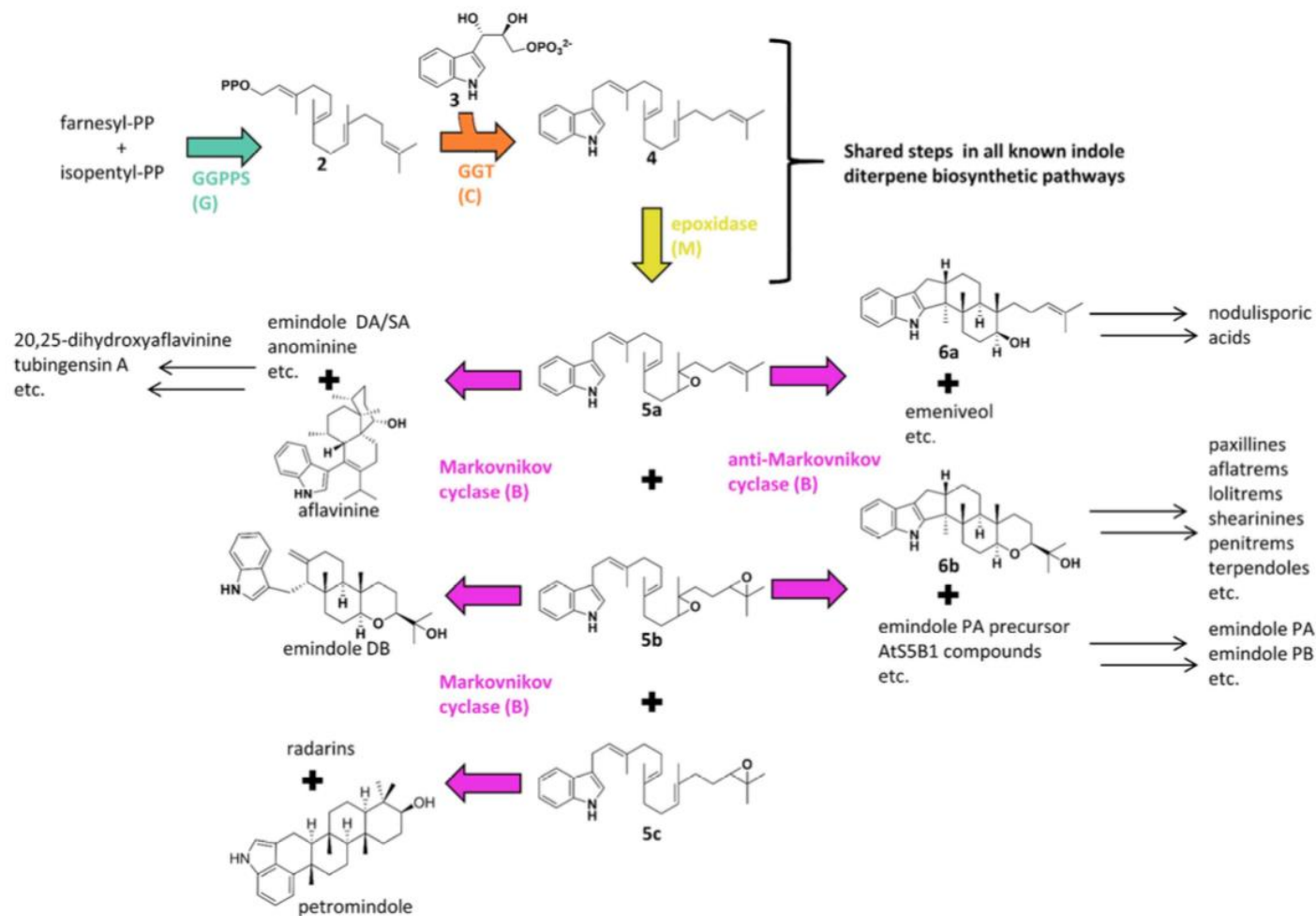


Figure 4.1: Schematic of the diversity of early pathway indole diterpene (IDT) compounds produced by the four core genes (G, C, M, and B- coloured) in fungi. Diversity is achieved through either markovnikov or anti-markovnikov cyclisation by M and single or double epoxidation by B (Van de Bittner *et al.*, 2018), taken from with permission from American Chemical Society.

Chapter four: Discussion

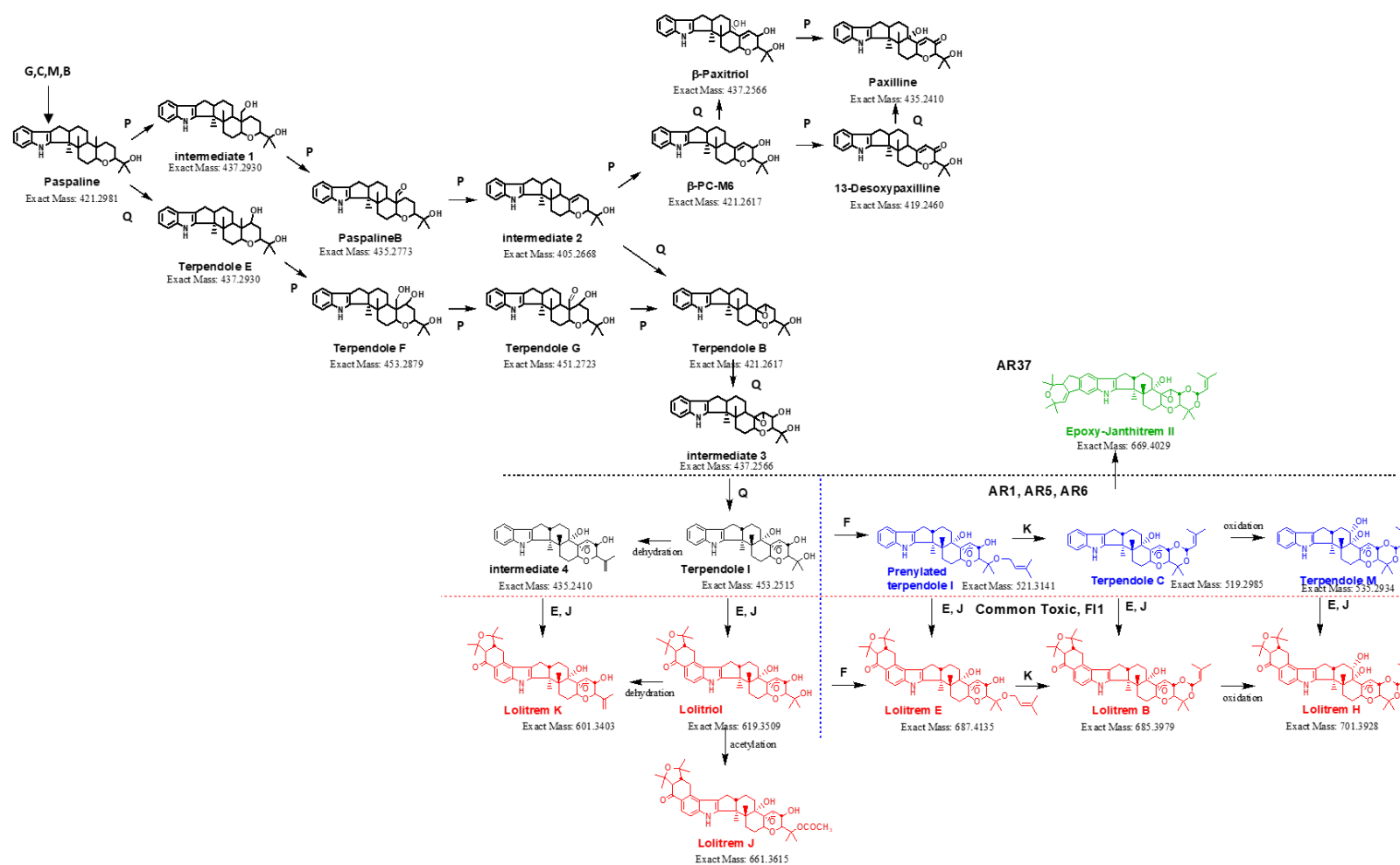


Figure 4.2: Simplified lolitrem B pathway in *Epichloë*. Genes (single letter *e.g.* indole-diterpene (IDT) = *idtP* = P) next to associated reaction. The section containing the end products of a strain is indicated. P/Q derived IDTs (black). E/J derived IDTs (red). F/K derived IDTs (blue/red). Epoxy-janthitrem IDT green).

4.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass

4.2.1 *Mcf* gene characterisation in *Epichloë*

Peramine and lolitrem B are both *Epichloë* bioactive SM however the characteristics of these two compounds are very different. Peramine is synthesised by a single gene *perA*, a non-ribosomal peptide synthetase (NRPS), that is not part of a cluster and is located in a GC rich non sub-telomeric region (Tanaka *et al.*, 2005). Lolitrem B is the end product of a biosynthetic pathway network involving 11 different genes (*idt*). These genes are located in a AT rich sub-telomeric region and group into three sub-clusters (Figure 4.3) (Young *et al.*, 2009, Saikia *et al.*, 2012).

The *perA* gene and the *idt* gene cluster have maintained syntony between and within *Epichloë* species (Tanaka *et al.*, 2005, Young *et al.*, 2009). The *perA* gene is located in all *Epichloë* strains analysed to date with different allelic variations identified with varying degrees of functionality (Tanaka *et al.*, 2005, Berry *et al.*, 2015). The lolitrem B cluster is not always present in *Epichloë* strains, and if present variation is seen in both the presence/absence of genes and functionality of the genes (Young *et al.*, 2009). Both the *perA* gene and *idt* gene cluster are widely distributed in the *Epichloë* genus and are unique to *Epichloë* (Tanaka *et al.*, 2005, Young *et al.*, 2009). Finally, peramine has insect bioactivity that targets specifically ASW (Rowan *et al.*, 1990), while lolitrem B has mammalian bioactivity that targets a range of grazing mammals, *i.e.* sheep and cattle (Gallagher *et al.*, 1981), and the intermediate compounds of this pathway have varying degrees of insect and mammalian bioactivity (Finch *et al.*, 2010).

Bioinformatics analysis of *mcf* within *Epichloë* identified that *mcf* is present in all analysed strains, which covered a wide range of species within the genus, and that there were two allelic variants of the *mcf* gene, with only one of the allelic variants present in each analysed strain but with varying degrees of functionality. The “AR48” allele has two introns and is predicted to contain two N-terminal cysteine protease domain (CPD1 and CPD2) and a central transmembrane domain (TMD). The AR48 allele

is identical to the *E. typhina* subsp *Poa* *Ps1 mcf* gene that has CC bioactivity (Ambrose *et al.*, 2014). The “FI1” allele has only the second intron and is predicted to contain only one N-terminal CPD (CPD2), and a central TMD. While the FI1 allele has been shown to be expressed we do not yet know whether the protein product functions as an endotoxin (Eaton *et al.*, 2015, Schardl *et al.*, 2013c). The presence of two *Epichloë mcf* alleles parallels to *P. luminescens mcf* which also has two *mcf* alleles; *mcf1* and *mcf2* (Dowling & Waterfield, 2007). The *mcf2* allele is slightly shorter than the *mcf1* allele at the N-terminal region (Dowling & Waterfield, 2007), and this reduction at the N-terminal region is also observed between the FI1 *mcf* and AR48 *mcf* alleles respectively.

The *Epichloë mcf* gene is located in a GC rich region that is non sub-telomeric and has maintained syntony within the *Epichloë* genus in relation to the surrounding genes. These surrounding genes do not have a functional connection to Mcf regulation, synthesis, post-translational modification or transportation. The *Epichloë mcf* gene is therefore not part of a cluster (Figure 4.3). Although the original data (Ambrose *et al.*, 2014) suggested that *mcf* might be present in *Epichloë* as the result of a horizontal gene transfer (HGT) event, recent evidence suggests otherwise (Dupont 2017; Tian *et al.* 2017). Finally, the protein produced by *mcf* (Mcf), does not require additional genes to be active (Ambrose *et al.*, 2014). Mcf has insect bioactivity which currently has only been tested against CC (Ambrose *et al.*, 2014). The characterisation of *mcf*/Mcf therefore parallels *perA*/peramine and not *idt*/lolitrem B, when comparing the genomic location, functionality, and distribution as well as protein synthesis and bioactivity. A major difference between *perA*/peramine and *mcf*/Mcf is that the former is the metabolic product of an NRPS encoded by *perA* whereas Mcf is the direct translational product of *mcf*.

The *Epichloë mcf* gene and protein characteristics also parallels to the bacterial *mcf*/Mcf, but with some variation to the bacterial *P. fluorescence* insect toxin (*fitD*/FitD). Both *Epichloë mcf* and bacterial *mcf1/mcf2* genes are not part of a cluster, and the synthesis of Mcf1/Mcf2 has been shown to occur through a single gene (Daborn *et al.*, 2002, Waterfield *et al.*, 2003). However, *Mcf1* and *Mcf2* are in genomic

locations that are associated with type IV and type I secretory machinery genes respectively, and the Mcf1/Mcf2 have predicted secretory domains, *e.g.* RTX-like (repeat-in-toxin) exportation domains, that can be recognised by these systems (Daborn *et al.*, 2002, Waterfield *et al.*, 2003). However, there is no direct evidence for secretion of Mcf1/Mcf2 by these transport systems. In contrast to the bacterial *mcf* genes, the bacterial *fitD* gene is part of a cluster but additional cluster genes are involved in transport (*fitA*, *fitB*, and *fitC*) and regulation (*fitE*, *fitF*, and *fitG*), therefore *fitD* is still solely involved in FitD synthesis (Péchy - Tarr *et al.*, 2008). The *Epichloë mcf* and bacterial *mcf1/mcf2* are present in all of the respective strains analysed to date and with allelic variants, but only *Epichloë mcf* and bacterial *mcf2* have maintained syntony in the gene genomic location (Dowling & Waterfield, 2007). In contrast, the *fitD* cluster, which also has *fitD* allelic variants, is only present in a select few strains, and has only maintained syntony within the cluster but not in the clusters genomic location (Péchy - Tarr *et al.*, 2008). The bioactivity of both the *Epichloë* Mcf and bacterial Mcf/FitD proteins target insect species within the Lepidoptera family (Péchy - Tarr *et al.*, 2008, Waterfield *et al.*, 2003, Daborn *et al.*, 2002, Ambrose *et al.*, 2014).

4.2.2 Proposed role of *Epichloë* Mcf

All Mcf-like proteins have the general domain composition of a N-terminal toxin domain, with the specific cytotoxic mechanism variable between strains, a N-terminal CPD, a central TMD and a variable C-terminal region that can be absent of domains or have secretion and/or receptor domains (Dowling & Waterfield, 2007). This general domain composition is also observed for the *C. difficile* TcdA and TcdB toxins (Reineke *et al.*, 2007), in which the Mcf TMD is commonly aligned to when analysed with online tools designed to predict protein domain structure, *i.e.* BLASTp, InterPro Scan, and Phyre2. Overall, the *Epichloë* Mcf protein domain composition has two N-terminal CPD (CPD1 and CPD2 labelled in order from the N-terminus), a central TMD and a variable C-terminal region with no domain predictions except for a secretion domain predicted for only the *E. festucae* Fl1 *mcf* gene. The difference between the two *Epichloë mcf* alleles is that the AR48 variant has both CPD1 and CPD2, while Fl1 variant has only the CPD2. The role of the *Epichloë* Mcf protein in providing insect bioprotection for

Chapter four: Discussion

endophyte infected ryegrass was therefore proposed by combining the *Epichloë* domain composition, and how this relates to other Mcf like proteins which have experimental evidence for both location, target cells, and cellular mechanism, *i.e.* *P. luminescens* Mcf1 as well as *C. difficile* TcdA and TcdB toxins.

The *Epichloë mcf* gene is expressed by the endophyte when the endophyte is present in the plant host (Eaton *et al.*, 2015, Winter *et al.*, 2018). The protein has two possible locations; either secreted by an unknown mechanism, as no secretion domain or genes predicted to be involved in secretion were identified, or retained in the cytosol of the mycelia. Mcf is hypothesized to enter the insect's digestive tract passively, *i.e.* through ingestion of endophyte infected grass material that once in the midgut is chemically and physically digested resulting in release of Mcf regardless of the *in planta* location. This contrasts with the active delivery of the bacterial Mcf *i.e.* upon infection, the bacteria are regurgitated from the nematode into the midgut where Mcf is secreted by a type I/IV secretory system out of the bacteria (Dowling & Waterfield, 2007, Forst *et al.*, 1997).

Mcf either targets the midgut epithelial cells (Dowling *et al.*, 2004, Daborn *et al.*, 2002) through receptor mediated endocytosis (Sauerborn *et al.*, 1997), or is passively taken up through the natural absorption of nutrients by the midgut (Takeda, 2012). There is no C-terminal receptor domain predicted to be present in any of the *Epichloë* Mcf proteins, making receptor mediated endocytosis an unlikely mechanism. However, as this domain is most likely involved in the target insect specificity which could be unique to *Epichloë*, and given that the fungal *mcf* gene is not widely distributed or well-studied, this domain might not have been previously annotated and therefore would have been missed in the bioinformatics analysis. Assuming endocytosis of Mcf by the midgut epithelial cells, regardless of mechanism, acidification of the endosome will cause a conformational change resulting in insertion of the TMD into the membrane, and translocation of the N-terminal CPD1 into the cytosol (Qa'Dan *et al.*, 2000). Interaction with a cytosolic component or another stimulus, which could be another point for target insect specificity, will cause another conformational change

resulting in activation of the CPD2 and self-cleavage. This will release the N-terminally located CPD1 into the cytosol (Voth & Ballard, 2005, Jank & Aktories, 2008).

CPD domains are present in bacterial cytotoxic necrotizing factors (CNF) (Boquet, 2001). However, the presence of two N-terminal CPD domains has been predicted to be present in all Mcf proteins analysed in this study, apart from *P. fluorescens* FitD and the *E. festucae* Fl1 Mcf allele that only have CPD2. For CPD1, the bioinformatics prediction therefore might not be specific for the presence of CPD1, but more a prediction for the presence of a “cellular toxin domain” which could vary for each protein, *i.e.* the CPD1 domain overlaps with the BH3 and HrmA for Mcf1 and Mcf2 respectively (Dowling & Waterfield, 2007). The CPD2 is most likely a CPD required for self-cleavage, a key step in the cellular mechanism hypothesised for all Mcf like proteins (Figure 4.4).

The modification of the midgut epithelial cells by the Mcf N-terminal CPD1 (Dowling *et al.*, 2004, Daborn *et al.*, 2002) therefore most likely results in dysfunction of the midgut, the primary organ involved in osmoregulation (Giordana *et al.*, 1985), and this loss of osmoregulation presents as a “floppy” phenotype (Ambrose *et al.*, 2014). The dysfunctional midgut may become leaky allowing Mcf to enter the haemocoel, and depending on target cell specificity, target a wider range of cell types, *e.g.* haemocytes, which would result in weakening of the insect immune system (Daborn *et al.*, 2002).

4.2.3 *Epichloë festucae* Fg1 Δ mcf characterisation

To date, the focus of reverse genetic studies in *Epichloë* has typically been on characterising genes involved in the establishment and maintenance of the symbiotic interaction that forms between the endophyte and plant host as well as dissecting secondary metabolism. Analysis of the symbiotic interaction is then assessed through in culture and *in planta* macroscopic and microscopic phenotypes, and/or the secondary metabolism *in planta* profile (Tanaka *et al.*, 2008, Charlton *et al.*, 2012, Scott *et al.*, 2012, Johnson *et al.*, 2013b, Becker *et al.*, 2015, Saikia *et al.*, 2008).

For this project, a *mcf* deletion strain (Δmcf) was created in Fg1, the genetically malleable AR48 model strain, to investigate the possible role of Mcf in the bioactivities observed in AR48 infected ryegrass. There was no obvious abnormal phenotypic variation between Fg1 wild type (WT) and Fg1 Δmcf confirming that deletion of this gene had no effect on growth in culture or *in planta*. This would be expected for a gene encoding a bioprotective SM (Saikia *et al.*, 2012) but also shows that the proposed ectopic integrations have not affected important genes for overall fungal functionality. The Fg1 Δmcf infected plants were therefore assessed for changes in insect bioactivity in relation to Fg1 WT infected plants. However, the lack of bioactivity of Fg1 WT infected plants was not known before the creation of the Fg1 Δmcf strain or before the Fg1 Δmcf infected plant insect bioactivity trial. As such, the Fg1 Δmcf strain cannot be used to study the potential role of Mcf in insect bioactivity unless conditions can be established for suitable Mcf expression *in planta*, *e.g.* *mcf* might be expressed in the native plant host for Fg1 but not in perennial ryegrass.

4.3 Test the insect bioactivity capabilities of AR48 and Fg1 infected ryegrass

4.3.1 AR48 and Fg1 new indole-diterpene potential bioactivity

There is strong evidence to suggest that the new IDT compound three has bioactivity against SBF because the new IDT compound three has been detected in AR48 and AR47 infected plant material and not in AR37 or AR1 infected plant material. This directly correlates with SBF bioactivity, confirmed in three independent feeding trials, presence in AR48 and AR47 infected plant material and absence in AR37 and AR1 infected plant material. The potential for the new IDT compound three to have CC bioactivity cannot be assessed due to the uncertain results obtained in this study from two different CC feeding trials. The lolitrem B pathway intermediate compounds, in which the new IDT compound three is predicted to be included, have a range of non-bioactive, insect bioactive, and mammalian bioactive activities (Parker & Scott, 2004, Saikia *et al.*, 2008, Imlach *et al.*, 2011). The different structures of these bioactive compounds cannot be correlated to the presence or absence of bioactivity, and if bioactive, mammalian or insect target species (Sarah Finch, AgResearch; personal

communication). As such, an insect trial using the purified AR48 new IDT compound three would need to be performed to unequivocally prove that the AR48 new IDT compound three is the causal agent for SBF bioprotection. In general the mechanism through which IDT compounds are bioactive is by binding to cellular ion channels causing disruption of functionality that results in loss of membrane potential and cellular death (Smith *et al.*, 2000). The specificity of the IDT is dependent on the specificity of the ion channel that the compound interacts with, therefore IDT compounds that only disrupt ion channels present in insects and not mammals are ideal for plant bioprotective compounds, *e.g.* glutamate-gated chloride channels (Wolstenholme, 2012) and not calcium activated potassium channels (Imlach *et al.*, 2011). Alternatively, if the IDT does interact with an ion channel present in both mammals and insects, *e.g.* sodium channel (Dong, 2007), if the presence of the IDT is high enough in the plant material for insect mortality or deterrence, but low enough in grass associated consumables to elicit no effect on animals, then the IDT could still be considered as a commercial bioprotectant (Bloomquist, 1996). Currently, there is no evidence of the AR48 new IDT compound three mode of action in terms of disruption of ion channels or an alternative mechanism.

4.3.2 *Epichloë Mcf* infected ryegrass potential bioactivity

There is evidence from multiple experiments performed in independent laboratories that show that both the fungal and bacterial Mcf proteins have CC bioactivity (Ambrose *et al.*, 2014, Daborn *et al.*, 2002), however there is not a strong correlation between the presence of Mcf and the presence of CC bioactivity in this study. For both trials, Fl1 infected plant material had strong CC bioactivity, AR48, AR1, and AR37 infected plant material had no or weak CC bioactivity, and Fg1 infected material had no bioactivity. The Fg1 Δmcf infected plants did not have CC bioactivity that is expected given that the Fg1 WT infected plants also do not have CC bioactivity. However, all strains had a *mcf* gene predicted to be functional, with AR48 and Fg1 having the AR48 *mcf* allele (Ambrose *et al.*, 2014), and the remaining strains (Fl1, AR1, and AR37) having Fl1 *mcf* allele. Overall, there was no correlation between presence or absence, functional or non-functional, or AR48 or Fl1 *mcf* alleles, and presence of CC bioactivity. These results are therefore unclear and appear to contradict the previous

Chapter four: Discussion

USA trials. Due to these ambiguous results the AR48 new IDT compound three possible role in CC bioactivity can also not be predicted (Table 4.1).

The major flaw in the experimental design of both CC feeding trials is that *mcf* expression levels and/or Mcf protein amount was not analysed before, during, or after the trials. In addition, the functionality of the different *mcf* allelic variants has never been assessed making it nearly impossible to predict the effect that Mcf has on CC bioactivity. As previously noted, the CC bioactivity observed in F11 infected plants may be due to the presence of ergot alkaloids which have been suggested to have CC bioactivity (Potter *et al.*, 2008) adding another variable to take into consideration.

In addition, how CC detached tiller no choice (CDTN) trial was performed could have influenced the outcomes. Although the CDTN trial was based upon the methodology of the USA trials, experiments were performed under non-ideal conditions. This could cause increased background variation resulting in unclear results. The PC1 plants were at different stages of growth as the F11 and Fg1 plants were inoculated into seedlings, which retards the initial growth, rather than planted from infected seeds like AR48, AR37, and CT. The PC2 plants were younger than the PC1 plants as the Fg1 Δmcf strain was only confirmed just in time for inclusion in this trial, and so were inoculated into seedlings approximately 6 weeks after the PC1 plants. The 2017/2018 summer in New Zealand was both late and short. This delayed the breeding season of the cutworm moth (CM-*Agrotis ipsilon*) and reduced the window of CM availability. The trial could only have been performed late summer/early autumn, *i.e.* March/April, instead of mid/late summer, *i.e.* January/February. This meant that the plants were prepared for the trial too early, 5-6 months old rather than 3-4 months old, apart from the PC2 plants. Factors such as plant senescence, microbial infection, and the presence of additional insects (as the plants cannot be treated with chemical insecticides) might have affected the insect trial. These two factors, early plant preparation and delayed breeding season, were amplified when the Fg1 Δmcf strain caused the trial to be further delayed, *i.e.* April/May. The SM levels are known to drop in winter due to reduced sunlight and temperatures, therefore the levels of the bioactive compounds

Chapter four: Discussion

during the trial might have been at lower levels than present in the peak of summer (Wade Mace, AgResearch; personal communication).

In contrast to the CC whole plant choice (CWPC) and CDTN trials, the porina caterpillar (PC-*Wiseana* spp) detached tiller no choice (PDTN) trial detected PC bioactivity in AR48 infected ryegrass along with AR37 infected ryegrass, but not AR1, Fl1, and Fg1 infected ryegrasses, and as the PDTN trial was performed under more ideal conditions than the CDTN trial (all plants at 3-4 months old in the same glasshouse and during the middle of the porina breeding season), the AR48 PC bioactivity potentially could be due to the presence of Mcf. Although, *mcf* expression levels and/or Mcf amount would need to be assessed. In addition, the absence of PC bioactivity for Fg1 correlates to the hypothesized lack of *mcf* expression providing further evidence for *mcf* being a PC bioactive. Despite these limitations these results do suggest that Mcf has a broader target range that includes other Lepidoptera species (Table 4.1). This is supported by the literature, *e.g.* Mcf has been shown to have tobacco hornworm caterpillar (*M. sexta*) bioactivity (Daborn *et al.*, 2002).

By combining the PC and CC bioactivity results, the Fl1 *mcf* allele does not appear to have bioactivity against PC and therefore inferred lack of CC bioactivity. This is because the CC bioactivity in Fl1 infected ryegrass is most likely due to the presence of ergot alkaloids (Potter *et al.*, 2008) and not the presence of a functional Fl1 *mcf* allele. The ryegrass plants infected with AR37, which also has a Fl1 *mcf* allele, does not have CC bioactivity and does not produce ergot alkaloids. The PC bioactivity detected in AR37 infected ryegrass is due to the presence of *epoxy-janthitrems*, not the presence of a functional Fl1 *mcf* allele, and the absence of PC bioactivity in Fl1 infected ryegrass is due to the absence of *epoxy-janthitrems* (Hennessy *et al.*, 2016). Ryegrass infected with AR1, which has a Fl1 *mcf* allele, does not have CC and PC bioactivities, which correlates to the absence of ergot alkaloids or *epoxy-janthitrems* in AR1 infected material. Ryegrass infected with Fg1, which has the AR48 *mcf* allele, has no bioactivity detected in any trials performed to date. This is possibly due to host incompatibility resulting in changes in gene expression, *e.g.* downregulation of *mcf* (Leuchtman *et al.*, 2000). Ryegrass infected with AR48, which has the AR48 *mcf* allele, has PC

bioactivity and should have CC bioactivity. Both activities could therefore be tentatively due to the presence of the AR48 Mcf protein.

Finally, AR48, AR37, and AR1 infected ryegrasses, but not AR47 infected ryegrass, did have light brown apple moth caterpillar (LBAM- *Epiphyas postvittana*) bioactivity detected in the LBAM artificial diet no choice (LADN) trial. This trial does not provide information on the bioactive but is designed as a “universal” insect bioactive producing strain identifier. The trial was therefore in most cases successful. Overall, the presence of the AR48 *mcf* allele correlates with the presence of PC bioactivity, and inferred CC bioactivity, in AR48 infected plants. Therefore, Mcf could be a general Lepidoptera caterpillar toxin. However, this hypothesis is very tentative and requires thorough investigation (Table 4.1).

4.3.3 Difference in AR48 and *Epichloë festucae* var *lolii* AR47 infected ryegrass bioactivities

The two *E. festucae* var *lolii* strains AR48 and AR47 are very difficult to distinguish by SSR, and therefore are most closely related to each other compared to other strains in the AR48 clade. However, despite this very close relationship differences have been observed in insect bioactivity trials between AR48 and AR47 infected plants. AR48 infected ryegrass has ASW bioactivity whilst AR47 infected ryegrass apparently does not (Alison Popay, AgResearch; personal communication). Differences in bioactivity were also apparent in the insect bioactivity feeding trials performed in this study. AR48 had subtle differences in the SBF pupae survival rate in comparison to AR47, and AR48 had LBAM bioactivity and AR47 did not (Table 4.1). These differences could be due to a range of reasons such as gene expression levels, gene functionality, and presence or absence of additional genes within the genome. Further comparative analysis of AR47 and 48 is therefore warranted.

4.3.4 Potential alternative bioactives for AR48 infected ryegrass novel insect bioactivity

The SM profile of each *Epichloë* strain is both extraordinarily complex and exceptionally varied. The strain unique SM profiles account for a large proportion of

the diverse range of naturally occurring characteristics observed in *Epichloë* infected plants. This study has identified a new potential insect bioactive SM (the new IDT compound three) produced by AR48 and Fg1 strains that potentially has SBF. In addition, Mcf was also identified as a potential bioactive for CC and/or PC but with less certainty. However, due to the complexity of the SM profile of each strain, unless definitive evidence for the direct effect of a SM on a specific insect is provided, the insect bioactivity of interest could be due to the presence of other compound/s.

NRPS, polyketide synthase (PKS), and NRPS-PKS hybrids are commonly linked to bioactivity towards a range of organisms including insects. NRPS genes are the most commonly studied of the three. NRPSs have been identified in *Epichloë* as either being directly involved in the synthesis of the bioactive compound alone, *e.g.* Peramine produced by the NRPS *perA*, (Berry, 2011), or as being part of a more complex bioactive synthesis pathway, *e.g.* *lpsA*, *lpsB*, and *lpsC* which are involved in the production of a range of bioactive ergot alkaloids (Schardl *et al.*, 2012). There appears to be equal numbers of PKS and NRPS but very few NRPS-PKS genes (Schardl *et al.*, 2013c). Currently there is one NRPS-PKS bioactive product identified (Song *et al.*, 2016) and no PKS bioactive products identified in *Epichloë*. However, bioactive PKS products have been identified in other fungal species (TePaske *et al.*, 1992).

The paper published by Song (Song *et al.*, 2016) has detected and solved the structure of a PKS-NRPS compound (dahurelmusin A) produced by *Epichloë bromicola*, which has tentative aphid bioactivity. MS detected the same compound in AR48 infected ryegrass (Wade Mace, AgResearch; personal communication). A bioinformatics analysis identified only one PKS-NRPS gene in the genome of AR48 and therefore this compound is most likely the product of this gene, but further experimental analysis is required. This PKS-NRPS is therefore another potential bioactive which could be responsible for either the SBF or CC bioactivity of AR48 infected ryegrass. This also suggests that AR48 infected ryegrass might have aphid bioactivity.

4.3.5 Comparison between different insect bioactivity trial methodologies

There are three main types of insect bioactivity trials performed in this study; whole plant choice (WPC) trial, detached tiller no choice (DTN) trial, and artificial diet no choice (ADN) trial. Each trial type has different advantages and disadvantages that need to be considered when assessing a specific insect bioactivity. Currently all insects, apart from the LBAM, are sourced from the New Zealand environment, therefore the trials can only be performed at set times during the year and can be heavily affected by seasonal variation in the insect populations (Table 4.2).

For the WPC trial the major advantage is that, apart from the plant preparation and insect preparation (which will vary depending on the bioactivity tested) the trial requires very little work once set up. Also, the WPC trial mimics the natural environment more effectively than the DTN and ADN trials. This is an advantage for assessment of naturally occurring insect pests. The WPC trial is more suited to assessing bioactives that deter insects rather than bioactives that are toxic to insects because the plants rather than the insects are assessed therefore the effect of the bioactive on the different stages of the insect's life cycle can be missed. However, this is dependent on the insect bioactivity assessed *i.e.* the WPC for SBF assessed the complete life cycle, but the WPC for CC did not collect any data on the effect of the bioactive on the CC, however the DTN for CC did (Table 4.2).

Conversely, the DTN and ADN trials can assess and distinguish between deterrent and toxin bioactives, and there is more focus on the insect assessment rather than the plant assessment, resulting in increased sensitivity and robustness. However, both the DTN and ADN preparation as well as the actual trial require a lot of work that can reduce the replication and/or sample numbers assessed in each trial. Both the DTN and ADN trials mimic the scenario encountered in a field planted with mono-cultivars where there is no choice. Therefore, insects that are agricultural pests could better suit these trials. The major disadvantage of both the DTN and ADN trials is that the use of detached tillers or artificial diet can result in inactivation of the bioactive leading to false negatives. Bioactive inactivation is less likely to occur in the DTN trial than the ADN trial as the bioactives are still within the plant material. Also, the detachment of

Chapter four: Discussion

the tiller before ingestion is mimicked by the feeding behaviour of some insects (including CC and PC) so the corresponding bioactive would be expected to remain functional (Table 4.2).

The major disadvantage of the ADN trial is that each insect requires a specific artificial diet that needs to be designed before the ADN trial can be performed. Also, not all insect bioactives can be assessed using the ADN trial as some insect's natural environment might be hard to artificially recreate, *e.g.* the SBF larvae remain in the leaf tissue during development and so cannot be fed like the CC which develop in the soil. However, if a diet and appropriate artificial environment can be designed, and the added bioactive is not inactivated, the insect bioactivity can be assessed in a neutral chemical background resulting in very accurate bioactivity assessment. In contrast, in both the WPC and DTN trials, multiple potential bioactives are present simultaneously during bioactivity assessment that can lead to misinterpretation of results (Table 4.2).

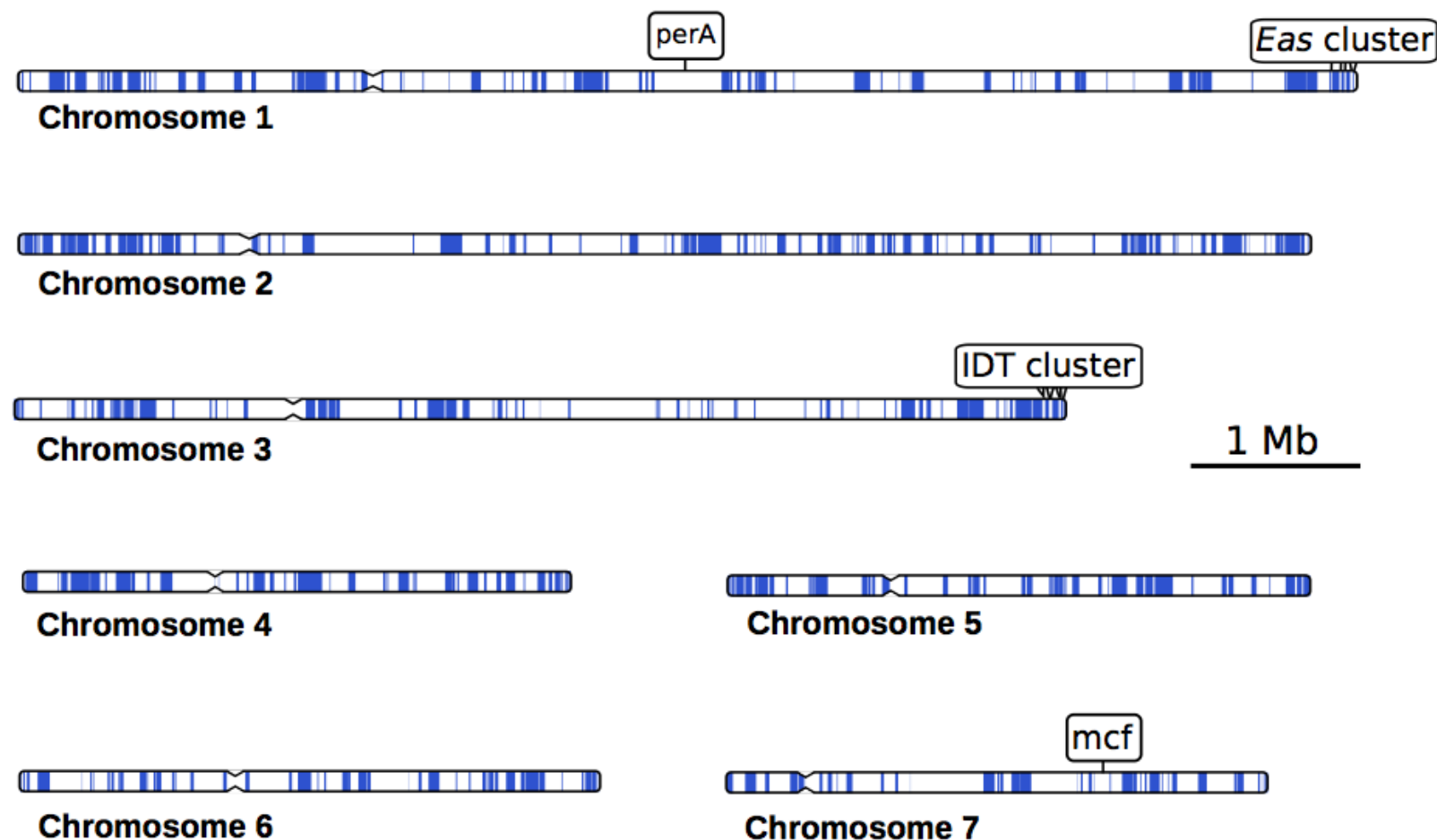


Figure 4.3: Graphical representation of the genomic location of secondary metabolite genes that produce bioactive compounds, in *Epichloë festucae* FI1 complete assembled genome. The gene locations are indicated by a labelled box where *perA* produces peramine, *Eas* cluster produces ergot alkaloids, *IDT* cluster products indole-diterpenes, and *mcf* products Mcf. The AT rich repeat regions are coloured blue, and GC rich regions coloured white.

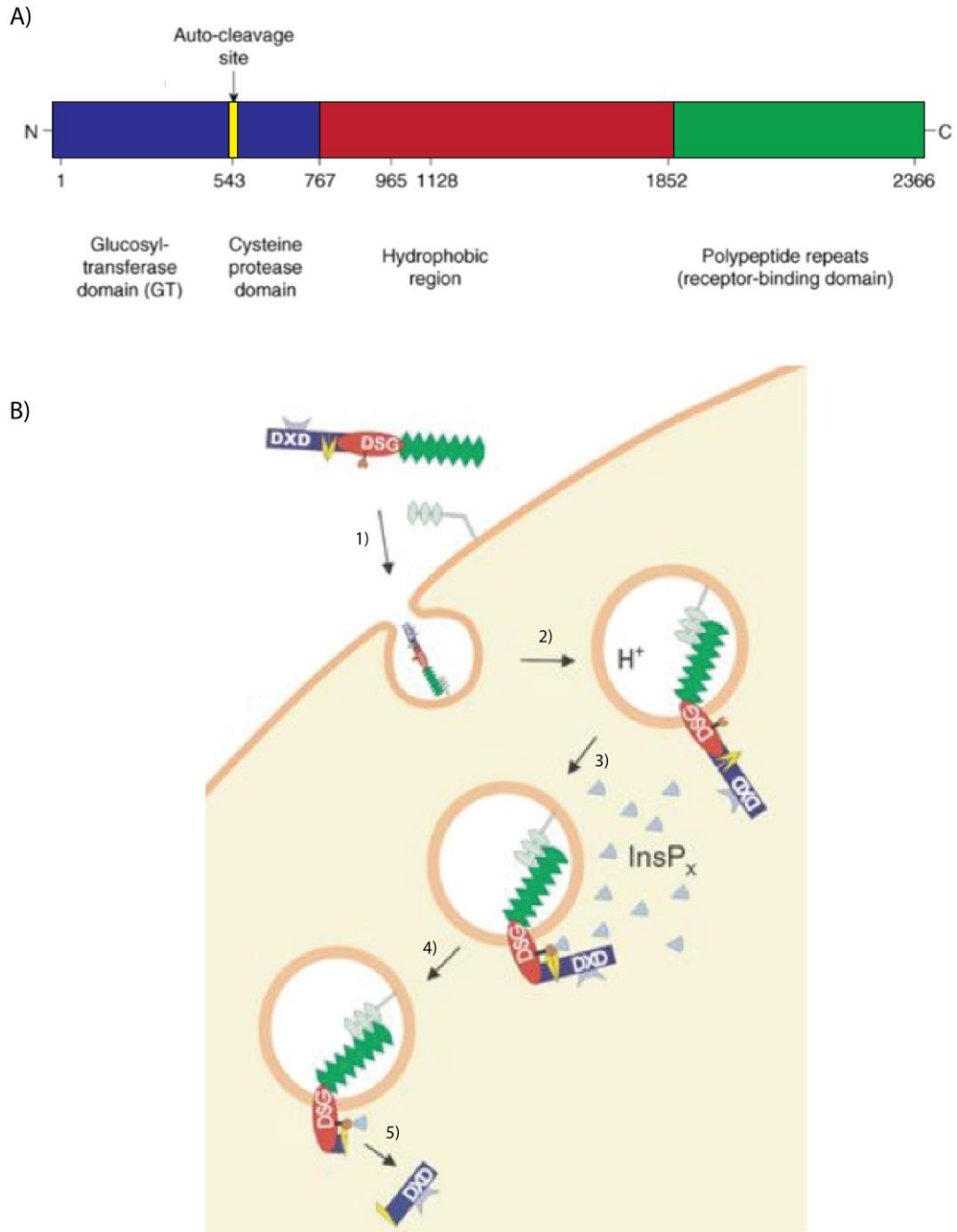


Figure 4.4: Proposed mode of action for the *Epichloë* makes caterpillars floppy (Mcf) protein based on the *Clostridium difficile* TcdA and TcdB toxins. A) Graphical representation of the TcdA/TcdB toxin domain composition. Domains are coloured, with amino acid number and domain labelled below. B) TcdA/TcdB mode of action. 1) Protein enters cell through receptor-mediated endocytosis via the receptor-binding domain (green). 2) Acidification of the endosome causes the first conformational change resulting in inserting of the hydrophobic region (red) and translocation of cytotoxic domain (blue) into the cytosol. 3) Interaction with host components leads to second conformational change resulting auto-cleavage via the cysteine protease domain (orange). 4) The released cytotoxic domain (blue) modifies key host components resulting in cell death via apoptosis. Modified from (Reineke *et al.*, 2007, Jank & Aktories, 2008) with permission from Springer Nature and Elsevier.

Chapter four: Discussion

Table 4.1: Overall insect bioactivities of *E. festucae* strains against a range of insects using different methodologies.

<i>Epichloë festucae</i> strain						1
	Grass					Fruit
	Diptera	Lepidoptera				2
	Larva/Caterpillar					3
	SWC	CWC	CDN	PDN	LAN	4
AR48	✓✓✓	×	✓	✓✓✓	✓✓	
AR47	✓✓✓	×	N/A	N/A	×	
Fg1	N/A	×	×	×	N/A	
Fl1	N/A	✓✓✓	✓✓✓	×	N/A	
AR37	×	✓	✓	✓✓✓	✓✓✓	
AR1	×	✓	N/A	N/A	✓	

1. Plant material targeted by insect. 2. Insect order. 3. Insect life staged targeted by the bioactive. 4. Trial method where SWPC (stem boring fly-*Cerodontha australis*-whole plant choice), CWPC (cutworm moth caterpillar- *Agrotis ipsilon*-whole plant choice), CDTN (cutworm moth caterpillars detached tiller no choice), PDTN (porina caterpillar- *Wiseana* spp-detached tiller no choice) and LADN (light brown apple moth caterpillar- *Epiphyas postvittana*-artificial diet no choice). ✓✓✓ strong activity, ✓✓ medium activity, ✓ weak activity, × no activity, and N/A not assessed

Chapter four: Discussion

Table 4.2: Comparison of the different parameters between the insect trials used in this study

	SWC Sem boring fly whole plant choice trial	CWC Cutworm moth whole plant choice trial	CDN Cutworm moth detached tiller no choice trial	PDN Porina detached tiller no choice trial	ALAN Light brown apple moth artificial diet no choice trial
Insect					
Type	Stem boring fly	Cutworm moth	Cutworm moth	Porina	Light brown apple moth
Life stage	Fly	Moth	Moth	Moth	Eggs
Collection	New Zealand environment	New Zealand environment	New Zealand environment	New Zealand environment	Plant and Food
Method	Nets	Light trap	Light trap	Light trap	Ordered
Processing	Sorted and sexed	Sorted	Sorted, sexed, ranked by weight	Sorted, sexed, ranked by weight	None
Trial					
Plant structure	Whole plant	Whole plant	Detached tillers	Detached tillers	Artificial diet
Insect	1 day old fly	3 weeks old caterpillars	3 weeks old caterpillars	3 weeks old caterpillars	1 day old caterpillar
Location	PC0 Glasshouse	PC0 Glasshouse	PC2 Laboratory	PC0 Temperature controlled chamber	PC0 Temperature controlled chamber
Replications	20	20	PC1 16 (3 biological and 5+1 technical) PC2 9 (3 biological and 3 technical) PC1 7 and PC2 2	9	25
Endophyte strains per trial	6	8	1	5	6
Endophyte strains per replication	6	8	1	1	1
Insects per replication	20 male and 20 female	40 mixed	1	1	1
Duration	6 weeks	2 weeks	8 days	10 days	16 days
Measurements	Mine number, pupa number, fly emergence	Plant tiller difference, plant visual score	Caterpillar weight, tiller weight	Caterpillar weight, tiller weight	Establishment time, molt time

SWPC (stem boring fly-*Cerodontha australis*-whole plant choice), CWPC (cutworm moth caterpillar- *Agrotis ipsilon*-whole plant choice), CDTN (cutworm moth caterpillars detached tiller no choice), PDTN (porina caterpillar- *Wiseana spp*-detached tiller no choice) and LADN (light brown apple moth caterpillar-*Epiphyas postvittana*-artificial diet no choice)

5.0 CONCLUSION

5.1 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1

The known bioactive secondary metabolite (SM) pathways in *Epichloë* were successfully analysed in the *E. festucae* strains AR48 and Fg1. The genomes of both strains were first sequenced, and then analysed for the presence and functionality of each gene involved in the four pathways using alignments with gene models (F11 indole diterpene (IDT), ergot alkaloid and peramine gene models as well as E2368 loline gene model) followed by manual annotations. Both the genomes of AR48 and Fg1 do not contain any of the genes involved in the ergot alkaloid and loline pathways. The peramine gene is present but non-functional due to a large deletion that is identical between AR48 and Fg1. All the genes involved in the IDT pathway are present, however *idtK* and *idtF* are non-functional due to SNPs, with the *idtF* SNP identical between AR48 and Fg1. In addition, *idtP* and *idtQ* from AR48 and Fg1 are divergent in sequence identity with the corresponding genes from other *Epichloë* but nearly identical with one another. Given the identical SM profiles, in addition to simple sequence repeat (SSR) analysis, Fg1 was identified as a suitable model experimental system for AR48 as this strain is much more amenable to genetic manipulation.

The IDT profile of AR48 and Fg1 was analysed using IDT extracts from plant material infected with AR48 or Fg1 and analysed using mass spectrometry (MS). All the key IDT compounds predicted to be produced on the basis of the genes identified by bioinformatics were identified in this material. In addition, four new IDT compounds were identified in just AR48 and Fg1 material. The new IDT compound three was further investigated with the structure tentatively solved using MS. The presence of this new IDT compound three is likely due to the modified activity of the divergent *IdtP* and *IdtQ*. The possible role of these genes in the production of the new IDT compound three was investigated using heterologous expression in appropriate *P. paxilli* gene deletion strains, however no new intermediate or new IDT compound three products were identified.

5.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass

The gene *mcf* was identified in all *Epichloë* strains analysed in this study. In addition, two *Epichloë* allelic variants were identified, with approximately half of the genes annotated as functional. Bioinformatics analysis predicted two N-terminal cysteine protease domain (CPD) and a central transmembrane domain (TMD). In preparation for bioactivity analysis by reverse genetics, makes caterpillars floppy (*mcf*) was successfully deleted (Δ) in Fg1 using homologous recombination and the presence of the deletion confirmed by both restriction digest as well as Southern blot analysis. The axenic culture phenotype of this Fg1 Δmcf strain did not differ in morphology or growth to the Fg1 wild type (WT) strain, and plants infected with Fg1 Δmcf had no distinguishable host interaction phenotype compared to plants infected with Fg1 WT. This lack of a host interaction phenotype is consistent with what has been published for other mutants that are defective in the synthesis of SMs.

5.3 Test the insect bioactivity capabilities of *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1 infected ryegrass

A stem boring fly (SBF-*Cerodontha australis*) whole plant choice trial (SWPC) successfully identified SBF bioactivity in AR48 and AR47 infected ryegrass and the absence of SBF bioactivity in AR37 and AR1 infected ryegrass. Both cutworm moth caterpillar (CC-*Agrotis ipsilon*) whole plant choice (CWPC) and CC detached tiller no choice (CDTN) trials successfully identified CC bioactivity in F11 infected ryegrass while the CC bioactivity of the remaining strains, which included AR48 and Fg1, were inconclusive. The porina caterpillar (PC-*Wiseana* spp) detached tiller no choice (PDTN) trial successfully identified PC bioactivity in AR37 and AR48 infected ryegrass and the absence of PC bioactivity in AR1 and F11 infected ryegrass. Finally, the light brown apple moth (LBAM-*Epiphyas postvittana*) artificial diet no choice (LADN) trial identified bioactivity in all strains apart from AR47.

5.4 Overall conclusion of the project

In conclusion, while the specific bioactive(s) in AR48 and Fg1 that targets CC and SBF were not identified two strong candidates, a new IDT compound and Mcf (a likely insect toxin) have been characterised. To test whether either, or both, of these candidate bioactives confers specific bioactivity against these insects, feeding experiments using ryegrass infected with deletion mutants of each of these genes singly and together will need to be performed. While the Δmcf strain has been generated, deletions of *idtP* or *idtQ* are yet to be made. The *Epichloë* SBF bioactive was tentatively identified as a new IDT compound three produced in AR48 by the substrate divergent *IdtP* and/or *IdtQ* using a newly developed SWPC trial. By combining the CDTN and PDTN trial results, the AR48 Mcf allelic variant was very tentatively identified as the CC bioactive produced by AR48 infected ryegrass. To conclusively identify the new IDT compound and Mcf as the SBF and CC bioactives, respectively, these compounds would need to be assessed for bioactivity using artificial diet insect feeding trials to eliminate potential background compound interference.

6.0 FUTURE EXPERIMENTS

6.1 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1

6.1.1 AR48 and Fg1 genome assembly

The genomes of both AR48 and Fg1 have been sequenced by Illumina paired-end technology that produces a large number of short reads with high sequence accuracy. This accuracy is very important for bioinformatics analysis in predicting the functionality of genes. However, for *Epichloë*, Illumina sequencing tends to produce fragmented genome assemblies due to the very large numbers of repeats present throughout *Epichloë* genomes. Fragmented genome assemblies are problematic as it can prevent analysis of the gene organisation within the genome, *i.e.* gene clusters can be spread across multiple scaffolds and contigs, and genes can be missed *i.e.* genes can be split across scaffolds and contigs. This is apparent for the indole-diterpene (IDT) clusters in AR48 and Fg1. A complete genome assembly could be generated for AR48 and Fg1 by sequencing the genomic DNA using long read platforms such as PacBio technology (Winter *et al.*, 2018). These technologies produce a higher number of very long reads but with a higher sequence error rate. The Illumina reads/scaffolds/contigs, which are very accurate, can then be mapped onto these larger reads, and in most cases, the genome can be fully assembled.

6.1.2 *Epichloë festucae* AR48 and Fg1 new indole-diterpene compound three structure

The structure of the new IDT compound three identified only in AR48 and Fg1 infected ryegrass has been analysed through mass spectrometry (MS). However, it is difficult to completely resolve the structure of metabolites using this technique. To resolve the structure of the new IDT compound three it will be necessary to purify the compound and determine its structure by nuclear magnetic resonance (NMR). This could be achieved through extraction of the IDT fraction from a plant source such as seed where the compound is abundant.

6.1.3 AR48 and Fg1 new indole-diterpene compound three synthesis pathway

The current hypothesis is that the new IDT compound three present only in AR48 and Fg1 infected ryegrass is a result of novel catalytic activities of IdtP and IdtQ acting on the first stable IDT paspaline. The biosynthesis pathway of this new IDT compound three was not successfully recreated when AR48 *idtP* and *idtQ* genes were individually heterologously expressed in the corresponding *P. paxilli* mutant backgrounds, *i.e.* AR48 *idtP* and *idtQ* were expressed in $\Delta paxP$ and $\Delta paxQ$ backgrounds, respectively. It is likely that the failure to detect any new intermediates is because IdtQ rather than IdtP uses paspaline as the substrate. A key experiment to do is to introduce *idtQ* into the *P. paxilli* $\Delta paxP$ mutant background. Generation of a $\Delta paxP\Delta paxQ$ double mutant would be also very helpful for this analysis. Alternatively, MIDAS (Modular Idempotent DNA Assembly System) can be used to efficiently produce *P. paxilli* strains with different IDT gene combinations that could then be analysed for the resultant IDT compound profile using MS.

6.1.4 AR48 and Fg1 new indole-diterpene compound three phylogenetic distribution

Currently the new IDT compound three has only been identified through MS in AR48, Fg1, and a few AR48-like strains (Wade Mace, AgResearch; personal communication) and not in AR1, AR37, common toxic (CT), and FI1. The distribution of the new IDT compound three within *Epichloë* can be analysed by identifying other strains that produce the new IDT compound three through IDT seed and/or infected plant material profiling. The seeds can be obtained from the Margo Forde Germplasm centre, and phylogeny through the AgResearch forage endophyte simple sequence repeat (SSR) dendrogram (unpublished data). In addition, the role of *idtP* and *idtQ* genes in the synthesis of the new IDT compound three can be supported by analysing the presence and sequence identity of the *idtP* and *idtQ* genes in the corresponding strains from the distribution experiment described above. This could provide a correlation between the presence of the sequence divergent *idtP* and/or *idtQ* genes and the presence of the new IDT compound three.

6.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass

6.2.1 *Epichloë* *mcf* allelic variants

The *Epichloë* makes caterpillars floppy (*mcf*) gene has two allelic variants, the AR48 allele which should have bioactivity (Ambrose *et al.*, 2014) and the Fl1 allele for which the bioactivity status is unknown. Both CC bioactivity trials tentatively suggest that only the AR48 allele has bioactivity against the CC and/or porina (*PC-Wiseana* spp). The same bioactivity trials described in section 5.4 could be used to assess the bioactivity potential of both *Epichloë* Mcf allelic variants. The SWPC and CADN trials would involve a range of strains chosen based on the presence of AR48 *mcf* or Fl1 *mcf* variants, with the addition of the expression levels of the *mcf* allele and/or amount of Mcf protein measured. The CADN trial in addition would require purification of the products of the two Mcf allelic variants. Alternatively, the same artificial trial as described by Ambrose *et al.* (2014) could be performed with *E. coli* and/or *P. paxilli* expressing either the AR48 *mcf* or Fl1 *mcf* genes.

6.2.2 *Epichloë* Mcf domain functions and bioactivity mechanism

The Mcf proteins are predicted to have a variable bioactive N-terminal toxin domain, a N-terminal cysteine protease domain (CPD), a central transmembrane domain (TMD), and C-terminal receptor/secretory domain (Dowling & Waterfield, 2007). To better understand the functionality of the two *Epichloë* *mcf* alleles, different *mcf* alleles or *mcf* truncations, with or without a fluorescent tag, could be expressed in *E. coli* and/or *P. paxilli* and then tested for bioactivity using the same artificial insect trial described by Ambrose *et al.* (2014). The insects could then be dissected, and protein location analysed using fluorescent microscopy (Ambrose *et al.*, 2014). In addition, mammalian cell lines expressing these constructs could then be used to analyse the specific cellular mechanism of the bioactivity (Dowling *et al.*, 2004).

6.2.3 *Epichloë Mcf* in culture, in planta, and target insect localisation

To identify where the Mcf protein is located in *Epichloë* the gene could be tagged with a fluorescent marker and expressed under a constitutively expressing promoter. Total protein content of the mycelia and media could then be extracted separately and analysed for the tagged Mcf protein by a western blot analysis. In addition, *mcf* could also be tagged with a fluorescent marker and expressed under its native promoter. This strain could then be inoculated into seedlings and analysed for Mcf location. This material could then be fed to insects, the insects dissected, and protein location analysed (Ambrose *et al.*, 2014).

6.3 Test the insect bioactivity capabilities of *Epichloë festucae* var *lolii*

AR48 and *Epichloë festucae* Fg1 infected ryegrass

6.3.1 *Epichloë festucae* AR48 and Fg1 new indole-diterpene compound three insect bioactivity

The new IDT compound three could have the potential to have stem boring fly (SBF-*Cerodontha australis*) and/or cutworm moth caterpillar (CC-*Agrotis ipsilon*) bioactivity, with the strongest evidence towards SBF bioactivity. Another SBF whole plant choice (SWPC) trial could be performed, but using a wider range of strains expressing or not expressing the new IDT compound three, to gather more evidence towards the correlation between SBF bioactivity and the new IDT compound three. Strains would be identified through the previous new IDT compound three distribution analysis described in section 5.4. In addition, or alternatively, purified compound could be assessed for bioactivity either directly (if an artificial diet can be developed for SBF) or indirectly by supplying the compound to the plants. Since SBF larva remain in the plant tissue throughout development this environment could be difficult to replicate for using an artificial diet. The artificial diet could be set into capillary tubes or between two slides to create an artificial tiller for the larva to form a mine down, with the top left empty to form a well. A female fly or egg or larva is then added into the well, and the emerging larva should mine down the artificial tiller. The rate of the mine formation would then be measured to assess bioactivity. For the CC bioactivity potential of the new IDT compound three, a CC detached tiller not choice (CDTN) trial

could be performed with the same range of strains in the SWPC trial described above. Also, a CC artificial diet no choice (CADN) trial could be performed with the purified new IDT compound three extract. However, an artificial CC diet would need to be developed, but this should be very similar to the porina artificial diet.

6.3.2 *Epichloë festucae* Fg1 mcf reverse genetics

Though Fg1 is a model AR48 strain in relation to the bioactive SM pathway profile, bioactivity towards SFB, CC, and PC have not currently been detected in Fg1 infected plant material. This precludes Fg1 Δmcf (Δ deletion) being used in a reverse genetics studies to assess Mcf bioactivity. The lack of Fg1 wild type (WT) bioactivity could be due to host incompatibility. By measuring the expression levels of Mcf in a range of different host plant backgrounds (including its native host) inoculated with Fg1 WT, a more suitable association could be identified. Light, temperature, and other factors known to affect gene expression levels could also be analysed to create a high Mcf expressing environment. The Fg1 Δmcf could then be assessed for loss of bioactivity.

For most gene functionality analysis, multiple independent gene deletion strains are usually tested to provide validity to the resultant phenotype analysis (Scott *et al.*, 2012). To increase the chance of creating a gene deletion two alternative approaches could be taken; a split marker system (Rahnama *et al.*, 2018), which still relies on homologous recombination, or a gene editing platform such as CRISPR-CAS9 (Ran *et al.*, 2013, Liu *et al.*, 2015), which potentially provides much higher precision and recombination at the target site.

7.0 LIMITATIONS

7.1 Analyse the bioactive secondary metabolite pathways in *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1

7.1.1 AR48 and Fg1 new indole diterpene three unresolved structure

Mass spectrometry (MS) analysis of the indole diterpenes (IDTs) produced by AR48 and Fg1 infected ryegrass identified four new IDT compounds. The new IDT compound three was chosen for further structural investigation through additional MS analysis, and a tentative structure was obtained. However, given this structure, the placement of the new IDT compound three into the current working IDT pathway was not obvious given the unusual absence of the OH group on carbon 27, which is present on all IDT compounds synthesised after the first stable intermediate paspaline. This structure was resolved at the limitations of the MS machinery and therefore the only way of conclusively solving the structure of the new IDT compound three is to perform nuclear magnetic resonance (NMR) on the purified compound (Future experiments 6.1.2). This is paramount in not only the placement and theoretical synthesis pathway of the new IDT compound three, but also as conclusive evidence that the new IDT compound three is novel and not a stereoisomer of paxitriol, given that the different stereoisomer standards of paxitriol were not available.

7.1.2 AR48 and Fg1 new indole diterpene three unresolved synthesis pathway

The synthesis of IDT compounds in *Epichloë* is complex due to the network of pathways catalysed by multiple enzymes. To add complexity each branch point can either be major or minor (shunt). This makes identifying the exact pathways and branches routinely synthesised *in planta* extremely difficult. Bioinformatics analysis identified two genes, *idtP* and *idtQ* (due to sequence identity divergence and in combination with the gene function and predicted new IDT compound three MS structure) as potentially being involved in the synthesis of the new IDT compound three. These two genes were heterologously expressed in *P. paxilli* in an attempt to recreate the new IDT compound three synthesis pathway. However, neither a partial or complete pathway was achieved. The limitation of this approach is that it is nearly impossible to accurately predict the resultant IDT synthesis network of the new gene

combination, so newly synthesised IDT pathway intermediate compounds can be missed if not accounted for prior to MS analysis.

However, when the new IDT compound three structure is resolved (Future experiments 6.1.2) then more accurate synthesis pathways could be hypothesised reducing the risk of missing pathway intermediate compounds. Also, when the genomes of AR48 and Fg1 are fully assembled (Future experiments 6.1.1), then bioinformatics analysis could be performed to identify any additional AR48 and Fg1 unique genes, in close proximity to the IDT cluster, that might have the potential to be involved in the new IDT compound three synthesis. Finally, MIDAS (Modular Idempotent DNA Assembly System) could be used to efficiently produce *P. paxilli* strains with differing IDT gene combinations with the resultant IDT compound profiles analysed through MS (Future experiments 6.1.3).

7.2 Investigate “makes caterpillars floppy” (Mcf) as a potential bioactive for the new bioactivities observed in *Epichloë festucae* var *lolii* AR48 infected ryegrass

7.2.1 *Epichloë* limited genetic manipulation capabilities

One of the major limitations of this project was producing an *Epichloë festucae* gene deletion strain. This is because *Epichloë* as a system has multiple limitations such as; transformations can only be performed on protoplasts, *Epichloë* has a slow growth rate, the rate of targeted homologous recombination at each site can vary, and to date no targeted homologous recombination event has been successfully achieved in an asexual *Epichloë* strain. However, non-homologous recombination has been achieved *i.e.* gene complementation.

These limitations are why a sexual AR48 model strain was investigated, and although *Epichloë festucae* Fg1 was identified as a candidate based on secondary metabolite (SM) and simple sequence repeat (SSR) profiles, Fg1 does not appear to have the same insect bioactivity *in planta* as AR48. In addition, to obtain a single *mcf* gene deletion in Fg1 required two different plasmid designs and screening of over 500 transformants.

Finally, as an alternative approach, complementation through non-homologous recombination of *Epichloë festucae* var *lolii* AR1 and AR37, which have potentially non-functional or non-bioactive *mcf* genes, with the AR48 *mcf* gene to gain bioactivity was attempted but these were unsuccessful. Alternative gene deletion methods are yet to be investigated (Future experiments 6.3.2).

7.2.2 *Epichloë in planta* only expressed secondary metabolites

Epichloë SMs linked to either mammalian or insect bioactivity, apart from a few exceptions, are only expressed *in planta*. Any assessment of a new SM for bioactivity therefore requires the use of an *Epichloë* infected seed line. If a seed line is not available for the *Epichloë* strain of interest then seedling inoculation is required. This vital step is a major limiting factor due to potentially low infection rate and timing. One way of avoiding the requirement of *in planta* expression is to heterologously express the required genes in a different microorganism that does not require *in planta* expression, and then either incorporating the purified compound or whole inoculum into the insect trial or respective assay. This has currently not been attempted for the Fg1 *mcf* gene. However, *P. paxilli* was used to heterologously express *idtP* and *idtQ* in an attempt to synthesis the new IDT compound three.

7.3 Test the insect bioactivity capabilities of *Epichloë festucae* var *lolii* AR48 and *Epichloë festucae* Fg1 infected ryegrass

7.3.1 *Epichloë festucae* var *lolii* complex interaction between bioactive secondary metabolite profiles and insect bioactive capabilities

Identifying the bioactive compound of interest as well as the synthesis pathway is vital for the development of *Epichloë* as a commercialised bioprotectant agent by assisting in the identification of *Epichloë* strains with the best insect bioactive profile. Routinely, the initial step is to either use forward or reverse genetics to link a gene/compound with an insect bioactivity. However, this is not trivial due to the complex nature of the *Epichloë* bioactive secondary metabolite profile (Limitations 7.1.2), genetic component/s are typically only expressed *in planta* (Limitations 7.2.2), and each *Epichloë* strain has a complex and unique range of insect bioactive capabilities *i.e.*

redundancy. In an attempt to simplify the interaction between bioactives and the insect of interest, once a gene has been identified, the most accurate method of assessing the insect bioactivity of the resultant product is to purify the compound, either from *Epichloë* plant/seed or an alternative expression system (Limitations 7.2.2), and feed the single compound to the target insect through an artificial diet (Future experiments 6.3.1).

7.3.2 Non-model system insect species

Many of the agricultural insect pests studied in the AgResearch *Epichloë* bioprotectant program are non-model systems. The insects are typically only available over the natural breeding seasons, and have to be collected from the surrounding environment. This is a major limiting factor when assessing insect bioprotectant capabilities not only in the reduced available time to perform trials but also in synchronisation of the plant preparation with insect availability *i.e.* unforeseeable breeding season variations. For some of the insects an artificial diet has been developed *e.g.* porina, or an easy to obtain plant food source identified *e.g.* cutworm moth caterpillar, therefore the adult insect can be caught and offspring raised extending insect availability. But currently none of the insect pests studied are able to be bred all year round in the laboratory. Other factors to consider when understanding the bioprotectant capabilities of an *Epichloë* strain is that some bioprotectants only effect a particular life stage *e.g.* adult verses larva, redundancy in insect bioprotectants, and the potential of unidentified agricultural pest bioprotectant capabilities resulting in missed *Epichloë* strain potential.

8.0 APPENDICES

Chapter eight: Appendices

idtG		FI1	E2368	AR48	Fg1	AR5	AR1	AR37
	FI1							
	E2368							
	AR48	99.7						
	Fg1	99.7		100				
	AR5	100		99.7	99.7			
	AR1	100		99.7	99.7	100		
	AR37	99.7		99.4	99.4	99.7	99.7	

idtC		FI1	E2368	AR48	Fg1	AR5	AR1	AR37
	FI1							
	E2368	99.4						
	AR48	99.7	99.1					
	Fg1	99.7	99.1	99.7				
	AR5	100	99.4	99.7	99.7			
	AR1	99.7	99.1	99.4	99.4	99.7		
	AR37	100	99.4	99.7	99.7	100	99.7	

idtM		FI1	E2368	AR48	Fg1	AR5	AR1	AR437
	FI1							
	E2368							
	AR48	99.8						
	Fg1	99.8		100				
	AR5	99.8		99.6	99.6			
	AR1	99.8		99.6	99.6	100		
	AR37	99.6		99.8	99.8	99.4	99.4	

Chapter eight: Appendices

idtB		FI1	E2368	AR48	Fg1	AR5	AR1	AR37
	FI1							
	E2368	99.1						
	AR48	99.6	99.6					
	Fg1	99.6	99.6	100				
	AR5	100	99.1	99.6	99.6			
	AR1	100	99.1	99.6	99.6	100		
	AR37	100	99.1	99.6	99.6	100	100	

idtP		FI1	E2368	AR48	Fg1	AR5	AR1	AR37
	FI1							
	E2368	98.6						
	AR48	92.8	94					
	Fg1	92.6	93.8	99.8				
	AR5	99.8	98.4	92.6	92.4			
	AR1	100	98.6	92.8	92.6	99.8		
	AR37	100	92.8	92.8	92.6	99.8	100	

idtQ		FI1	E2368	AR48	Fg1	AR5	AR1	AR437
	FI1							
	E2368	98.1						
	AR48	90.3	91					
	Fg1	90.3	91	99.1				
	AR5	100	98.1	90.3	90.3			
	AR1	100	98.1	90.3	90.3	100		
	AR37	100	98.1	90.3	90.3	100	100	

idtE

	FI1	E2368	AR48	Fg1	AR5	AR1	AR37
FI1							
E2368							
AR48	99.9						
Fg1	99.7		99.9				
AR5							
AR1							
AR37							

idtJ

	FI1	E2368	AR48	Fg1	AR5	AR1	AR37
FI1							
E2368							
AR48	99						
Fg1	100		99				
AR5							
AR1							
AR37							

idtF

	FI1	E2368	AR48	Fg1	AR5	AR1	AR37
FI1							
E2368	97.7						
AR48							
Fg1							
AR5	99.5	97.3					
AR1	99.8	97.5			99.8		
AR37	100	97.7			99.5	99.8	

idtK		FI1	E2368	AR48	Fg1	AR5	AR1	AR37
FI1								
E2368								
AR48								
Fg1								
AR5		99.8						
AR1		100				99.8		
AR37		99.2				99.1	99.2	

idtS		FI1	E2368	AR48	Fg1	AR5	AR1	AR37
FI1								
E2368								
AR48		99.3						
Fg1		98.9		99.6				
AR5		100		99.3	98.9			
AR1		100		99.3	98.9	100		
AR37		100		99.3	98.9	100	100	

Appendix 1: Alignment of indole-diterpene (IDT) protein sequences from *Epichloë festucae* species. Protein sequences of the 11 genes involved in IDT synthesis from FI1, E2368, AR48, Fg1, AR5, AR1, and AR37 strains were aligned to each corresponding gene in each genome using BLASTp tool on Geneious. The sequence identity (%) was analysed.

Chapter eight: Appendices

IdtP	Amino acid	From	To	Non-conserved	From	To
	2	L	F			
	8	P	L			
	10	G	S			
	12	C	W	✓	Sulfide moiety	Hydrophobic
	23	K	R			
	49	D	G	✓	Charged/negative	Uncharged/small
	57	H	Y	✓	Charged/negative	Hydrophobic/aromatic
	72	I	M			
	130	K	R			
	134	T	A			
	153	G	S			
	161	I	V			
	177	T	A			
	185	L	P	✓	Hydrophobic	Aromatic
	191	I	H	✓	Hydrophobic	Uncharged/small
	208	S	F	✓	Polar	Hydrophobic/aromatic
	212	S	T			
	219	H	Y	✓	Uncharged/small	Hydrophobic/aromatic
	221	F	L			
	226 (Fg1)	S	P	✓	Polar	Aromatic
	230	E	K	✓	Charged/negative	Charged/postive
	299	L	S			
	310	D	N	✓	Charged/negative	Polar
	311	S	I	✓	Polar	Hydrophobic
	317	R	Q	✓	Charged/postive	Polar
	318	R	K			
	322	N	D	✓	Polar	Charged/negative
	352	I	V			
	374	Y	F			
	395	K	I	✓	Charged/postive	Hydrophobic
	397	S	P			
	412	G	S			
	415	T	P			
	488	L	F			
	496	T	P	✓	Polar	Aromatic
IdtQ	Amino acid	From	To	Non-conserved	From	To
	6	H	R			
	11	K	E	✓	Charged/postive	Charged/negative
	13	N	D	✓	Polar	Charged/negative
	15	A	V			
	20	S	T			
	21	G	S			
	34	N	D	✓	Polar	Charged/negative

Chapter eight: Appendices

IdtQ	Amino acid	From	To	Non-conserved	From	To
	40	N	D	✓	Polar	Charged/negative
	46	I	V			
	57	I	V			
	58	I	M			
	62	H	Y	✓	Charged/postive	Hydrophobic/aromatic
	76	D	N	✓	Charged/negative	Polar
	88	E	D			
	114	M	I			
	115	T	A			
	118	F	L			
	129	H	P	✓	Charged/postive	Aromatic
	133	I	T	✓	Hydrophobic	Polar
	160	S	A			
	162 (Fg1)	S	F	✓	Polar	Hydrophobic/aromatic
	166	M	I			
	173	M	V			
	177 (AR48)	I	S	✓	Hydrophobic	Polar
	178	Q	E	✓	Polar	Charged/negative
	179	Y	D	✓	Hydrophobic/aromatic	Charged/negative
	183	S	L			
	185	M	A	✓	Hydrophobic/sulfide	Hydrophobic
	189	S	P	✓	Polar	Aromatic
	217 (AR48)	T	I	✓	Polar	Hydrophobic
	237	Q	R	✓	Polar	Charged/postive
	242	I	V			
	269	V	L			
	270	M	V			
	276	I	T	✓	Hydrophobic	Polar
	279	V/I	A			
	306	R	C	✓	Charged/postive	Sulfide moiety
	311	S/T	G			
	313	D	N	✓	Charged/negative	Polar
	317	I	V			
	321	M/V	T			
	354	L	R	✓	Hydrophobic	Charged/postive
	358	D	H	✓	Charged/negative	Charged/postive
	362	E	S	✓	Charged/negative	Polar
	376	F	K			
	411	N	H			
	414	K	R			
	425	I	L			
	454	L	T	✓	Hydrophobic	Polar
	470	T	I	✓	Polar	Hydrophobic
	484	E	A	✓	Charged/negative	Hydrophobic
	532(Fg1)	R	M			
	533	E/K	I (Fg1)/M (AR48)	✓	Charged	Hydrophobic
	535	N	D	✓	Polar	Charged/negative

Appendix 2: Unique amino acid changes in indole-diterpene (IDT) IdtP and IdtQ from *Epichloë festucae* strains AR48 and Fg1, when compared in an alignment of corresponding genes in *E. festucae* strains Fl1, E2368, AR1, AR37, and AR5.

Amino acid	saccharomyces cerevisiae lanosterol 14-alpha demethylase with 2 lanosterol bound	x-ray structure of cyp51 from trypanosoma brucei in complex with posaconazole in two different conformations	crystal structure of human prostacyclin synthase	crystal structure of arabidopsis thaliana allene oxide synthase (aos, 2 cytochrome p450 74a, cyp74a) complexed with 13(s)-hod at 1.85 Å resolution	human cytochrome p450 2e1 in complex with the inhibitor 4-methylpyrazole	Chytochrom P450	crystal structure of allene oxide synthase	structure of cytochrome p450 4b1 (cyp4b1) complexed with octane: an n-2 alkane and fatty acid omega-hydroxylase with a covalently bound heme	crystal structure of sterol 14-alpha demethylase (cyp51) from a2 pathogenic yeast candida albicans in complex with the antifungal drug3 posaconazole	crystal structure of human cyp11a1 in complex with 20,22-2 dihydroxycholesterol
12										
49							-			-
57			-				-		-	✓
185		-				✓				
191		✓				-	✓			
208		✓		✓			✓	✓		-
219						✓				-
226 (Fg1)										-
230				-	-	✓				-
310				-						
311				-						
317				-						
<u>322</u>										
395			✓						✓	
496										

Appendix 3: Phyre2 analysis of *Epichloë festucae* strains AR48 and Fg1 IdtP sequences aligned to the top 10 hits looking at non-conserved amino acid changes in pocket predictions. Underlined amino acid changes are shared with E2368. ✓ means the amino acid change is within the predicted pocket and – means the amino acid change is next to an amino acid predicted in the pocket.

Chapter eight: Appendices

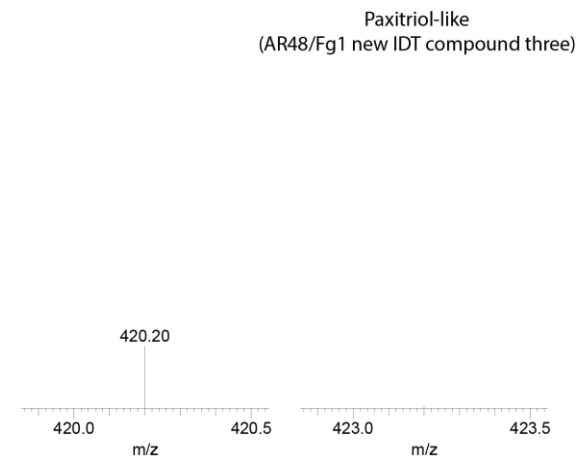
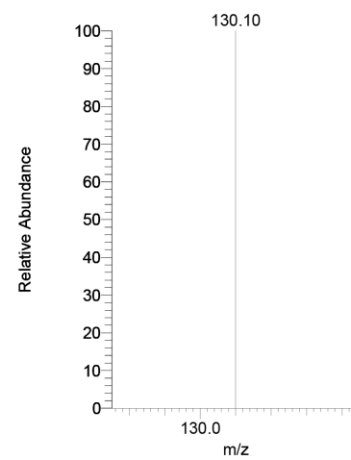
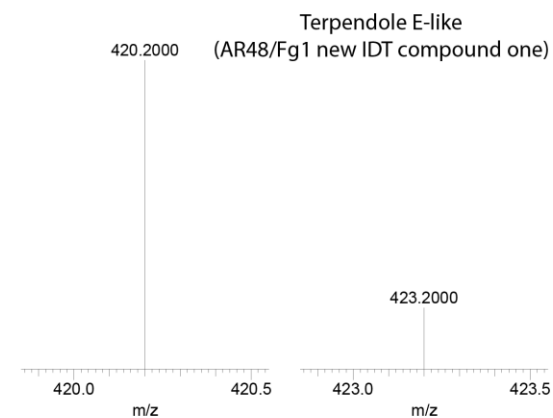
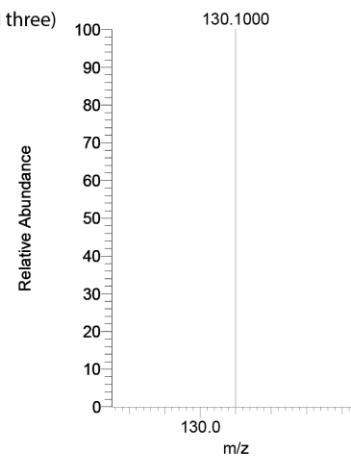
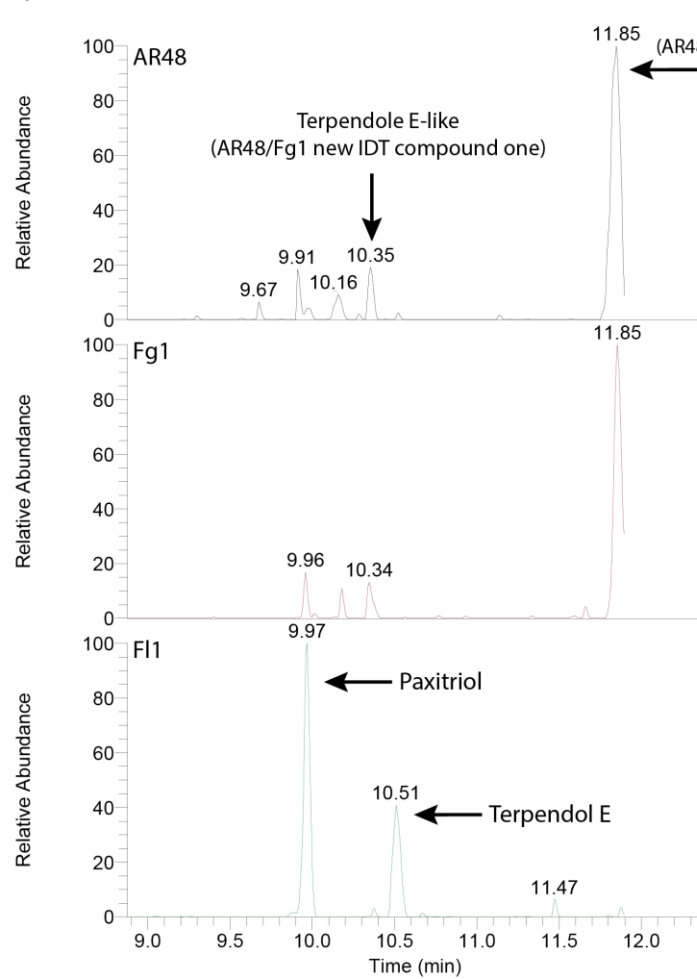
Amino acid	saccharomyces cerevisiae lanosterol 14-alpha demethylase with 2 lanosterol bound	crystal structure of human prostacyclin synthase	x-ray structure of cyp51 from trypanosoma brucei in complex with posaconazole in two different conformations	crystal structure of human cyp11a1 in complex with 20,22-2 dihydroxycholesterol	crystal structure of sterol 14-alpha demethylase (cyp51) from a2 pathogenic yeast candida albicans in complex with the antifungal drug3 posaconazole	crystal structure of human cyp7a1	structure of cytochrome p450 4b1 (cyp4b1) complexed with octane: an n-2 alkane and fatty acid omega-hydroxylase with a covalently bound heme	crystal structure of arabidopsis thaliana allene oxide synthase (aos,2 cytochrome p450 74a, cyp74a) complexed with 13(s)-hod at 1.85 a3 resolution	Cytochrome P450	human cytochrome p450 2e1 in complex with the inhibitor 4-methylpyrazole
11										
13										
34										
40										
62		✓	✓			✓	✓	✓		
76								✓		
129								✓	✓	
133							✓	✓	✓	-
162 (Fg1)							-		-	✓
177 (AR48)					✓	-		-	-	✓
178					-			-	-	-
179								✓	✓	
185					✓					
189										
217 (AR48)				-			-	-	✓	✓

Chapter eight: Appendices

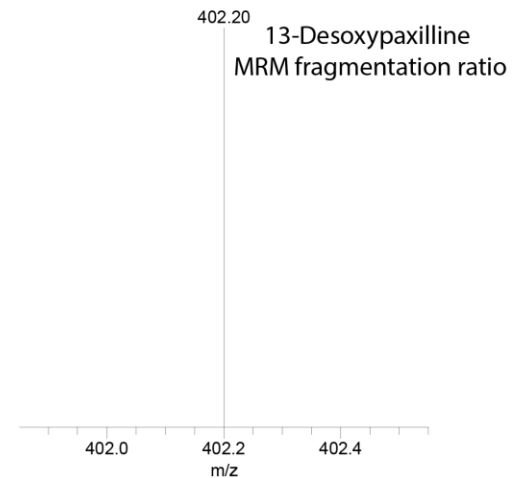
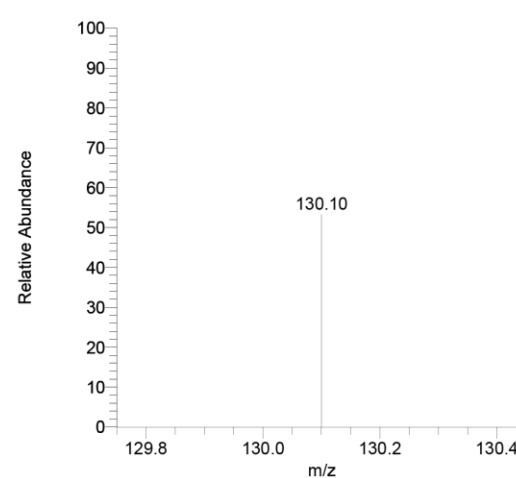
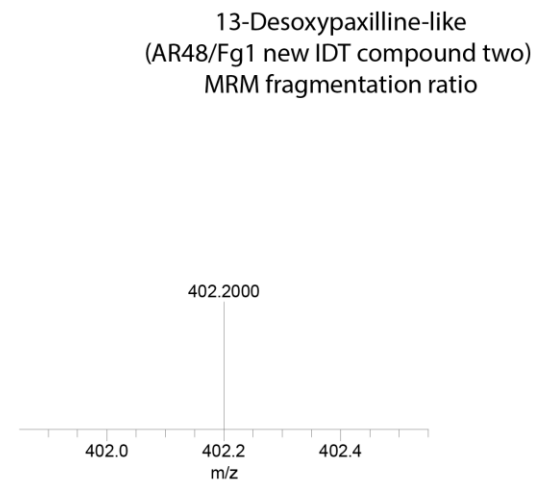
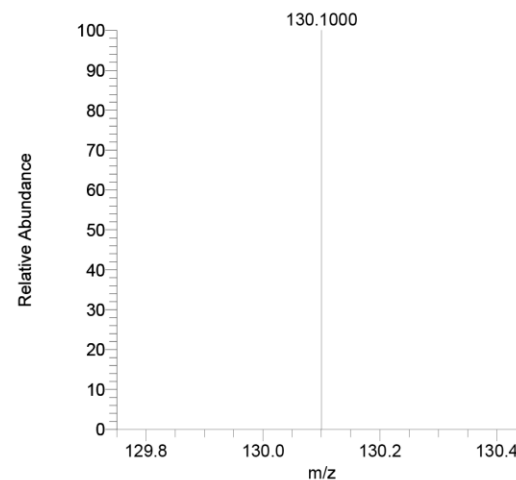
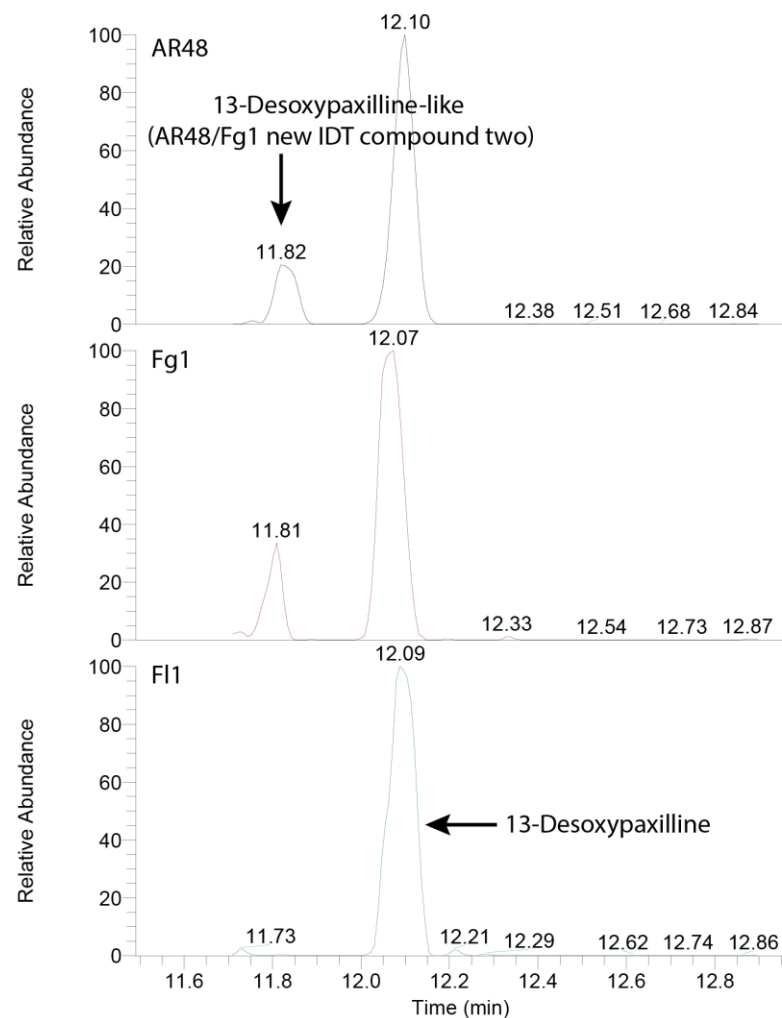
Amino acid	saccharomyces cerevisiae lanosterol 14-alpha demethylase with 2 lanosterol bound	crystal structure of human prostacyclin synthase	x-ray structure of cyp51 from trypanosoma brucei in complex with posaconazole in two different conformations	crystal structure of human cyp11a1 in complex with 20,22-2 dihydroxycholesterol	crystal structure of sterol 14-alpha demethylase (cyp51) from a2 pathogenic yeast candida albicans in complex with the antifungal drug3 posaconazole	crystal structure of human cyp7a1	structure of cytochrome p450 4b1 (cyp4b1) complexed with octane: an n-2 alkane and fatty acid omega-hydroxylase with a covalently bound heme	crystal structure of arabidopsis thaliana allene oxide synthase (aos,2 cytochrome p450 74a, cyp74a) complexed with 13(s)-hod at 1.85 a3 resolution	Cytochrome P450	human cytochrome p450 2e1 in complex with the inhibitor 4-2 methylpyrazole
237			-				-		✓	✓
276							✓		✓	✓
306				-						
313				-						
354										
358										
362					-					
454						-			✓	
470	✓	-	-	-			-	✓	✓	-
484	-	✓		-		✓	-	✓	✓	
533										
535										

Appendix 4: Phyre2 analysis of *Epichloë festucae* strains AR48 and Fg1 indole-diterpene (IDT) ldtQ sequences aligned to the top 10 hits looking at non-conserved amino acid changes in pocket predictions. Underlined amino acid changes are shared with E2368. ✓ means the amino acid change is within the predicted pocket and – means the amino acid change is next to an amino acid predicted in the pocket.

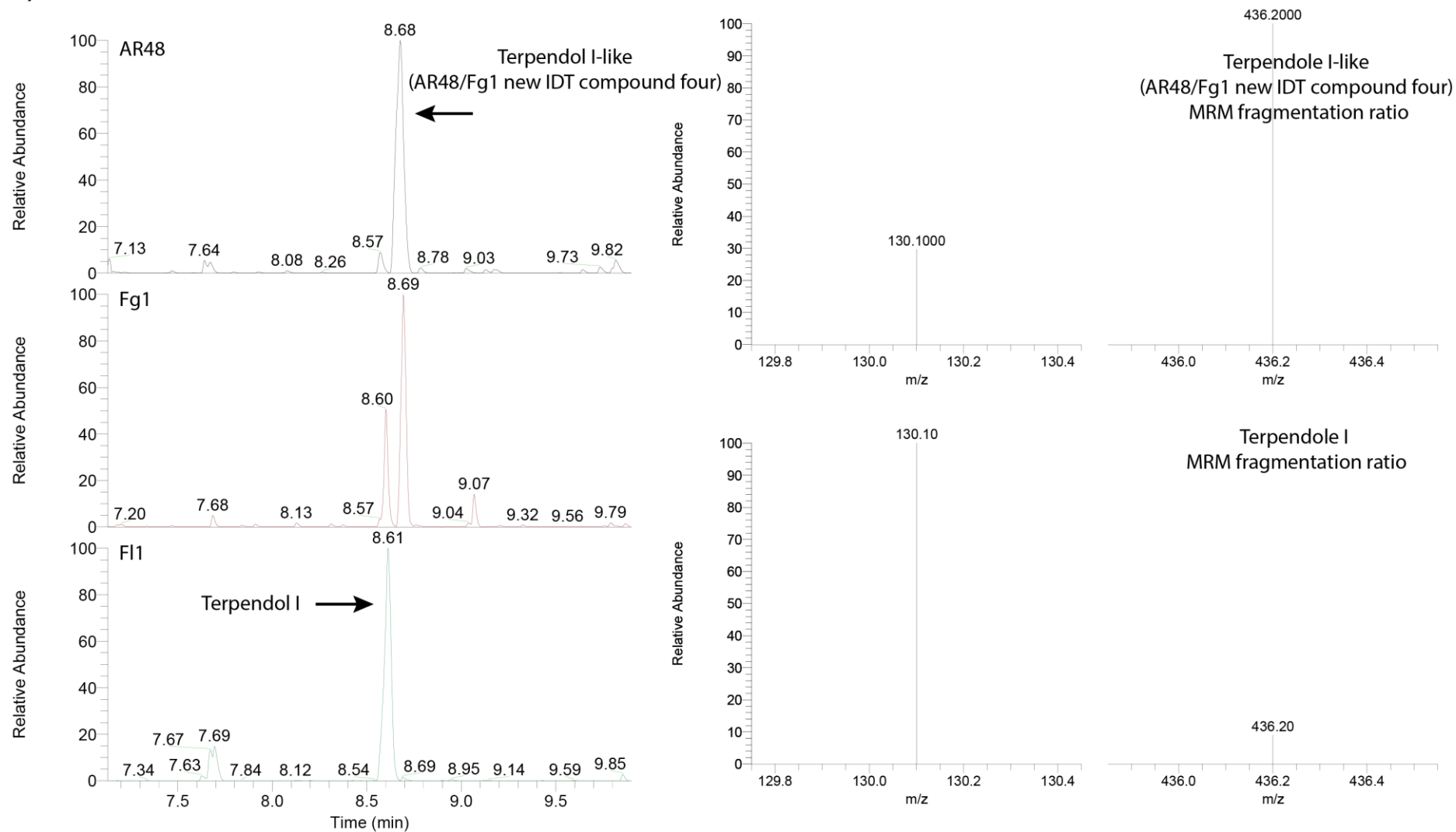
A)

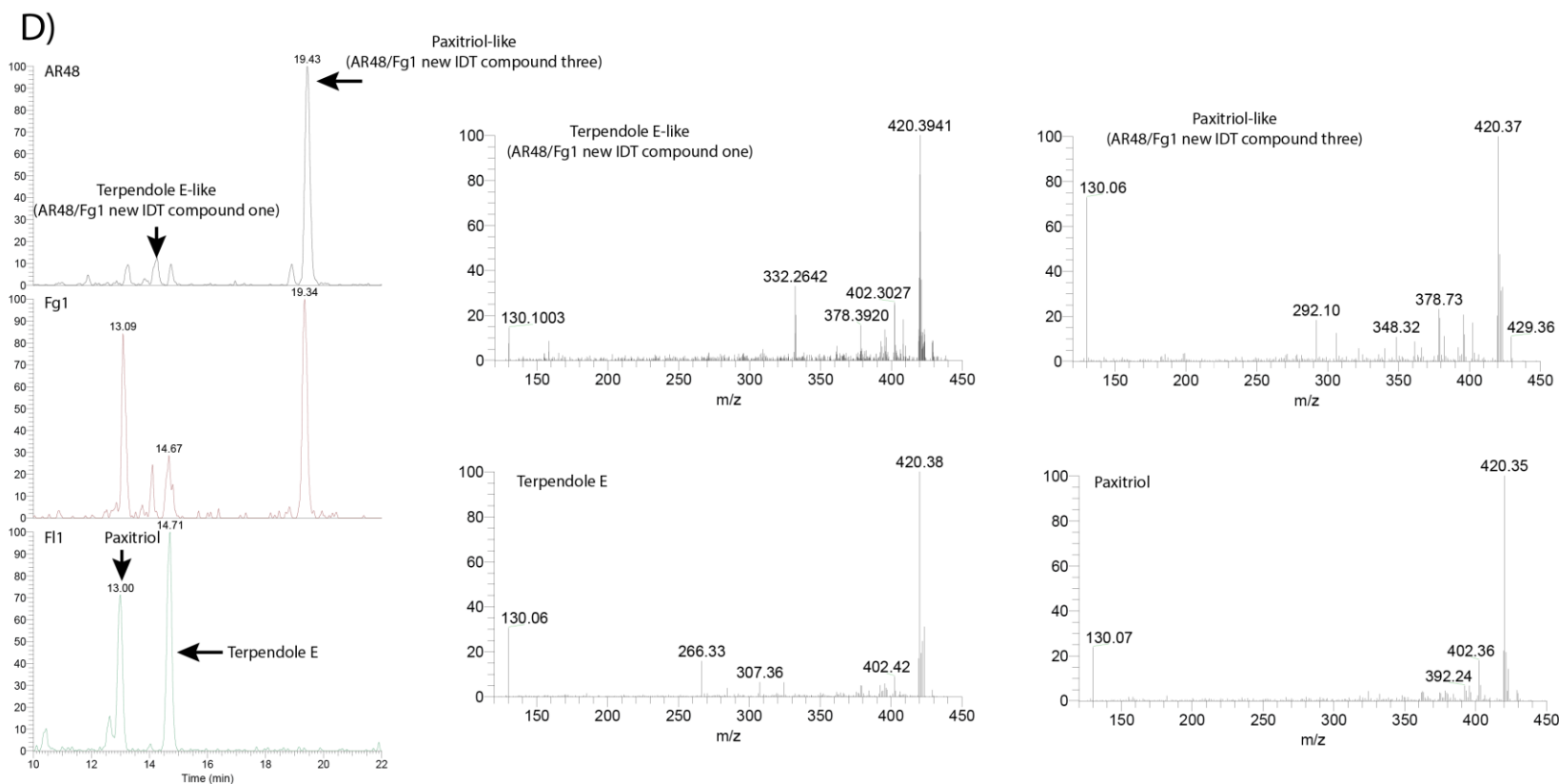


B)

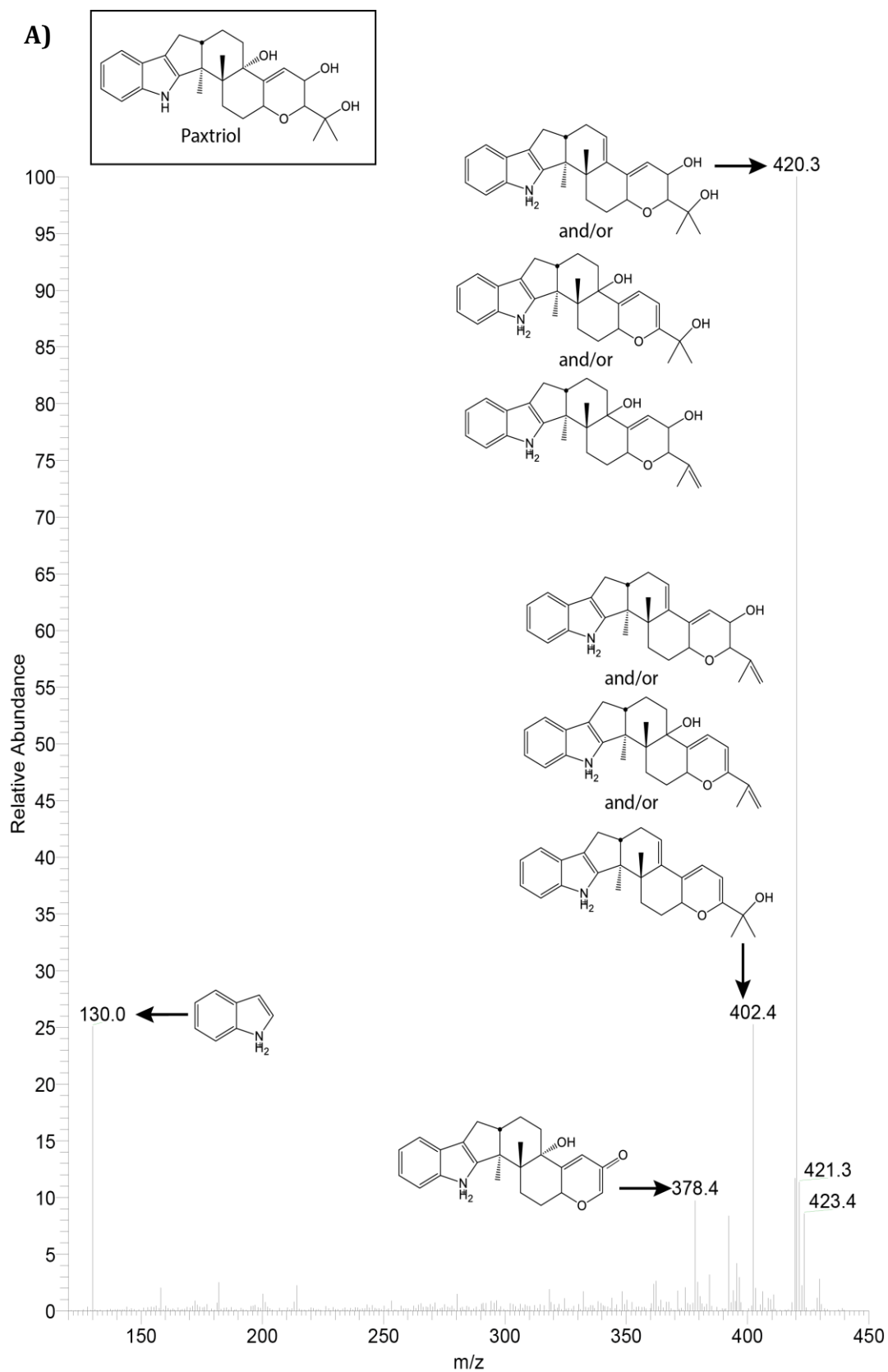


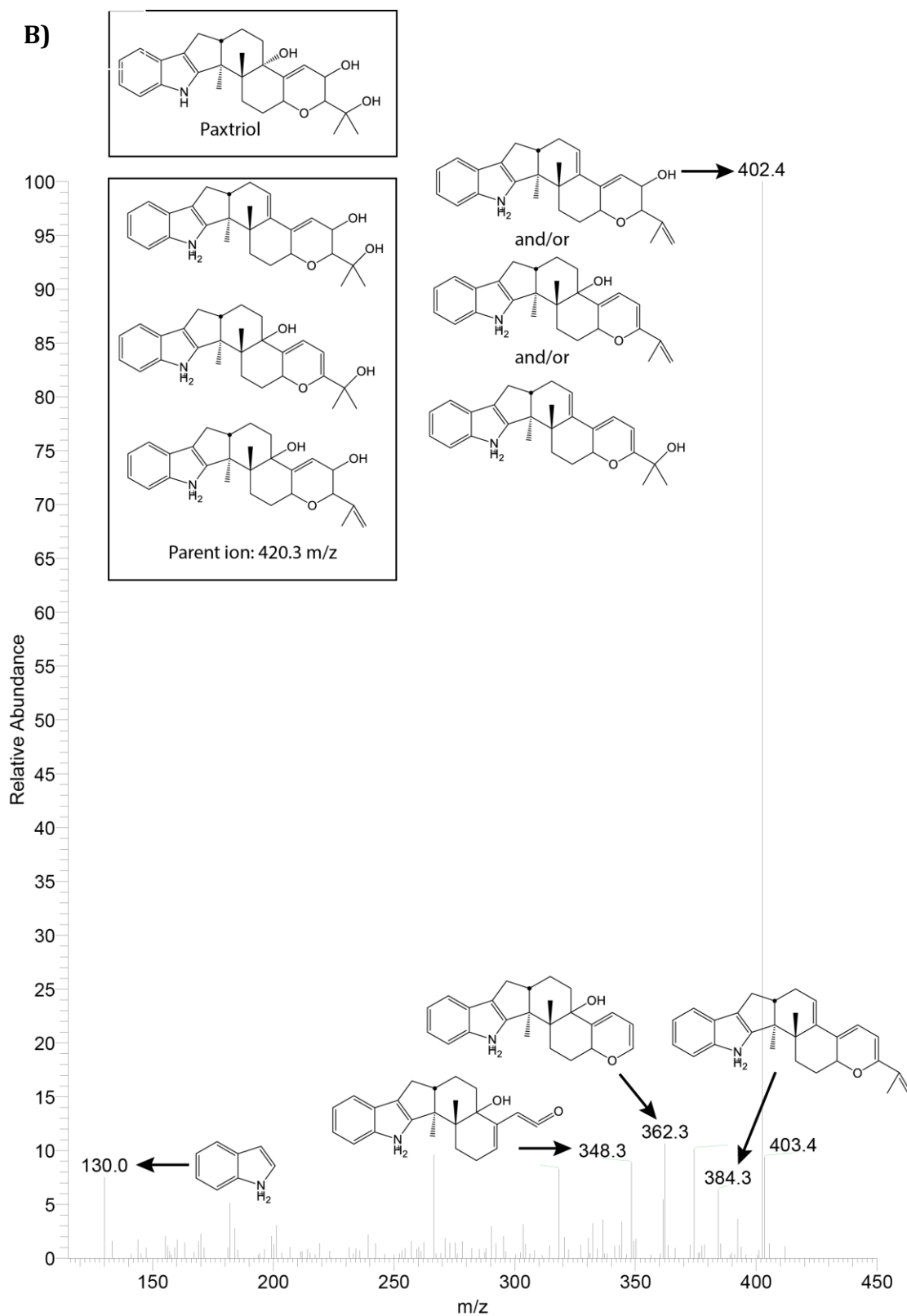
C)

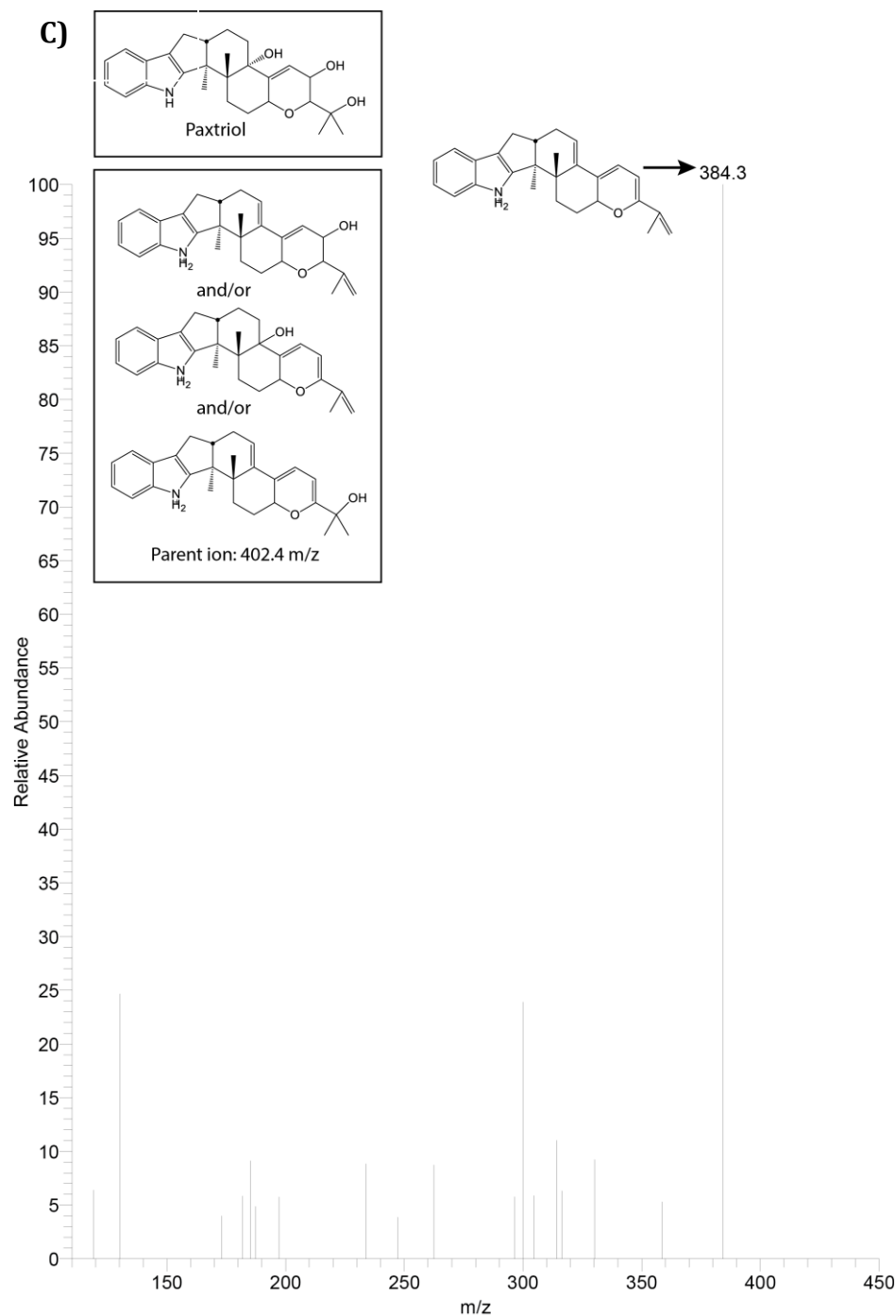




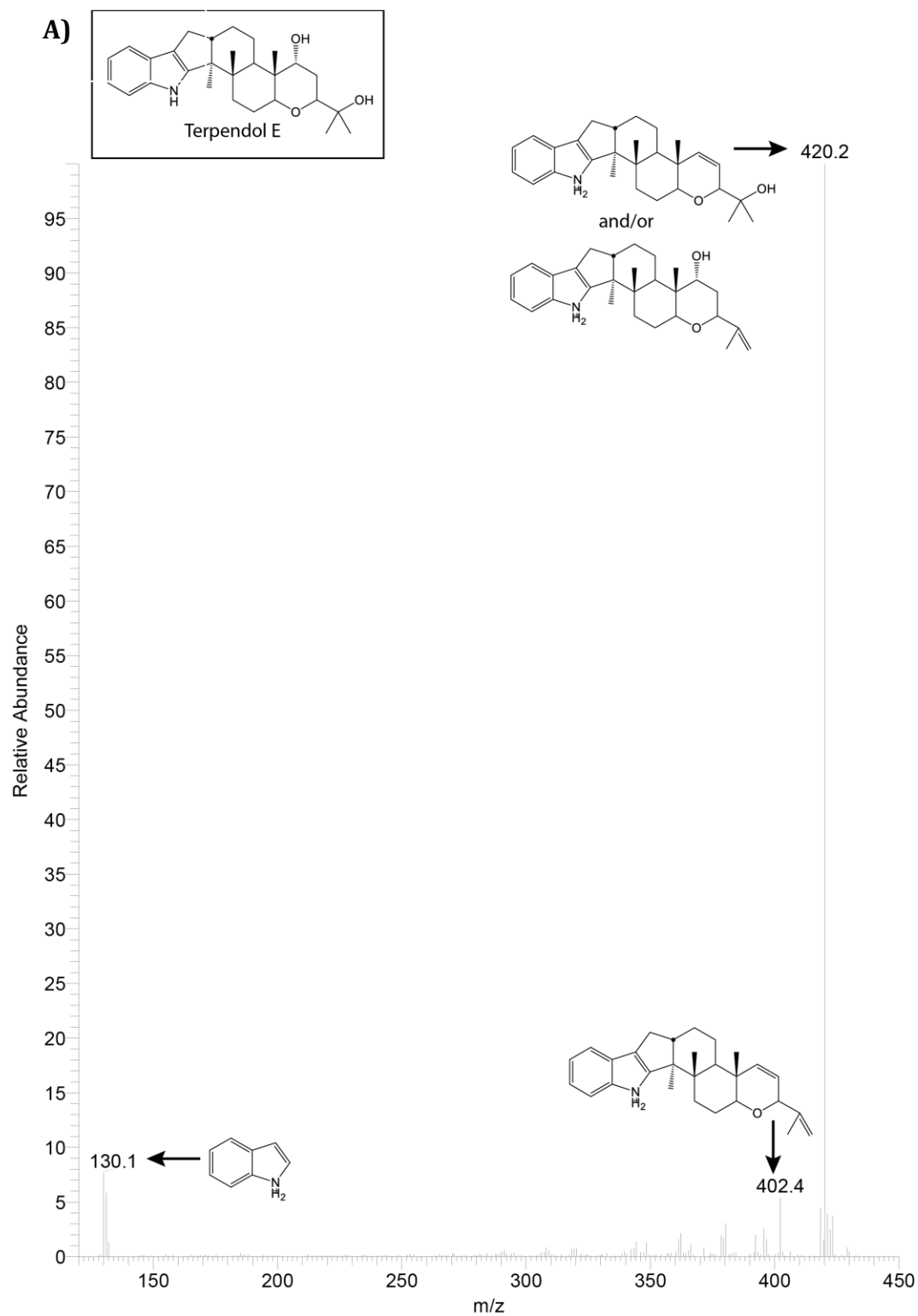
Appendix 5: *Epichloë festucae* strains AR48 and Fg1 mass spectrometry raw data of new indole-diterpene (IDT) peaks. Initial screening was undertaken using the TSQ (triple-quad) with multiple reaction monitoring (MRM) optimised for the indole diterpene products from *Epichloë* endophytes (parent-18 *m/z* and 130 *m/z* core). A) Terpendole E-like peak (AR48/Fg1 new IDT compound one) and Paxitriol-like peak (AR48/Fg1 new IDT compound three). B) 13-desoxypaxilline-like peak (AR48/Fg1 new IDT compound two). C) Terpendole I-like peak (AR48/Fg1 new IDT compound four). D) The linear ion-trap (LTQxl) to obtain a full MS² fragmentation spectrum for the paxitriol, terpendole E, paxitriol-like (AR48/Fg1 new IDT compound three), and terpendole E-like (AR48/Fg1 new IDT compound four). Due to the different chromatographic conditions required for the two instruments (triple-quad and linear ion-trap) the retention times were different (19.4 *c.f.* 11.8)

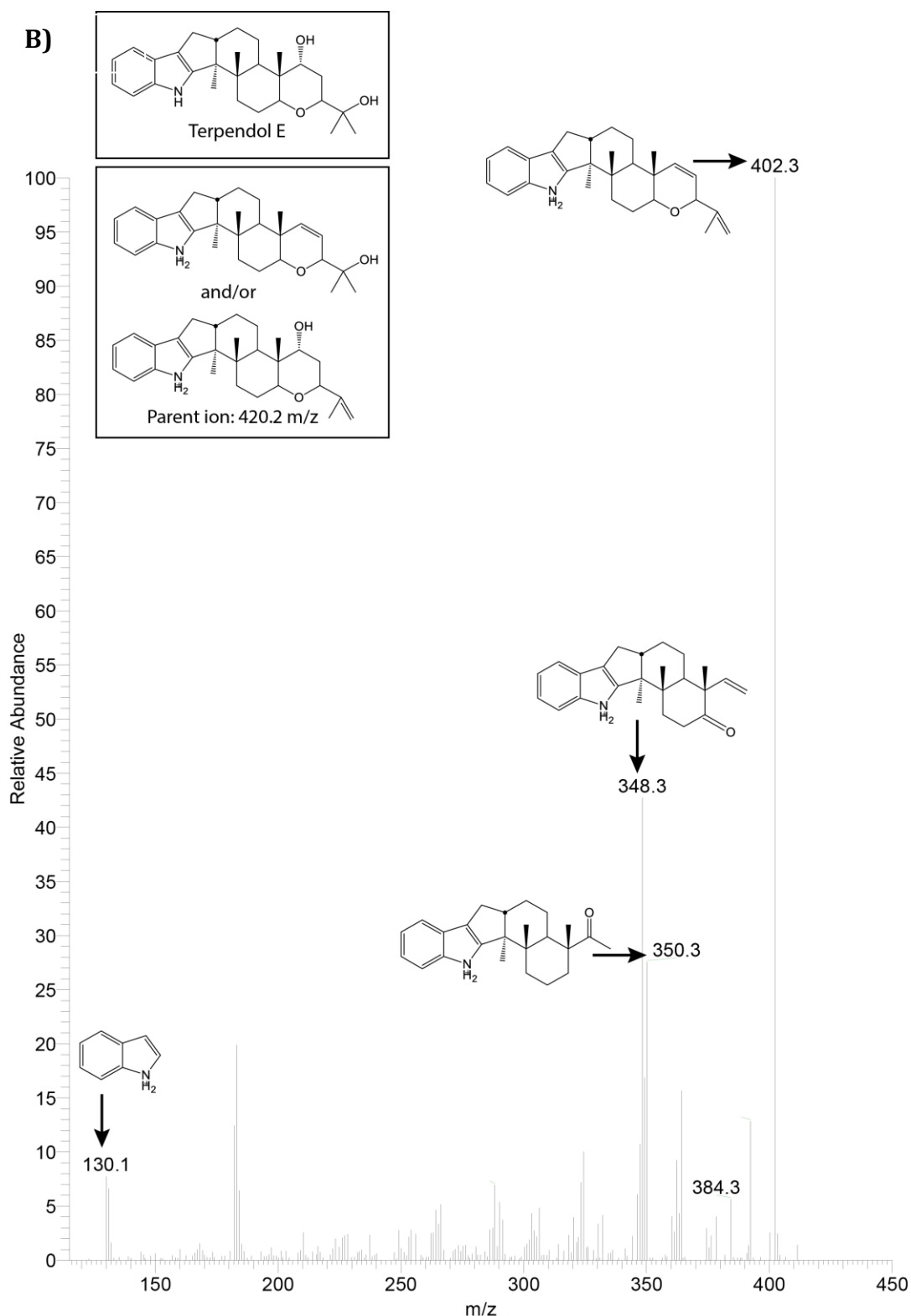






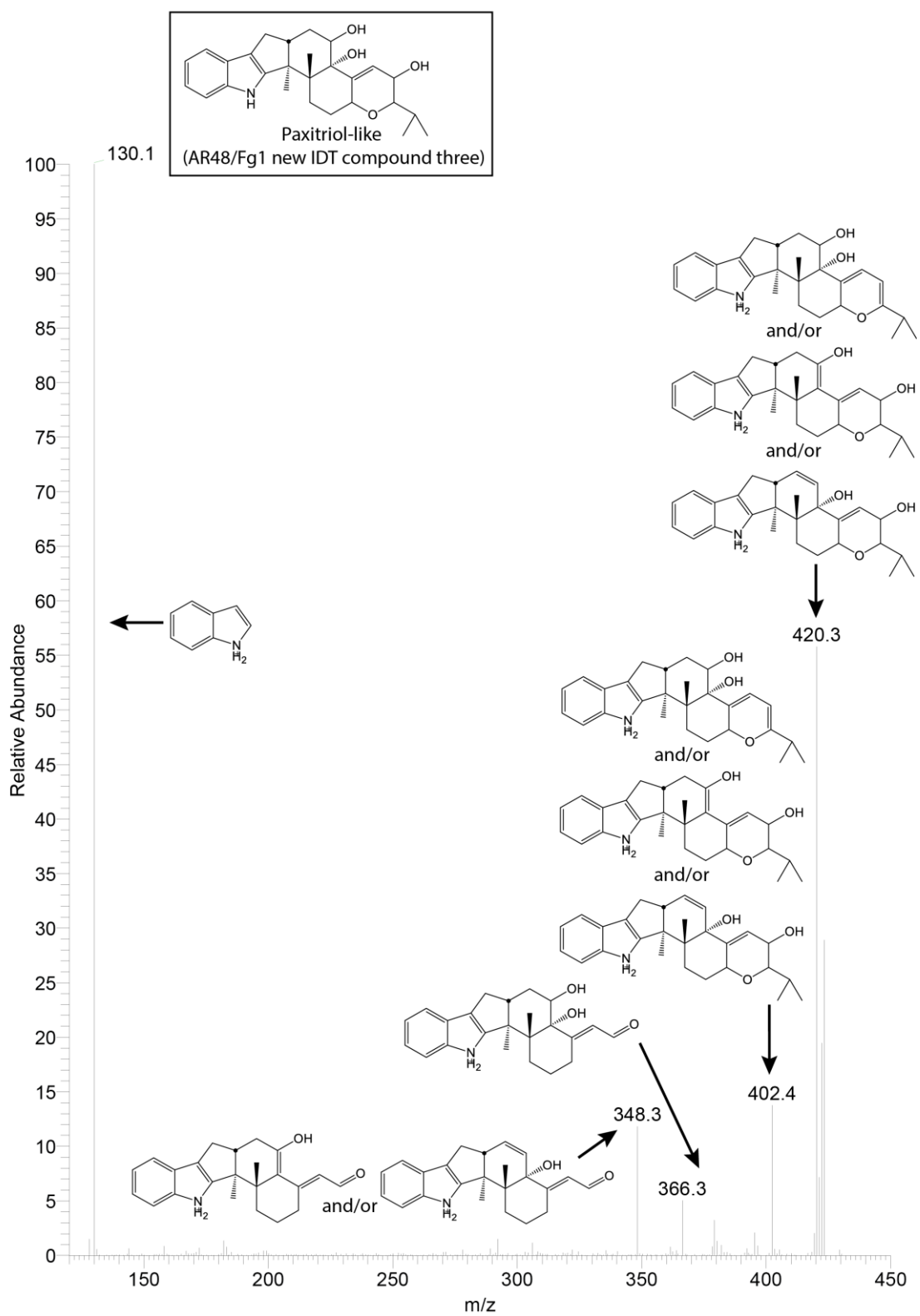
Appendix 6: Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of paxtriol from *Epichloë festucae* F11 infected ryegrass. A) Collision-induced fragmentation spectrum of the 438 m/z peak. Key ions are 420 m/z (loss of H_2O), 402 m/z (loss of two H_2O), and 378 m/z (loss of C_3H_7O). B) Collision-induced fragmentation spectrum of the 420 m/z peak from the 438 m/z fragmentation spectrum. Key ions are 402 m/z (loss of two H_2O), 384 m/z (loss of three H_2O), 362 m/z (loss of H_2O and C_3H_6O), and 348 m/z (loss of H_2O and C_4H_8O). C) Collision-induced fragmentation spectrum of the 402 m/z peak from the 420 m/z fragmentation spectrum from the 438 m/z fragmentation spectrum. Key peak is 348 m/z (loss of H_2O and C_4H_8O). The structure of paxtriol and parent ions are inserted into the spectra as reference.

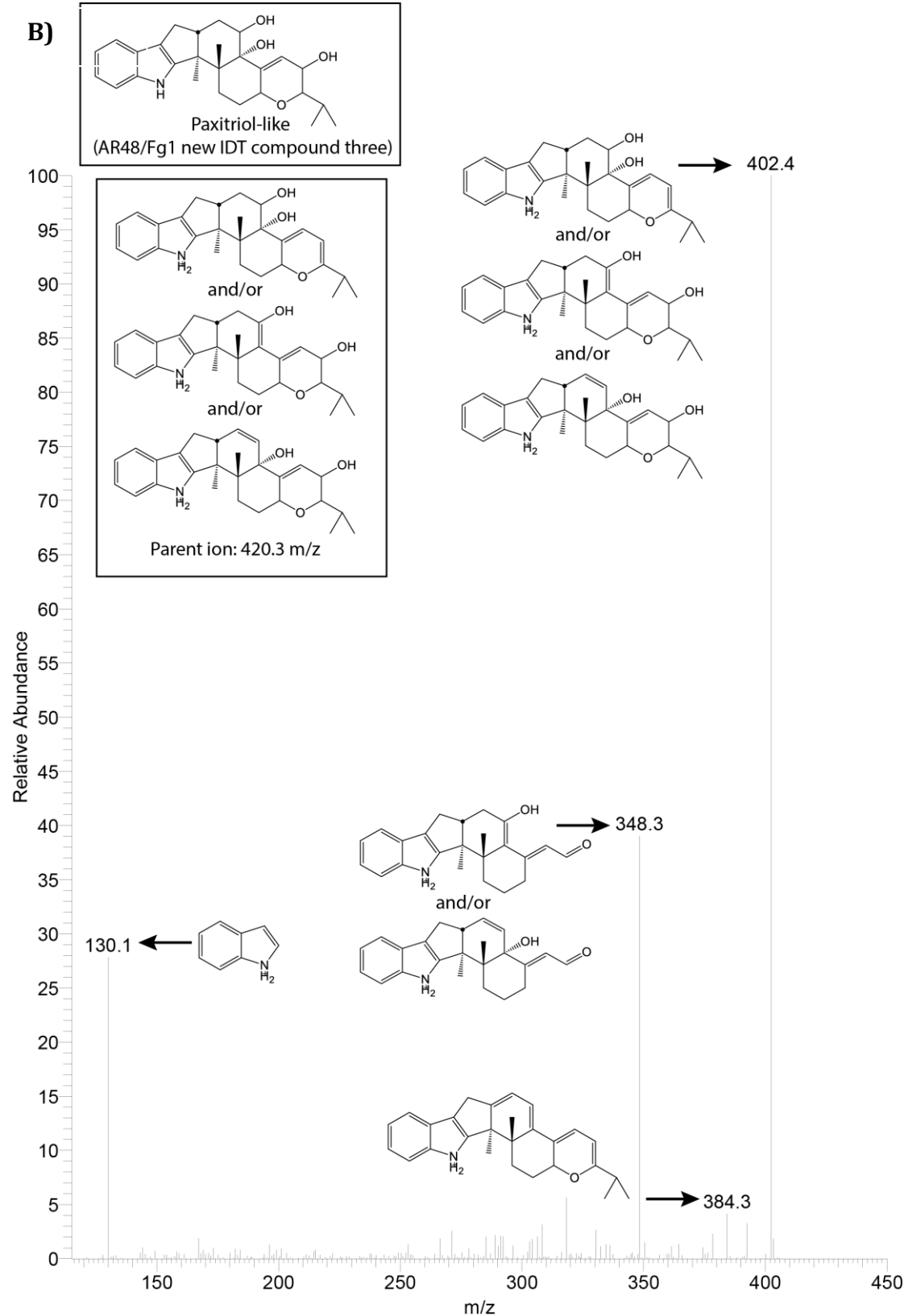


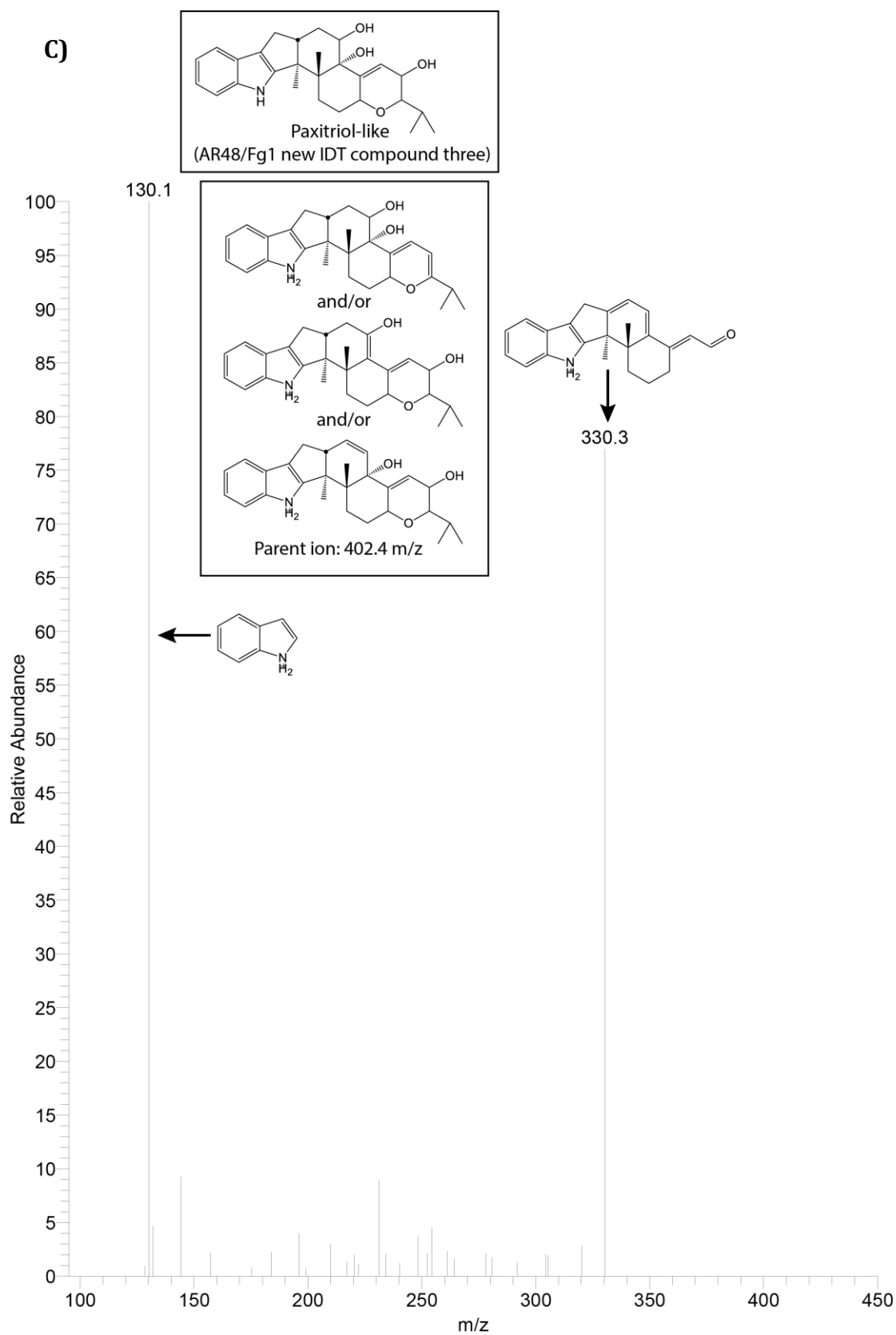


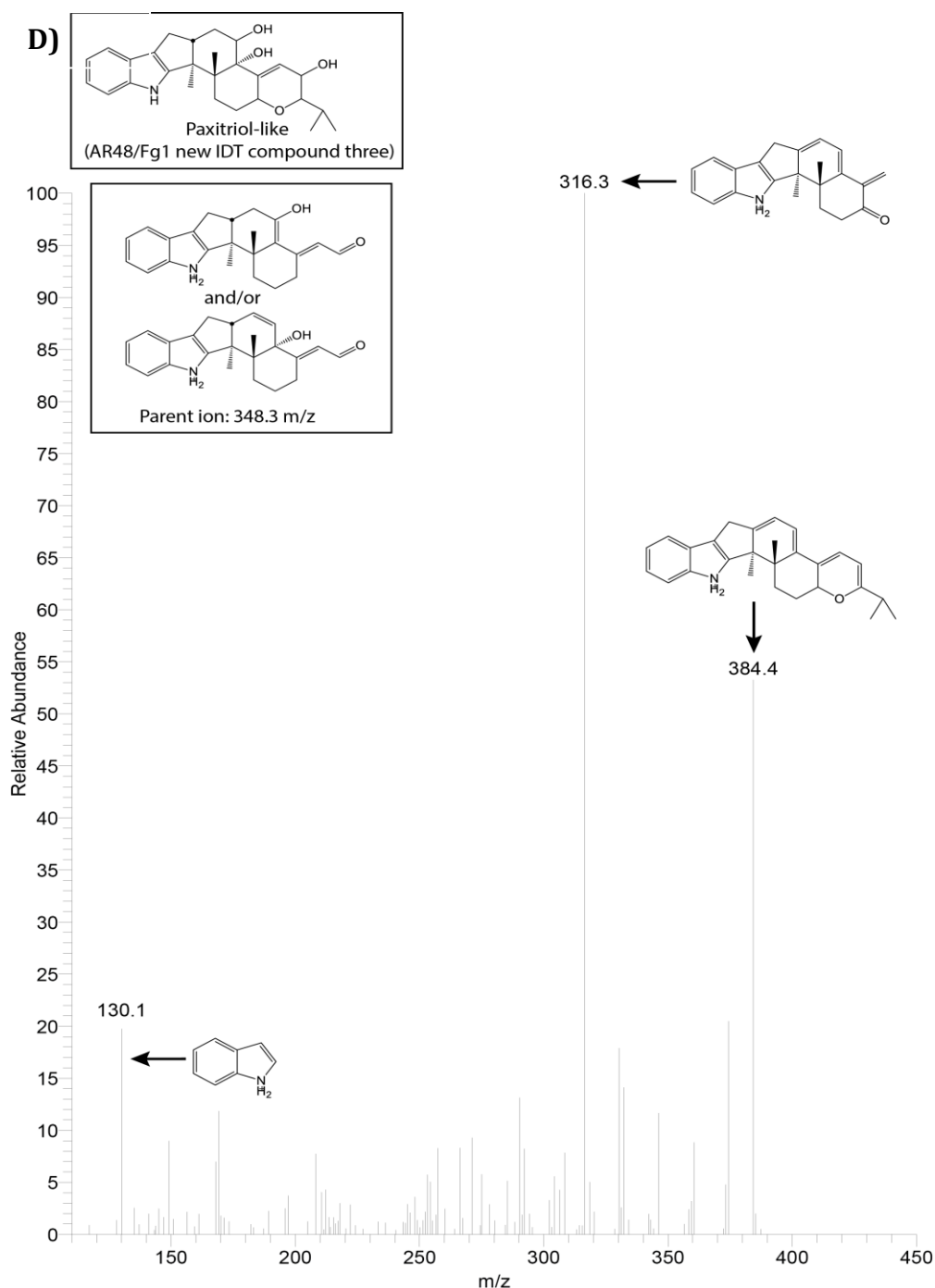
Appendix 7: Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of terpendole E from *Epichloë festucae* F11 infected ryegrass. A) Collision-induced fragmentation spectrum of the 438 m/z peak. Key ions are 420 m/z (loss of H_2O), and 402 m/z (loss of two H_2O). B) Collision-induced fragmentation spectrum of the 420 m/z peak from the 438 m/z fragmentation spectrum. Key ions are 402 m/z (loss of two H_2O), 350 m/z (loss of H_2O and C_4H_7O), and 348 m/z (loss of H_2O and C_4H_8O). The structure of terpendole E and parent ions are inserted into the spectra as reference.

A)

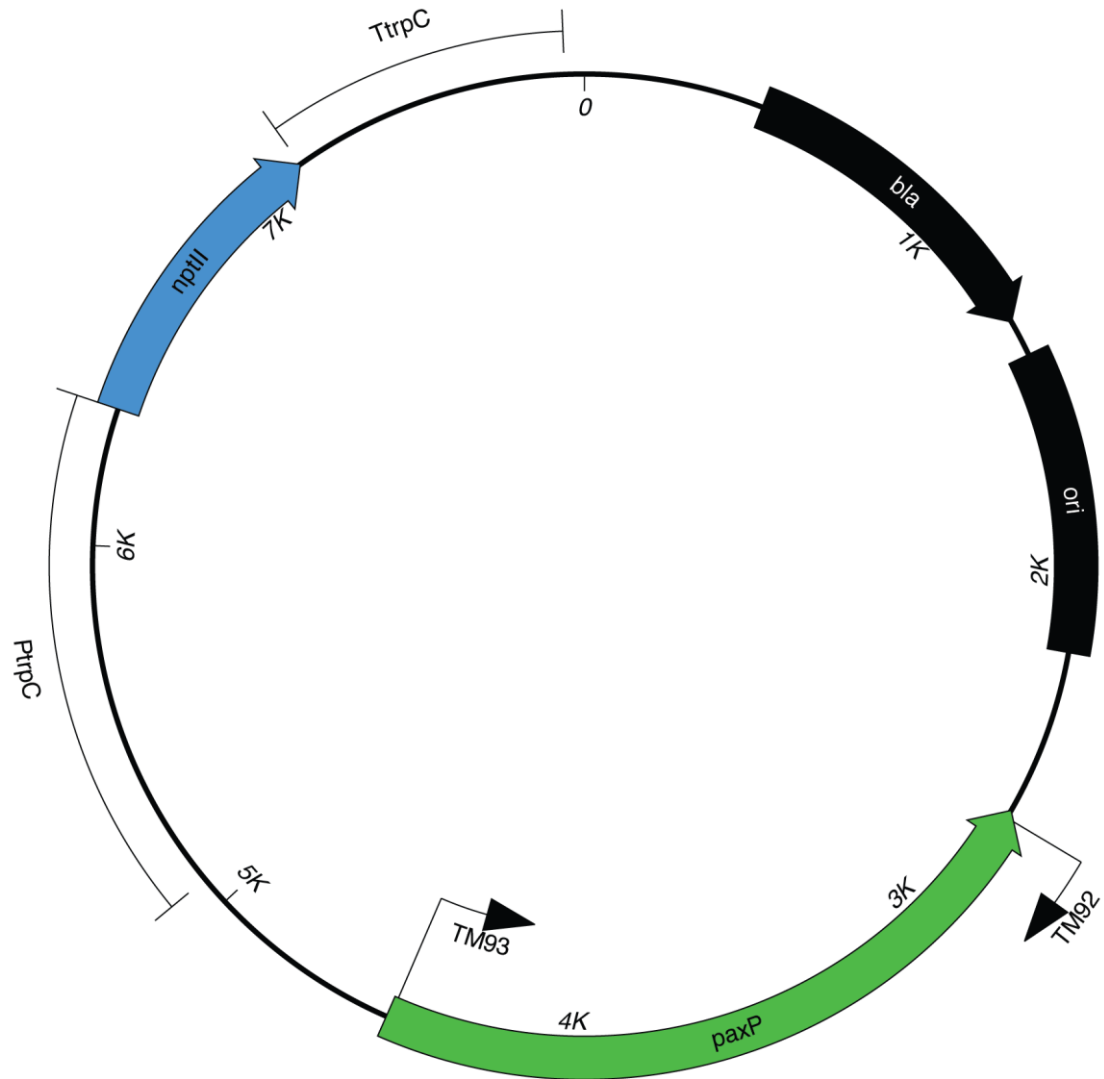




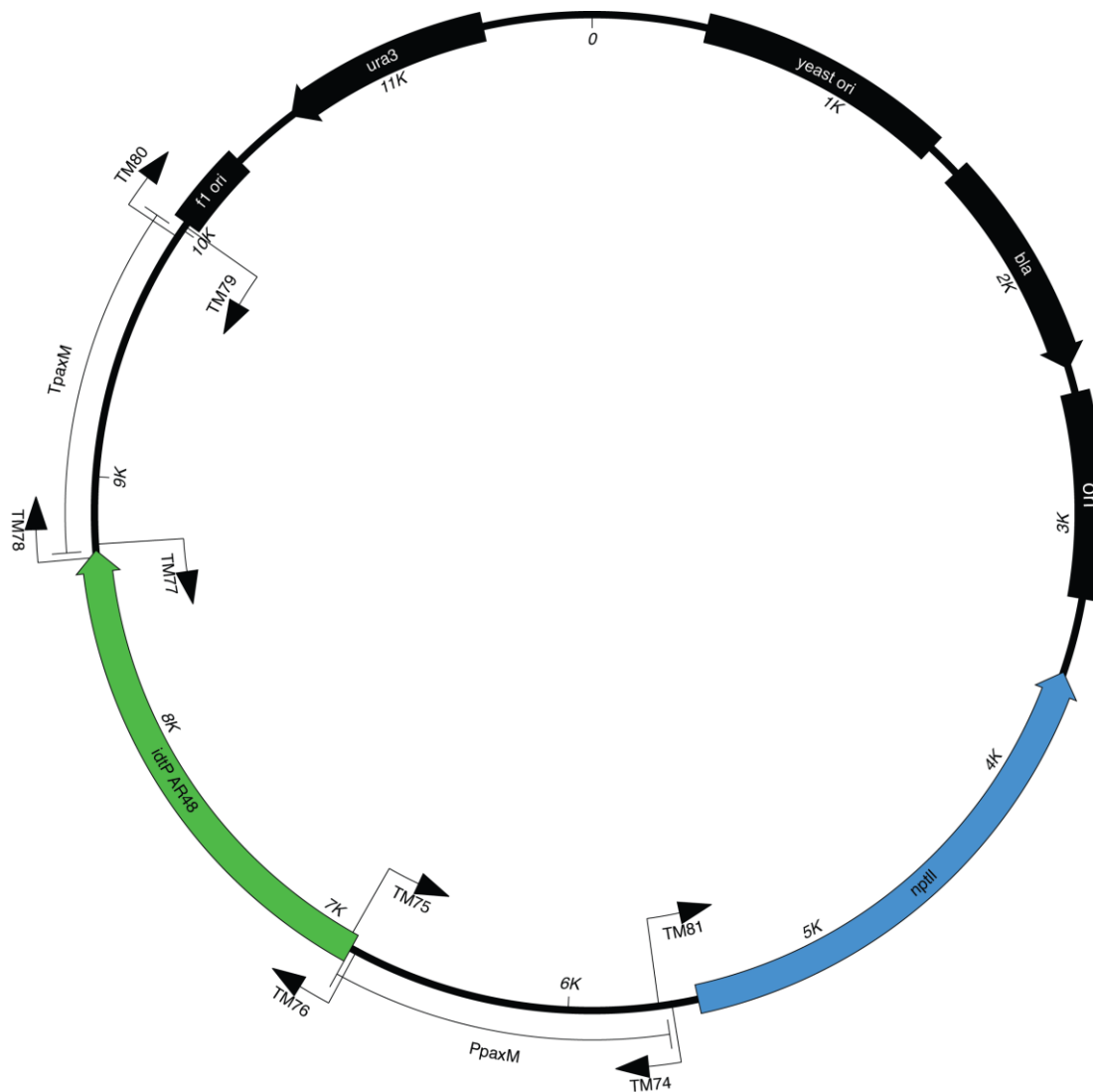




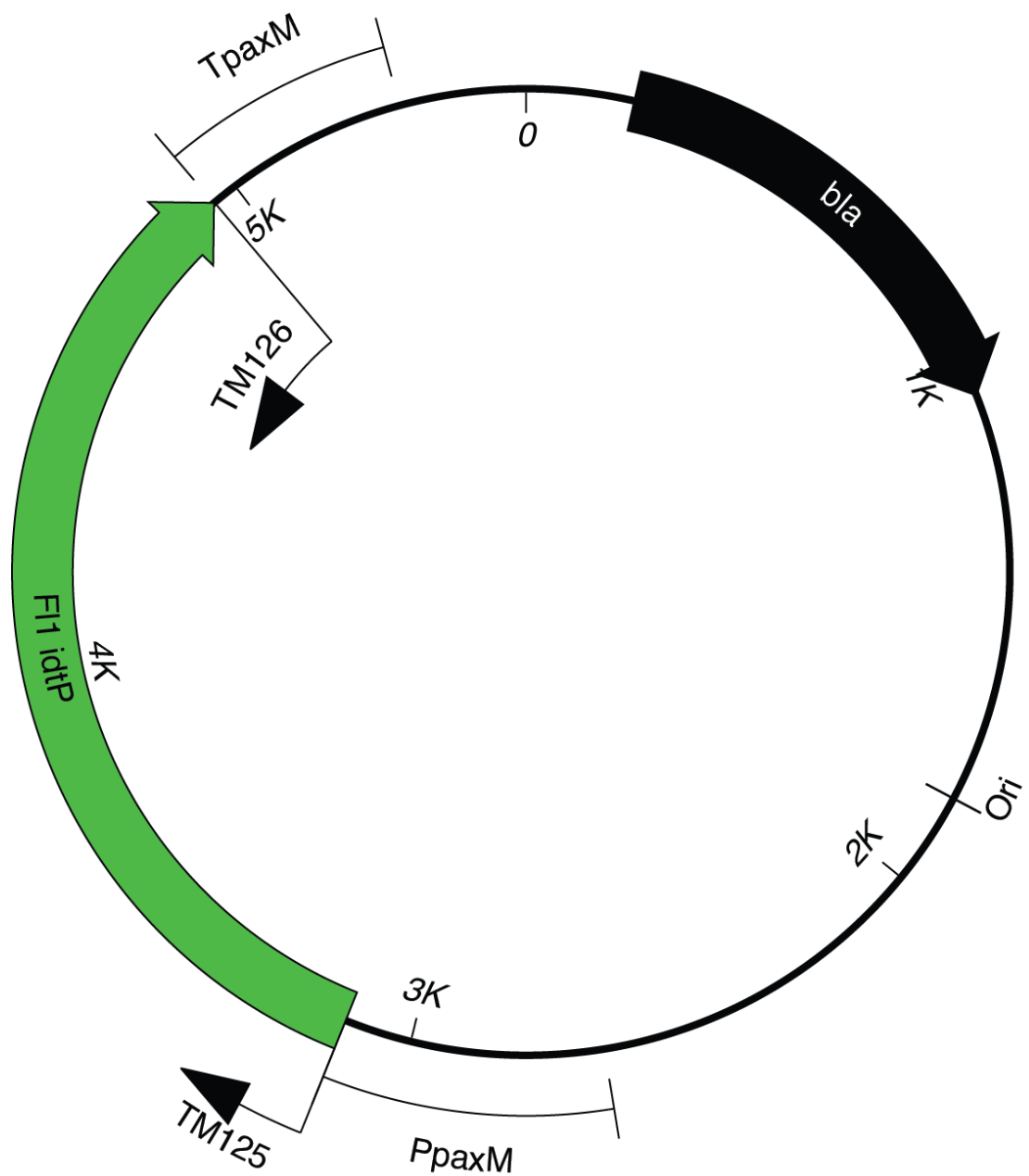
Appendix 8: Liquid chromatography tandem mass spectrometry (LC-MS/MS) analysis of new indole-diterpene (IDT) compound three from *Epichloë festucae* AR48 and Fg1 infected ryegrass. A) Collision-induced fragmentation spectrum of the 438 m/z peak. Key ions are 420 m/z (loss of H_2O), 402 m/z (loss of two H_2O), 366 m/z (loss of C_4H_8O), and 348 m/z (loss of H_2O and C_4H_8O). B) Collision-induced fragmentation spectrum of the 420 m/z peak from the 438 m/z fragmentation spectrum. Key ions are 402 m/z (loss of two H_2O), 384 m/z (loss of three H_2O), and 348 m/z (loss of H_2O and C_4H_8O). C) Collision-induced fragmentation spectrum of the 348 m/z peak from the 420 m/z fragmentation spectrum from the 438 m/z fragmentation spectrum. Key ion is 330 m/z (loss of two H_2O and C_4H_8O). D) Collision-induced fragmentation spectrum of the 402 m/z peak from the 420 m/z fragmentation spectrum from the 438 m/z fragmentation spectrum. Key peaks are 384 m/z (loss of three H_2O), and 316 m/z (loss of two H_2O and $C_5H_{12}O$). The predicted structure of the novel IDT 3# is inserted into the spectra as reference.



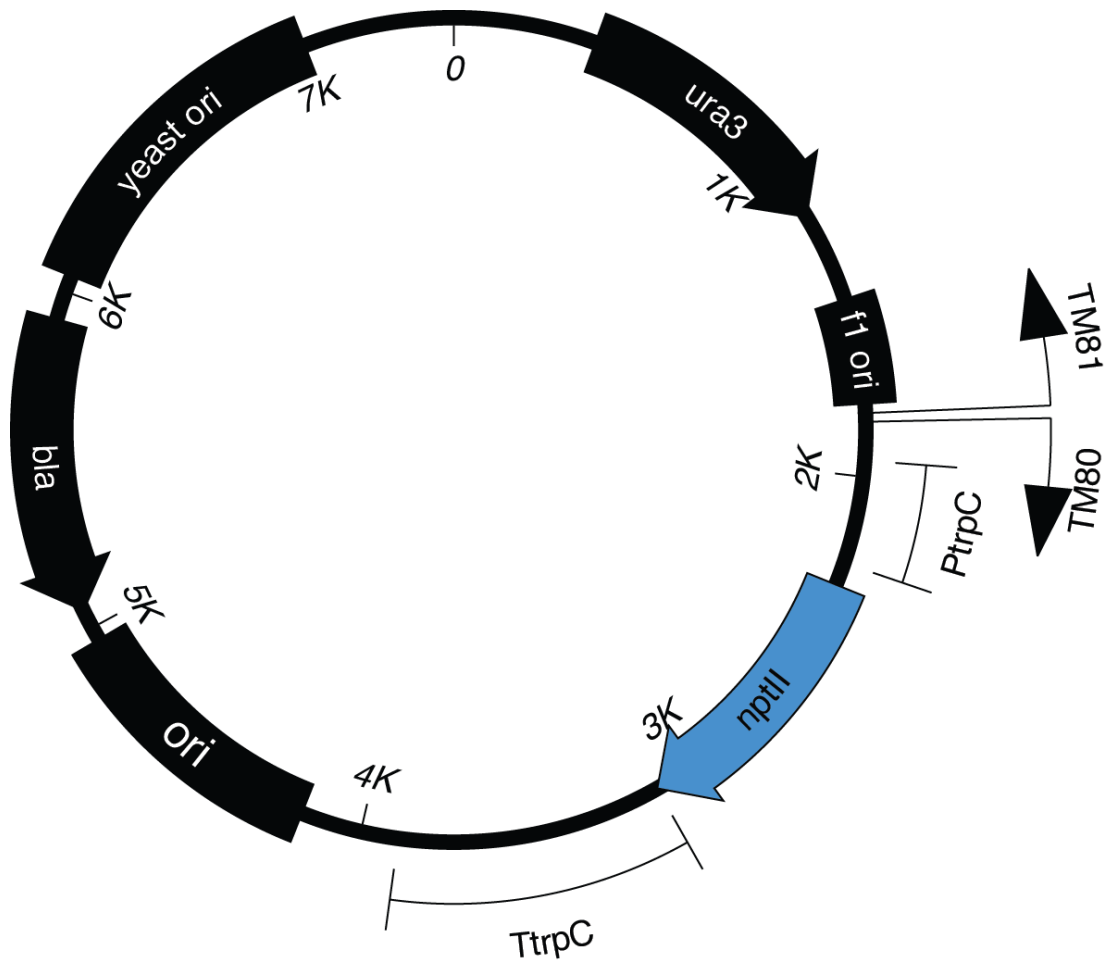
Appendix 9: *Penicillium paxilli* *paxP* complementation construct (pSS1, 7930 bp). NptII (geneticin resistance gene). Ori (*E. coli* origin of replication point). Bla (ampicillin resistance gene). PtrpC (promoter). TtrpC (terminator). Primers for screening transformants are indicated by black arrows.



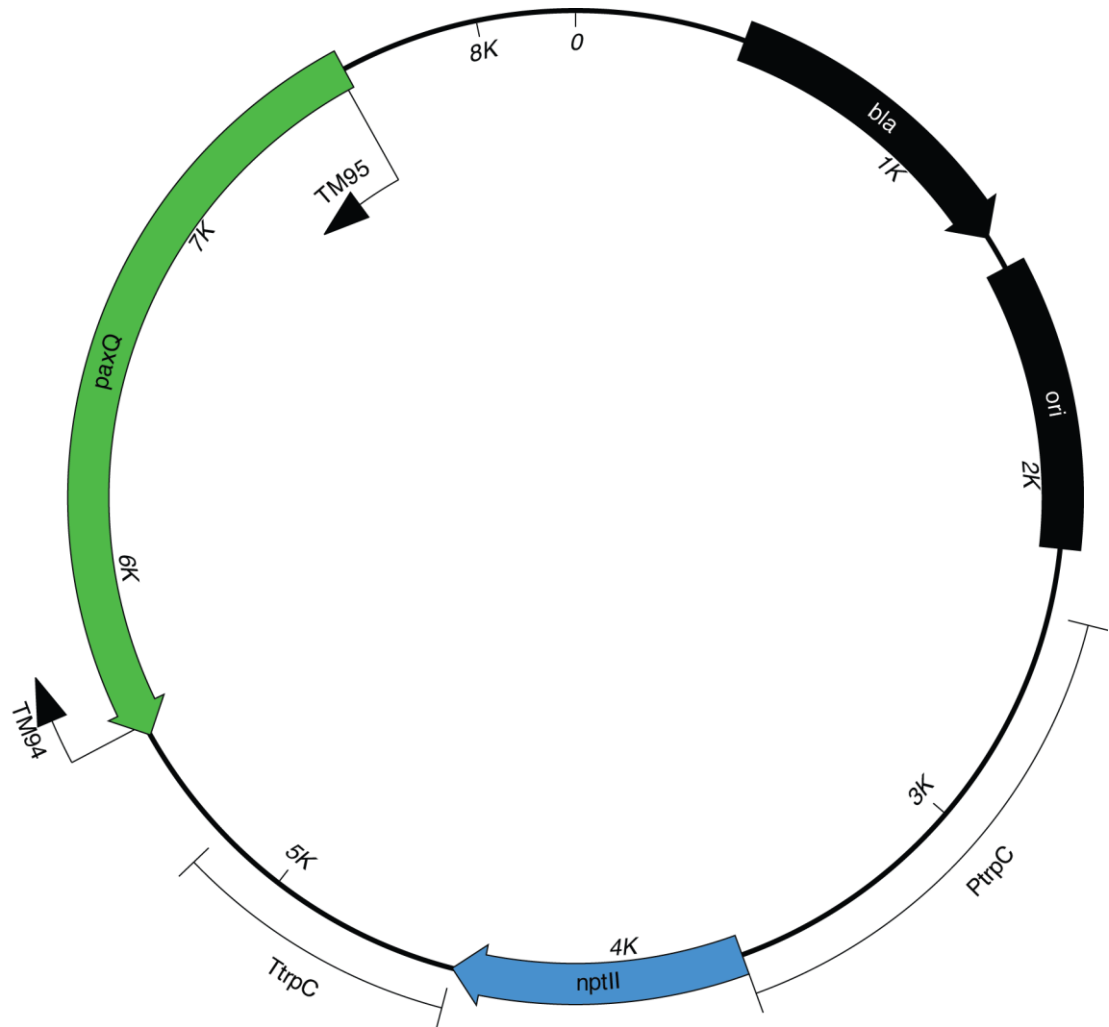
Appendix 10: *Epichloë festucae* AR48 indole diterpene (IDT) *idtP* complementation construct (pTM06, 11818 bp). NptII (geneticin resistance gene). Ori (*E.coli* origin of replication point). Bla (ampicillin resistance gene). PpaxM (promoter). TrpaxM (terminator). Primers for screening transformants (TM76/TM77), and for plasmid construction (all) are indicated by black arrows.



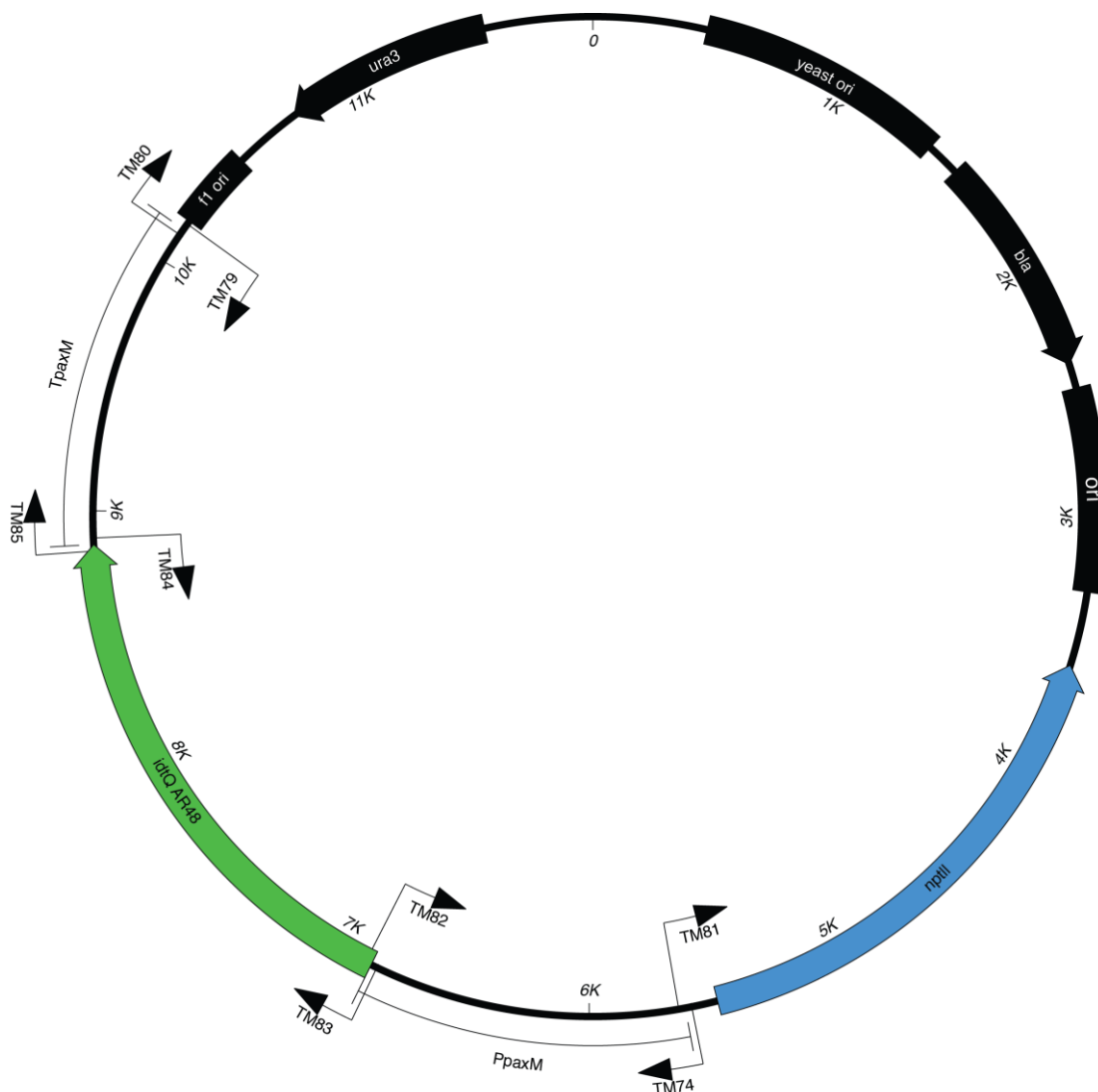
Appendix 11: *Epichloë festucae* Fl1 indole-diterpene (IDT) *idtP* complementation construct (pSS56, 5572 bp). Ori (*E.coli* origin of replication point). Bla (ampicillin resistance gene). PpaxM (promoter). TpaxM (terminator). Primers for screening transformants are indicated by black arrows (TM125/TM126).



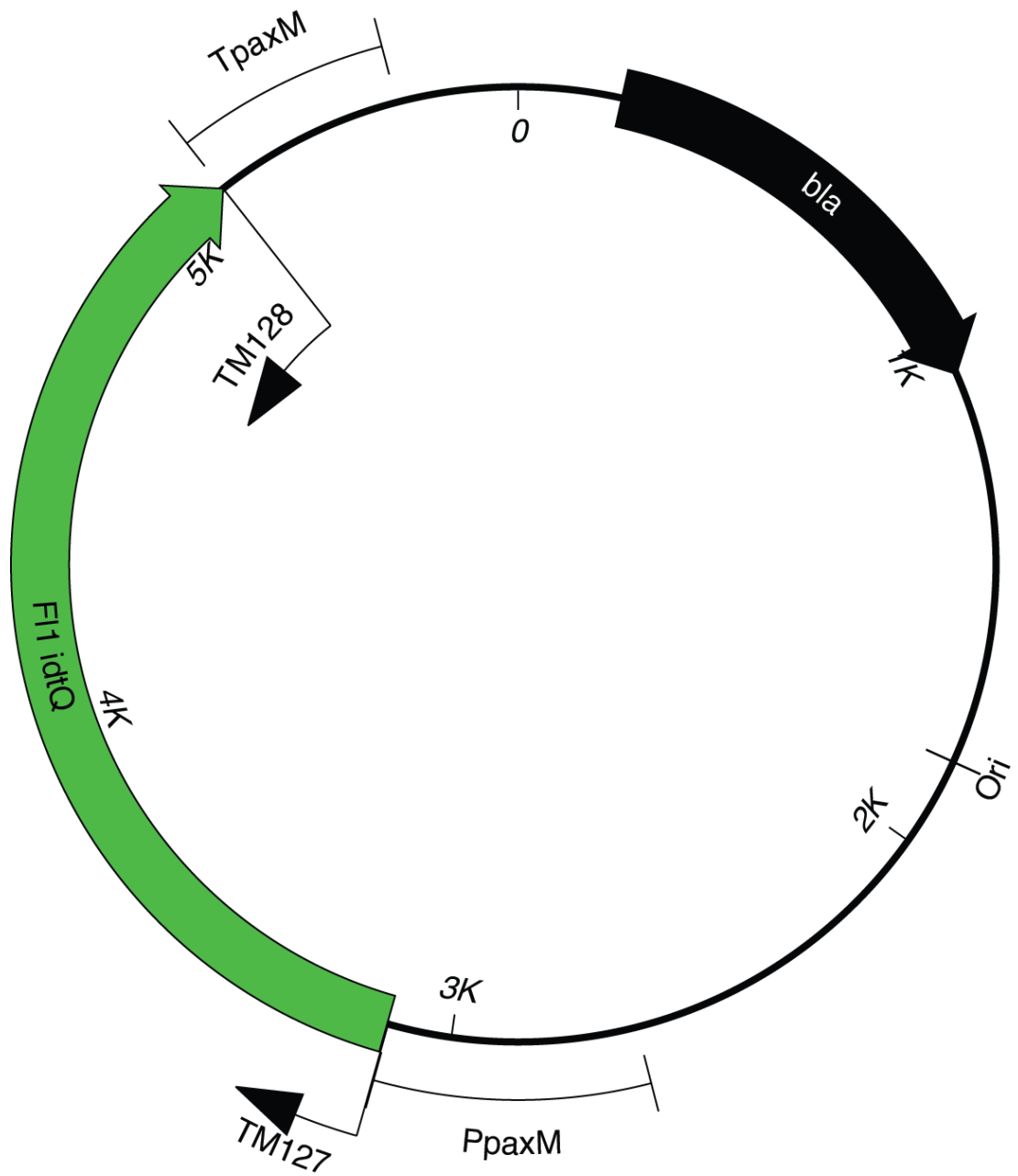
Appendix 12: Geneticin construct (pDB49, 7458 bp). NptII (geneticin resistance gene). Ori (*E. coli* origin of replication point). Bla (ampicillin resistance gene). PptrpC (promoter). TtrpC (terminator). Primers for backbone amplification are indicated by black arrows (TM80/TM81).



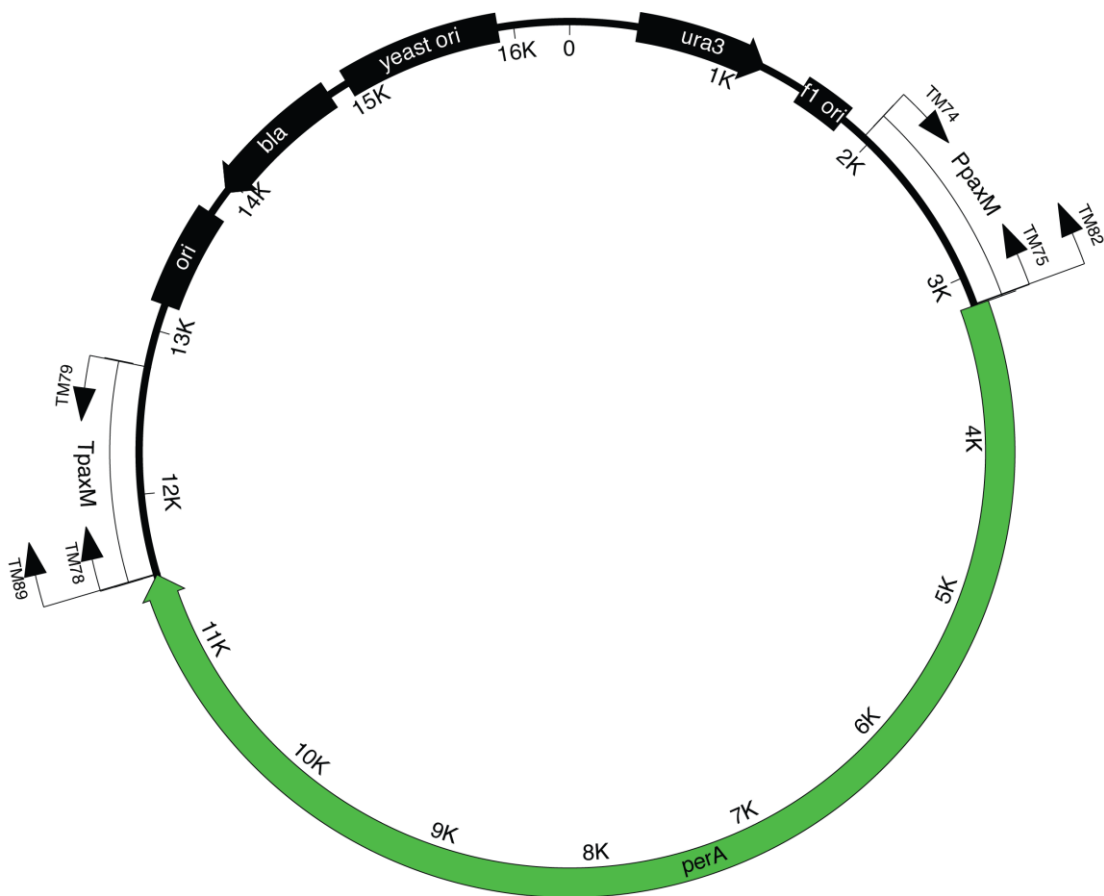
Appendix 13: *Penicillium paxilli* *paxQ* complementation construct (pSS2, 8270 bp). NptII (geneticin resistance gene). Ori (*E.coli* origin of replication point). Bla (ampicillin resistance gene). PptrpC (promoter). TtrpC (terminator). Primers for screening transformants are indicated by black arrows (TM94/TM95).



Appendix 14: *Epichloë festucae* AR48 indole-diterpene (IDT) *idQ* complementation construct (pTM07, 11970 bp). NptII (geneticin resistance gene). Ori (*E.coli* origin of replication point). Bla (ampicillin resistance gene). PpaxM (promoter). TpaxM (terminator). Primers for screening transformants (TM74/TM82) and well as plasmid construction (all) are indicated by black arrows.



Appendix 15: *Epichloë festucae* Fl1 indole-diterpene (IDT) *idtQ* complementation construct (pSS58, 5743 bp). Ori (*E.coli* origin of replication point). Bla (ampicillin resistance gene). P_{trpC} (promoter). T_{trpC} (terminator). Primers for screening transformants are indicated by black arrows (TM127/TM128).



Appendix 16: *Epichloë festucae* Fl1 *perA* complementation construct (pDB05, 16340 bp). Ori (*E.coli* origin of replication point). Bla (ampicillin resistance gene). PpaxM (promoter). TpaxM (terminator). Primers for amplifying PpaxM (TM74/TM75 or TM82) and TpaxM (TM78 or TM89/TM79) are indicated by black arrows

Chapter eight: Appendices

A)

Sample Name	Emindole 5B	Paspaline	Paspaline B	Paxitriol	PC-M6	13-Desoxypaxilline	Paxilline	Prenyl-Paxilline
WT	17918977	37578332	8075647	2927898	32508715	10436887	26170219	935380
Δ paxP	3029584	91094265	4209	71901	0	91456	194559	0
PaxP 1	6592671	105294518	500150	853192	64065367	600602	18697037	2038062
PaxP 2	674742	59260895	501772	472912	19265297	79575	18852009	642213
PaxP 3	16900737	135026875	630529	710940	55319948	2275266	20472823	1054703
PaxP 4	14099296	123294389	488534	594888	67660262	1761989	18036770	278737
PaxP 5	12891209	103134682	1094406	752215	45541583	5727201	24494919	1140592
AR48 idtP 1	2482041	108142833	6352	935234	1401704	3023137	187247	394236
AR48 idtP 2	1542348	127138139	6923	249436	4064938	13709	847779	0
AR48 idtP 3	532566	92582313	0	460618	1279818	0	261135	4089
AR48 idtP 4	833300	78150456	0	120313	534384	32235	126066	264504
AR48 idtP 5	397293	102190873	0	776247	4297276	21924	1090626	58507
Fl1 idtP 1	26769	145987	0	0	63225	14823	1262358	13514
Fl1 idtP 2	9284304	3254345	1892685	299168	2090625	16758196	163431	29825
Fl1 idtP 3	27787	2204310	0	0	0	0	22651	0
Fl1 idtP 4	1899401	38027830	0	12943	1171161	10564	60895	12962
Fl1 idtP 5	473715	59128029	0	84760	1944481	0	231401	0
Δ paxQ	13054340	18357323	1505389	584175	9844740	21689912	58014	0
PaxQ 1	2285600	4432365	35477	216113	3134116	224860	18684353	248886
PaxQ 2	1087373	1880513	20900	205195	2557373	106461	15900262	113072
PaxQ 3	642404	3002494	116656	143488	3000385	193580	14824034	84852
PaxQ 4	4798563	17265020	1038662	826374	11393434	522381	22761180	591540
PaxQ 5	767176	1725430	0	30723	424866	21674	3987396	21851
AR48 idtQ 1	24003867	27761677	437569	582158	18870809	18126596	778364	46075
AR48 idtQ 2	17201458	20149840	1529485	646728	15413967	20411402	1446045	167865
AR48 idtQ 3	12818468	11053630	2117029	411201	8540654	19894342	912881	140229
AR48 idtQ 4	7875884	5779140	2429370	416185	7343449	19008538	928543	0
AR48 idtQ 5	295087	619772	1636936	248864	979511	14399058	964380	0
Fl1 idtQ 1	1451588	2982559	693159	484303	4286858	12359124	577140	0
Fl1 idtQ 2	0	0	0	0	0	12287	2241	0
Fl1 idtQ 3	2799408	13624157	1385013	540638	7338274	17733240	624483	110034
Fl1 idtQ 4	5317667	7974847	373519	523375	13700297	15927909	101287	0
Fl1 idtQ 5	22827870	34635839	1881418	1396849	19819352	25754918	1095717	181800

B)

Sample Name	406_1	406_2	406_3	406_4	406_5	422_1	436_1	438_1	438_2	438_3	452_1	452_2
WT	1517495	305439	11997490	1597872	3607009	358347	14303014	440512	409373	24290	1687018	7352610
$\Delta paxP$	207263	33292	152788	110097	689456	97187	15006	0	0	1068032	0	11345
PaxP 1	340881	92302	26406486	304214	1045262	258782	12127790	2094979	308268	0	543766	8606249
PaxP 2	163675	37908	3913643	138120	239347	125923	2681550	330691	7241	56674	1583592	5337059
PaxP 3	404234	122056	22714310	387148	2108246	262944	13651948	1764261	425397	1047106	213449	12784720
PaxP 4	547078	72442	16538446	356536	2038552	252445	18073730	2646684	581634	534363	186913	13057553
PaxP 5	366180	105418	19407619	366606	1680068	225122	11427348	1042582	136260	140026	200197	11998505
AR48 <i>idtP</i> 1	135936	35011	485319	227676	240921	129819	863487	70066	15118	212985	1414	285485
AR48 <i>idtP</i> 2	266904	19817	118108	185147	222849	242051	1385273	190437	66755	245226	3023	563015
AR48 <i>idtP</i> 3	162247	59169	155667	76953	92771	184419	887354	82669	50507	150014	1430	169825
AR48 <i>idtP</i> 4	82975	34501	225572	57539	228609	73136	348885	45740	0	97240	798	52317
AR48 <i>idtP</i> 5	408185	58244	109707	189064	130472	232971	2088521	226987	48393	503675	6212	603410
Fl1 <i>idtP</i> 1	0	0	55324	0	6184	0	19479	0	0	0	166716	31133
Fl1 <i>idtP</i> 2	183751	173088	2091596	143194	750557	351596	450848	11660	527755	0	0	1723321
Fl1 <i>idtP</i> 3	2807	0	0	0	15097	0	20987	6547	0	20878	0	10506
Fl1 <i>idtP</i> 4	36803	37095	158578	12034	232500	71881	749404	584534	6117	220363	0	512861
Fl1 <i>idtP</i> 5	106851	15815	9256	23272	115543	99902	1490575	645053	5648	158483	0	595516
$\Delta paxQ$	359190	195549	6823101	312732	1126179	372556	2359058	69373	448961	16003	0	4136953
PaxQ 1	208549	72913	1349722	238253	325670	131597	766694	21140	46346	0	3825470	1280787
PaxQ 2	159011	46810	539349	136957	267343	117443	427508	18939	26014	0	3914376	1428075
PaxQ 3	69181	15635	1776571	34841	105715	62533	625674	14799	12487	0	385119	1036072
PaxQ 4	420058	142561	3324042	440887	1080044	316234	2749240	119326	351096	23755	562301	5942380
PaxQ 5	23133	6350	345024	5048	52625	0	222896	5200	4090	0	57293	365944
AR48 <i>idtQ</i> 1	313641	89542	8590519	663534	2657837	198104	4720119	117324	338815	0	0	5682017
AR48 <i>idtQ</i> 2	396487	104225	5461310	401410	1663142	278154	4313133	102557	462922	0	0	4542130
AR48 <i>idtQ</i> 3	300666	133741	5101310	235374	1194673	225154	2133607	47581	659038	0	0	3150312
AR48 <i>idtQ</i> 4	298708	131627	1524459	172874	745873	264641	1715706	34019	497924	0	0	2632723
AR48 <i>idtQ</i> 5	128726	52388	104502	43630	51725	290761	217801	11134	70160	0	0	1318525
Fl1 <i>idtQ</i> 1	180707	24421	991075	137972	277420	189691	486232	36114	34622	0	0	3612324
Fl1 <i>idtQ</i> 2	0	0	0	0	0	0	0	0	0	0	0	1077
Fl1 <i>idtQ</i> 3	192929	65700	4111243	179487	284746	364324	2039514	129379	65325	27464	0	2972341
Fl1 <i>idtQ</i> 4	208875	53662	1334895	101097	346883	279005	1837040	120583	25660	35736	0	5791002
Fl1 <i>idtQ</i> 5	572774	207127	12390215	485855	1760363	518131	4942215	195392	574664	50722	0	6616585

Appendix 17: *Penicillium paxilli* (pax) complementation raw data of A) known indole-diterpenes compound and B) unknown indole-diterpene (IDT)-like compounds. For all transformants; wild type (WT), gene deletions ($\Delta paxP$ and $\Delta paxQ$) and complementations (*paxP*, *E. festucae* var *loll* AR48 *idtP*, or *E. festucae* Fl1 *idtP* into $\Delta paxP$) and (*paxQ*, AR48 *E. festucae* var *loll* *idtQ*, or Fl1 *E. festucae* *idtQ* into $\Delta paxQ$). The new IDT compounds are labelled with the *m/z* and then the unknown IDT order in that chromatogram.

Chapter eight: Appendices

<i>Epichloë festucae_AR48</i>	1 ATGGCTCATAAGTAAGAGCTTCCCTCTCTTTTCTAATTCTGTTCTGTCATGATCGGACTA 60
<i>Epichloë festucae_Fg1</i>	1 ATGGCTCATAAGTAAGAGCTTCCCTCTCTTTTCTAATTCTGTTCTGTCATGATCGGACTA 60
<i>Epichloë festucae_Fl1</i>	1 -----ACGCATCGGCAGTCCA 16
<i>Epichloë festucae_E2368</i>	1 -----ACGCATCGGCAGTCCA 16
<i>Epichloë festucae_AR1</i>	1 ATGGCTCATAAGTAAGAGCTTCCCTCTCTTTTCTAATTCTGTTCTGTCATGATCGGACTA 60
<i>Epichloë festucae_AR37</i>	-----
<i>Epichloë festucae_AR48</i>	61 ACATGTATCTTTG-----CAGCGCTAACGAAACGTCCATTGTCGAA-----TTTTCGA 108
<i>Epichloë festucae_Fg1</i>	61 ACATGTATCTTTG-----CAGCGCTAACGAAACGTCCATTGTCGAA-----TTTTCGA 108
<i>Epichloë festucae_Fl1</i>	17 ACAAGCCGAAGTCAGGGGTGAGAACAAAAAAGCGAATTGCAAGGTCTCTTCTCGT 75
<i>Epichloë festucae_E2368</i>	17 ACAAGCCGAAGTCAGGGGTGAGAACAAAAAAGCGAATTGCAAGGTCTCTTCTCGT 76
<i>Epichloë festucae_AR1</i>	61 ACATGTATTTTTC-----CAGCGCTAACGAAACGTCCATTGTCGAA-----TTTTCGA 108
<i>Epichloë festucae_AR37</i>	-----
<i>Epichloë festucae_AR48</i>	109 AAGATCC-----CTTGGTTTATCA-----CGAAGGG-----CGAAAAAGG 145
<i>Epichloë festucae_Fg1</i>	109 AAGATCC-----CTTGGTTTATCA-----CGAAGGG-----CGAAAAAGG 145
<i>Epichloë festucae_Fl1</i>	76 GGCCCTCGGACTCTTCGCGTTTTCATTCTGCGCGCGGCGACGGTTCGGGATCCACGACCG 135
<i>Epichloë festucae_E2368</i>	77 GGCCCTCGGACTCTTCGCGTTTTCATTCTGCGCGCGGCGACGGTTCGGGATCCACGACCG 136
<i>Epichloë festucae_AR1</i>	109 AAGATCC-----CTTGGTTTATCA-----CGAAGGG-----CGAAAAAGG 145
<i>Epichloë festucae_AR37</i>	-----
<i>Epichloë festucae_AR48</i>	146 CTATGCCGTC-----ATCAGCTCGGACAAACATTCTGGACGACG--TCCAAATGTTTTTA 198
<i>Epichloë festucae_Fg1</i>	146 CTATGCCGTC-----ATCAGCTCGGACAAACATTCTGGACGACG--TCCAAATGTTTTTA 198
<i>Epichloë festucae_Fl1</i>	136 CGCGGCCGCGCGCGAACCGGTCCAACGCTCTCGGAGGCCGAGGCTTCGGATTCTAGACA 195
<i>Epichloë festucae_E2368</i>	137 CGCGGCCGCGCGCGAACCGGTCCAACGCTCTCGGAGGCCGAGGCTTCGGATTCTAGACA 196
<i>Epichloë festucae_AR1</i>	146 CTATGCCGTC-----ATCAGCTCGGACAAACATTCTGGACGACG--TCCAAATGTTTTTA 198
<i>Epichloë festucae_AR37</i>	-----
<i>Epichloë festucae_AR48</i>	199 TCGGAGACGAA-----GGACATTTGAGATTGACAGCGTCGGAATCTAGATCAAC 249
<i>Epichloë festucae_Fg1</i>	199 TCGGAGACGAA-----GGACATTTGAGATTGACAGCGTCGGAATCTAGATCAAC 249
<i>Epichloë festucae_Fl1</i>	196 GCGGCC--CGAACCGCTGTGGGGCCATTGCGAGGA--AATAGCCTGTCTCTCGTACGAAG 252
<i>Epichloë festucae_E2368</i>	197 GCGGCC--CGAACCGCTGTGGGGCCATTGCGAGGA--AATAGCCTGTCTCTCGTACGAAG 253
<i>Epichloë festucae_AR1</i>	199 TCGGAGACGAA-----GGACATTTGAGATTGACAGCGTCGGAATCTAGATCAAC 249
<i>Epichloë festucae_AR37</i>	-----
<i>Epichloë festucae_AR48</i>	250 CAGCGT--TCG--AAATCAGGTACCATGGAGCCGACGCTGGCCCGACACCGT----- 298
<i>Epichloë festucae_Fg1</i>	250 CAGCGT--TCG--AAATCAGGTACCATGGAGCCGACGCTGGCCCGACACCGT----- 298
<i>Epichloë festucae_Fl1</i>	253 GACCGTGTTCGGAACCTCGCGCCCTGACGCTAATAATATAGTTATTATAATAAT 312
<i>Epichloë festucae_E2368</i>	254 GACCGTGTTCGGAACCTCGCGCCCTGACGCTAATAATATAGTTATTATAATAAT 313
<i>Epichloë festucae_AR1</i>	250 CAGCGT--TCG--AAATCAGGTACCATGGAGCCGACGCTGGCCCGACACCGT----- 298
<i>Epichloë festucae_AR37</i>	-----
<i>Epichloë festucae_AR48</i>	299 -----CTCGGCGTATCACTTGGGATACAATGGAGGCGCGACAGCTCTGGACGCCCGC 352
<i>Epichloë festucae_Fg1</i>	299 -----CTCGGCGTATCACTTGGGATACAATGGAGGCGCGACAGCTCTGGACGCCCGC 352
<i>Epichloë festucae_Fl1</i>	313 AATAAACACGGGCTAATTAGTAATAGTATCATAAAGGCATGCAGCCCTC--GCTGCCTAC 370
<i>Epichloë festucae_E2368</i>	314 AATAAACACGGGCTAATTAGTAATAGTATCATAAAGGCATGCAGCCCTC--GCTGCCTAC 371
<i>Epichloë festucae_AR1</i>	299 -----CTCGGCGTATCACTTGGGATACAATGGAGGCGCGACAGCTCTGGACGCCCGC 352
<i>Epichloë festucae_AR37</i>	-----
<i>Epichloë festucae_AR48</i>	353 C-CAAAATCGATATCCCCAAGATAAAACCCGAA--CATAACTTGGTTTTG--ACAGGT-- 404
<i>Epichloë festucae_Fg1</i>	353 C-CAAAATCGATATCCCCAAGATAAAACCCGAA--CATAACTTGGTTTTG--ACAGGT-- 404
<i>Epichloë festucae_Fl1</i>	371 CGCACCTCG-TCTCCAACGGACCTACATGTAATCGGTATGTAGGGCTTCTGTCAGGTGA 429
<i>Epichloë festucae_E2368</i>	372 CGCACCTCG-TCTCCAACGGACCTACATGTAATCGGTATGTAGGGCTTCTGTCAGGTGA 430
<i>Epichloë festucae_AR1</i>	353 C-CAAAATCGATATCCCCAAGATAAAACCCGAA--CATAACTTGGTTTTG--ACAGGT-- 404
<i>Epichloë festucae_AR37</i>	-----
<i>Epichloë festucae_AR48</i>	405 ---TCTCTCTCGGT-TGCTCCGTC-----ATAGTAACGAACCTCAACGACAACCA 451
<i>Epichloë festucae_Fg1</i>	405 ---TCTCTCTCGGT-TGCTCCGTC-----ATAGTAACGAACCTCAACGACAACCA 451
<i>Epichloë festucae_Fl1</i>	430 AAAGCCAGGGTCTGGTGGCATCGCGCGCAGATAGTAACGAACCTCAACGACAACCA 489
<i>Epichloë festucae_E2368</i>	431 AAAGCCAGGGTCTGGTGGCATCGCGCGCAGATAGTAACGAACCTCAACGACAACCA 490
<i>Epichloë festucae_AR1</i>	405 ---TCTCTCTCGGT-TGCTCCGTC-----ATAGTAACGAACCTCAACGACAACCA 451
<i>Epichloë festucae_AR37</i>	-----
<i>Epichloë festucae_AR48</i>	452 GTACCGTGTCTATCAGGACACTCGACAGGATAGCTCGTTGTTGTACAATGACGTCGTCTAT 511
<i>Epichloë festucae_Fg1</i>	452 GTACCGTGTCTATCAGGACACTCGACAGGATAGCTCGTTGTTGTACAATGACGTCGTCTAT 511
<i>Epichloë festucae_Fl1</i>	490 GTACCGTGTCTATCAGGACACTCGACAGGATAGCTCGTTGTTGTACAATGACGTCGTCTAT 549
<i>Epichloë festucae_E2368</i>	491 GTACCGTGTCTATCAGGACACTCGACAGGATAGCTCGTTGTTGTACAATGACGTCGTCTAT 550
<i>Epichloë festucae_AR1</i>	452 GTACCGTGTCTATCAGGACACTCGACAGGATAGCTCGTTGTTGTACAATGACGTCGTCTAT 511
<i>Epichloë festucae_AR37</i>	1 -----ATGACGTCGTCTAT 13
<i>Epichloë festucae_AR48</i>	512 GGCAGTTGACTACAGAGACTATAAA-CATCGCGATGCTAGTACTGGGTATGCCTGCGCAT 570
<i>Epichloë festucae_Fg1</i>	512 GGCAGTTGACTACAGAGACTATAAA-CATCGCGATGCTAGTACTGGGTATGCCTGCGCAT 570
<i>Epichloë festucae_Fl1</i>	550 GGCAGTTGACTACAGAGACTATAAA-CATCGCGATGCTAGTACTGGGTATGCCTGCGCAT 608
<i>Epichloë festucae_E2368</i>	551 GGCAGTTGACTACAGAGACTATAAA-CATCGCGATGCTAGTACTGGGTATGCCTGCGCAT 609
<i>Epichloë festucae_AR1</i>	512 GGCAGTTGACTACAGAGACTATAAA-CATCGCGATGCTAGTACTGGGTATGCCTGCGCAT 570
<i>Epichloë festucae_AR37</i>	14 GGCAGTTGACTACAGAGACTATAAA-CATCGCGATGCTAGTACTGGGTATGCCTGCGCAT 73
<i>Epichloë festucae_AR48</i>	571 TCATGCACTATCGGGAAGGTGCGTGGTCTCTGTGTTTCCAGAGGCCAAACCTACTTCAAA 630
<i>Epichloë festucae_Fg1</i>	571 TCATGCACTATCGGGAAGGTGCGTGGTCTCTGTGTTTCCAGAGGCCAAACCTACTTCAAA 630
<i>Epichloë festucae_Fl1</i>	609 TCATGCACTATCGGGAAGGTGCGTGGTCTCTGTGTTTCCAGAGGCCAAACCTACTTCAAA 668
<i>Epichloë festucae_E2368</i>	610 TCATGCACTATCGGGAAGGTGCGTGGTCTCTGTGTTTCCAGAGGCCAAACCTACTTCAAA 669
<i>Epichloë festucae_AR1</i>	571 TCATGCACTATCGTGAAGGTGCGTGGTCTCTGTGTTTCCAGAGGCCAAACCTACTTCAAA 630
<i>Epichloë festucae_AR37</i>	74 TCATGCACTATCGGGAAGGTGCGTGGTCTCTGTGTTTCCAGAGGCCAAACCTACTTCAAA 133
<i>Epichloë festucae_AR48</i>	631 ATGCACGTGTTGTCCTGTACGATCCGCTGCCGAGAGATGGCCCATCCATAGTAGGGACAG 690
<i>Epichloë festucae_Fg1</i>	631 ATGCACGTGTTGTCCTGTACGATCCGCTGCCGAGAGATGGCCCATCCATAGTAGGGACAG 690
<i>Epichloë festucae_Fl1</i>	669 ATGCACGTGTTGTCCTGTACGATCCGCTGCCGAGAGATGGCCCATCCATAGTAGGGACAG 728
<i>Epichloë festucae_E2368</i>	670 ATGCACGTGTTGTCCTGTACGATCCGCTGCCGAGAGATGGCCCATCCATAGTAGGGACAG 729
<i>Epichloë festucae_AR1</i>	631 ATGCACGTGTTGTCCTGTACGATCCGCTGCCGAGAGATGGCCCATCCATAGTAGGGACAG 690
<i>Epichloë festucae_AR37</i>	134 ATGCACGTGTTGTCCTGTACGATCCGCTGCCGAGAGATGGCCCATCCATAGTAGGGACAG 193
<i>Epichloë festucae_AR48</i>	691 AGCCCTTGATTGAGATGGTGCCAAATCGTATAACCCGGAGCTAGTTCAATCGCGTTTCG 750
<i>Epichloë festucae_Fg1</i>	691 AGCCCTTGATTGAGATGGTGCCAAATCGTATAACCCGGAGCTAGTTCAATCGCGTTTCG 750
<i>Epichloë festucae_Fl1</i>	729 AGCCCTTGATTGAGATGGTGCCAAATCGTATAACCCGGAGCTAGTTCAATCGCGTTTCG 788
<i>Epichloë festucae_E2368</i>	730 AGCCCTTGATTGAGATGGTGCCAAATCGTATAACCCGGAGCTAGTTCAATCGCGTTTCG 789
<i>Epichloë festucae_AR1</i>	691 AGCCCTTGATTGAGATGGTGCCAAATCGTATAACCCGGAGCTAGTTCAATCGCGTTTCG 750
<i>Epichloë festucae_AR37</i>	194 AGCCCTTGATTGAGATGGTGCCAAATCGTATAACCCGGAGCTAGTTCAATCGCGTTTCG 253

Chapter eight: Appendices

Epichloë_festucae_AR48	751	ACGAGAGTCGCGAAAAGTGCTTGGAGCGCTTGGGGACGCTCGCACGAAGCTTTCTAACG	810
Epichloë_festucae_Fg1	751	ACGAGAGTCGCGAAAAGTGCTTGGAGCGCTTGGGGACGCTCGCACGAAGCTTTCTAACG	810
Epichloë_festucae_F11	789	ACGAGAGTCGCGAAAAGTGCTTGGAGCGCTTGGGGACGCTCGCACGAAGCTTTCTAACG	848
Epichloë_festucae_E2368	790	ACGAGAGTCGCGAAAAGTGCTTGGAGCGCTTGGGGACGCTCGCACGAAGCTTTCTAACG	849
Epichloë_festucae_AR1	751	ACGAGAGTCGCGAAAAGTGCTTGGAGCGCTTGGGGACGCTCGCACGAAGCTTTCTAACG	810
Epichloë_festucae_AR37	254	ACGAGAGTCGCGAAAAGTGCTTGGAGCGCTTGGGGACGCTCGCACGAAGCTTTCTAACG	313
Epichloë_festucae_AR48	811	ACCCCTTTTCATTACGAAGATGGTGAATTTCAACCATTTCGAAGAAAACACATCAGTCTTG	870
Epichloë_festucae_Fg1	811	ACCCCTTTTCATTACGAAGATGGTGAATTTCAACCATTTCGAAGAAAACACATCAGTCTTG	870
Epichloë_festucae_F11	849	ACCCCTTTTCATTACGAAGATGGTGAATTTCAACCATTTCGAAGAAAACACATCAGTCTTG	908
Epichloë_festucae_E2368	850	ACCCCTTTTCATTACGAAGATGGTGAATTTCAACCATTTCGAAGAAAACACATCAGTCTTG	909
Epichloë_festucae_AR1	811	ACCCCTTTTCATTACGAAGATGGTGAATTTCAACCATTTCGAAGAAAACACATCAGTCTTG	870
Epichloë_festucae_AR37	314	ACCCCTTTTCATTACGAAGATGGTGAATTTCAACCATTTCGAAGAAAACACATCAGTCTTG	373
Epichloë_festucae_AR48	871	ACAATGAAGCCGTTGGCTATTACAAAGGACTTAGAACCGAGCTTGATGGCATTCTCAGAG	930
Epichloë_festucae_Fg1	871	ACAATGAAGCCGTTGGCTATTACAAAGGACTTAGAACCGAGCTTGATGGCATTCTCAGAG	930
Epichloë_festucae_F11	909	ACAATGAAGCCGTTGGCTATTACAAAGGACTTAGAACCGAGCTTGATGGCATTCTCAGAG	968
Epichloë_festucae_E2368	910	ACAATGAAGCCGTTGGCTATTACAAAGGACTTAGAACCGAGCTTGATGGCATTCTCAGAG	969
Epichloë_festucae_AR1	871	ACAATGAAGCCGTTGGCTATTACAAAGGACTTAGAACCGAGCTTGATGGCATTCTCAGAG	930
Epichloë_festucae_AR37	374	ACAATGAAGCCGTTGGCTATTACAAAGGACTTAGAACCGAGCTTGATGGCATTCTCAGAG	433
Epichloë_festucae_AR48	931	ATAGGCCCTTATCCAACCTGAACCCAAATGCTGATCTCAATCCACAGGAGTTGGTGTCACTCA	990
Epichloë_festucae_Fg1	931	ATAGGCCCTTATCCAACCTGAACCCAAATGCTGATCTCAATCCACAGGAGTTGGTGTCACTCA	990
Epichloë_festucae_F11	969	ATAGGCCCTTATCCAACCTGAACCCAAATGCTGATCTCAATCCACAGGAGTTGGTGTCACTCA	1028
Epichloë_festucae_E2368	970	ATAGGCCCTTATCCAACCTGAACCCAAATGCTGATCTCAATCCACAGGAGTTGGTGTCACTCA	1029
Epichloë_festucae_AR1	931	ATAGGCCCTTATCCAACCTGAACCCAAATGCTGATCTCAATCCACAGGAGTTGGTGTCACTCA	990
Epichloë_festucae_AR37	434	ATAGGCCCTTATCCAACCTGAACCCAAATGCTGATCTCAATCCACAGGAGTTGGTGTCACTCA	493
Epichloë_festucae_AR48	991	GCGACCAGCTGTTCTAAGCGAAAGGTTTGTAGGCGAACCTATGACGCTCTTCTCGGAATT	1050
Epichloë_festucae_Fg1	991	GCGACCAGCTGTTCTAAGCGAAAGGTTTGTAGGCGAACCTATGACGCTCTTCTCGGAATT	1050
Epichloë_festucae_F11	1029	GCGACCAGCTGTTCTAAGCGAAAGGTTTGTAGGCGAACCTATGACGCTCTTCTCGGAATT	1088
Epichloë_festucae_E2368	1030	GCGACCAGCTGTTCTAAGCGAAAGGTTTGTAGGCGAACCTATGACGCTCTTCTCGGAATT	1089
Epichloë_festucae_AR1	991	GCGACCAGCTGTTCTAAGCGAAAGGTTTGTAGGCGAACCTATGACGCTCTTCTCGGAATT	1050
Epichloë_festucae_AR37	494	GCGACCAGCTGTTCTAAGCGAAAGGTTTGTAGGCGAACCTATGACGCTCTTCTCGGAATT	553
Epichloë_festucae_AR48	1051	ACGACTTATACATACCTCTGGCTGAAGCAAAAGGAGGAAAGGGGGTTTGCAGCAGTCGTGA	1110
Epichloë_festucae_Fg1	1051	ACGACTTATACATACCTCTGGCTGAAGCAAAAGGAGGAAAGGGGGTTTGCAGCAGTCGTGA	1110
Epichloë_festucae_F11	1089	ACGACTTATACATACCTCTGGCTGAAGCAAAAGGAGGAAAGGGGGTTTGCAGCAGTCGTGA	1148
Epichloë_festucae_E2368	1090	ACGACTTATACATACCTCTGGCTGAAGCAAAAGGAGGAAAGGGGGTTTGCAGCAGTCGTGA	1149
Epichloë_festucae_AR1	1051	ACGACTTATACATACCTCTGGCTGAAGCAAAAGGAGGAAAGGGGGTTTGCAGCAGTCGTGA	1110
Epichloë_festucae_AR37	554	ACGACTTATACATACCTCTGGCTGAAGCAAAAGGAGGAAAGGGGGTTTGCAGCAGTCGTGA	613
Epichloë_festucae_AR48	1111	GAGAAGGCGAGCATCGGCAAAACACCTCTAGGAGGCACAGCCGGCCAAACGTCCTCCGAAC	1170
Epichloë_festucae_Fg1	1111	GAGAAGGCGAGCATCGGCAAAACACCTCTAGGAGGCACAGCCGGCCAAACGTCCTCCGAAC	1170
Epichloë_festucae_F11	1149	GAGAAGGCGAGCATCGGCAAAACACCTCTAGGAGGCACAGCCGGCCAAACGTCCTCCGAAC	1208
Epichloë_festucae_E2368	1150	GAGAAGGCGAGCATCGGCAAAACACCTCTAGGAGGCACAGCCGGCCAAACGTCCTCCGAAC	1209
Epichloë_festucae_AR1	1111	GAGAAGGCGAGCATCGGCAAAACACCTCTAGGAGGCACAGCCGGCCAAACGTCCTCCGAAC	1170
Epichloë_festucae_AR37	614	GAGAAGGCGAGCATCGGCAAAACACCTCTAGGAGGCACAGCCGGCCAAACGTCCTCCGAAC	673
Epichloë_festucae_AR48	1171	AAAGGTTTCAGGGAGCTTTTACGGGGCGATAACGAGTTTTTCAAGGGGATACAATACATATG	1230
Epichloë_festucae_Fg1	1171	AAAGGTTTCAGGGAGCTTTTACGGGGCGATAACGAGTTTTTCAAGGGGATACAATACATATG	1230
Epichloë_festucae_F11	1209	AAAGGTTTCAGGGAGCTTTTACGGGGCGATAACGAGTTTTTCAAGGGGATACAATACATATG	1268
Epichloë_festucae_E2368	1210	AAAGGTTTCAGGGAGCTTTTACGGGGCGATAACGAGTTTTTCAAGGGGATACAATACATATG	1269
Epichloë_festucae_AR1	1171	AAAGGTTTCAGGGAGCTTTTACGGGGCGATAACGAGTTTTTCAAGGGGATACAATACATATG	1230
Epichloë_festucae_AR37	674	AAAGGTTTCAGGGAGCTTTTACGGGGCGATAACGAGTTTTTCAAGGGGATACAATACATATG	733
Epichloë_festucae_AR48	1231	AATCAGTCGAGATTTTCGGGATACGAGCATGACATGACACTATCCGAAATGGTACAGTTGT	1290
Epichloë_festucae_Fg1	1231	AATCAGTCGAGATTTTCGGGATACGAGCATGACATGACACTATCCGAAATGGTACAGTTGT	1290
Epichloë_festucae_F11	1269	AATCAGTCGAGATTTTCGGGATACGAGCATGACATGACACTATCCGAAATGGTACAGTTGT	1328
Epichloë_festucae_E2368	1270	AATCAGTCGAGATTTTCGGGATACGAGCATGACATGACACTATCCGAAATGGTACAGTTGT	1329
Epichloë_festucae_AR1	1231	AATCAGTCGAGATTTTCGGGATACGAGCATGACATGACACTATCCGAAATGGTACAGTTGT	1290
Epichloë_festucae_AR37	734	AATCAGTCGAGATTTTCGGGATACGAGCATGACATGACACTATCCGAAATGGTACAGTTGT	793
Epichloë_festucae_AR48	1291	TGCACCGATCGTCGACAAGCTTGACACAAACCGAACAAAGCGCGTTACTTCGTGCGATTG	1350
Epichloë_festucae_Fg1	1291	TGCACCGATCGTCGACAAGCTTGACACAAACCGAACAAAGCGCGTTACTTCGTGCGATTG	1350
Epichloë_festucae_F11	1329	TGCACCGATCGTCGACAAGCTTGACACAAACCGAACAAAGCGCGTTACTTCGTGCGATTG	1388
Epichloë_festucae_E2368	1330	TGCACCGATCGTCGACAAGCTTGACACAAACCGAACAAAGCGCGTTACTTCGTGCGATTG	1389
Epichloë_festucae_AR1	1291	TGCACCGATCGTCGACAAGCTTGACACAAACCGAACAAAGCGCGTTACTTCGTGCGATTG	1350
Epichloë_festucae_AR37	794	TGCACCGATCGTCGACAAGCTTGACACAAACCGAACAAAGCGCGTTACTTCGTGCGATTG	853
Epichloë_festucae_AR48	1351	ACTTGGCCAGAAAGGAGTTGTTCAATGAGTCTGTGTGGCAGAAAACCAACGACGTCATTG	1410
Epichloë_festucae_Fg1	1351	ACTTGGCCAGAAAGGAGTTGTTCAATGAGTCTGTGTGGCAGAAAACCAACGACGTCATTG	1410
Epichloë_festucae_F11	1389	ACTTGGCCAGAAAGGAGTTGTTCAATGAGTCTGTGTGGCAGAAAACCAACGACGTCATTG	1448
Epichloë_festucae_E2368	1390	ACTTGGCCAGAAAGGAGTTGTTCAATGAGTCTGTGTGGCAGAAAACCAACGACGTCATTG	1449
Epichloë_festucae_AR1	1351	ACTTGGCCAGAAAGGAGTTGTTCAATGAGTCTGTGTGGCAGAAAACCAACGACGTCATTG	1410
Epichloë_festucae_AR37	854	ACTTGGCCAGAAAGGAGTTGTTCAATGAGTCTGTGTGGCAGAAAACCAACGACGTCATTG	913
Epichloë_festucae_AR48	1411	CTATGTTCCAAGAGATGGGGGTTACACGAAACCTATGCCACAAGACATTCTTCTCCATG	1470
Epichloë_festucae_Fg1	1411	CTATGTTCCAAGAGATGGGGGTTACACGAAACCTATGCCACAAGACATTCTTCTCCATG	1470
Epichloë_festucae_F11	1449	CTATGTTCCAAGAGATGGGGGTTACACGAAACCTATGCCACAAGACATTCTTCTCCATG	1508
Epichloë_festucae_E2368	1450	CTATGTTCCAAGAGATGGGGGTTACACGAAACCTATGCCACAAGACATTCTTCTCCATG	1509
Epichloë_festucae_AR1	1411	CTATGTTCCAAGAGATGGGGGTTACACGAAACCTATGCCACAAGACATTCTTCTCCATG	1470
Epichloë_festucae_AR37	914	CTATGTTCCAAGAGATGGGGGTTACACGAAACCTATGCCACAAGACATTCTTCTCCATG	973
Epichloë_festucae_AR48	1471	CAATTCCCAGATGAGTATGGCGGGCGCGTTGCTATCCTCTGGTCTATGCCATGTCAGTGG	1530
Epichloë_festucae_Fg1	1471	CAATTCCCAGATGAGTATGGCGGGCGCGTTGCTATCCTCTGGTCTATGCCATGTCAGTGG	1530
Epichloë_festucae_F11	1509	CAATTCCCAGATGAGTATGGCGGGCGCGTTGCTATCCTCTGGTCTATGCCATGTCAGTGG	1568
Epichloë_festucae_E2368	1510	CAATTCCCAGATGAGTATGGCGGGCGCGTTGCTATCCTCTGGTCTATGCCATGTCAGTGG	1569
Epichloë_festucae_AR1	1471	CAATTCCCAGATGAGTATGGCGGGCGCGTTGCTATCCTCTGGTCTATGCCATGTCAGTGG	1530
Epichloë_festucae_AR37	974	CAATTCCCAGATGAGTATGGCGGGCGCGTTGCTATCCTCTGGTCTATGCCATGTCAGTGG	1033
Epichloë_festucae_AR48	1531	CACCTGGCATCGTCGGATTTCCGCATTGAGCAACTCTGCGCCAAGCTGGTGGGCTCTCCC	1590
Epichloë_festucae_Fg1	1531	CACCTGGCATCGTCGGATTTCCGCATTGAGCAACTCTGCGCCAAGCTGGTGGGCTCTCCC	1590
Epichloë_festucae_F11	1569	CACCTGGCATCGTCGGATTTCCGCATTGAGCAACTCTGCGCCAAGCTGGTGGGCTCTCCC	1628
Epichloë_festucae_E2368	1570	CACCTGGCATCGTCGGATTTCCGCATTGAGCAACTCTGCGCCAAGCTGGTGGGCTCTCCC	1629
Epichloë_festucae_AR1	1531	CACCTGGCATCGTCGGATTTCCGCATTGAGCAACTCTGCGCCAAGCTGGTGGGCTCTCCC	1590
Epichloë_festucae_AR37	1034	CACCTGGCATCGTCGGATTTCCGCATTGAGCAACTCTGCGCCAAGCTGGTGGGCTCTCCC	1093

Chapter eight: Appendices

<i>Epichloë festucae_AR48</i>	1591	CTAACAATCAAGCCGACATGAAGAACCGCGGAGTTGCTCAAGCGATGTTTGGAAGATCTTC	1650
<i>Epichloë festucae_Fg1</i>	1591	CTAACAATCAAGCCGACATGAAGAACCGCGGAGTTGCTCAAGCGATGTTTGGAAGATCTTC	1650
<i>Epichloë festucae_FI1</i>	1629	CTAACAATCAAGCCGACATGAAGAACCGCGGTGTTGCTCAAGCGATGTTTGGAAGATCTTC	1688
<i>Epichloë festucae_E2368</i>	1630	CTAACAATCAAGCCGACATGAAGAACCGCGGTGTTGCTCAAGCGATGTTTGGAAGATCTTC	1689
<i>Epichloë festucae_AR1</i>	1591	CTAACAATCAAGCCGACATGAAGAACCGCGGAGTTGCTCAAGCGATGTTTGGAAGATCTTC	1650
<i>Epichloë festucae_AR37</i>	1094	CTAACAATCAAGCCGACATGAAGAACCGCGGAGTTGCTCAAGCGATGTTTGGAAGATCTTC	1153
<i>Epichloë festucae_AR48</i>	1651	ACACCAGCTACCCAGCAGCAGAGGCTTCAAGGCCCATCGGCAATATGACGCTTGAGGAGG	1710
<i>Epichloë festucae_Fg1</i>	1651	ACACCAGCTACCCAGCAGCAGAGGCTTCAAGGCCCATCGGCAATATGACGCTTGAGGAGG	1710
<i>Epichloë festucae_FI1</i>	1689	ACACCAGCTACCCAGCAGCAGAGGCTTCAAGGCCCATCGGCAATATGACGCTTGAGGAGG	1748
<i>Epichloë festucae_E2368</i>	1690	ACACCAGCTACCCAGCAGCAGAGGCTTCAAGGCCCATCGGCAATATGACGCTTGAGGAGG	1749
<i>Epichloë festucae_AR1</i>	1651	ACACCAGCTACCCAGCAGCAGAGGCTTCAAGGCCCATCGGCAATATGACGCTTGAGGAGG	1710
<i>Epichloë festucae_AR37</i>	1154	ACACCAGCTACCCAGCAGCAGAGGCTTCAAGGCCCATCGGCAATATGACGCTTGAGGAGG	1213
<i>Epichloë festucae_AR48</i>	1711	CCGTGAGCATGCTCGAGAGAAGCACCAGAACCCACCATAGCAATGCACACAGAAGTAC	1770
<i>Epichloë festucae_Fg1</i>	1711	CCGTGAGCATGCTCGAGAGAAGCACCAGAACCCACCATAGCAATGCACACAGAAGTAC	1770
<i>Epichloë festucae_FI1</i>	1749	CCGTGAGCATGCTCGAGAGAAGCACCAGAACCCACCATAGCAATGCACACAGAAGTAC	1808
<i>Epichloë festucae_E2368</i>	1750	CCGTGAGCATGCTCGAGAGAAGCACCAGAACCCACCATAGCAATGCACACAGAAGTAC	1809
<i>Epichloë festucae_AR1</i>	1711	CCGTGAGCATGCTCGAGAGAAGCACCAGAACCCACCATAGCAATGCACACAGAAGTAC	1770
<i>Epichloë festucae_AR37</i>	1214	CCGTGAGCATGCTCGAGAGAAGCACCAGAACCCACCATAGCAATGCACACAGAAGTAC	1273
<i>Epichloë festucae_AR48</i>	1771	ATGCAATGTTGCTGGGCTTACAAAGAATGGCAATTCAACCTCGTGGCATTTCTATGATC	1830
<i>Epichloë festucae_Fg1</i>	1771	ATGCAATGTTGCTGGGCTTACAAAGAATGGCAATTCAACCTCGTGGCATTTCTATGATC	1830
<i>Epichloë festucae_FI1</i>	1809	ATGCAATGTTGCTGGGCTTACAAAGAATGGCAATTCAACCTCGTGGCATTTCTATGATC	1868
<i>Epichloë festucae_E2368</i>	1810	ATGCAATGTTGCTGGGCTTACAAAGAATGGCAATTCAACCTCGTGGCATTTCTATGATC	1869
<i>Epichloë festucae_AR1</i>	1771	ATGCAATGTTGCTGGGCTTACAAAGAATGGCAATTCAACCTCGTGGCATTTCTATGATC	1830
<i>Epichloë festucae_AR37</i>	1274	ATGCAATGTTGCTGGGCTTACAAAGAATGGCAATTCAACCTCGTGGCATTTCTATGATC	1333
<i>Epichloë festucae_AR48</i>	1831	CGAATCTCGCCATTGCCACGTTCAAGTCAGGGGAAGCGCTACTTGAAGCCACCACCAAGT	1890
<i>Epichloë festucae_Fg1</i>	1831	CGAATCTCGCCATTGCCACGTTCAAGTCAGGGGAAGCGCTACTTGAAGCCACCACCAAGT	1890
<i>Epichloë festucae_FI1</i>	1869	CGAATCTCGCCATTGCCACGTTCAAGTCAGGGGAAGCGCTACTTGAAGCCACCACCAAGT	1928
<i>Epichloë festucae_E2368</i>	1870	CGAATCTCGCCATTGCCACGTTCAAGTCAGGGGAAGCGCTACTTGAAGCCACCACCAAGT	1929
<i>Epichloë festucae_AR1</i>	1831	CGAATCTCGCCATTGCCACGTTCAAGTCAGGGGAAGCGCTACTTGAAGCCACCACCAAGT	1890
<i>Epichloë festucae_AR37</i>	1334	CGAATCTCGCCATTGCCACGTTCAAGTCAGGGGAAGCGCTACTTGAAGCCACCACCAAGT	1393
<i>Epichloë festucae_AR48</i>	1891	TCTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCCAGGGTCAGACACCCAGTTTCG	1950
<i>Epichloë festucae_Fg1</i>	1891	TCTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCCAGGGTCAGACACCCAGTTTCG	1950
<i>Epichloë festucae_FI1</i>	1929	TCTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCCAGGGTCAGACACCCAGTTTCG	1988
<i>Epichloë festucae_E2368</i>	1930	TCTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCCAGGGTCAGACACCCAGTTTCG	1989
<i>Epichloë festucae_AR1</i>	1891	TCTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCCAGGGTCAGACACCCAGTTTCG	1950
<i>Epichloë festucae_AR37</i>	1394	TCTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCCAGGGTCAGACACCCAGTTTCG	1453
<i>Epichloë festucae_AR48</i>	1951	ACTTTTTCCGGATTGATGCGGAAAGGGTGCTCTCGCATCGGATTTGAAACCGACTTGACCG	2010
<i>Epichloë festucae_Fg1</i>	1951	ACTTTTTCCGGATTGATGCGGAAAGGGTGCTCTCGCATCGGATTTGAAACCGACTTGACCG	2010
<i>Epichloë festucae_FI1</i>	1989	ACTTTTTCCGGATTGATGCGGAAAGGGTGCTCTCGCATCGGATTTGAAACCGACTTGACCG	2048
<i>Epichloë festucae_E2368</i>	1990	ACTTTTTCCGGATTGATGCGGAAAGGGTGCTCTCGCATCGGATTTGAAACCGACTTGACCG	2049
<i>Epichloë festucae_AR1</i>	1951	ACTTTTTCCGGATTGATGCGGAAAGGGTGCTCTCGCATCGGATTTGAAACCGACTTGACCG	2010
<i>Epichloë festucae_AR37</i>	1454	ACTTTTTCCGGATTGATGCGGAAAGGGTGCTCTCGCATCGGATTTGAAACCGACTTGACCG	1513
<i>Epichloë festucae_AR48</i>	2011	TCGCCGACCTGGTTGAGCCGGAGACCTGCTCGAGACCATAGCCTCCGAGCATAAGACGG	2070
<i>Epichloë festucae_Fg1</i>	2011	TCGCCGACCTGGTTGAGCCGGAGACCTGCTCGAGACCATAGCCTCCGAGCATAAGACGG	2070
<i>Epichloë festucae_FI1</i>	2049	TCGCCGACCTGGTTGAGCCGGAGACCTGCTCGAGACCATAGCCTCCGAGCATAAGACGG	2108
<i>Epichloë festucae_E2368</i>	2050	TCGCCGACCTGGTTGAGCCGGAGACCTGCTCGAGACCATAGCCTCCGAGCATAAGACGG	2109
<i>Epichloë festucae_AR1</i>	2011	TCGCCGACCTGGTTGAGCCGGAGACCTGCTCGAGACCATAGCCTCCGAGCATAAGACGG	2070
<i>Epichloë festucae_AR37</i>	1514	TCGCCGACCTGGTTGAGCCGGAGACCTGCTCGAGACCATAGCCTCCGAGCATAAGACGG	1573
<i>Epichloë festucae_AR48</i>	2071	CGACTTTTCATACAGGACCTCTGCGCAGTTGACGCTTCCCGCACTTTTAGCGCCCAAACCG	2130
<i>Epichloë festucae_Fg1</i>	2071	CGACTTTTCATACAGGACCTCTGCGCAGTTGACGCTTCCCGCACTTTTAGCGCCCAAACCG	2130
<i>Epichloë festucae_FI1</i>	2109	CGACTTTTCATACAGGACCTCTGCGCAGTTGACGCTTCCCGCACTTTTAGCGCCCAAACCG	2168
<i>Epichloë festucae_E2368</i>	2110	CGACTTTTCATACAGGACCTCTGCGCAGTTGACGCTTCCCGCACTTTTAGCGCCCAAACCG	2169
<i>Epichloë festucae_AR1</i>	2071	CGACTTTTCATACAGGACCTCTGCGCAGTTGACGCTTCCCGCACTTTTAGCGCCCAAACCG	2130
<i>Epichloë festucae_AR37</i>	1574	CGACTTTTCATACAGGACCTCTGCGCAGTTGACGCTTCCCGCACTTTTAGCGCCCAAACCG	1633
<i>Epichloë festucae_AR48</i>	2131	AGCTTTTGGAAATCTTGGGCTTGGGGGAGGCAGCTTGGCAGCATGCCACAGCCAGGCTGG	2190
<i>Epichloë festucae_Fg1</i>	2131	AGCTTTTGGAAATCTTGGGCTTGGGGGAGGCAGCTTGGCAGCATGCCACAGCCAGGCTGG	2190
<i>Epichloë festucae_FI1</i>	2169	AGCTTTTGGAAATCTTGGGCTTGGGGGAGGCAGCTTGGCAGCATGCCACAGCCAGGCTGG	2228
<i>Epichloë festucae_E2368</i>	2170	AGCTTTTGGAAATCTTGGGCTTGGGGGAGGCAGCTTGGCAGCATGCCACAGCCAGGCTGG	2229
<i>Epichloë festucae_AR1</i>	2131	AGCTTTTGGAAATCTTGGGCTTGGGGGAGGCAGCTTGGCAGCATGCCACAGCCAGGCTGG	2190
<i>Epichloë festucae_AR37</i>	1634	AGCTTTTGGAAATCTTGGGCTTGGGGGAGGCAGCTTGGCAGCATGCCACAGCCAGGCTGG	1693
<i>Epichloë festucae_AR48</i>	2191	AAGAAAGCACTGGTATGGGTGAGCACTGGATGCCCATCCTTGAACGATGAAGGAGGGCG	2250
<i>Epichloë festucae_Fg1</i>	2191	AAGAAAGCACTGGTATGGGTGAGCACTGGATGCCCATCCTTGAACGATGAAGGAGGGCG	2250
<i>Epichloë festucae_FI1</i>	2229	AAGAAAGCACTGGTATGGGTGAGCACTGGATGCCCATCCTTGAACGATGAAGGAGGGCG	2288
<i>Epichloë festucae_E2368</i>	2230	AAGAAAGCACTGGTATGGGTGAGCACTGGATGCCCATCCTTGAACGATGAAGGAGGGCG	2289
<i>Epichloë festucae_AR1</i>	2191	AAGAAAGCACTGGTATGGGTGAGCACTGGATGCCCATCCTTGAACGATGAAGGAGGGCG	2250
<i>Epichloë festucae_AR37</i>	1694	AAGAAAGCACTGGTATGGGTGAGCACTGGATGCCCATCCTTGAACGATGAAGGAGGGCG	1753
<i>Epichloë festucae_AR48</i>	2251	GTGAGAAAGGGTCTATGAGGTGCAATTATCAATCTTAAGAACAAGAATGAGACCAAGT	2310
<i>Epichloë festucae_Fg1</i>	2251	GTGAGAAAGGGTCTATGAGGTGCAATTATCAATCTTAAGAACAAGAATGAGACCAAGT	2310
<i>Epichloë festucae_FI1</i>	2289	GTGAGAAAGGGTCTATGAGGTGCAATTATCAATCTTAAGAACAAGAATGAGACCAAGT	2348
<i>Epichloë festucae_E2368</i>	2290	GTGAGAAAGGGTCTATGAGGTGCAATTATCAATCTTAAGAACAAGAATGAGACCAAGT	2349
<i>Epichloë festucae_AR1</i>	2251	GTGAGAAAGGGTCTATGAGGTGCAATTATCAATCTTAAGAACAAGAATGAGACCAAGT	2310
<i>Epichloë festucae_AR37</i>	1754	GTGAGAAAGGGTCTATGAGGTGCAATTATCAATCTTAAGAACAAGAATGAGACCAAGT	1813
<i>Epichloë festucae_AR48</i>	2311	GGATTAGTACGGAAGTCCCGCCATCAAAGATTTCAAGGCGCGTCTTGATGAGCACCTCG	2370
<i>Epichloë festucae_Fg1</i>	2311	GGATTAGTACGGAAGTCCCGCCATCAAAGATTTCAAGGCGCGTCTTGATGAGCACCTCG	2370
<i>Epichloë festucae_FI1</i>	2349	GGATTAGTACGGAAGTCCCGCCATCAAAGATTTCAAGGCGCGTCTTGATGAGCACCTCG	2408
<i>Epichloë festucae_E2368</i>	2350	GGATTAGTACGGAAGTCCCGCCATCAAAGATTTCAAGGCGCGTCTTGATGAGCACCTCG	2409
<i>Epichloë festucae_AR1</i>	2311	GGATTAGTACGGAAGTCCCGCCATCAAAGATTTCAAGGCGCGTCTTGATGAGCACCTCG	2370
<i>Epichloë festucae_AR37</i>	1814	GGATTAGTACGGAAGTCCCGCCATCAAAGATTTCAAGGCGCGTCTTGATGAGCACCTCG	1873
<i>Epichloë festucae_AR48</i>	2371	AGACTCTAAGCAAAACATACGAGTTCGAGTCAGGGTCTTTTATGCGGAAGGAAAACCTGG	2430
<i>Epichloë festucae_Fg1</i>	2371	AGACTCTAAGCAAAACATACGAGTTCGAGTCAGGGTCTTTTATGCGGAAGGAAAACCTGG	2430
<i>Epichloë festucae_FI1</i>	2409	AGACTCTAAGCAAAACATACGAGTTCGAGTCAGGGTCTTTTATGCGGAAGGAAAACCTGG	2468
<i>Epichloë festucae_E2368</i>	2410	AGACTCTAAGCAAAACATACGAGTTCGAGTCAGGGTCTTTTATGCGGAAGGAAAACCTGG	2469
<i>Epichloë festucae_AR1</i>	2371	AGACTCTAAGCAAAACATACGAGTTCGAGTCAGGGTCTTTTATGCGGAAGGAAAACCTGG	2430
<i>Epichloë festucae_AR37</i>	1874	AGACTCTAAGCAAAACATACGAGTTCGAGTCAGGGTCTTTTATGCGGAAGGAAAACCTGG	1933

Chapter eight: Appendices

Epichloe_festucae_AR48	2431	CGCACGCCGAAGCCATTGATGGCTTGAATGCAATGTTTATTGTGAGAACACTGATAGAGC	2490
Epichloe_festucae_Fg1	2431	CGCACGCCGAAGCCATTGATGGCTTGAATGCAATGTTTATTGTGAGAACACTGATAGAGC	2490
Epichloe_festucae_Fl1	2469	CGCACGCCGAAGCCATTGATGGCTTGAATGCAATGTTTATTGTGAGAACACTGATAGAGC	2528
Epichloe_festucae_E2368	2470	CGCACGCCGAAGCCATTGATGGCTTGAATGCAATGTTTATTGTGAGAACACTGATAGAGC	2529
Epichloe_festucae_AR1	2431	CGCACGCCGAAGCCATTGATGGCTTGAATGCAATGTTTATTGTGAGAACACTGATAGAGC	2490
Epichloe_festucae_AR37	1934	CGCACGCCGAAGCCATTGATGGCTTGAATGCAATGTTTATTGTGAGAACACTGATAGAGC	1993
Epichloe_festucae_AR48	2491	ACTTTGCCGGCAAAAAGACTGAAGAGAGCACGACCAACGCCGAGCTCGCAGACGGCTCA	2550
Epichloe_festucae_Fg1	2491	ACTTTGCCGGCAAAAAGACTGAAGAGAGCACGACCAACGCCGAGCTCGCAGACGGCTCA	2550
Epichloe_festucae_Fl1	2529	ACTTTGCCGGCAAAAAGACTGAAGAGAGCACGACCAACGCCGAGCTCGCAGACGGCTCA	2588
Epichloe_festucae_E2368	2530	ACTTTGCCGGCAAAAAGACTGAAGAGAGCACGACCAACGCCGAGCTCGCAGACGGCTCA	2589
Epichloe_festucae_AR1	2491	ACTTTGCCGGCAAAAAGACTGAAGAGAGCACGACCAACGCCGAGCTCGCAGACGGCTCA	2550
Epichloe_festucae_AR37	1994	ACTTTGCCGGCAAAAAGACTGAAGAGAGCACGACCAACGCCGAGCTCGCAGACGGCTCA	2053
Epichloe_festucae_AR48	2551	TGATACACAGCTATCTCAACCTCACCAGATTGGTCACCAGACTTTGGGTGACGTAGGGA	2610
Epichloe_festucae_Fg1	2551	TGATACACAGCTATCTCAACCTCACCAGATTGGTCACCAGACTTTGGGTGACGTAGGGA	2610
Epichloe_festucae_Fl1	2589	TGATACACAGCTATCTCAACCTCACCAGATTGGTCACCAGACTTTGGGTGACGTAGGGA	2648
Epichloe_festucae_E2368	2590	TGATACACAGCTATCTCAACCTCACCAGATTGGTCACCAGACTTTGGGTGACGTAGGGA	2649
Epichloe_festucae_AR1	2551	TGATACACAGCTATCTCAACCTCACCAGATTGGTCACCAGACTTTGGGTGACGTAGGGA	2610
Epichloe_festucae_AR37	2054	TGATACACAGCTATCTCAACCTCACCAGATTGGTCACCAGACTTTGGGTGACGTAGGGA	2113
Epichloe_festucae_AR48	2611	AGATGGTCAATCTCGTCAAGGATATGCTTGAGACGGGGCAAGTAGCCAAATCGTCGCTGT	2670
Epichloe_festucae_Fg1	2611	AGATGGTCAATCTCGTCAAGGATATGCTTGAGACGGGGCAAGTAGCCAAATCGTCGCTGT	2670
Epichloe_festucae_Fl1	2649	AGATGGTCAATCTCGTCAAGGATATGCTTGAGACGGGGCAAGTAGCCAAATCGTCGCTGT	2708
Epichloe_festucae_E2368	2650	AGATGGTCAATCTCGTCAAGGATATGCTTGAGACGGGGCAAGTAGCCAAATCGTCGCTGT	2709
Epichloe_festucae_AR1	2611	AGATGGTCAATCTCGTCAAGGATATGCTTGAGACGGGGCAAGTAGCCAAATCGTCGCTGT	2670
Epichloe_festucae_AR37	2114	AGATGGTCAATCTCGTCAAGGATATGCTTGAGACGGGGCAAGTAGCCAAATCGTCGCTGT	2173
Epichloe_festucae_AR48	2671	CAACTCTCGTCAAAGGCTTTGGTAATGCCTCAGAAGGCTTCGGCGTGCTCCTTGGCGGTG	2730
Epichloe_festucae_Fg1	2671	CAACTCTCGTCAAAGGCTTTGGTAATGCCTCAGAAGGCTTCGGCGTGCTCCTTGGCGGTG	2730
Epichloe_festucae_Fl1	2709	CAACTCTCGTCAAAGGCTTTGGTAATGCCTCAGAAGGCTTCGGCGTGCTCCTTGGCGGTG	2768
Epichloe_festucae_E2368	2710	CAACTCTCGTCAAAGGCTTTGGTAATGCCTCAGAAGGCTTCGGCGTGCTCCTTGGCGGTG	2769
Epichloe_festucae_AR1	2671	CAACTCTCGTCAAAGGCTTTGGTAATGCCTCAGAAGGCTTCGGCGTGCTCCTTGGCGGTG	2730
Epichloe_festucae_AR37	2174	CAACTCTCGTCAAAGGCTTTGGTAATGCCTCAGAAGGCTTCGGCGTGCTCCTTGGCGGTG	2233
Epichloe_festucae_AR48	2731	CAAACGTTATCCTCGACGCCTACGAGCTTGCCACACGGACAATGATGCCAGAGAGCCG	2790
Epichloe_festucae_Fg1	2731	CAAACGTTATCCTCGACGCCTACGAGCTTGCCACACGGACAATGATGCCAGAGAGCCG	2790
Epichloe_festucae_Fl1	2769	CAAACGTTATCCTCGACGCCTACGAGCTTGCCACACGGACAATGATGCCAGAGAGCCG	2828
Epichloe_festucae_E2368	2770	CAAACGTTATCCTCGACGCCTACGAGCTTGCCACACGGACAATGATGCCAGAGAGCCG	2829
Epichloe_festucae_AR1	2731	CAAACGTTATCCTCGACGCCTACGAGCTTGCCACACGGACAATGATGCCAGAGAGCCG	2790
Epichloe_festucae_AR37	2234	CAAACGTTATCCTCGACGCCTACGAGCTTGCCACACGGACAATGATGCCAGAGAGCCG	2293
Epichloe_festucae_AR48	2791	TCTTTGGCACACAGTTGGCTTTTGATTGGTCACGTTCTAGCAAGTGTTGGTACCGTTG	2850
Epichloe_festucae_Fg1	2791	TCTTTGGCACACAGTTGGCTTTTGATTGGTCACGTTCTAGCAAGTGTTGGTACCGTTG	2850
Epichloe_festucae_Fl1	2829	TCTTTGGCACACAGTTGGCTTTTGATTGGTCACGTTCTAGCAAGTGTTGGTACCGTTG	2888
Epichloe_festucae_E2368	2830	TCTTTGGCACACAGTTGGCTTTTGATTGGTCACGTTCTAGCAAGTGTTGGTACCGTTG	2889
Epichloe_festucae_AR1	2791	TCTTTGGCACACAGTTGGCTTTTGATTGGTCACGTTCTAGCAAGTGTTGGTACCGTTG	2850
Epichloe_festucae_AR37	2294	TCTTTGGCACACAGTTGGCTTTTGATTGGTCACGTTCTAGCAAGTGTTGGTACCGTTG	2353
Epichloe_festucae_AR48	2851	GTGCCGGACTCTTAGGAGCCACTACCGTCGTGCGCGTCGTGGGAGGTGTCAGTGTTATTC	2910
Epichloe_festucae_Fg1	2851	GTGCCGGACTCTTAGGAGCCACTACCGTCGTGCGCGTCGTGGGAGGTGTCAGTGTTATTC	2910
Epichloe_festucae_Fl1	2889	GTGCCGGACTCTTAGGAGCCACTACCGTCGTGCGCGTCGTGGGAGGTGTCAGTGTTATTC	2948
Epichloe_festucae_E2368	2890	GTGCCGGACTCTTAGGAGCCACTACCGTCGTGCGCGTCGTGGGAGGTGTCAGTGTTATTC	2949
Epichloe_festucae_AR1	2851	GTGCCGGACTCTTAGGAGCCACTACCGTCGTGCGCGTCGTGGGAGGTGTCAGTGTTATTC	2910
Epichloe_festucae_AR37	2354	GTGCCGGACTCTTAGGAGCCACTACCGTCGTGCGCGTCGTGGGAGGTGTCAGTGTTATTC	2413
Epichloe_festucae_AR48	2911	TGGGAGGACTTGCCCTTTGGCGTTGGCGCTCTGGCATCCGGCTTTGCACAAATTGCCGCCA	2970
Epichloe_festucae_Fg1	2911	TGGGAGGACTTGCCCTTTGGCGTTGGCGCTCTGGCATCCGGCTTTGCACAAATTGCCGCCA	2970
Epichloe_festucae_Fl1	2949	TGGGAGGACTTGCCCTTTGGCGTTGGCGCTCTGGCATCCGGCTTTGCACAAATTGCCGCCA	3008
Epichloe_festucae_E2368	2950	TGGGAGGACTTGCCCTTTGGCGTTGGCGCTCTGGCATCCGGCTTTGCACAAATTGCCGCCA	3009
Epichloe_festucae_AR1	2911	TGGGAGGACTTGCCCTTTGGCGTTGGCGCTCTGGCATCCGGCTTTGCACAAATTGCCGCCA	2970
Epichloe_festucae_AR37	2414	TGGGAGGACTTGCCCTTTGGCGTTGGCGCTCTGGCATCCGGCTTTGCACAAATTGCCGCCA	2473
Epichloe_festucae_AR48	2971	AAGCAGAGGCTGTGGGTGCGTATTTCCGTTGACGCCGACGAGGCCTACAAAGCTGGAGGAT	3030
Epichloe_festucae_Fg1	2971	AAGCAGAGGCTGTGGGTGCGTATTTCCGTTGACGCCGACGAGGCCTACAAAGCTGGAGGAT	3030
Epichloe_festucae_Fl1	3009	AAGCAGAGGCTGTGGGTGCGTATTTCCGTTGACGCCGACGAGGCCTACAAAGCTGGAGGAT	3068
Epichloe_festucae_E2368	3010	AAGCAGAGGCTGTGGGTGCGTATTTCCGTTGACGCCGACGAGGCCTACAAAGCTGGAGGAT	3069
Epichloe_festucae_AR1	2971	AAGCAGAGGCTGTGGGTGCGTATTTCCGTTGACGCCGACGAGGCCTACAAAGCTGGAGGAT	3030
Epichloe_festucae_AR37	2474	AAGCAGAGGCTGTGGGTGCGTATTTCCGTTGACGCCGACGAGGCCTACAAAGCTGGAGGAT	2533
Epichloe_festucae_AR48	3031	TCAAGTACGATGAGAACCATAAGATTCTTGTCTCTGTCTGGTGCTGTCATCAGCGAAG	3090
Epichloe_festucae_Fg1	3031	TCAAGTACGATGAGAACCATAAGATTCTTGTCTCTGTCTGGTGCTGTCATCAGCGAAG	3090
Epichloe_festucae_Fl1	3069	TCAAGTACGATGAGAACCATAAGATTCTTGTCTCTGTCTGGTGCTGTCATCAGCGAAG	3128
Epichloe_festucae_E2368	3070	TCAAGTACGATGAGAACCATAAGATTCTTGTCTCTGTCTGGTGCTGTCATCAGCGAAG	3129
Epichloe_festucae_AR1	3031	TCAAGTACGATGAGAACCATAAGATTCTTGTCTCTGTCTGGTGCTGTCATCAGCGAAG	3090
Epichloe_festucae_AR37	2534	TCAAGTACGATGAGAACCATAAGATTCTTGTCTCTGTCTGGTGCTGTCATCAGCGAAG	2593
Epichloe_festucae_AR48	3091	TCGACGGCGCCGGTAACGTCAAATTCGACAGCCAATACATCTATCGCACCTGGCACGGTG	3150
Epichloe_festucae_Fg1	3091	TCGACGGCGCCGGTAACGTCAAATTCGACAGCCAATACATCTATCGCACCTGGCACGGTG	3150
Epichloe_festucae_Fl1	3129	TCGACGGCGCCGGTAACGTCAAATTCGACAGCCAATACATCTATCGCACCTGGCACGGTG	3188
Epichloe_festucae_E2368	3130	TCGACGGCGCCGGTAACGTCAAATTCGACAGCCAATACATCTATCGCACCTGGCACGGTG	3189
Epichloe_festucae_AR1	3091	TCGACGGCGCCGGTAACGTCAAATTCGACAGCCAATACATCTATCGCACCTGGCACGGTG	3150
Epichloe_festucae_AR37	2594	TCGACGGCGCCGGTAACGTCAAATTCGACAGCCAATACATCTATCGCACCTGGCACGGTG	2653
Epichloe_festucae_AR48	3151	CCACAGGGTCGGGCAGAATCAACTACTTCTTCTGGGTGGCGACAAGCCAGAATGATCC	3210
Epichloe_festucae_Fg1	3151	CCACAGGGTCGGGCAGAATCAACTACTTCTTCTGGGTGGCGACAAGCCAGAATGATCC	3210
Epichloe_festucae_Fl1	3189	CCACAGGGTCGGGCAGAATCAACTACTTCTTCTGGGTGGCGACAAGCCAGAATGATCC	3248
Epichloe_festucae_E2368	3190	CCACAGGGTCGGGCAGAATCAACTACTTCTTCTGGGTGGCGACAAGCCAGAATGATCC	3249
Epichloe_festucae_AR1	3151	CCACAGGGTCGGGCAGAATCAACTACTTCTTCTGGGTGGCGACAAGCCAGAATGATCC	3210
Epichloe_festucae_AR37	2654	CCACAGGGTCGGGCAGAATCAACTACTTCTTCTGGGTGGCGACAAGCCAGAATGATCC	2713
Epichloe_festucae_AR48	3211	ACGATAAGTCCCAGGCTATTAATGTGCGAGAAGGCATTGAGCCCCGGCCAGCGGAAAAAC	3270
Epichloe_festucae_Fg1	3211	ACGATAAGTCCCAGGCTATTAATGTGCGAGAAGGCATTGAGCCCCGGCCAGCGGAAAAAC	3270
Epichloe_festucae_Fl1	3249	ACGATAAGTCCCAGGCTATTAATGTGCGAGAAGGCATTGAGCCCCGGCCAGCGGAAAAAC	3308
Epichloe_festucae_E2368	3250	ACGATAAGTCCCAGGCTATTAATGTGCGAGAAGGCATTGAGCCCCGGCCAGCGGAAAAAC	3309
Epichloe_festucae_AR1	3211	ACGATAAGTCCCAGGCTATTAATGTGCGAGAAGGCATTGAGCCCCGGCCAGCGGAAAAAC	3270
Epichloe_festucae_AR37	2714	ACGATAAGTCCCAGGCTATTAATGTGCGAGAAGGCATTGAGCCCCGGCCAGCGGAAAAAC	2773

Chapter eight: Appendices

Epichloë_festucae_AR48	3271	TTACGAATACTCGAGACTACACCGCAATCATCTCCCCGCCACGCCAAATCATACATCA	3330
Epichloë_festucae_Fg1	3271	TTACGAATACTCGAGACTACACCGCAATCATCTCCCCGCCACGCCAAATCATACATCA	3330
Epichloë_festucae_FI1	3309	TTACGAATACTCGAGACTACACCGCAATCATCTCCCCGCCACGCCAAATCATACATCA	3368
Epichloë_festucae_E2368	3310	TTACGAATACTCGAGACTACACCGCAATCATCTCCCCGCCACGCCAAATCATACATCA	3369
Epichloë_festucae_AR1	3271	TTACGAATACTCGAGACTACACCGCAATCATCTCCCCGCCACGCCAAATCATACATCA	3330
Epichloë_festucae_AR37	2774	TTACGAATACTCGAGACTACACCGCAATCATCTCCCCGCCACGCCAAATCATACATCA	2833
Epichloë_festucae_AR48	3331	GCTACGAATGGCAAATCCTTCCGTTCTGTACAGGCCGACATGACTACGGCTTCGATGTGA	3390
Epichloë_festucae_Fg1	3331	GCTACGAATGGCAAATCCTTCCGTTCTGTACAGGCCGACATGACTACGGCTTCGATGTGA	3390
Epichloë_festucae_FI1	3369	GCTACGAATGGCAAATCCTTCCGTTCTGTACAGGCCGACATGACTACGGCTTCGATGTGA	3428
Epichloë_festucae_E2368	3370	GCTACGAATGGCAAATCCTTCCGTTCTGTACAGGCCGACATGACTACGGCTTCGATGTGA	3429
Epichloë_festucae_AR1	3331	GCTACGAATGGCAAATCCTTCCGTTCTGTACAGGCCGACATGACTACGGCTTCGATGTGA	3390
Epichloë_festucae_AR37	2834	GCTACGAATGGCAAATCCTTCCGTTCTGTACAGGCCGACATGACTACGGCTTCGATGTGA	2893
Epichloë_festucae_AR48	3391	TCCGGAGACTTGAAGAAGACAGAGCGATTGCACTATGACTTTTACATCTTCCCTAGTGAAT	3450
Epichloë_festucae_Fg1	3391	TCCGGAGACTTGAAGAAGACAGAGCGATTGCACTATGACTTTTACATCTTCCCTAGTGAAT	3450
Epichloë_festucae_FI1	3429	TCCGGAGACTTGAAGAAGACAGAGCGATTGCACTATGACTTTTACATCTTCCCTAGTGAAT	3488
Epichloë_festucae_E2368	3430	TCCGGAGACTTGAAGAAGACAGAGCGATTGCACTATGACTTTTACATCTTCCCTAGTGAAT	3489
Epichloë_festucae_AR1	3391	TCCGGAGACTTGAAGAAGACAGAGCGATTGCACTATGACTTTTACATCTTCCCTAGTGAAT	3450
Epichloë_festucae_AR37	2894	TCCGGAGACTTGAAGAAGACAGAGCGATTGCACTATGACTTTTACATCTTCCCTAGTGAAT	2953
Epichloë_festucae_AR48	3451	ACATCATTCACAAAATCACACACGAGTTTGTGAGAACACCCATTGCGGTTCAGGCTCGACC	3510
Epichloë_festucae_Fg1	3451	ACATCATTCACAAAATCACACACGAGTTTGTGAGAACACCCATTGCGGTTCAGGCTCGACC	3510
Epichloë_festucae_FI1	3489	ACATCATTCACAAAATCACACACGAGTTTGTGAGAACACCCATTGCGGTTCAGGCTCGACC	3548
Epichloë_festucae_E2368	3490	ACATCATTCACAAAATCACACACGAGTTTGTGAGAACACCCATTGCGGTTCAGGCTCGACC	3549
Epichloë_festucae_AR1	3451	ACATCATTCACAAAATCACACACGAGTTTGTGAGAACACCCATTGCGGTTCAGGCTCGACC	3510
Epichloë_festucae_AR37	2954	ACATCATTCACAAAATCACACACGAGTTTGTGAGAACACCCATTGCGGTTCAGGCTCGACC	3013
Epichloë_festucae_AR48	3511	GTCCGGTCAGTGCAGATTCAAGTCGCAGAGCTGGATGAGAGCCTACACAAATGTCTCGAAT	3570
Epichloë_festucae_Fg1	3511	GTCCGGTCAGTGCAGATTCAAGTCGCAGAGCTGGATGAGAGCCTACACAAATGTCTCGAAT	3570
Epichloë_festucae_FI1	3549	GTCCGGTCAGTGCAGATTCAAGTCGCAGAGCTGGATGAGAGCCTACACAAATGTCTCGAAT	3608
Epichloë_festucae_E2368	3550	GTCCGGTCAGTGCAGATTCAAGTCGCAGAGCTGGATGAGAGCCTACACAAATGTCTCGAAT	3609
Epichloë_festucae_AR1	3511	GTCCGGTCAGTGCAGATTCAAGTCGCAGAGCTGGATGAGAGCCTACACAAATGTCTCGAAT	3570
Epichloë_festucae_AR37	3014	GTCCGGTCAGTGCAGATTCAAGTCGCAGAGCTGGATGAGAGCCTACACAAATGTCTCGAAT	3073
Epichloë_festucae_AR48	3571	ACACCATATATGGCGCAGGAGCCAATTACACCATCGGGCTCAATCCTGGCGTGGCCATGA	3630
Epichloë_festucae_Fg1	3571	ACACCATATATGGCGCAGGAGCCAATTACACCATCGGGCTCAATCCTGGCGTGGCCATGA	3630
Epichloë_festucae_FI1	3609	ACACCATATATGGCGCAGGAGCCAATTACACCATCGGGCTCAATCCTGGCGTGGCCATGA	3668
Epichloë_festucae_E2368	3610	ACACCATATATGGCGCAGGAGCCAATTACACCATCGGGCTCAATCCTGGCGTGGCCATGA	3669
Epichloë_festucae_AR1	3571	ACACCATATATGGCGCAGGAGCCAATTACACCATCGGGCTCAATCCTGGCGTGGCCATGA	3630
Epichloë_festucae_AR37	3074	ACACCATATATGGCGCAGGAGCCAATTACACCATCGGGCTCAATCCTGGCGTGGCCATGA	3133
Epichloë_festucae_AR48	3631	CGTTGTCTTTCGGGCTGGAGCAGCACATGTTGGGTTTTGGACTGCGGAAAGTTGGACGGGG	3690
Epichloë_festucae_Fg1	3631	CGTTGTCTTTCGGGCTGGAGCAGCACATGTTGGGTTTTGGACTGCGGAAAGTTGGACGGGG	3690
Epichloë_festucae_FI1	3669	CGTTGTCTTTCGGGCTGGAGCAGCACATGTTGGGTTTTGGACTGCGGAAAGTTGGACGGGG	3728
Epichloë_festucae_E2368	3670	CGTTGTCTTTCGGGCTGGAGCAGCACATGTTGGGTTTTGGACTGCGGAAAGTTGGACGGGG	3729
Epichloë_festucae_AR1	3631	CGTTGTCTTTCGGGCTGGAGCAGCACATGTTGGGTTTTGGACTGCGGAAAGTTGGACGGGG	3690
Epichloë_festucae_AR37	3134	CGTTGTCTTTCGGGCTGGAGCAGCACATGTTGGGTTTTGGACTGCGGAAAGTTGGACGGGG	3193
Epichloë_festucae_AR48	3691	AGAACATCGTGATTGAGGCCCGGGCCGCTCAATCTCAGGTTTTCCGGGTGAACCTGGCAG	3750
Epichloë_festucae_Fg1	3691	AGAACATCGTGATTGAGGCCCGGGCCGCTCAATCTCAGGTTTTCCGGGTGAACCTGGCAG	3750
Epichloë_festucae_FI1	3729	AGAACATCGTGATTGAGGCCCGGGCCGCTCAATCTCAGGTTTTCCGGGTGAACCTGGCAG	3788
Epichloë_festucae_E2368	3730	AGAACATCGTGATTGAGGCCCGGGCCGCTCAATCTCAGGTTTTCCGGGTGAACCTGGCAG	3789
Epichloë_festucae_AR1	3691	AGAACATCGTGATTGAGGCCCGGGCCGCTCAATCTCAGGTTTTCCGGGTGAACCTGGCAG	3750
Epichloë_festucae_AR37	3194	AGAACATCGTGATTGAGGCCCGGGCCGCTCAATCTCAGGTTTTCCGGGTGAACCTGGCAG	3253
Epichloë_festucae_AR48	3751	ACACCTTATTTCGAGTCCATGCTCATCTGCAAACCCAACGGCGAGATCCTACAAGTGGACT	3810
Epichloë_festucae_Fg1	3751	ACACCTTATTTCGAGTCCATGCTCATCTGCAAACCCAACGGCGAGATCCTACAAGTGGACT	3810
Epichloë_festucae_FI1	3789	ACACCTTATTTCGAGTCCATGCTCATCTGCAAACCCAACGGCGAGATCCTACAAGTGGACT	3848
Epichloë_festucae_E2368	3790	ACACCTTATTTCGAGTCCATGCTCATCTGCAAACCCAACGGCGAGATCCTACAAGTGGACT	3849
Epichloë_festucae_AR1	3751	ACACCTTATTTCGAGTCCATGCTCATCTGCAAACCCAACGGCGAGATCCTACAAGTGGACT	3810
Epichloë_festucae_AR37	3254	ACACCTTATTTCGAGTCCATGCTCATCTGCAAACCCAACGGCGAGATCCTACAAGTGGACT	3313
Epichloë_festucae_AR48	3811	TTCCCAATAGAACCACCTTTCCCCATAAAGGAAGATGGTGACAGGTACCAGGGAGGAAGCC	3870
Epichloë_festucae_Fg1	3811	TTCCCAATAGAACCACCTTTCCCCATAAAGGAAGATGGTGACAGGTACCAGGGAGGAAGCC	3870
Epichloë_festucae_FI1	3849	TTCCCAATAGAACCACCTTTCCCCATAAAGGAAGATGGTGACAGGTACCAGGGAGGAAGCC	3908
Epichloë_festucae_E2368	3850	TTCCCAATAGAACCACCTTTCCCCATAAAGGAAGATGGTGACAGGTACCAGGGAGGAAGCC	3909
Epichloë_festucae_AR1	3811	TTCCCAATAGAACCACCTTTCCCCATAAAGGAAGATGGTGACAGGTACCAGGGAGGAAGCC	3870
Epichloë_festucae_AR37	3314	TTCCCAATAGAACCACCTTTCCCCATAAAGGAAGATGGTGATAGGTACCAGGGAGGAAGCC	3373
Epichloë_festucae_AR48	3871	AGAAACTCACAGAGCATCTCAACGATTTGAGCGACAAGCACCTGCTTGGCACCAGGCTCA	3930
Epichloë_festucae_Fg1	3871	AGAAACTCACAGAGCATCTCAACGATTTGAGCGACAAGCACCTGCTTGGCACCAGGCTCA	3930
Epichloë_festucae_FI1	3909	AGAAACTCACAGAGCATCTCAACGATTTGAGCGACAAGCACCTGCTTGGCACCAGGCTCA	3968
Epichloë_festucae_E2368	3910	AGAAACTCACAGAGCATCTCAACGATTTGAGCGACAAGCACCTGCTTGGCACCAGGCTCA	3969
Epichloë_festucae_AR1	3871	AGAAACTCACAGAGCATCTCAACGATTTGAGCGACAAGCACCTGCTTGGCACCAGGCTCA	3930
Epichloë_festucae_AR37	3374	AGAAACTCACAGAGCATCTCAACGATTTGAGCGACAAGCACCTGCTTGGCACCAGGCTCA	3433
Epichloë_festucae_AR48	3931	TCATCGTGGACAAGTATACAACGCCCGCTGGCCAGTCTGTTGGTCCGGCTTCTACGAAC	3990
Epichloë_festucae_Fg1	3931	TCATCGTGGACAAGTATACAACGCCCGCTGGCCAGTCTGTTGGTCCGGCTTCTACGAAC	3990
Epichloë_festucae_FI1	3969	TCATCGTGGACAAGTATACAACGCCCGCTGGCCAGTCTGTTGGTCCGGCTTCTACGAAC	4028
Epichloë_festucae_E2368	3970	TCATCGTGGACAAGTATACAACGCCCGCTGGCCAGTCTGTTGGTCCGGCTTCTACGAAC	4029
Epichloë_festucae_AR1	3931	TCATCGTGGACAAGTATACAACGCCCGCTGGCCAGTCTGTTGGTCCGGCTTCTACGAAC	3990
Epichloë_festucae_AR37	3434	TCATCGTGGACAAGTATACAACGCCCGCTGGCCAGTCTGTTGGTCCGGCTTCTACGAAC	3493
Epichloë_festucae_AR48	3991	CGACGAGCAAACGCTCTTCTCTACACCGTCGATGCTCCTGAAGAATTGACCAACAGTGCCG	4050
Epichloë_festucae_Fg1	3991	CGACGAGCAAACGCTCTTCTCTACACCGTCGATGCTCCTGAAGAATTGACCAACAGTGCCG	4050
Epichloë_festucae_FI1	4029	CGACGAGCAAACGCTCTTCTCTACACCGTCGATGCTCCTGAAGAATTGACCAACAGTGCCG	4088
Epichloë_festucae_E2368	4030	CGACGAGCAAACGCTCTTCTCTACACCGTCGATGCTCCTGAAGAATTGACCAACAGTGCCG	4089
Epichloë_festucae_AR1	3991	CGACGAGCAAACGCTCTTCTCTACACCGTCGATGCTCCTGAAGAATTGACCAACAGTGCCG	4050
Epichloë_festucae_AR37	3494	CGACGAGCAAACGCTCTTCTCTACACCGTCGATGCTCCTGAAGAATTGACCAACAGTGCCG	3553
Epichloë_festucae_AR48	4051	AGGTTGGTGCCCTGACTGCTGGTGAAAAAGTCTTCTTCTACAATACAGAGCATAGTGCCA	4110
Epichloë_festucae_Fg1	4051	AGGTTGGTGCCCTGACTGCTGGTGAAAAAGTCTTCTTCTACAATACAGAGCATAGTGCCA	4110
Epichloë_festucae_FI1	4089	AGGTTGGTGCCCTGACTGCTGGTGAAAAAGTCTTCTTCTACAATACAGAGCATAGTGCCA	4148
Epichloë_festucae_E2368	4090	AGGTTGGTGCCCTGACTGCTGGTGAAAAAGTCTTCTTCTACAATACAGAGCATAGTGCCA	4149
Epichloë_festucae_AR1	4051	AGGTTGGTGCCCTGACTGCTGGTGAAAAAGTCTTCTTCTACAATACAGAGCATAGTGCCA	4110
Epichloë_festucae_AR37	3554	AGGTTGGTGCCCTGACTGCTGGTGAAAAAGTCTTCTTCTACAATACAGAGCATAGTGCCA	3613

Chapter eight: Appendices

Epichloë_festucae_AR48	4111	TCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAAGCAAAGTACCATGCCCTATGCCCGT	4170
Epichloë_festucae_Fg1	4111	TCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAAGCAAAGTACCATGCCCTATGCCCGT	4170
Epichloë_festucae_F11	4149	TCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAAGCAAAGTACCATGCCCTATGCCCGT	4208
Epichloë_festucae_E2368	4150	TCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAAGCAAAGTACCATGCCCTATGCCCGT	4209
Epichloë_festucae_AR1	4111	TCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAAGCAAAGTACCATGCCCTATGCCCGT	4170
Epichloë_festucae_AR37	3614	TCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAAGCAAAGTACCATGCCCTATGCCCGT	3673
Epichloë_festucae_AR48	4171	TTTCTAAAAGAACCCTTCAACGCGTCTGGGTAGATGGTAGGTGGAATTATTTTCATACAAG	4230
Epichloë_festucae_Fg1	4171	TTTCTAAAAGAACCCTTCAACGCGTCTGGGTAGATGGTAGGTGGAATTATTTTCATACAAG	4230
Epichloë_festucae_F11	4209	TTTCTAAAAGAACCCTTCAACGCGTCTGGGTAGATGGTAGGTGGAATTATTTTCATACAAG	4268
Epichloë_festucae_E2368	4210	TTTCTAAAAGAACCCTTCAACGCGTCTGGGTAGATGGTAGGTGGAATTATTTTCATACAAG	4269
Epichloë_festucae_AR1	4171	TTTCTAAAAGAACCCTTCAACGCGTCTGGGTAGATGGTAGGTGGAATTATTTTCATACAAG	4230
Epichloë_festucae_AR37	3674	TTTCTAAAAGAACCCTTCAACGCGTCTGGGTAGATGGTAGGTGGAATTATTTTCATACAAG	3733
Epichloë_festucae_AR48	4231	TAGCGTACCTGTACCTCTGTCACTAATTGTTTATCCAGTGGACAATCAGATTACCGCTCT	4290
Epichloë_festucae_Fg1	4231	TAGCGTACCTGTACCTCTGTCACTAATTGTTTATCCAGTGGACAATCAGATTACCGCTCT	4290
Epichloë_festucae_F11	4269	TAGCGTACCTGTACCTCTGTCACTAATTGTTTATCCAGTGGACAATCAGATTACCGCTCT	4328
Epichloë_festucae_E2368	4270	TAGCGTACCTGTACCTCTGTCACTAATTGTTTATCCAGTGGACAATCAGATTACCGCTCT	4329
Epichloë_festucae_AR1	4231	TAGCGTACCTGTACCTCTGTCACTAATTGTTTATCCAGTGGACAATCAGATTACCGCTCT	4290
Epichloë_festucae_AR37	3734	TAGCGTACCTGTACCTCTGTCACTAATTGTTTATCCAGTGGACAATCAGATTACCGCTCT	3793
Epichloë_festucae_AR48	4291	TTTCCGCCACCAGTTGAGCGAGGATTATTTTCGGAACCTCTCAACTATATCCTCACC GCCGA	4350
Epichloë_festucae_Fg1	4291	TTTCCGCCACCAGTTGAGCGAGGATTATTTTCGGAACCTCTCAACTATATCCTCACC GCCGA	4350
Epichloë_festucae_F11	4329	TTTCCGCCACCAGTTGAGCGAGGATTATTTTCGGAACCTCTCAACTATATCCTCACC GCCGA	4388
Epichloë_festucae_E2368	4330	TTTCCGCCACCAGTTGAGCGAGGATTATTTTCGGAACCTCTCAACTATATCCTCACC GCCGA	4389
Epichloë_festucae_AR1	4291	TTTCCGCCACCAGTTGAGCGAGGATTATTTTCGGAACCTCTCAACTATATCCTCACC GCCGA	4350
Epichloë_festucae_AR37	3794	TTTCCGCCACCAGTTGAGCGAGGATTATTTTCGGAACCTCTCAACTATATCCTCACC GCCGA	3853
Epichloë_festucae_AR48	4351	TAGCATGAACCTCGTTGCCATGGTTGGAGGCCCTGCCTTGCTTGCCAAGCTCCATGAAGA	4410
Epichloë_festucae_Fg1	4351	TAGCATGAACCTCGTTGCCATGGTTGGAGGCCCTGCCTTGCTTGCCAAGCTCCATGAAGA	4410
Epichloë_festucae_F11	4389	TAGCATGAACCTCGTTGCCATGGTTGGAGGCCCTGCCTTGCTTGCCAAGCTCCATGAAGA	4448
Epichloë_festucae_E2368	4390	TAGCATGAACCTCGTTGCCATGGTTGGAGGCCCTGCCTTGCTTGCCAAGCTCCATGAAGA	4449
Epichloë_festucae_AR1	4351	TAGCATGAACCTCGTTGCCATGGTTGGAGGCCCTGCCTTGCTTGCCAAGCTCCATGAAGA	4410
Epichloë_festucae_AR37	3854	TAGCATGAACCTCGTTGCCATGGTTGGAGGCCCTGCCTTGCTTGCCAAGCTCCATGAAGA	3913
Epichloë_festucae_AR48	4411	AGACAAGTGGACAGGCGAGGCTACACTTCTACTGGAAGACTACTACACTGGGCCGAGCGA	4470
Epichloë_festucae_Fg1	4411	AGACAAGTGGACAGGCGAGGCTACACTTCTACTGGAAGACTACTACACTGGGCCGAGCGA	4470
Epichloë_festucae_F11	4449	AGACAAGTGGACAGGCGAGGCTACACTTCTACTGGAAGACTACTACACTGGGCCGAGCGA	4508
Epichloë_festucae_E2368	4450	AGACAAGTGGACAGGCGAGGCTACACTTCTACTGGAAGACTACTACACTGGGCCGAGCGA	4509
Epichloë_festucae_AR1	4411	AGACAAGTGGACAGGCGAGGCTACACTTCTACTGGAAGACTACTACACTGGGCCGAGCGA	4470
Epichloë_festucae_AR37	3914	AGACAAGTGGACAGGCGAGGCTACACTTCTACTGGAAGACTACTACACTGGGCCGAGCGA	3973
Epichloë_festucae_AR48	4471	GCTTATGCTCAAGCTCAAGCCATTGGAAGCCCTAGCTGGAGCCGATATCGATGCGGCCAT	4530
Epichloë_festucae_Fg1	4471	GCTTATGCTCAAGCTCAAGCCATTGGAAGCCCTAGCTGGAGCCGATATCGATGCGGCCAT	4530
Epichloë_festucae_F11	4509	GCTTATGCTCAAGCTCAAGCCATTGGAAGCCCTAGCTGGAGCCGATATCGATGCGGCCAT	4568
Epichloë_festucae_E2368	4510	GCTTATGCTCAAGCTCAAGCCATTGGAAGCCCTAGCTGGAGCCGATATCGATGCGGCCAT	4569
Epichloë_festucae_AR1	4471	GCTTATGCTCAAGCTCAAGCCATTGGAAGCCCTAGCTGGAGCCGATATCGATGCGGCCAT	4530
Epichloë_festucae_AR37	3974	GCTTATGCTCAAGCTCAAGCCATTGGAAGCCCTAGCTGGAGCCGATATCGATGCGGCCAT	4033
Epichloë_festucae_AR48	4531	AGATCCTCATTTGATTTTTGTGCTGGGACCCAAAGGCAAAGATCGTTACTTTTACCATCA	4590
Epichloë_festucae_Fg1	4531	AGATCCTCATTTGATTTTTGTGCTGGGACCCAAAGGCAAAGATCGTTACTTTTACCATCA	4590
Epichloë_festucae_F11	4569	AGATCCTCATTTGATTTTTGTGCTGGGACCCAAAGGCAAAGATCGTTACTTTTACCATCA	4628
Epichloë_festucae_E2368	4570	AGATCCTCATTTGATTTTTGTGCTGGGACCCAAAGGCAAAGATCGTTACTTTTACCATCA	4629
Epichloë_festucae_AR1	4531	AGATCCTCATTTGATTTTTGTGCTGGGACCCAAAGGCAAAGATCGTTACTTTTACCATCA	4590
Epichloë_festucae_AR37	4034	AGATCCTCATTTGATTTTTGTGCTGGGACCCAAAGGCAAAGATCGTTACTTTTACCATCA	4093
Epichloë_festucae_AR48	4591	ATTCTGGATACGAATGTCGACCGAACTGTTATCAAACCTCATCCTGACATTACACCTTAA	4650
Epichloë_festucae_Fg1	4591	ATTCTGGATACGAATGTCGACCGAACTGTTATCAAACCTCATCCTGACATTACACCTTAA	4650
Epichloë_festucae_F11	4629	ATTCTGGATACGAATGTCGACCGAACTGTTATCAAACCTCATCCTGACATTACACCTTAA	4688
Epichloë_festucae_E2368	4630	ATTCTGGATACGAATGTCGACCGAACTGTTATCAAACCTCATCCTGACATTACACCTTAA	4689
Epichloë_festucae_AR1	4591	ATTCTGGATACGAATGTCGACCGAACTGTTATCAAACCTCATCCTGACATTACACCTTAA	4650
Epichloë_festucae_AR37	4094	ATTCTGGATACGAATGTCGACCGAACTGTTATCAAACCTCATCCTGACATTACACCTTAA	4153
Epichloë_festucae_AR48	4651	TTACCTGCTTGTGCGGAACCATTGCTTCGACAGATGGCAGTGGTGAAGTGTGTTTGCTTCTT	4710
Epichloë_festucae_Fg1	4651	TTACCTGCTTGTGCGGAACCATTGCTTCGACAGATGGCAGTGGTGAAGTGTGTTTGCTTCTT	4710
Epichloë_festucae_F11	4689	TTACCTGCTTGTGCGGAACCATTGCTTCGACAGATGGCAGTGGTGAAGTGTGTTTGCTTCTT	4748
Epichloë_festucae_E2368	4690	TTACCTGCTTGTGCGGAACCATTGCTTCGACAGATGGCAGTGGTGAAGTGTGTTTGCTTCTT	4749
Epichloë_festucae_AR1	4651	TTACCTGCTTGTGCGGAACCATTGCTTCGACAGATGGCAGTGGTGAAGTGTGTTTGCTTCTT	4710
Epichloë_festucae_AR37	4154	TTACCTGCTTGTGCGGAACCATTGCTTCGACAGATGGCAGTGGTGAAGTGTGTTTGCTTCTT	4213
Epichloë_festucae_AR48	4711	CTCATACAATCAACACAAGCTCGTCGTCCAACGAGGAAACGGCAAACAGGCAGAGAAGACC	4770
Epichloë_festucae_Fg1	4711	CTCATACAATCAACACAAGCTCGTCGTCCAACGAGGAAACGGCAAACAGGCAGAGAAGACC	4770
Epichloë_festucae_F11	4749	CTCATACAATCAACACAAGCTCGTCGTCCAACGAGGAAACGGCAAACAGGCAGAGAAGACC	4808
Epichloë_festucae_E2368	4750	CTCATACAATCAACACAAGCTCGTCGTCCAACGAGGAAACGGCAAACAGGCAGAGAAGACC	4809
Epichloë_festucae_AR1	4711	CTCATACAATCAACACAAGCTCGTCGTCCAACGAGGAAACGGCAAACAGGCAGAGAAGACC	4770
Epichloë_festucae_AR37	4214	CTCATACAATCAACACAAGCTCGTCGTCCAACGAGGAAACGGCAAACAGGCAGAGAAGACC	4273
Epichloë_festucae_AR48	4771	AAGGCCTGTCACAATTTCCCCCGAGCTCGGAACCATCTCAAACCTCTTCTGCGCCAACAA	4830
Epichloë_festucae_Fg1	4771	AAGGCCTGTCACAATTTCCCCCGAGCTCGGAACCATCTCAAACCTCTTCTGCGCCAACAA	4830
Epichloë_festucae_F11	4809	AAGGCCTGTCACAATTTCCCCCGAGCTCGGAACCATCTCAAACCTCTTCTGCGCCAACAA	4868
Epichloë_festucae_E2368	4810	AAGGCCTGTCACAATTTCCCCCGAGCTCGGAACCATCTCAAACCTCTTCTGCGCCAACAA	4869
Epichloë_festucae_AR1	4771	AAGGCCTGTCACAATTTCCCCCGAGCTCGGAACCATCTCAAACCTCTTCTGCGCCAACAA	4830
Epichloë_festucae_AR37	4274	AAGGCCTGTCACAATTTCCCCCGAGCTCGGAACCATCTCAAACCTCTTCTGCGCCAACAA	4333
Epichloë_festucae_AR48	4831	TAACTTGTTTTCCATTACGAATGCGGGTTTCATTCTCCGCTTGACAAGCCACTGTACACT	4890
Epichloë_festucae_Fg1	4831	TAACTTGTTTTCCATTACGAATGCGGGTTTCATTCTCCGCTTGACAAGCCACTGTACACT	4890
Epichloë_festucae_F11	4869	TAACTTGTTTTCCATTACGAATGCGGGTTTCATTCTCCGCTTGACAAGCCACTGTACACT	4928
Epichloë_festucae_E2368	4870	TAACTTGTTTTCCATTACGAATGCGGGTTTCATTCTCCGCTTGACAAGCCACTGTACACT	4929
Epichloë_festucae_AR1	4831	TAACTTGTTTTCCATTACGAATGCGGGTTTCATTCTCCGCTTGACAAGCCACTGTACACT	4890
Epichloë_festucae_AR37	4334	TAACTTGTTTTCCATTACGAATGCGGGTTTCATTCTCCGCTTGACAAGCCACTGTACACT	4393
Epichloë_festucae_AR48	4891	CGCTCTGGAAGCCGTCAACCATCAGTGGCTCGAGCACTACGAAAAGGACGTAGACGGCGG	4950
Epichloë_festucae_Fg1	4891	CGCTCTGGAAGCCGTCAACCATCAGTGGCTCGAGCACTACGAAAAGGACGTAGACGGCGG	4950
Epichloë_festucae_F11	4929	CGCTCTGGAAGCCGTCAACCATCAGTGGCTCGAGCACTACGAAAAGGACGTAGACGGCGG	4988
Epichloë_festucae_E2368	4930	CGCTCTGGAAGCCGTCAACCATCAGTGGCTCGAGCACTACGAAAAGGACGTAGACGGCGG	4989
Epichloë_festucae_AR1	4891	CGCTCTGGAAGCCGTCAACCATCAGTGGCTCGAGCACTACGAAAAGGACGTAGACGGCGG	4950
Epichloë_festucae_AR37	4394	CGCTCTGGAAGCCGTCAACCATCAGTGGCTCGAGCACTACGAAAAGGACGTAGACGGCGG	4453

Chapter eight: Appendices

Epichloë_festucae_AR48	4951	CCCTGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCCGACGAATTGTCTCCAT	5010
Epichloë_festucae_Fg1	4951	CCCTGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCCGACGAATTGTCTCCAT	5010
Epichloë_festucae_FI1	4989	CCCTGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCCGACGAATTGTCTCCAT	5048
Epichloë_festucae_E2368	4990	CCCTGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCCGACGAATTGTCTCCAT	5049
Epichloë_festucae_AR1	4951	CCCTGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCCGACGAATTGTCTCCAT	5010
Epichloë_festucae_AR37	4454	CCCTGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCCGACGAATTGTCTCCAT	4513
Epichloë_festucae_AR48	5011	AGTTGGCCTTCGCGATGCCGAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTGACCGATT	5070
Epichloë_festucae_Fg1	5011	AGTTGGCCTTCGCGATGCCGAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTGACCGATT	5070
Epichloë_festucae_FI1	5049	AGTTGGCCTTCGCGATGCCGAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTGACCGATT	5108
Epichloë_festucae_E2368	5050	AGTTGGCCTTCGCGATGCCGAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTGACCGATT	5109
Epichloë_festucae_AR1	5011	AGTTGGCCTTCGCGATGCCGAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTGACCGATT	5070
Epichloë_festucae_AR37	4514	AGTTGGCCTTCGCGATGCCGAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTGACCGATT	4573
Epichloë_festucae_AR48	5071	TGTCGTTGCAGGACCCTCTCTACGTGGAAAACCGCGGCACATGGCAGGACTGACAGAAGG	5130
Epichloë_festucae_Fg1	5071	TGTCGTTGCAGGACCCTCTCTACGTGGAAAACCGCGGCACATGGCAGGACTGACAGAAGG	5130
Epichloë_festucae_FI1	5109	TGTCGTTGCAGGACCCTCTCTACGTGGAAAACCGCGGCACATGGCAGGACTGACAGAAGG	5168
Epichloë_festucae_E2368	5110	TGTCGTTGCAGGACCCTCTCTACGTGGAAAACCGCGGCACATGGCAGGACTGACAGAAGG	5169
Epichloë_festucae_AR1	5071	TGTCGTTGCAGGACCCTCTCTACGTGGAAAACCGCGGCACATGGCAGGACTGACAGAAGG	5130
Epichloë_festucae_AR37	4574	TGTCGTTGCAGGACCCTCTCTACGTGGAAAACCGCGGCACATGGCAGGACTGACAGAAGG	4633
Epichloë_festucae_AR48	5131	GGGATCCAAGGCTTGGCTGTGGCACATCGAGTCGGAAGACAGCGGCCACGTTTACGCTCA	5190
Epichloë_festucae_Fg1	5131	GGGATCCAAGGCTTGGCTGTGGCACATCGAGTCGGAAGACAGCGGCCACGTTTACGCTCA	5190
Epichloë_festucae_FI1	5169	GGGATCCAAGGCTTGGCTGTGGCACATCGAGTCGGAAGACAGCGGCCACGTTTACGCTCA	5228
Epichloë_festucae_E2368	5170	GGGATCCAAGGCTTGGCTGTGGCACATCGAGTCGGAAGACAGCGGCCACGTTTACGCTCA	5229
Epichloë_festucae_AR1	5131	GGGATCCAAGGCTTGGCTGTGGCACATCGAGTCGGAAGACAGCGGCCACGTTTACGCTCA	5190
Epichloë_festucae_AR37	4634	GGGATCCAAGGCTTGGCTGTGGCACATCGAGTCGGAAGACAGCGGCCACGTTTACGCTCA	4693
Epichloë_festucae_AR48	5191	GCCTACTGTACGGCGCAAGGAACCTCGAGACTGATTTTAGTCCCAAGGCTCCATTCTGTC	5250
Epichloë_festucae_Fg1	5191	GCCTACTGTACGGCGCAAGGAACCTCGAGACTGATTTTAGTCCCAAGGCTCCATTCTGTC	5250
Epichloë_festucae_FI1	5229	GCCTACTGTACGGCGCAAGGAACCTCGAGACTGATTTTAGTCCCAAGGCTCCATTCTGTC	5288
Epichloë_festucae_E2368	5230	GCCTACTGTACGGCGCAAGGAACCTCGAGACTGATTTTAGTCCCAAGGCTCCATTCTGTC	5289
Epichloë_festucae_AR1	5191	GCCTACTGTACGGCGCAAGGAACCTCGAGACTGATTTTAGTCCCAAGGCTCCATTCTGTC	5250
Epichloë_festucae_AR37	4694	GCCTACTGTACGGCGCAAGGAACCTCGAGACTGATTTTAGTCCCAAGGCTCCATTCTGTC	4753
Epichloë_festucae_AR48	5251	AGCTGAAGCCGTGCCAGATGGTCTGGCGTGCTCGTAGAGCACCATTCAAGACAGTAGG	5310
Epichloë_festucae_Fg1	5251	AGCTGAAGCCGTGCCAGATGGTCTGGCGTGCTCGTAGAGCACCATTCAAGACAGTAGG	5310
Epichloë_festucae_FI1	5289	AGCTGAAGCCGTGCCAGATGGTCTGGCGTGCTCGTAGAGCACCATTCAAGACAGTAGG	5348
Epichloë_festucae_E2368	5290	AGCTGAAGCCGTGCCAGATGGTCTGGCGTGCTCGTAGAGCACCATTCAAGACAGTAGG	5349
Epichloë_festucae_AR1	5251	AGCTGAAGCCGTGCCAGATGGTCTGGCGTGCTCGTAGAGCACCATTCAAGACAGTAGG	5310
Epichloë_festucae_AR37	4754	AGCTGAAGCCGTGCCAGATGGTCTGGCGTGCTCGTAGAGCACCATTCAAGACAGTAGG	4813
Epichloë_festucae_AR48	5311	TTTGACAGAGAGCGGACTGCGGTACACCACCAAGAAGGAGTTGTCTTGATTCTTGCAAG	5370
Epichloë_festucae_Fg1	5311	TTTGACAGAGAGCGGACTGCGGTACACCACCAAGAAGGAGTTGTCTTGATTCTTGCAAG	5370
Epichloë_festucae_FI1	5349	TTTGACAGAGAGCGGACTGCGGTACACCACCAAGAAGGAGTTGTCTTGATTCTTGCAAG	5408
Epichloë_festucae_E2368	5350	TTTGACAGAGAGCGGACTGCGGTACACCACCAAGAAGGAGTTGTCTTGATTCTTGCAAG	5409
Epichloë_festucae_AR1	5311	TTTGACAGAGAGCGGACTGCGGTACACCACCAAGAAGGAGTTGTCTTGATTCTTGCAAG	5370
Epichloë_festucae_AR37	4814	TTTGACAGAGAGCGGACTGCGGTACACCACCAAGAAGGAGTTGTCTTGATTCTTGCAAG	4873
Epichloë_festucae_AR48	5371	CGAGAGAAGTATGAGGCTCTACGGTGTGACAAAGTCTGGCAGCAGAACCGGGGCGATCT	5430
Epichloë_festucae_Fg1	5371	CGAGAGAAGTATGAGGCTCTACGGTGTGACAAAGTCTGGCAGCAGAACCGGGGCGATCT	5430
Epichloë_festucae_FI1	5409	CGAGAGAAGTATGAGGCTCTACGGTGTGACAAAGTCTGGCAGCAGAACCGGGGCGATCT	5468
Epichloë_festucae_E2368	5410	CGAGAGAAGTATGAGGCTCTACGGTGTGACAAAGTCTGGCAGCAGAACCGGGGCGATCT	5469
Epichloë_festucae_AR1	5371	CGAGAGAATATGAGGCTCTACGGTGTGACAAAGTCTGGCAGCAGAACCGGGGCGATCT	5430
Epichloë_festucae_AR37	4874	CGAGAGAAGTATGAGGCTCTACGGTGTGACAAAGTCTGGCAGCAGAACCGGGGCGATCT	4933
Epichloë_festucae_AR48	5431	CAGTGCAGAACTCGCGACTTTGGTGAATACATGGCCACGGAGAGACCGTCTGTCATGTT	5490
Epichloë_festucae_Fg1	5431	CAGTGCAGAACTCGCGACTTTGGTGAATACATGGCCACGGAGAGACCGTCTGTCATGTT	5490
Epichloë_festucae_FI1	5469	CAGTGCAGAACTCGCGACTTTGGTGAATACATGGAGCCACGGAGAGACCGTCTGTCATGTT	5528
Epichloë_festucae_E2368	5470	CAGTGCAGAACTCGCGACTTTGGTGAATACATGGAGCCACGGAGAGACCGTCTGTCATGTT	5529
Epichloë_festucae_AR1	5431	CAGTGCAGAACTCGCGACTTTGGTGAATACATGGCCACGGAGAGACCGTCTGTCATGTT	5476
Epichloë_festucae_AR37	4934	CAGTGCAGAACTCGCGACTTTGGTGAATACATGGAGCCACGGAGAGACCGTCTGTCATGTT	4993
Epichloë_festucae_AR48	5491	GGGTTCTGAACCGCCGCAATGGTATCTGATGTCTTCTGGAAGATTCTCGCGGCAGCAGA	5550
Epichloë_festucae_Fg1	5491	GGGTTCTGAACCGCCGCAATGGTATCTGATGTCTTCTGGAAGATTCTCGCGGCAGCAGA	5550
Epichloë_festucae_FI1	5529	GGGTTCTGAACCGCCGCAATGGTATCTGATGTCTTCTGGAAGATTCTCGCGGCAGCAGA	5588
Epichloë_festucae_E2368	5530	GGGTTCTGAACCGCCGCAATGGTATCTGATGTCTTCTGGAAGATTCTCGCGGCAGCAGA	5589
Epichloë_festucae_AR1	5477	-----ACCGCCGCAATGGTATCTGATGTCTTCTGGAAGATTCTCGCGGCAGCAGA	5527
Epichloë_festucae_AR37	4994	GGGTTCTGAACCGCCGCAATGGTATCTGATGTCTTCTGGAAGATTCTCGCGGCAGCAGA	5053
Epichloë_festucae_AR48	5551	GGCGACTTTTACTTGGCTCGATGCCCCACGTTGGTGGCGATCCCAGCGGTGCAAG	5610
Epichloë_festucae_Fg1	5551	GGCGACTTTTACTTGGCTCGATGCCCCACGTTGGTGGCGATCCCAGCGGTGCAAG	5610
Epichloë_festucae_FI1	5589	GGCGACTTTTACTTGGCTCGATGCCCCACGTTGGTGGCGATCCCAGCGGTGCAAG	5648
Epichloë_festucae_E2368	5590	GGCGACTTTTACTTGGCTCGATGCCCCACGTTGGTGGCGATCCCAGCGGTGCAAG	5649
Epichloë_festucae_AR1	5528	GGCGACTTTTACTTGGCTCGATGCCCCACGTTGGTGGCGATCCCAGCGGTGCAAG	5587
Epichloë_festucae_AR37	5054	GGCGACTTTTACTTGGCTCGATGCCCCACGTTGGTGGCGATCCCAGTTGGTGGCAAG	5113
Epichloë_festucae_AR48	5611	AGGATACGCCTATGTGCGCGCCACAGAGAATCTACGAATTAGGAGAGAGTTCTGCAGA	5670
Epichloë_festucae_Fg1	5611	AGGATACGCCTATGTGCGCGCCACAGAGAATCTACGAATTAGGAGAGAGTTCTGCAGA	5670
Epichloë_festucae_FI1	5649	AGGATACGCCTATGTGCGCGCCACAGAGAATCTACGAATTAGGAGAGAGTTCTGCAGA	5708
Epichloë_festucae_E2368	5650	AGGATACGCCTATGTGCGCGCCACAGAGAATCTACGAATTAGGAGAGAGTTCTGCAGA	5709
Epichloë_festucae_AR1	5588	AGGATACGCCTATGTGCGCGCCACAGAGAATCTACGAATTAGGAGAGAGTTCTGCAGA	5647
Epichloë_festucae_AR37	5114	AGGATACGCCTATGTGCGCGCCACAGAGAATCTACGAATTAGGAGAGAGTTCTGCAGA	5173
Epichloë_festucae_AR48	5671	GGGAAAAAAGTCGGCTGCGTCCAGGAAGTCGCCCTTGGCTCAGCCTTCCAGGATGTTCT	5730
Epichloë_festucae_Fg1	5671	GGGAAAAAAGTCGGCTGCGTCCAGGAAGTCGCCCTTGGCTCAGCCTTCCAGGATGTTCT	5730
Epichloë_festucae_FI1	5709	GGAAAGAAAAGTCGGCTGCGTCCAGGAAGTCGCCCTTGGCTCAGCCTTCCAGGATGTTCT	5768
Epichloë_festucae_E2368	5710	GGGAAAAAAGTCGGCTGCGTCCAGGAAGTCGCCCTTGGCTCAGCCTTCCAGGATGTTCT	5769
Epichloë_festucae_AR1	5648	GGAAAGAAAAGTCGGCTGCGTCCAGGAAGTCGCCCTTGGCTCAGCCTTCCAGGATGTTCT	5707
Epichloë_festucae_AR37	5174	GGGAAAAAAGTCGGCTGCGTCCAGGAAGTCGCCCTTGGCTCAGCCTTCCAGGATGTTCT	5233
Epichloë_festucae_AR48	5731	GGCTGTCAAGCCACGCCGAGGACCAAGCTTTCGTGAGTTTGGCTGGAGAATGTCCTGTA	5790
Epichloë_festucae_Fg1	5731	GGCTGTCAAGCCACGCCGAGGACCAAGCTTTCGTGAGTTTGGCTGGAGAATGTCCTGTA	5790
Epichloë_festucae_FI1	5769	GGCTGTCAAGCCACGCCGAGGACCAAGCTTTCGTGAGTTTGGCTGGAGAATGTCCTGTA	5828
Epichloë_festucae_E2368	5770	GGCTGTCAAGCCACGCCGAGGACCAAGCTTTCGTGAGTTTGGCTGGAGAATGTCCTGTA	5829
Epichloë_festucae_AR1	5708	GGCTGTCAAGCCACGCCGAGGACCAAGCTTTCGTGAGTTTGGCTGGAGAATGTCCTGTA	5767
Epichloë_festucae_AR37	5234	GGCTGTCAAGCCACGCCGAGGACCAAGCTTTCGTGAGTTTGGCTGGAGAATGTCCTGTA	5293

Chapter eight: Appendices

<i>Epichloë festucae</i> _AR48	5791	TACCATACTGTCTCAATTTGAGGGCGATACTAGCTTCATGGAGTGTGTTGTTCCGAGCTC	5850
<i>Epichloë festucae</i> _Fg1	5791	TACCATACTGTCTCAATTTGAGGGCGATACTAGCTTCATGGAGTGTGTTGTTCCGAGCTC	5850
<i>Epichloë festucae</i> _F11	5829	TACCATACTGTCTCAATTTGAGGGCGATACTAGCTTCATGGAGTGTGTTGTTCCGAGCTC	5888
<i>Epichloë festucae</i> _E2368	5830	TACCATACTGTCTCAATTTGAGGGCGATACTAGCTTCATGGAGTGTGTTGTTCCGAGCTC	5889
<i>Epichloë festucae</i> _AR1	5768	TACCATACTGTCTCAATTTGAGGGCGATACTAGCTTCATGGAGTGTGTTGTTCCGAGCTC	5827
<i>Epichloë festucae</i> _AR37	5294	TACCATACTGTCTCAATTTGAGGGCGATACTAGCTTCATGGAGTGTGTTGTTCCGAGCTC	5353
<i>Epichloë festucae</i> _AR48	5851	CAGCTGGGAGTCCTTGACAGGACTTGTCAATTGAGTGAAGGATCAGGGTCAAGTTAAGAT	5910
<i>Epichloë festucae</i> _Fg1	5851	CAGCTGGGAGTCCTTGACAGGACTTGTCAATTGAGTGAAGGATCAGGGTCAAGTTAAGAT	5910
<i>Epichloë festucae</i> _F11	5889	CAGCTGGGAGTCCTTGACAGGACTTGTCAATTGAGTGAAGGATCAGGGTCAAGTTAAGAT	5948
<i>Epichloë festucae</i> _E2368	5890	CAGCTGGGAGTCCTTGACAGGACTTGTCAATTGAGTGAAGGATCAGGGTCAAGTTAAGAT	5949
<i>Epichloë festucae</i> _AR1	5828	CAGCTGGGAGTCCTTGACAGGACTTGTCAATTGAGTGAAGGATCAGGGTCAAGTTAAGAT	5887
<i>Epichloë festucae</i> _AR37	5354	CAGCTGGGAGTCCTTGACAGGACTTGTCAATTGAGTGAAGGATCAGGGTCAAGTTAAGAT	5413
<i>Epichloë festucae</i> _AR48	5911	TGAGGGTTCTACGAGGCATCCGAGACCGGCTGACTCGTTTCTCGGAAAGAGATTGGACGA	5970
<i>Epichloë festucae</i> _Fg1	5911	TGAGGGTTCTACGAGGCATCCGAGACCGGCTGACTCGTTTCTCGGAAAGAGATTGGACGA	5970
<i>Epichloë festucae</i> _F11	5949	TGAGGGTTCTACGAGGCATCCGAGACCGGCTGACTCGTTTCTCGGAAAGAGATTGGACGA	6008
<i>Epichloë festucae</i> _E2368	5950	TGAGGGTTCTACGAGGCATCCGAGACCGGCTGACTCGTTTCTCGGAAAGAGATTGGACGA	6009
<i>Epichloë festucae</i> _AR1	5888	TGAGGGTTCTACGAGGCATCCGAGACCGGCTGACTCGTTTCTCGGAAAGAGATTGGACGA	5947
<i>Epichloë festucae</i> _AR37	5414	TGAGGGTTCTACGAGGCATCCGAGACCGGCTGACTCGTTTCTCGGAAAGAGATTGGACGA	5473
<i>Epichloë festucae</i> _AR48	5971	CGATCTCATAATGATGGAAATATCGACTGGTCGCTTCTTAAAAAATTTCCAGAGGACTCGT	6030
<i>Epichloë festucae</i> _Fg1	5971	CGATCTCATAATGATGGAAATATCGACTGGTCGCTTCTTAAAAAATTTCCAGAGGACTCGT	6030
<i>Epichloë festucae</i> _F11	6009	CGATCTCATAATGATGGAAATATCGACTGGTCGCTTCTTAAAAAATTTCCAGAGGACTCGT	6068
<i>Epichloë festucae</i> _E2368	6010	CGATCTCATAATGATGGAAATATCGACTGGTCGCTTCTTAAAAAATTTCCAGAGGACTCGT	6069
<i>Epichloë festucae</i> _AR1	5948	CGATCTCATAATGATGGAAATATCGACTGGTCGCTTCTTAAAAAATTTCCAGAGGACTCGT	6007
<i>Epichloë festucae</i> _AR37	5474	CGATCTCATAATGATGGAAATATCGACTGGTCGCTTCTTAAAAAATTTCCAGAGGACTCGT	5533
<i>Epichloë festucae</i> _AR48	6031	TATGGATCCTTCGTGTGTGATTCCGGTTCACGTGATAAGCTACTGACCGTGGGCAATGGGAG	6090
<i>Epichloë festucae</i> _Fg1	6031	TATGGATCCTTCGTGTGTGATTCCGGTTCACGTGATAAGCTACTGACCGTGGGCAATGGGAG	6090
<i>Epichloë festucae</i> _F11	6069	TATGGATCCTTCGTGTGTGATTCCGGTTCACGTGATAAGCTACTGACCGTGGGCAATGGGAG	6128
<i>Epichloë festucae</i> _E2368	6070	TATGGATCCTTCGTGTGTGATTCCGGTTCACGTGATAAGCTACTGACCGTGGGCAATGGGAG	6129
<i>Epichloë festucae</i> _AR1	6008	TATGGATCCTTCGTGTGTGATTCCGGTTCACGTGATAAGCTACTGACCGTGGGCAATGGGAG	6067
<i>Epichloë festucae</i> _AR37	5534	TATGGATCCTTCGTGTGTGATTCCGGTTCACGTGATAAGCTACTGACCGTGGGCAATGGGAG	5593
<i>Epichloë festucae</i> _AR48	6091	CAATGAAATTCAGTAG	6106
<i>Epichloë festucae</i> _Fg1	6091	CAATGAAATTCAGTAG	6106
<i>Epichloë festucae</i> _F11	6129	CGCTGCAAAATCAGTAG	6144
<i>Epichloë festucae</i> _E2368	6130	CAATGAAATTCAGTAG	6145
<i>Epichloë festucae</i> _AR1	6068	CAATGAAATTCAGTAG	6083
<i>Epichloë festucae</i> _AR37	5594	CAATGAAATTCAGTAG	5609

Appendix 18: Alignment of makes caterpillars floppy (*mcf*) genes from a range of *Epichloë festucae* strains using the alignment function of Geneious.

Chapter eight: Appendices

<i>Epichloë festucae_AR48</i>	1 MAHNANETSIVEFSKDP LGFITKGEKGYAVISSDNIPGRRPNVFIGDEGHFRFDSVGNLD	60
<i>Epichloë festucae_Fg1</i>	1 MAHNANETSIVEFSKDP LGFITKGEKGYAVISSDNIPGRRPNVFIGDEGHFRFDSVGNLD	60
<i>Epichloë festucae_FI1</i>	-----	
<i>Epichloë festucae_E2368</i>	1 MAHNANETSIVEFSKDP LGFITKGEKGYAVISSDNIPGRRPNVFIGDEGHFRFDSVGNLD	60
<i>Epichloë festucae_AR1</i>	-----	
<i>Epichloë festucae_AR37</i>	-----	
<i>Epichloë festucae_AR48</i>	61 QPAFEIRYHGADAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSV	120
<i>Epichloë festucae_Fg1</i>	61 QPAFEIRYHGADAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSV	120
<i>Epichloë festucae_FI1</i>	-----	
<i>Epichloë festucae_E2368</i>	61 QPAFEIRYHGADAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSV	120
<i>Epichloë festucae_AR1</i>	-----	
<i>Epichloë festucae_AR37</i>	-----	
<i>Epichloë festucae_AR48</i>	121 IVTNLNDNQYRVYHDTQRDSSLLYNDVVMAVDYRDYKHRDASTGYACAFMHYREGRWSLC	180
<i>Epichloë festucae_Fg1</i>	121 IVTNLNDNQYRVYHDTQRDSSLLYNDVVMAVDYRDYKHRDASTGYACAFMHYREGRWSLC	180
<i>Epichloë festucae_FI1</i>	1 -----MAVDYRDYKHRDASTGYACAFMHYREGRWSLC	32
<i>Epichloë festucae_E2368</i>	1 -----MAVDYRDYKHRDASTGYACAFMHYREGRWSLC	32
<i>Epichloë festucae_AR1</i>	121 IVTNLNDNQYRVYHDTQRDSSLLYNDVVMAVDYRDYKHRDASTGYACAFMHYREGRWSLC	180
<i>Epichloë festucae_AR37</i>	1 -----MTSSWQLTTETINHRDASTGYACAFMHYREGRWSLC	36
<i>Epichloë festucae_AR48</i>	181 FQRQTLLQNARVVLYDPLPRDGP SIVGTEPLIEMVPKSYNRELVSQSRFDESREKCLERLR	240
<i>Epichloë festucae_Fg1</i>	181 FQRQTLLQNARVVLYDPLPRDGP SIVGTEPLIEMVPKSYNRELVSQSRFDESREKCLERLR	240
<i>Epichloë festucae_FI1</i>	33 FQRQTLLQNARVVLYDPLPRDGP SIVGTEPLIEMVPESYNRELVSQSRFDESREKCLERLR	92
<i>Epichloë festucae_E2368</i>	33 FQRQTLLQNARVVLYDPLPRDGP SIVGTEPLIEMVPESYNRELVSQSRFDESREKCLERLR	92
<i>Epichloë festucae_AR1</i>	181 FQRQTLLQNARVVLYDPLPRDGP SIVGTEPLIEMVPKSYNRELVSQSRFDESREKCLERLR	240
<i>Epichloë festucae_AR37</i>	37 FQRQTLLQNARVVLYDPLPRDGP SIVGTEPLIEMVPESYNRELVSQSRFDESREKCLERLR	96
<i>Epichloë festucae_AR48</i>	241 DARTKLSNDPFHYEDGEFQPFEEHNHISLDNEAVGYSQGLRTEL DGLILDRPYPTEPNADL	300
<i>Epichloë festucae_Fg1</i>	241 DARTKLSNDPFHYEDGEFQPFEEHNHISLDNEAVGYSQGLRTEL DGLILDRPYPTEPNADL	300
<i>Epichloë festucae_FI1</i>	93 DARTKLSNDPFHYEDGEFQPFEEHNHISLDNEAVGYSQGLRTEL DGLILDRPYPTEPNADL	152
<i>Epichloë festucae_E2368</i>	93 DARTKLSNDPFHYEDGEFQPFEEHNHISLDNEAVGYSQGLRTEL DGLILDRPYPTEPNADL	152
<i>Epichloë festucae_AR1</i>	241 DARTKLSNDPFHYEDGEFQPFEEHNHISLDNEAVGYSQGLRTEL DGLILDRPYPTEPNADL	300
<i>Epichloë festucae_AR37</i>	97 DARTKLSNDPFHYEDGEFQPFEEHNHISLDNEAVGYSQGLRTEL DGLILDRPYPTEPNADL	156
<i>Epichloë festucae_AR48</i>	301 NPELVLSLSDQLLLSERFVRRVTSSRNYDFTYLWLKQKEERGFAAVRREGEHRQTP LGG	360
<i>Epichloë festucae_Fg1</i>	301 NPELVLSLSDQLLLSERFVRRVTSSRNYDFTYLWLKQKEERGFAAVRREGEHRQTP LGG	360
<i>Epichloë festucae_FI1</i>	153 NAQELVLSLSDQLLLSERFVRRVTSSRNYDFTYLWLKQKEERGFAAVRREGEHRQTP LGG	212
<i>Epichloë festucae_E2368</i>	153 NAQELVLSLSDQLLLSERFVRRVTSSRNYDFTYLWLKQKEERGFAAVRREGEHRQTP LGG	212
<i>Epichloë festucae_AR1</i>	301 NPELVLSLSDQLLLSERFVRRVTSSRNYDFTYLWLKQKEERGFAAVRREGEHRQTP LGG	360
<i>Epichloë festucae_AR37</i>	157 NAQELVLSLSDQLLLSERFVRRVTSSRNYDFTYLWLKQKEERGFAAVRREGEHRQTP LGG	216
<i>Epichloë festucae_AR48</i>	361 TAGQRLSEQRRELLAGDNEFSRGYNTYESVEISGYEHDMT LSEMVQLFDRSSTS LTQT E	420
<i>Epichloë festucae_Fg1</i>	361 TAGQRLSEQRRELLAGDNEFSRGYNTYESVEISGYEHDMT LSEMVQLFDRSSTS LTQT E	420
<i>Epichloë festucae_FI1</i>	213 TAGQRLSEQRRELLAGDNEFSRGYNTYESVEISGYEHDMT LSEMVQLFDRSSTS LTQT E	272
<i>Epichloë festucae_E2368</i>	213 TAGQRLSEQRRELLAGDNEFSRGYNTYESVEISGYEHDMT LSEMVQLFDRSSTS LTQT E	272
<i>Epichloë festucae_AR1</i>	361 TAGQRLSEQRRELLAGDNEFSRGYNTYESVEISGYEHDMT LSEMVQLFDRSSTS LTQT E	420
<i>Epichloë festucae_AR37</i>	217 TAGQRLSEQRRELLAGDNEFSRGYNTYESVEISGYEHDMT LSEMVQLFDRSSTS LTQT E	276
<i>Epichloë festucae_AR48</i>	421 QGALLRRIDLARKELFNESVWQKTNDVIAMFQEMGGYTKMPQDILLHAIPDEYGGGRCY	480
<i>Epichloë festucae_Fg1</i>	421 QGALLRRIDLARKELFNESVWQKTNDVIAMFQEMGGYTKMPQDILLHAIPDEYGGGRCY	480
<i>Epichloë festucae_FI1</i>	273 QGALLRRIDLARKELFNESVWQKTNDVIAMFQEMGGYTKMPQDILLHAIPDEYGGGRCY	332
<i>Epichloë festucae_E2368</i>	273 QGALLRRIDLARKELFNESVWQKTNDVIAMFQEMGGYTKMPQDILLHAIPDEYGGGRCY	332
<i>Epichloë festucae_AR1</i>	421 QGALLRRIDLARKELFNESVWQKTNDVIAMFQEMGGYTKMPQDILLHAIPDEYGGGRCY	480
<i>Epichloë festucae_AR37</i>	277 QGALLRRIDLARKELFNESVWQKTNDVIAMFQEMGGYTKMPQDILLHAIPDEYGGGRCY	336
<i>Epichloë festucae_AR48</i>	481 PLVYAMSVALASSDFAIEQLCAKLVGLSPNNQADMKNAE LLKRCLEDLHTSYPAAEASRP	540
<i>Epichloë festucae_Fg1</i>	481 PLVYAMSVALASSDFAIEQLCAKLVGLSPNNQADMKNAE LLKRCLEDLHTSYPAAEASRP	540
<i>Epichloë festucae_FI1</i>	333 PLVYAMSVALASSDFAIEQLCAKLVGLSPNNQADMKNAE LLKRCLEDLHTSYPAAEASRP	392
<i>Epichloë festucae_E2368</i>	333 PLVYAMSVALASSDFAIEQLCAKLVGLSPNNQADMKNAE LLKRCLEDLHTSYPAAEASRP	392
<i>Epichloë festucae_AR1</i>	481 PLVYAMSVALASSDFAIEQLCAKLVGLSPNNQADMKNAE LLKRCLEDLHTSYPAAEASRP	540
<i>Epichloë festucae_AR37</i>	337 PLVYAMSVALASSDFAIEQLCAKLVGLSPNNQADMKNAE LLKRCLEDLHTSYPAAEASRP	396
<i>Epichloë festucae_AR48</i>	541 IGNTMLEEAVSMLERSTETTTLAMHTEVHAMLLGLTKNGNSTSWHFYDPNFAIATFKSGE	600
<i>Epichloë festucae_Fg1</i>	541 IGNTMLEEAVSMLERSTETTTLAMHTEVHAMLLGLTKNGNSTSWHFYDPNFAIATFKSGE	600
<i>Epichloë festucae_FI1</i>	393 IGNTMLEEAVSMLERSTETTTLAMHTEVHAMLLGLTKNGNSTSWHFYDPNFAIATFKSGE	452
<i>Epichloë festucae_E2368</i>	393 IGNTMLEEAVSMLERSTETTTLAMHTEVHAMLLGLTKNGNSTSWHFYDPNFAIATFKSGE	452
<i>Epichloë festucae_AR1</i>	541 IGNTMLEEAVSMLERSTETTTLAMHTEVHAMLLGLTKNGNSTSWHFYDPNFAIATFKSGE	600
<i>Epichloë festucae_AR37</i>	397 IGNTMLEEAVSMLERSTETTTLAMHTEVHAMLLGLTKNGNSTSWHFYDPNFAIATFKSGE	456
<i>Epichloë festucae_AR48</i>	601 ALLEATTKFFEEESGFAKVYEAQGQTPSFDFRIDAERVSRI GF EHDLTVADLVQPETLLE	660
<i>Epichloë festucae_Fg1</i>	601 ALLEATTKFFEEESGFAKVYEAQGQTPSFDFRIDAERVSRI GF EHDLTVADLVQPETLLE	660
<i>Epichloë festucae_FI1</i>	453 ALLEATTKFFEEESGFAKVYEAQGQTPSFDFRIDAERVSRI GF AHDLTVADLVQPETLLE	512
<i>Epichloë festucae_E2368</i>	453 ALLEATTKFFEEESGFAKVYEAQGQTPSFDFRIDAERVSRI GF AHDLTVADLVQPETLLE	512
<i>Epichloë festucae_AR1</i>	601 ALLEATTKFFEEESGFAKVYEAQGQTPSFDFRIDAERVSRI GF EHDLTVADLVQPETLLE	660
<i>Epichloë festucae_AR37</i>	457 ALLEATTKFFEEESGFAKVYEAQGQTPSFDFRIDAERVSRI GF AHDLTVADLVQPETLLE	516
<i>Epichloë festucae_AR48</i>	661 TIAS EHKATFIQDPAQLTSSRTFSAQTELEILGLGEAAWHDATARLEESTGMGEHWMP	720
<i>Epichloë festucae_Fg1</i>	661 TIAS EHKATFIQDPAQLTSSRTFSAQTELEILGLGEAAWHDATARLEESTGMGEHWMP	720
<i>Epichloë festucae_FI1</i>	513 TIAS EHKATFIQDPAQLTSSRTFSAQTELEILGLGEAAWHDATARLEESTGMGEHWMP	572
<i>Epichloë festucae_E2368</i>	513 TIAS EHKATFIQDPAQLTSSRTFSAQTELEILGLGEAAWHDATARLEESTGMGEHWMP	572
<i>Epichloë festucae_AR1</i>	661 TIAS EHKATFIQDPTQLTSSRTFSAQTELEILGLGEAAWHDATARLEESTGMGEHWMP	720
<i>Epichloë festucae_AR37</i>	517 TIAS EHKATFIQDPAQLTSSRTFSAQTELEILGLGEAAWHDATARLEESTGMGEHWMP	576
<i>Epichloë festucae_AR48</i>	721 ILETMKEGGEGKSYEVQFINLKNKNETKWI STESPAIKDFKARLDEHLETLSKTYEFESG	780
<i>Epichloë festucae_Fg1</i>	721 ILETMKEGGEGKSYEVQFINLKNKNETKWI STESPAIKDFKARLDEHLETLSKTYEFESG	780
<i>Epichloë festucae_FI1</i>	573 ILETMKEGGEGKSYEVQFINLKNKNETKWI STESPAIKDFKARLDEHLETLSKTYEFESG	632
<i>Epichloë festucae_E2368</i>	573 ILETMKEGGEGKSYEVQFINLKNKNETKWI STESPAIKDFKARLDEHLETLSKTYEFESG	632
<i>Epichloë festucae_AR1</i>	721 ILETMKEGGEGKSYEVQFINLKNKNETKWI STESPAIKDFKARLDEHLETLSKTYEFESG	780
<i>Epichloë festucae_AR37</i>	577 ILETMKEGGEGKSYEVQFINLKNKNETKWI STESPAIKDFKARLDEHLETLSKTYEFESG	636
<i>Epichloë festucae_AR48</i>	781 SFMRKENLAHAAEIDGLNAMFIVRTLIEHFAGKKT EESTTNAELADALM IHSYLNLTQIG	840
<i>Epichloë festucae_Fg1</i>	781 SFMRKENLAHAAEIDGLNAMFIVRTLIEHFAGKKT EESTTNAELADALM IHSYLNLTQIG	840
<i>Epichloë festucae_FI1</i>	633 SFMRKENLAHAAEIDGLNAMFIVRTLIEHFAGKKT EESTTNAELADALM IHSYLNLTQIG	692
<i>Epichloë festucae_E2368</i>	633 SFMRKENLAHAAEIDGLNAMFIVRTLIEHFAGKKT EESTTNAELADALM IHSYLNLTQIG	692
<i>Epichloë festucae_AR1</i>	781 SFMRKENLAHAAEIDGLNAMFIVRTLIEHFAGKKT EESTTNAELADALM IHSYLNLTQIG	840
<i>Epichloë festucae_AR37</i>	637 SFMRKENLAHAAEIDGLNAMFIVRTLIEHFAGKKT EESTTNAELADALM IHSYLNLTQIG	696

Chapter eight: Appendices

Epichloe_festucae_AR48	841	HQT LGDVGKMVNLVK	DMLETGQVAKSS	LSTLVKGLGNASEG	FVLLGGANVIL	DAYELAH	900				
Epichloe_festucae_Fg1	841	HQT LGDVGKMVNLVK	YMETTQVAKSS	LSTLVKGLGNASEG	FVLLGGANVIL	DAYELAH	900				
Epichloe_festucae_Fl1	693	HQT LGDVGKMVNLVK	DMLETGQVAKSS	LSTLVKGLGNASEG	FVLLGGANVIL	DAYELAH	752				
Epichloe_festucae_E2368	693	HQT LGDVGKMVNLVK	DMLETGQVAKSS	LSTLVKGLGNASEG	FVLLGGANVIL	DAYELAH	752				
Epichloe_festucae_AR1	841	HQT LGDVGKMVNLVK	DMLETGQVAKSS	LSTLVKGLGNASEG	FVLLGGANVIL	DAYELAH	900				
Epichloe_festucae_AR37	697	HQT LGDVGKMVNLVK	DMLETGQVAKSS	LSTLVKGLGNASEG	FVLLGGANVIL	DAYELAH	756				
Epichloe_festucae_AR48	901	TDNDAQRAVFGTQLAFDSVT	FLASVGTVGAGLLGATT	TVVAVVGGVSVI	LGGLAFGVGALA		960				
Epichloe_festucae_Fg1	901	TDNDAQRAVFGTQLAFDSVT	FLASVGTVGAGLLGATT	TVVAVVGGVSVI	LGGLAFGVGALA		960				
Epichloe_festucae_Fl1	753	TDNDAQRAVFGTQLAFDSVT	FLASVGTVGAGLLGATT	TVVAVVGGVSVI	LGGLAFGVGALA		812				
Epichloe_festucae_E2368	753	TDNDAQRAVFGTQLAFDSVT	FLASVGTVGAGLLGATT	TVVAVVGGVSVI	LGGLAFGVGALA		812				
Epichloe_festucae_AR1	901	TDNDAQRAVFGTQLAFDSVT	FLASVGTVGAGLLGATT	TVVAVVGGVSVI	LGGLAFGVGALA		960				
Epichloe_festucae_AR37	757	TDNDAQRAVFGTQLAFDSVT	FLASVGTVGAGLLGATT	TVVAVVGGVSVI	LGGLAFGVGALA		816				
Epichloe_festucae_AR48	961	SGFAQIAAKAE	AVGRYFGDAEAYKAGG	FKYDENHKILVPL	SGAVISEVDAAGNVK	FDSQ	1020				
Epichloe_festucae_Fg1	961	SGFAQIAAKAE	AVGRYFGDAEAYKAGG	FKYDENHKILVPL	SGAVISEVDAAGNVK	FDSQ	1020				
Epichloe_festucae_Fl1	813	SGFAQIAAKAE	AVGRYFGDAEAYKAGG	FKYDENHKILVPL	SGAVISEVDAAGNVK	FDSQ	872				
Epichloe_festucae_E2368	813	SGFAQIAAKAE	AVGRYFGDAEAYKAGG	FKYDENHKILVPL	SGAVISEVDAAGNVK	FDSQ	872				
Epichloe_festucae_AR1	961	SGFAQIAAKAE	AVGRYFGDAEAYKAGG	FKYDENHKILVPL	SGAVISEVDAAGNVK	FDSQ	1020				
Epichloe_festucae_AR37	817	SGFAQIAAKAE	AVGRYFGDAEAYKAGG	FKYDENHKILVPL	SGAVISEVDAAGNVK	FDSQ	876				
Epichloe_festucae_AR48	1021	YIYRTWHGATGSGRIN	YFFWVGDKPRMIHDK	SQAINVREGIRAPAS	GKLTNTRDYTAIIL		1080				
Epichloe_festucae_Fg1	1021	YIYRTWHGATGSGRIN	YFFWVGDKPRMIHDK	SQAINVREGIRAPAS	GKLTNTRDYTAIIL		1080				
Epichloe_festucae_Fl1	873	YIYRTWHGATGSGRIN	YFFWVGDKPRMIHDK	SQAINVREGIRAPAS	GKLTNTRDYTAIIL		932				
Epichloe_festucae_E2368	873	YIYRTWHGATGSGRIN	YFFWVGDKPRMIHDK	SQAINVREGIRAPAS	GKLTNTRDYTAIIL		932				
Epichloe_festucae_AR1	1021	YIYRTWHGATGSGRIN	YFFWVGDKPRMIHDK	SQAINVREGIRAPAS	GKLTNTRDYTAIIL		1080				
Epichloe_festucae_AR37	877	YIYRTWHGATGSGRIN	YFFWVGDKPRMIHDK	SQAINVREGIRAPAS	GKLTNTRDYTAIIL		936				
Epichloe_festucae_AR48	1081	PATPKSYISYEWQILP	FCTGRHDYGFVIR	IRLEEDERFDYDFY	IFPSEYIIHKITHEFVR		1140				
Epichloe_festucae_Fg1	1081	PATPKSYISYEWQILP	FCTGRHDYGFVIR	IRLEEDERFDYDFY	IFPSEYIIHKITHEFVR		1140				
Epichloe_festucae_Fl1	933	PATPKSYISYEWQILP	FCTGRHDYGFVIR	IRLEEDERFDYDFY	IFPSEYIIHKITHEFVR		992				
Epichloe_festucae_E2368	933	PATPKSYISYEWQILP	FCTGRHDYGFVIR	IRLEEDERFDYDFY	IFPSEYIIHKITHEFVR		992				
Epichloe_festucae_AR1	1081	PATPKSYISYEWQILP	FCTGRHDYGFVIR	IRLEEDERFDYDFY	IFPSEYIIHKITHEFVR		1140				
Epichloe_festucae_AR37	937	PATPKSYISYEWQILP	FCTGRHDYGFVIR	IRLEEDERFDYDFY	IFPSEYIIHKITHEFVR		996				
Epichloe_festucae_AR48	1141	TPIAVRLDRRSVRVQVAELDES	LHNVLLEYTIYGAGANYT	IGLNP	GVAMT	LSSGWSSTCWV	1200				
Epichloe_festucae_Fg1	1141	TPIAVRLDRRSVRVQVAELDES	LHNVLLEYTIYGAGANYT	IGLNP	GVAMT	LSSGWSSTCWV	1200				
Epichloe_festucae_Fl1	993	TPIAVRLDRRSVRVQVAELDES	LHNVLLEYTIYGAGANYT	IGLNP	GVAMT	LSSGWSSTCWV	1052				
Epichloe_festucae_E2368	993	TPIAVRLDRRSVRVQVAELDES	LHNVLLEYTIYGAGANYT	IGLNP	GVAMT	LSSGWSSTCWV	1052				
Epichloe_festucae_AR1	1141	TPIAVRLDRRSVRVQVAELDES	LHNVLLEYTIYGAGANYT	IGLNP	GVAMT	LSSGWSSTCWV	1200				
Epichloe_festucae_AR37	997	TPIAVRLDRRSVRVQVAELDES	LHNVLLEYTIYGAGANYT	IGLNP	GVAMT	LSSGWSSTCWV	1056				
Epichloe_festucae_AR48	1201	LDCGKLDGENIVI	EARAVSISGFRVNLADTL	FESMLICKPNGEIL	QVDFFPNRTTFFIKED		1260				
Epichloe_festucae_Fg1	1201	LDCGKLDGENIVI	EARAVSISGFRVNLADTL	FESMLICKPNGEIL	QVDFFPNRTTFFIKED		1260				
Epichloe_festucae_Fl1	1053	LDCGKLDGENIVI	EARAVSISGFRVNLADTL	FESMLICKPNGEIL	QVDFFPNRTTFFIKED		1112				
Epichloe_festucae_E2368	1053	LDCGKLDGENIVI	EARAVSISGFRVNLADTL	FESMLICKPNGEIL	QVDFFPNRTTFFIKED		1112				
Epichloe_festucae_AR1	1201	LDCGKLDGENIVI	EARAVSISGFRVNLADTL	FESMLICKPNGEIL	QVDFFPNRTTFFIKED		1260				
Epichloe_festucae_AR37	1057	LDCGKLDGENIVI	EARAVSISGFRVNLADTL	FESMLICKPNGEIL	QVDFFPNRTTFFIKED		1116				
Epichloe_festucae_AR48	1261	CDRYQGGSQKLT	EHLNDSL	SKHLLGTLEI	IVDKYTT	PAGQSVGRAFY	EPTSKRLLYT	1320			
Epichloe_festucae_Fg1	1261	CDRYQGGSQKLT	EHLNDSL	SKHLLGTLEI	IVDKYTT	PAGQSVGRAFY	EPTSKRLLYT	1320			
Epichloe_festucae_Fl1	1113	CDRYQGGSQKLT	EHLNDSL	SKHLLGTLEI	IVDKYTT	PAGQSVGRAFY	EPTSKRLLYT	1172			
Epichloe_festucae_E2368	1113	CDRYQGGSQKLT	EHLNDSL	SKHLLGTLEI	IVDKYTT	PAGQSVGRAFY	EPTSKRLLYT	1172			
Epichloe_festucae_AR1	1261	CDRYQGGSQKLT	EHLNDSL	SKHLLGTLEI	IVDKYTT	PAGQSVGRAFY	EPTSKRLLYT	1320			
Epichloe_festucae_AR37	1117	CDRYQGGSQKLT	EHLNDSL	SKHLLGTLEI	IVDKYTT	PAGQSVGRAFY	EPTSKRLLYT	1176			
Epichloe_festucae_AR48	1321	PEELTNSAQVGALT	AGGKVFFYNT	EHSAIWRVDVST	GVCEAKYHALCP	FSKRTLQRVWVD		1380			
Epichloe_festucae_Fg1	1321	PEELTNSAQVGALT	AGGKVFFYNT	EHSAIWRVDVST	GVCEAKYHALCP	FSKRTLQRVWVD		1380			
Epichloe_festucae_Fl1	1173	PEELTNSAQVGALT	AGGKVFFYNT	EHSAIWRVDVST	GVCEAKYHALCP	FSKRTLQRVWVD		1232			
Epichloe_festucae_E2368	1173	PEELTNSAQVGALT	AGGKVFFYNT	EHSAIWRVDVST	GVCEAKYHALCP	FSKRTLQRVWVD		1232			
Epichloe_festucae_AR1	1321	PEELTNSAQVGALT	AGGKVFFYNT	EHSAIWRVDVST	GVCEAKYHALCP	FSKRTLQRVWVD		1380			
Epichloe_festucae_AR37	1177	PEELTNSAQVGALT	AGGKVFFYNT	EHSAIWRVDVST	GVCEAKYHALCP	FSKRTLQRVWVD		1236			
Epichloe_festucae_AR48	1381	V	DNQIHALFRHQLSE	DYFGT	LN	YIL	TADSMNLVAMVGGP	ALLAKLHEEDKWT	GEATL	1440	
Epichloe_festucae_Fg1	1381	V	DNQIHALFRHQLSE	DYFGT	LN	YIL	TADSMNLVAMVGGP	ALLAKLHEEDKWT	GEATL	1440	
Epichloe_festucae_Fl1	1233	V	DNQIHALFRHQLSE	DYFGT	LN	YIL	TADSMNLVAMVGGP	ALLAKLHEEDKWT	GEATL	1292	
Epichloe_festucae_E2368	1233	V	DNQIHALFRHQLSE	DYFGT	LN	YIL	TADSMNLVAMVGGP	ALLAKLHEEDKWT	GEATL	1291	
Epichloe_festucae_AR1	1381	V	DNQIHALFRHQLSE	DYFGT	LN	YIL	TADSMNLVAMVGGP	ALLAKLHEEDKWT	GEATL	1440	
Epichloe_festucae_AR37	1237	V	DNQIHALFRHQLSE	DYFGT	LN	YIL	TADSMNLVAMVGGP	ALLAKLHEEDKWT	GEATL	1296	
Epichloe_festucae_AR48	1441	DYYTGP	SELMMLKLP	FEALAGAD	IAAIDPHLI	FVLGPKGKDR	YFYHQFWIRMSDRTVIK		1500		
Epichloe_festucae_Fg1	1441	DYYTGP	SELMMLKLP	FEALAGAD	IAAIDPHLI	FVLGPKGKDR	YFYHQFWIRMSDRTVIK		1500		
Epichloe_festucae_Fl1	1293	DYYTGP	SELMMLKLP	FEALAGAD	IAAIDPHLI	FVLGPKGKDR	YFYHQFWIRMSDRTVIK		1352		
Epichloe_festucae_E2368	1292	DYYTGP	SELMMLKLP	FEALAGAD	IAAIDPHLI	FVLGPKGKDR	YFYHQFWIRMSDRTVIK		1351		
Epichloe_festucae_AR1	1441	DYYTGP	SELMMLKLP	FEALAGAD	IAAIDPHLI	FVLGPKGKDR	YFYHQFWIRMSDRTVIK		1500		
Epichloe_festucae_AR37	1297	DYYTGP	SELMMLKLP	FEALAGAD	IAAIDPHLI	FVLGPKGKDR	YFYHQFWIRMSDRTVIK		1356		
Epichloe_festucae_AR48	1501	PHPDIHLN	LLVGTIAS	T	DGSGELFC	FFSYNQHKLVVQ	RGNGKQAE	EPRPVT	ISPELGT	1560	
Epichloe_festucae_Fg1	1501	PHPDIHLN	LLVGTIAS	T	DGSGELFC	FFSYNQHKLVVQ	RGNGKQAE	EPRPVT	ISPELGT	1560	
Epichloe_festucae_Fl1	1353	PHPDIHLN	LLVGTIAS	T	DGSGELFC	FFSYNQHKLVVQ	RGNGKQAE	EPRPVT	ISPELGT	1412	
Epichloe_festucae_E2368	1352	PHPDIHLN	LLVGTIAS	T	DGSGELFC	FFSYNQHKLVVQ	RGNGKQAE	EPRPVT	ISPELGT	1411	
Epichloe_festucae_AR1	1501	PHPDIHLN	LLVGTIAS	T	DGSGELFC	FFSYNQHKLVVQ	RGNGKQAE	EPRPVT	ISPELGT	1560	
Epichloe_festucae_AR37	1357	PHPDIHLN	LLVGTIAS	T	DGSGELFC	FFSYNQHKLVVQ	RGNGKQAE	EPRPVT	ISPELGT	1416	
Epichloe_festucae_AR48	1561	SNFFCANN	NLFSITNAGFI	RLR	LTS	SHCT	LAL	EAVNHQWLEHY	EKDV	DGGPWWTALPKLAKD	1620
Epichloe_festucae_Fg1	1561	SNFFCANN	NLFSITNAGFI	RLR	LTS	SHCT	LAL	EAVNHQWLEHY	EKDV	DGGPWWTALPKLAKD	1620
Epichloe_festucae_Fl1	1413	SNFFCANN	NLFSITNAGFI	RLR	LTS	SHCT	LAL	EAVNHQWLEHY	EKDV	DGGPWWTALPKLAKD	1472
Epichloe_festucae_E2368	1412	SNFFCANN	NLFSITNAGFI	RLR	LTS	SHCT	LAL	EAVNHQWLEHY	EKDV	DGGPWWTALPKLAKD	1471
Epichloe_festucae_AR1	1561	SNFFCANN	NLFSITNAGFI	RLR	LTS	SHCT	LAL	EAVNHQWLEHY	EKDV	DGGPWWTALPKLAKD	1620
Epichloe_festucae_AR37	1417	SNFFCANN	NLFSITNAGFI	RLR	LTS	SHCT	LAL	EAVNHQWLEHY	EKDV	DGGPWWTALPKLAKD	1476
Epichloe_festucae_AR48	1621	HAAAIVS	IVGLRDAEGSPVQ	AWLCS	DRFVVAGP	SLRGKPRHMA	GLTEGG	SKAWLWHI	ESE	1680	
Epichloe_festucae_Fg1	1621	HAAAIVS	IVGLRDAEGSPVQ	AWLCS	DRFVVAGP	SLRGKPRHMA	GLTEGG	SKAWLWHI	ESE	1680	
Epichloe_festucae_Fl1	1473	HAAAIVS	IVGLRDAEGSPVQ	AWLCS	DRFVVAGP	SLRGKPRHMA	GLTEGG	SKAWLWHI	ESE	1532	
Epichloe_festucae_E2368	1472	HAAAIVS	IVGLRDAEGSPVQ	AWLCS	DRFVVAGP	SLRGKPRHMA	GLTEGG	SKAWLWHI	ESE	1531	
Epichloe_festucae_AR1	1621	HAAAIVS	IVGLRDAEGSPVQ	AWLCS	DRFVVAGP	SLRGKPRHMA	GLTEGG	SKAWLWHI	ESE	1680	
Epichloe_festucae_AR37	1477	HAAAIVS	IVGLRDAEGSPVQ	AWLCS	DRFVVAGP	SLRGKPRHMA	GLTEGG	SKAWLWHI	ESE	1536	

Chapter eight: Appendices

Epichloe_festucae_AR48	1681	DSGHVYAQPTVRS	GK	ELETVFSPKAPFVKAEAVPDGRGVLVEHPFKTVALTESGLRYTTKE	1740						
Epichloe_festucae_Fg1	1681	DSGHVYAQPTVRS	SK	ELETVFSPKAPFVKAEAVPDGRGVLVEHPFKTVALTESGLRYTTKE	1740						
Epichloe_festucae_F11	1533	DSGHVYAQPTVRS	SK	ELETVFSPKAPFVKAEAVPDGRGVLVEHPFKTVALTESGLRYTTKE	1592						
Epichloe_festucae_E2368	1532	DSGHVYAQPTVRS	SK	ELETVFSPKAPFVKAEAVPDGRGVLVEHPFKTVALTESGLRYTTKE	1591						
Epichloe_festucae_AR1	1681	DSGHVYAQPTVRS	GK	ELETVFSPKAPFVKAEAVPDGRGVLVEHPFKTVALTESGLRYTTKE	1740						
Epichloe_festucae_AR37	1537	DSGHVYAQPTVRS	SK	ELETVFSPKAPFVKAEAVPDGRGVLVEHPFKTVALTESGLRYTTKE	1596						
Epichloe_festucae_AR48	1741	GVVLLI	LASERSMR	LYGVDKVVQQNRGDL	SAELATLVNTWRHGETVVMVLGSEPPQWYLMSS	1800					
Epichloe_festucae_Fg1	1741	GVVLLI	LASERSMR	LYGVDKVVQQNRGDL	SAELATLVNTWSHGETVVMVLGSEPPQWYLMSS	1800					
Epichloe_festucae_F11	1593	GVVLLI	LASERSMR	LYGVDKVVQQNRGDL	SAELATLVNTWSHGETVVMVLGSEPPQWYLTSS	1652					
Epichloe_festucae_E2368	1592	GVVLLI	LASERSMR	LYGVDKVVQQNRGDL	SAELATLVNTWSHGETVVMVLGSEPPQWYLTSS	1651					
Epichloe_festucae_AR1	1741	GVVLLI	LASERNMR	LYGVDKVVQQNRGDL	SAELATLVNTWRHGETAAMVS-----	1789					
Epichloe_festucae_AR37	1597	GVVLLI	LASERSMR	LYGVDKVVQQNRGDL	SAELATLVNTWSHGETVVMVLGSEPPQWYLTSS	1656					
Epichloe_festucae_AR48	1801	GKILAAAEATFTWL	DAPT	WLGADPSGARGYAYVA	AHRR	IYELGESSAEGKKSAA	SQEVAF	1860			
Epichloe_festucae_Fg1	1801	GKILAAAEATFTWL	DAPT	WLGADPSGARGYAYVA	AHRR	IYELGESSAEGKKSAA	SQEVAF	1860			
Epichloe_festucae_F11	1653	GKILAAAEATFTWL	DAPT	WLGADPSGARGYAYVA	AHRR	IYELGESSAEEKKSAA	SQDVAF	1712			
Epichloe_festucae_E2368	1652	GKILAAAEATFTWL	DAPT	WLGADPSGARGYAYVA	AHRR	IYELGESSAEGKKSAA	SQEVAF	1711			
Epichloe_festucae_AR1	1790	-----	DVFWKDS	-----	RSRGDFYL	ARCP	-----	HVAWCR	SQRCKRIRL	1824	
Epichloe_festucae_AR37	1657	GKILAAAEATFTWL	DAPT	WLGADPSGARGYAYVA	AHRR	IYELGESSAEGKKSAA	SQEVAF	1716			
Epichloe_festucae_AR48	1861	ASRFQDV	LAVKP	SPGASFRQ	FALE	ENVLYTIL	LSQFEGDTSFME	CVVP	SSSWESLTGL	LVIEW	1920
Epichloe_festucae_Fg1	1861	ASRFQDV	LAVKP	SPGASFRQ	FALE	ENVLYTIL	LSQFEGDTSFME	CVVP	SSSWESLTGL	LVIEW	1920
Epichloe_festucae_F11	1713	ASRFQDV	LAVKP	SPGASFRQ	FALE	ENVLYTIL	LSQFEGDTSFME	CVVP	SSSWESLTGL	LVIEW	1772
Epichloe_festucae_E2368	1712	ASRFQDV	LAVKP	SPGASFRQ	FALE	ENVLYTIL	LSQFEGDTSFME	CVVP	SSSWESLTGL	LVIEW	1771
Epichloe_festucae_AR1	1825	CR	APQKNR	IR	-----	REFCRG	-----	RKVG	CVPGSR	LCLTLP	1858
Epichloe_festucae_AR37	1717	ASRFQDV	LAVKP	SPGASFRQ	FALE	ENVLYTIL	LSQFEGDTSFME	CVVP	SSSWESLTGL	LVIEW	1776
Epichloe_festucae_AR48	1921	KDQGQVQ	IEGSTR	HRPR	ADSF	LGKRLDDDL	IMMEISTGR	FLKISRGL	VMDPS	CVIRFTDK	1980
Epichloe_festucae_Fg1	1921	KDQGQVQ	IEGSTR	HRPR	ADSF	LGKRLDDDL	IMMEISTGR	FLKISRGL	VMDPS	CVIRFTDK	1980
Epichloe_festucae_F11	1773	KDQGQVQ	IEGSTR	HRPR	ADSF	LGKRLDDDL	IMMEISTGR	FLKISRGL	VMDPW	CVTRFTDK	1832
Epichloe_festucae_E2368	1772	KDQGQVQ	IEGSTR	HRPR	ADSF	LGKRLDDDL	IMMEISTGR	FLKISRGL	VMDPS	CVIRFTDK	1831
Epichloe_festucae_AR1	1859	-----	CSGCCQAQPR	-----	-----	SKLS	-----	VC	PGEC	PPVYHTVS	1885
Epichloe_festucae_AR37	1777	KDQGQVQ	IEGSTR	HRPR	ADSF	LGKRLDDDL	IMMEISTGR	FLKISRGL	VMDPS	CVIRFTDK	1836
Epichloe_festucae_AR48	1981	LLTV	GNGSNEIQ								1992
Epichloe_festucae_Fg1	1981	LLTV	GNGSNEIQ								1992
Epichloe_festucae_F11	1833	LLTV	GNGSAGNQ								1844
Epichloe_festucae_E2368	1832	LLTV	GNGSNEIQ								1843
Epichloe_festucae_AR1	1886	I	-----								
Epichloe_festucae_AR37	1837	LLTV	GNGSNEIQ								1848

Appendix 19: Alignment of makes caterpillars floppy (Mcf) proteins from a range of *Epichloë festucae* strains using the alignment function of Geneious.

Chapter eight: Appendices

Epichloe_amarillans_E57	1	ATGGCTCAT	AAGTAAGAGCTTCCC				TCTCTTTTT	TTTT																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																	</
-------------------------	---	-----------	-----------------	--	--	--	-----------	------	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	----

241

Chapter eight: Appendices

Epichloë_amarillans_E57_	435	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	486
Epichloë_amarillans_E4668_	431	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	482
Epichloë_aotearoae_MYA-1229_	448	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	499
Epichloë_brachyelytri_E4804_	441	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	492
Epichloë_bromicola_AL0434_	421	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	472
Epichloë_bromicola_AL04262_	421	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	472
Epichloë_elymi_ATCC_201551_	421	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	472
Epichloë_festucaae_AR1_	420	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	471
Epichloë_festucaae_AR37_					
Epichloë_festucaae_AR48_	420	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	471
Epichloë_festucaae_E2368_	451	TCCGTC	CGCGCGCAG	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	510
Epichloë_festucaae_Fg1_	420	TCCGTC	-A-----	TAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	471
Epichloë_festucaae_Fl1_	450	TCCGTC	CGCGCGCAG	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	509
Epichloë_gansuensis_e7080_					
Epichloë_glyceriae_ATCC_200747_	469	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	520
Epichloë_inebrians_MYA-1228_	435	TCCGTC	-----	ATAGTACCAAGCTCAATGACCAACAGTACCGTGTCTATCACGACT	486
Epichloë_mollis_AL9924_	421	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	472
Epichloë_typhina_ATCC_200736_	447	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	498
Epichloë_typhina_subsp_poae	448	TCCGTC	-A-----	TAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	499
Epichloë_typhina_subsp_Poae_Ps1_	443	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	494
Epichloë_uncinata_CBS_102646_	450	TCCGTC	-----	ATAGTAACGAACCTCAACGACAACCAGTACCGTGTCTATCACGACT	501
Epichloë_amarillans_E57_	487	CTCGAC	AGGATAGCTCGTGTGTTGTACGAAAAAGTCGTCATGGCAGTTGACTACAGAGACT	546	
Epichloë_amarillans_E4668_	483	CTCGAC	AGGATAGCTCGTGTGTTGTACGAAAAAGTCGTCATGGCAGTTGACTACAGAGACT	542	
Epichloë_aotearoae_MYA-1229_	500	CTCGAC	AGGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	559	
Epichloë_brachyelytri_E4804_	493	CTCGAC	AGGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	552	
Epichloë_bromicola_AL0434_	473	CTCGAC	AGGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	532	
Epichloë_bromicola_AL04262_	473	CTCGAC	AGGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	532	
Epichloë_elymi_ATCC_201551_	473	CTCGAC	AGGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	532	
Epichloë_festucaae_AR1_	472	CTCGAC	AGGATAGCTCGTGTGTTGTACAAAGCTCGTCATGGCAGTTGACTACAGAGACT	531	
Epichloë_festucaae_AR37_	1			ATAGCTCGTCATGGCAGTTGACTACAGAGACT	531
Epichloë_festucaae_AR48_	472	CTCGAC	AGGATAGCTCGTGTGTTGTACAAAGCTCGTCATGGCAGTTGACTACAGAGACT	531	
Epichloë_festucaae_E2368_	511	CTCGAC	AGGATAGCTCGTGTGTTGTACAAAGCTCGTCATGGCAGTTGACTACAGAGACT	570	
Epichloë_festucaae_Fg1_	472	CTCGAC	AGGATAGCTCGTGTGTTGTACAAAGCTCGTCATGGCAGTTGACTACAGAGACT	531	
Epichloë_festucaae_Fl1_	510	CTCGAC	AGGATAGCTCGTGTGTTGTACAAAGCTCGTCATGGCAGTTGACTACAGAGACT	569	
Epichloë_gansuensis_e7080_					
Epichloë_glyceriae_ATCC_200747_	521	CTCGACT	GGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	580	
Epichloë_inebrians_MYA-1228_	487	CTCGAAT	GGATAGCTCGTGTGTTGTACAGCAATGTCATCATGGCAGTTGACTACAGAGACT	546	
Epichloë_mollis_AL9924_	473	CTCGACT	GGATAGCTCGTGTGTTGTACAGCAATGTCATCATGGCAGTTGACTACAGAGACT	532	
Epichloë_typhina_ATCC_200736_	499	CTCGAC	AGGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	557	
Epichloë_typhina_subsp_poae	500	CTCGAC	AGGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	559	
Epichloë_typhina_subsp_Poae_Ps1_	495	CTCGAC	AGGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	554	
Epichloë_uncinata_CBS_102646_	502	CTCGACT	GGATAGCTCGTGTGTTGTACAGCAAGCTCGTCATGGCAGTTGACTACAGAGACT	561	
Epichloë_amarillans_E57_	547	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	605	
Epichloë_amarillans_E4668_	543	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	601	
Epichloë_aotearoae_MYA-1229_	560	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	618	
Epichloë_brachyelytri_E4804_	553	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	611	
Epichloë_bromicola_AL0434_	533	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	591	
Epichloë_bromicola_AL04262_	533	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	591	
Epichloë_elymi_ATCC_201551_	533	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	591	
Epichloë_festucaae_AR1_	532	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	590	
Epichloë_festucaae_AR37_	34	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	93	
Epichloë_festucaae_AR48_	532	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	590	
Epichloë_festucaae_E2368_	571	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	629	
Epichloë_festucaae_Fg1_	532	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	590	
Epichloë_festucaae_Fl1_	570	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	628	
Epichloë_gansuensis_e7080_					
Epichloë_glyceriae_ATCC_200747_	581	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCTGCGCATTATGCCTATCGCGAAGGT	639	
Epichloë_inebrians_MYA-1228_	547	ATAAAC	TCCGCGAAGATGCTGGAGGGTTGCCCTGCCGATTATGCCTATCGCGAAGGT	605	
Epichloë_mollis_AL9924_	533	ATAAAC	ATTTCCAGCCTAGTACTGGTTGCCCTGCCGATTATGCCTATCGCGAAGGT	591	
Epichloë_typhina_ATCC_200736_	558	-AAAC	ATCGGCTATGAGAACTACTGGGTATGCCAGCGATTATGCCTATCGCGAAGGT	614	
Epichloë_typhina_subsp_poae	560	ATAAAC	ATCGCAATGCTAATCTGGGTATGCCCTGCCGATTATGCCTATCGCGAAGGT	618	
Epichloë_typhina_subsp_Poae_Ps1_	555	ATAAAC	ATCGGCTATGAGAACTACTGGGTATGCCAGCATTCATGCCTATCGCGAAGGT	613	
Epichloë_uncinata_CBS_102646_	562	ATAAAC	ATCGCGATGCTAGTACTGGTTGCCAGCATTCATGCCTATCGCGAAGGT	620	
Epichloë_amarillans_E57_	606	CGCTGGTCTCTGTGTTCCAGAGGC	AAACCCCTACTTCAAAATGGAGCTGTTTCG	662	
Epichloë_amarillans_E4668_	602	CGCTGGTCTCTGTGTTCCAGAGGC	AAACCCCTACTTCAAAATGGAGCTGTTTCG	658	
Epichloë_aotearoae_MYA-1229_	619	CGCTGGTCATGTGTTTCCAGAGGC	AAACCTAGTTACAAATGACGCTATTGT	675	
Epichloë_brachyelytri_E4804_	612	CGCTGGTCATGTGTTTCCAGAGGC	AAACCATAGTTGCAAAATGCGGCTATTGT	668	
Epichloë_bromicola_AL0434_	592	CGCTGGTCATGTGTTTCCAGAGGC	AAACCTAGTTGGAATGACGCTATTGT	648	
Epichloë_bromicola_AL04262_	592	CGCTGGTCATGTGTTTCCAGAGGC	AAACCCCTAGTACCAATGACGCTATTGT	648	
Epichloë_elymi_ATCC_201551_	592	CGCTGGTCATGTGTTTCCAGAGGC	AAACCATAGTGCAAATGACGCTATTGT	648	
Epichloë_festucaae_AR1_	591	CGCTGGTCATGTGTTTCCAGAGGC	AAACCCCTACTTCAAAATGACGCTATTGT	647	
Epichloë_festucaae_AR37_	94	CGCTGGTCATGTGTTTCCAGAGGC	AAACCCCTACTTCAAAATGACGCTATTGT	150	
Epichloë_festucaae_AR48_	591	CGCTGGTCATGTGTTTCCAGAGGC	AAACCCCTACTTCAAAATGACGCTATTGT	647	
Epichloë_festucaae_E2368_	630	CGCTGGTCATGTGTTTCCAGAGGC	AAACCCCTACTTCAAAATGACGCTATTGT	686	
Epichloë_festucaae_Fg1_	591	CGCTGGTCATGTGTTTCCAGAGGC	AAACCCCTACTTCAAAATGACGCTATTGT	647	
Epichloë_festucaae_Fl1_	629	CGCTGGTCATGTGTTTCCAGAGGC	AAACCCCTACTTCAAAATGACGCTATTGT	685	
Epichloë_gansuensis_e7080_					
Epichloë_glyceriae_ATCC_200747_	640	CGCTGGTCTCTGTATTTCCAGAGGC	AAACCCCTAGTACGAGTATGCTATTGT	696	
Epichloë_inebrians_MYA-1228_	606	ATCTGGTCTTTGTATTTCCAGAGGC	AAATCAGACAAAGACCGTGTTTCCGTA	665	
Epichloë_mollis_AL9924_	592	CTCTGGTCTCTGTGTTTCCAGAGGC	AAACCCCTAGCTGCAATGACGCTATTGT	648	
Epichloë_typhina_ATCC_200736_	615	CGCTGGTCATTTGTTTCCAGAGGC	AAACCATAGTTGCAAAATGACGCTATTGT	671	
Epichloë_typhina_subsp_poae	619	ACTGGTCTCTGTGTTTCCAGAGGC	AAACCCCTAATTCGAAATGAGGCTTTGC	675	
Epichloë_typhina_subsp_Poae_Ps1_	614	CGCTGGTCATGTGTTTCCAGAGGC	AAACCATAGTTGCAAAATGACGCTATTGT	670	
Epichloë_uncinata_CBS_102646_	621	CGCTGGTCATGTGTTTCCAGAGGC	AAGTCACTGTTGGAATTTACGTTTTCG	677	
Epichloë_amarillans_E57_	663	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	719	
Epichloë_amarillans_E4668_	659	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	715	
Epichloë_aotearoae_MYA-1229_	676	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	732	
Epichloë_brachyelytri_E4804_	669	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	725	
Epichloë_bromicola_AL0434_	649	TACATTCCGCTGGTGAA	AAAGATCCCGCTACATAATAGGGGCAAGAGCCCTTGATTGAG	708	
Epichloë_bromicola_AL04262_	649	TACAATCCGCTGCCG	---AAATATATCTTACCAACGGCAGGCACTGCCCTTGATTGAG	705	
Epichloë_elymi_ATCC_201551_	649	TACGATCCGCTGCCG	---AGAGCTGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	705	
Epichloë_festucaae_AR1_	648	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	704	
Epichloë_festucaae_AR37_	151	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	207	
Epichloë_festucaae_AR48_	648	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	704	
Epichloë_festucaae_E2368_	687	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	743	
Epichloë_festucaae_Fg1_	648	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	704	
Epichloë_festucaae_Fl1_	686	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGCAAGAGCCCTTGATTGAG	742	
Epichloë_gansuensis_e7080_					
Epichloë_glyceriae_ATCC_200747_	697	TACAATCCGCTGCCG	---AGAGATGCCCATTCATAATAGGGGCAAGAGCCCTTGATTGAG	753	
Epichloë_inebrians_MYA-1228_	666	TACAATCCGCTGCCG	---AGGATACCTGTACATAATTTGGTGACAGCCCTTGATTGAG	722	
Epichloë_mollis_AL9924_	649	TACAATCCGCTGCCG	---AGAAATGCCGCTACATAATAGGGGCAAGAGCCCTTGATTGAG	705	
Epichloë_typhina_ATCC_200736_	672	TACGATCCGCTGCCG	---AGAGCTGCCCATTCATAGTAGGGGCAAGAGCCCTTGATTGAG	728	
Epichloë_typhina_subsp_poae	676	TCCGATCCGCTGCCG	---AGAGATGCCCATTCATAGTAGGGGTTGACCCCTTGATTGAG	732	
Epichloë_typhina_subsp_Poae_Ps1_	671	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAATAGGGGCAAGAGCCCTTGATTGAG	727	
Epichloë_uncinata_CBS_102646_	678	TACGATCCGCTGCCG	---AGAGATGCCCATTCATAATAGGGGCAAGAGCCCTTGATTGAG	734	

Chapter eight: Appendices

*Epichloë amarillans*_E57_
*Epichloë amarillans*_E4668_
*Epichloë aotearoae*_MYA-1229_
*Epichloë brachelytri*_E4804_
*Epichloë bromicola*_AL0434_
*Epichloë bromicola*_AL04262_
*Epichloë elymi*_ATCC_201551_
*Epichloë festucae*_AR1
*Epichloë festucae*_AR37
*Epichloë festucae*_AR48
*Epichloë festucae*_E2368
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë gansuensis*_e7080_
*Epichloë glyceriae*_ATCC_200747_
*Epichloë inebrians*_MYA-1228_
*Epichloë mollis*_AL9924_
*Epichloë typhina*_ATCC_200736_
*Epichloë typhina*_subsp._poae
*Epichloë typhina*_subsp._Poae_Ps1
*Epichloë uncinata*_CBS_102646_

*Epichloë amarillans*_E57_
*Epichloë amarillans*_E4668_
*Epichloë aotearoae*_MYA-1229_
*Epichloë brachelytri*_E4804_
*Epichloë bromicola*_AL0434_
*Epichloë bromicola*_AL04262_
*Epichloë elymi*_ATCC_201551_
*Epichloë festucae*_AR1
*Epichloë festucae*_AR37
*Epichloë festucae*_AR48
*Epichloë festucae*_E2368
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë gansuensis*_e7080_
*Epichloë glyceriae*_ATCC_200747_
*Epichloë inebrians*_MYA-1228_
*Epichloë mollis*_AL9924_
*Epichloë typhina*_ATCC_200736_
*Epichloë typhina*_subsp._poae
*Epichloë typhina*_subsp._Poae_Ps1
*Epichloë uncinata*_CBS_102646_

*Epichloë amarillans*_E57_
*Epichloë amarillans*_E4668_
*Epichloë aotearoae*_MYA-1229_
*Epichloë brachelytri*_E4804_
*Epichloë bromicola*_AL0434_
*Epichloë bromicola*_AL04262_
*Epichloë elymi*_ATCC_201551_
*Epichloë festucae*_AR1
*Epichloë festucae*_AR37
*Epichloë festucae*_AR48
*Epichloë festucae*_E2368
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë gansuensis*_e7080_
*Epichloë glyceriae*_ATCC_200747_
*Epichloë inebrians*_MYA-1228_
*Epichloë mollis*_AL9924_
*Epichloë typhina*_ATCC_200736_
*Epichloë typhina*_subsp._poae
*Epichloë typhina*_subsp._Poae_Ps1
*Epichloë uncinata*_CBS_102646_

*Epichloë amarillans*_E57_
*Epichloë amarillans*_E4668_
*Epichloë aotearoae*_MYA-1229_
*Epichloë brachelytri*_E4804_
*Epichloë bromicola*_AL0434_
*Epichloë bromicola*_AL04262_
*Epichloë elymi*_ATCC_201551_
*Epichloë festucae*_AR1
*Epichloë festucae*_AR37
*Epichloë festucae*_AR48
*Epichloë festucae*_E2368
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë gansuensis*_e7080_
*Epichloë glyceriae*_ATCC_200747_
*Epichloë inebrians*_MYA-1228_
*Epichloë mollis*_AL9924_
*Epichloë typhina*_ATCC_200736_
*Epichloë typhina*_subsp._poae
*Epichloë typhina*_subsp._Poae_Ps1
*Epichloë uncinata*_CBS_102646_

*Epichloë amarillans*_E57_
*Epichloë amarillans*_E4668_
*Epichloë aotearoae*_MYA-1229_
*Epichloë brachelytri*_E4804_
*Epichloë bromicola*_AL0434_
*Epichloë bromicola*_AL04262_
*Epichloë elymi*_ATCC_201551_
*Epichloë festucae*_AR1
*Epichloë festucae*_AR37
*Epichloë festucae*_AR48
*Epichloë festucae*_E2368
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë gansuensis*_e7080_
*Epichloë glyceriae*_ATCC_200747_
*Epichloë inebrians*_MYA-1228_
*Epichloë mollis*_AL9924_
*Epichloë typhina*_ATCC_200736_
*Epichloë typhina*_subsp._poae
*Epichloë typhina*_subsp._Poae_Ps1
*Epichloë uncinata*_CBS_102646_

720 ATCTGCCCAATCGTATAATCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 779
716 ATCTGCCCAATCGTATAATCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 775
733 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 792
726 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 785
709 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 768
706 -----CAAAAATTTGATGACCCGGAGATAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 759
706 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 765
705 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 764
208 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 267
705 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 764
744 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 803
705 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 804
743 ATGGTGCCCAATCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 762

754 CTGGTGCCCAATTCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 813
723 CTGGTGCCCAATTCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 782
706 CTGGTGCCCAATTCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 785
729 ATGGTGCCCAATTCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 768
733 ATGGTGCCCAATTCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 792
728 ATGGTGCCCAATTCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 787
735 ATGGTGCCCAATTCGTATAACCGGAGCTAGTTCAATCGCGTTTCGACGAGAGTCGGCAA 794

780 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGATCCCTTTCAATAC 839
776 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGATCCCTTTCAATAC 835
793 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGATCCCTTTCAATAC 852
786 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGATCCCTTTCAATAC 845
769 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGATCCCTTTCAATAC 828
760 AAGAACTGGAGAGCTTGGCAAAATTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 825
766 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 825
765 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 824
268 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 827
765 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 824
804 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 863
765 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 864
803 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 824

814 AAGAGCGGAGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGATCCCTTTCAATAC 873
783 CAGAACCGGAGAGCGTTTACAGGATTTTCAATGACCTTTTGGCCATCGCTACCAAGCGG 842
766 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 825
789 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 848
793 AAGTGCCCTGGAGCGTTTGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 852
788 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 847
795 AAGTGCCCTGGAGCGTTGCGGGAGCGCTTCACGAAGCTTTCTACGAAGCTTTCTACGAAGCTTT 854

840 GAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 899
836 GAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 895
853 GGGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 912
846 GAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 905
829 GTGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 888
820 ATGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 879
826 AAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 885
825 AAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 884
328 GAAGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 387
825 GAAGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 884
864 GAAGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 923
825 GAAGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 922
863 GAAGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 884

874 GTGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 933
843 GTGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 902
826 GAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 885
849 GAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 908
853 AAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 912
848 GAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 907
855 GAGGATGGTGAATTTCAACCGTTTGAAGAAACCGCATCAGTCTTCAAAATGAAGCGCTC 914

900 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 956
896 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 952
913 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 969
906 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 962
889 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 948
880 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 939
886 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 942
885 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 938
388 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 441
885 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 938
924 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 977
885 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 938
923 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 976

934 GCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 993
903 AGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 951
886 GCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 945
909 CGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 968
913 AGCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 972
908 GCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 967
915 GCTATTACAAAGGACTTGAAGACCGATCTTGAAGGATTCTCAACAATAGGGGGCCT--- 974

957 -----TATC--CAGCT--GAA--CTCA----AT-----GCTGAAGTCAATGTACAG 992
953 -----TATC--CAGCT--GAA--CTCA----AT-----GCTGAAGTCAATGTACAG 988
970 -----TATC--CAGCT--GAA--CCCG----AT-----GCTGAAGTCAATGTACAG 1005
963 -----A-----AA--CCCG----AT-----GCTGAAGTCAATGTACAG 989
949 AGCACTCATCA--TGCT--GAA--CTCAT--G-----G-----CTGAAGTCAATGTACAG 990
940 AATAGGATAGTAAAGATGAT--AGCA--ACACTTTTCCAGCTGAAGTCAATGTACAG 993
943 -----TATC--CAGCT--GAA--CCCAT--G-----G-----GCTGAAGTCAATGTACAG 978
939 -----TATC--CAACT--GAA--CCCAAT--G-----G-----CTGAAGTCAATGTACAG 974
442 -----TATC--CAACT--GAA--CCCAAT--G-----G-----CTGAAGTCAATGTACAG 477
939 -----TATC--CAACT--GAA--CCCAAT--G-----G-----CTGAAGTCAATGTACAG 974
978 -----TATC--CAACT--GAA--CCCAAT--G-----G-----CTGAAGTCAATGTACAG 1013
939 -----TATC--CAACT--GAA--CCCAAT--G-----G-----CTGAAGTCAATGTACAG 974
977 -----TATC--CAACT--GAA--CCCAAT--G-----G-----CTGAAGTCAATGTACAG 1012

994 ATCACTGATC--CAGCT--GAA--ACCAT--G-----G-----GCTGAAGTCAATGTACAG 1035
952 -----CAGCT--GAA--CTTGGT--G-----G-----CTGAAGTCAATGTACAG 986
946 GAGAGGGGATA--CGGATACAAAGGAT--C-----ATCAGCTGAAGTCAATGTACAG 993
969 CCAAGTATC--CAGCT--GAA--CTTGGT--G-----G-----GCTGAAGTCAATGTACAG 1007
973 GCAAGTAAAGCAAGCTCAT--CAAGT--G-----G-----GCTGAAGTCAATGTACAG 1017
968 CGAGATCATC--CAGCT--GACGAGATAT--G-----G-----GCTGAAGTCAATGTACAG 1009
975 CCAGATCATC--CAGCT--GACGAGATAT--G-----G-----GCTGAAGTCAATGTACAG 1016

Chapter eight: Appendices

Epichloë_amarillans_E57_	993	CAGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	1020	
Epichloë_amarillans_E4668_	989	CAGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	1016	
Epichloë_aotearoae_MYA-1229_	1006	CGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	1033	
Epichloë_brachelytri_E4804_	990	CATTTGGTGT	---	CACCTCAGCGACCAGCGGT	-----	1017	
Epichloë_bromicola_AL0434_	991	CACTTTGATT	---	CACCTCAGCGACCAGCTGT	TTGTGAGCGA---GTCTCTCAAACCTGCC	1044	
Epichloë_bromicola_AL04262_	994	CACTTTCTGT	---	CACACAGCGACAGATG	GAGGTGAGCGCATATGTCTCTTAG---GGCC	1047	
Epichloë_elymi_ATCC_201551_	979	CAGTTCCTGT	-T-	ACTCAGCAACCAAGCTG	-----	1006	
Epichloë_festucae_AR1	975	CAGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	1001	
Epichloë_festucae_AR37	478	CAGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	505	
Epichloë_festucae_AR48	975	CAGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	1002	
Epichloë_festucae_E2368	1014	CAGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	1041	
Epichloë_festucae_Fg1	975	CAGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	1001	
Epichloë_festucae_FI1	1013	CAGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	1040	
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	1036	CATTTGGTGT	---	CACCTCAGCGACCAGCTGT	TTGTGAGCGACATGTCTCTTAACCTGGCC	1092	
Epichloë_inebrians_MYA-1228_	984	CTCTTGGTGC	---	CACCTCAGCGACCAGCTGT	TACAGCGCATAGATTTCTCAAGCTG---	1037	
Epichloë_mollis_AL9924_	997	CACCTTGTGT	---	CACACAGCGAACAGCTGT	CTAGTGAGCGCATATGTCCCTTAGGCTGGCC	1053	
Epichloë_typhina_ATCC_200736_	1008	CTGTTGGAGT	-T-C-	T-CAGCGACCAGCTGT	-----	1036	
Epichloë_typhina_subsp_poae	1018	CAGTTGGTGT	---	CACCTCGCTCAGCAGCTGT	-----	1046	
Epichloë_typhina_subsp_Poae_Ps1	1010	TGTTGGTGT	CAC	ACTCTCGCGCAGCAGCTGT	-----	1041	
Epichloë_uncinata_CBS_102646_	1017	TGTTGGTGT	---	CACCTCAGCGACCAGCTGT	-----	1045	
Epichloë_amarillans_E57_	1021	-----TTCT	---	AAGCAA--AAATTTTAT	---TACG-----CGAATCTGAATCTT	1059	
Epichloë_amarillans_E4668_	1017	-----TTCT	---	AAGCAA--AAATTTTAT	---TACG-----CGAATCATGAATCTT	1055	
Epichloë_aotearoae_MYA-1229_	1034	-----TTCT	---	AAGCGA--AAGGTTTGT	---TAGG-----CGAACCATGGCATCTT	1072	
Epichloë_brachelytri_E4804_	1018	-----TTCT	---	AAGCAA--AAAGTTTGT	---TAGG-----CGAACCATGACATCTT	1056	
Epichloë_bromicola_AL0434_	1045	ATGCATCCTT	CTAGT	AAGCGT--GAATTTTAT	---ACCTTACACGGACCATGACGCTCTT	1099	
Epichloë_bromicola_AL04262_	1048	GATGAATCTT	CTAGG	AAGT--A--TGATTATGGA	TACCCAACTCGGACCATGACATCTT	1102	
Epichloë_elymi_ATCC_201551_	1007	-----TTCT	---	AAGCGA--AAGGTTTGT	---TAGGC-----GAACCATGACATCTT	1045	
Epichloë_festucae_AR1	1002	---C-----	TTCT	AAGCGA--AAGGTTTGT	---TAGG-----CGAACCGTGACGCTCTT	1041	
Epichloë_festucae_AR37	506	-----TTCT	---	AAGCGA--AAGGTTTGT	---TAGGC-----GAACCGTGACGCTCTT	544	
Epichloë_festucae_AR48	1003	-----TGCT	---	AAGCGA--AAGGTTTGT	---TAGG-----CGAACCATGACGCTCTT	1041	
Epichloë_festucae_E2368	1042	-----TTCT	---	AAGCGA--AAGGTTTGT	---TAGG-----CGAACCGTGACGCTCTT	1080	
Epichloë_festucae_Fg1	1002	C-----TTCT	---	AAGCGA--AAGGTTTGT	---TAGG-----CGAACCGTGACGCTCTT	1041	
Epichloë_festucae_FI1	1041	-----TTCT	---	AAGCGA--AAGGTTTGT	---TAGG-----CGAACCGTGACGCTCTT	1079	
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	1093	ATGGATCCTT	CTAGG	ACGT---ATGATTATAAAT	TACCTTAATCGGACCATGACATCTT	1147	
Epichloë_inebrians_MYA-1228_	1038	-----TTCT	---	CAGGCACTCTAGTATTTTGTATCAG	-----ATCAAGAAATCTT	1080	
Epichloë_mollis_AL9924_	1054	ATGGATCCTT	CTAGG	ACGT---ATGATTATGGA	TACTCACTCGGACCATGGCATCTT	1108	
Epichloë_typhina_ATCC_200736_	1037	-----TCT	---	AAGCGA--AAGGTTTGT	---TGTC-----CGAACCGTGACATCTT	1074	
Epichloë_typhina_subsp_poae	1047	-----TTT	---	AAGCGA--AAGGTTTGT	---TAGG-----CGAACCATGACATCTT	1084	
Epichloë_typhina_subsp_Poae_Ps1	1042	-----TTT	---	AAATGA--AAGGTTTGT	---TGGG-----CGAGCGCTGCATCTT	1079	
Epichloë_uncinata_CBS_102646_	1046	-----TCT	---	AAACAA--AAATTTTGT	---TAGGC-----GAATCTGACATCTT	1083	
Epichloë_amarillans_E57_	1060	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1119	
Epichloë_amarillans_E4668_	1056	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1115	
Epichloë_aotearoae_MYA-1229_	1073	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1132	
Epichloë_brachelytri_E4804_	1057	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1116	
Epichloë_bromicola_AL0434_	1100	CTGACAAGTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1159	
Epichloë_bromicola_AL04262_	1103	CTGACAAGTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1162	
Epichloë_elymi_ATCC_201551_	1046	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1105	
Epichloë_festucae_AR1	1042	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1101	
Epichloë_festucae_AR37	545	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	604	
Epichloë_festucae_AR48	1042	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1101	
Epichloë_festucae_E2368	1081	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1140	
Epichloë_festucae_Fg1	1042	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1101	
Epichloë_festucae_FI1	1080	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1139	
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	1148	CTGACAAGTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1207	
Epichloë_inebrians_MYA-1228_	1081	CTGACAAGTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1140	
Epichloë_mollis_AL9924_	1109	CTGACAAGTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1168	
Epichloë_typhina_ATCC_200736_	1075	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1134	
Epichloë_typhina_subsp_poae	1085	CTGACAAGTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1144	
Epichloë_typhina_subsp_Poae_Ps1	1080	CTCGGAATTAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1139	
Epichloë_uncinata_CBS_102646_	1084	CTCAGAGATAT	GACTAT	CTCTCGGCTGCAGCAAAAGATTAG	AAAGGGGATTTGAAG	1143	
Epichloë_amarillans_E57_	1120	CAGTCGTGA	AACAGGC--AT	CAGTCTGCA	GGCACCCTAGGAGGCACAGCCGGC	GAACGT	1178
Epichloë_amarillans_E4668_	1116	CAGTCTGTA	GAACAGGC--AT	CAGTCTGCA	GGCACCCTAGGAGGCACAGCCGGC	GAACGT	1174
Epichloë_aotearoae_MYA-1229_	1133	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCCGGC	CAACGT	1191
Epichloë_brachelytri_E4804_	1117	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCCGGC	CAACGT	1175
Epichloë_bromicola_AL0434_	1160	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCCGGC	CAACGT	1218
Epichloë_bromicola_AL04262_	1163	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCCGGC	GAACGT	1221
Epichloë_elymi_ATCC_201551_	1106	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCTGGC	GAACGT	1164
Epichloë_festucae_AR1	1102	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCTCTAGGAGGCACAGCCGGC	CAACGT	1160
Epichloë_festucae_AR37	605	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCTCTAGGAGGCACAGCCGGC	CAACGT	663
Epichloë_festucae_AR48	1102	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCTCTAGGAGGCACAGCCGGC	CAACGT	1160
Epichloë_festucae_E2368	1141	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCTCTAGGAGGCACAGCCGGC	CAACGT	1199
Epichloë_festucae_Fg1	1102	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCTCTAGGAGGCACAGCCGGC	CAACGT	1160
Epichloë_festucae_FI1	1140	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCTCTAGGAGGCACAGCCGGC	CAACGT	1198
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	1208	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCTGGC	GAACGT	1266
Epichloë_inebrians_MYA-1228_	1141	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCCGGC	CAACGT	1199
Epichloë_mollis_AL9924_	1169	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCCGGC	GAACGT	1227
Epichloë_typhina_ATCC_200736_	1135	CAGTTGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCCGGC	CAACGT	1193
Epichloë_typhina_subsp_poae	1145	CAGTCGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCCGGC	CAACGT	1203
Epichloë_typhina_subsp_Poae_Ps1	1140	CAGTTGTGAG	AGAGGCGGAGCA	-TCGGCAAA	CACCGCTAGGAGGCACAGCCGGC	CAACGT	1198
Epichloë_uncinata_CBS_102646_	1144	CAGTCGTGAG	AGAGGCGGAGCA	-TCGTCAAA	CACCGCTAGGAGGCACAGCCGGC	CAACGT	1202
Epichloë_amarillans_E57_	1179	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1238
Epichloë_amarillans_E4668_	1175	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1234
Epichloë_aotearoae_MYA-1229_	1192	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1251
Epichloë_brachelytri_E4804_	1176	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1235
Epichloë_bromicola_AL0434_	1219	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1278
Epichloë_bromicola_AL04262_	1222	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1281
Epichloë_elymi_ATCC_201551_	1165	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1224
Epichloë_festucae_AR1	1161	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1220
Epichloë_festucae_AR37	664	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	723
Epichloë_festucae_AR48	1161	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1220
Epichloë_festucae_E2368	1200	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1259
Epichloë_festucae_Fg1	1161	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1220
Epichloë_festucae_FI1	1199	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1258
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	1267	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1326
Epichloë_inebrians_MYA-1228_	1200	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1259
Epichloë_mollis_AL9924_	1287	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1287
Epichloë_typhina_ATCC_200736_	1194	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1253
Epichloë_typhina_subsp_poae	1204	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1263
Epichloë_typhina_subsp_Poae_Ps1	1199	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1258
Epichloë_uncinata_CBS_102646_	1203	CTCTCCGAAC	AGAGTTTCAGG	AGCTTTT	AGTGGCGATAACGAGTTTTTCAAC	GGGATAC	1262

Chapter eight: Appendices

<i>Epichloë amarillans_E57_</i>	1239	AAGGATTATGCGATCAGTCGAGATTCTCGGGATACGAGCATGACATGACACTATCCGAAATG	1298
<i>Epichloë amarillans_E4668_</i>	1235	AAGGATTATGGATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCTGAAATG	1294
<i>Epichloë aotearoae_MYA-1229_</i>	1252	AATGCATATGGATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1311
<i>Epichloë brachyleytrii_E4804_</i>	1236	AATGCATATGGATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1295
<i>Epichloë bromicola_AL0434_</i>	1279	AAGACATATGGATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1338
<i>Epichloë bromicola_AL04262_</i>	1282	AAGACATATGGATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1341
<i>Epichloë elymi_ATCC_201551_</i>	1225	AAGACATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1284
<i>Epichloë festucae_AR1_</i>	1221	AATACATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1280
<i>Epichloë festucae_AR37_</i>	724	AATACATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	783
<i>Epichloë festucae_AR48_</i>	1221	AATACATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1280
<i>Epichloë festucae_E2368_</i>	1260	AATACATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1319
<i>Epichloë festucae_Fg1_</i>	1221	AATACATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1280
<i>Epichloë festucae_F11_</i>	1259	AATACATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1318
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	1327	AAGACATATGCATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1386
<i>Epichloë inebrians_MYA-1228_</i>	1260	AAGACATATGCATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1319
<i>Epichloë mollis_AL9924_</i>	1288	GACGAGTATGCATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1347
<i>Epichloë typhina_ATCC_200736_</i>	1254	AATGCATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1313
<i>Epichloë typhina_subsp_poae</i>	1264	AATGCATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1323
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1259	AATGCATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1318
<i>Epichloë uncinata_CBS_102646_</i>	1263	AATGCATATGAATCAGTCGAGATTTCGGGATACGAGCATGACATGACACTATCCGAAATG	1322
<i>Epichloë amarillans_E57_</i>	1299	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1358
<i>Epichloë amarillans_E4668_</i>	1295	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1354
<i>Epichloë aotearoae_MYA-1229_</i>	1312	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1371
<i>Epichloë brachyleytrii_E4804_</i>	1296	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1355
<i>Epichloë bromicola_AL0434_</i>	1339	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1398
<i>Epichloë bromicola_AL04262_</i>	1342	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1401
<i>Epichloë elymi_ATCC_201551_</i>	1285	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1344
<i>Epichloë festucae_AR1_</i>	1281	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1340
<i>Epichloë festucae_AR37_</i>	784	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	843
<i>Epichloë festucae_AR48_</i>	1281	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1340
<i>Epichloë festucae_E2368_</i>	1320	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1379
<i>Epichloë festucae_Fg1_</i>	1281	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1340
<i>Epichloë festucae_F11_</i>	1319	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1378
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	1387	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1446
<i>Epichloë inebrians_MYA-1228_</i>	1320	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1379
<i>Epichloë mollis_AL9924_</i>	1348	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1407
<i>Epichloë typhina_ATCC_200736_</i>	1314	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1373
<i>Epichloë typhina_subsp_poae</i>	1324	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1383
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1319	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1378
<i>Epichloë uncinata_CBS_102646_</i>	1323	GTACAGTTGTTGCACCGATCGTCGACAAGCTTGACGCAAAATCCACAAGGAGCATTGCTT	1382
<i>Epichloë amarillans_E57_</i>	1359	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1418
<i>Epichloë amarillans_E4668_</i>	1355	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1414
<i>Epichloë aotearoae_MYA-1229_</i>	1372	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1431
<i>Epichloë brachyleytrii_E4804_</i>	1356	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1415
<i>Epichloë bromicola_AL0434_</i>	1399	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1458
<i>Epichloë bromicola_AL04262_</i>	1402	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1461
<i>Epichloë elymi_ATCC_201551_</i>	1345	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1404
<i>Epichloë festucae_AR1_</i>	1341	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1403
<i>Epichloë festucae_AR37_</i>	844	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	900
<i>Epichloë festucae_AR48_</i>	1341	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1400
<i>Epichloë festucae_E2368_</i>	1380	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1439
<i>Epichloë festucae_Fg1_</i>	1341	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1400
<i>Epichloë festucae_F11_</i>	1379	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1438
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	1447	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1506
<i>Epichloë inebrians_MYA-1228_</i>	1380	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1439
<i>Epichloë mollis_AL9924_</i>	1408	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1467
<i>Epichloë typhina_ATCC_200736_</i>	1374	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1433
<i>Epichloë typhina_subsp_poae</i>	1384	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1443
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1379	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1438
<i>Epichloë uncinata_CBS_102646_</i>	1383	CGTCGCATTGAACCTGGCCAGAAAGGAGTTGTTCAATGAGTCTGCTGGCAGAAAACCAAC	1442
<i>Epichloë amarillans_E57_</i>	1419	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1478
<i>Epichloë amarillans_E4668_</i>	1415	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1474
<i>Epichloë aotearoae_MYA-1229_</i>	1432	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1491
<i>Epichloë brachyleytrii_E4804_</i>	1416	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1475
<i>Epichloë bromicola_AL0434_</i>	1459	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1518
<i>Epichloë bromicola_AL04262_</i>	1462	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1521
<i>Epichloë elymi_ATCC_201551_</i>	1405	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1464
<i>Epichloë festucae_AR1_</i>	1401	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1460
<i>Epichloë festucae_AR37_</i>	904	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	963
<i>Epichloë festucae_AR48_</i>	1401	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1460
<i>Epichloë festucae_E2368_</i>	1440	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1499
<i>Epichloë festucae_Fg1_</i>	1401	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1460
<i>Epichloë festucae_F11_</i>	1439	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1498
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	1507	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1566
<i>Epichloë inebrians_MYA-1228_</i>	1440	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1499
<i>Epichloë mollis_AL9924_</i>	1468	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1527
<i>Epichloë typhina_ATCC_200736_</i>	1434	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1493
<i>Epichloë typhina_subsp_poae</i>	1444	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1503
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1439	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1498
<i>Epichloë uncinata_CBS_102646_</i>	1443	GACGTCATTGCTATGTTCCAAGATATGGGGGGTTATACGAAACCTATGCCACAAGACATT	1502
<i>Epichloë amarillans_E57_</i>	1479	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1538
<i>Epichloë amarillans_E4668_</i>	1475	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1534
<i>Epichloë aotearoae_MYA-1229_</i>	1492	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1551
<i>Epichloë brachyleytrii_E4804_</i>	1476	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1535
<i>Epichloë bromicola_AL0434_</i>	1519	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1578
<i>Epichloë bromicola_AL04262_</i>	1522	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1581
<i>Epichloë elymi_ATCC_201551_</i>	1465	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1524
<i>Epichloë festucae_AR1_</i>	1461	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1520
<i>Epichloë festucae_AR37_</i>	964	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1023
<i>Epichloë festucae_AR48_</i>	1461	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1520
<i>Epichloë festucae_E2368_</i>	1500	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1559
<i>Epichloë festucae_Fg1_</i>	1461	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1520
<i>Epichloë festucae_F11_</i>	1499	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1558
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	1567	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1626
<i>Epichloë inebrians_MYA-1228_</i>	1500	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1559
<i>Epichloë mollis_AL9924_</i>	1528	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1587
<i>Epichloë typhina_ATCC_200736_</i>	1494	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1553
<i>Epichloë typhina_subsp_poae</i>	1504	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1563
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1499	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1558
<i>Epichloë uncinata_CBS_102646_</i>	1503	CTTCTCCATGCAATTCGGATGAGTATGGCGGGCGGCGTTGCTATCCTCTGGTCTACGCC	1562

Chapter eight: Appendices

<i>Epichloë amarillans_E57</i>	1539	ATGTCAGTGGCACTGGCATCGTCGGAATTTCGG	C-----	ATTGACCAACTCTGC	1586
<i>Epichloë amarillans_E4668</i>	1535	ATGTCAGTGGCACTGGCATCGTCGGAATTTCGG	C-----	ATTGACCAACTCTGC	1582
<i>Epichloë aotearoae_MYA-1229</i>	1552	ATGTCAGTGGCACTGGCATCGTCGGAATTTCGG	C-----	ATTGACCAACTCTGC	1599
<i>Epichloë brachelytri_E4804</i>	1536	ATGTCAGTGGCACTGGCATCGTCGGAATTTCGG	C-----	ATTGACCAACTCTGC	1583
<i>Epichloë bromicola_AL0434</i>	1579	ATGTCAGTGGCACTAGCAACGTCGGATTTCGG	-----	CATTGACCAACTCTGC	1626
<i>Epichloë bromicola_AL04262</i>	1582	ATGTCAGTGGCACTAGCAACGTCGGATTTCGG	--C-----	ATTGACCAACTCTGC	1629
<i>Epichloë elymi_ATCC_201551</i>	1525	ATGTCAGTGGCACTAGCAACGTCGGATTTCGG	-----	CATTGACCAACTCTGC	1572
<i>Epichloë festucae_AR1</i>	1521	ATGTCAGTGGCACTGGCATCGTCGGATTTCGG	-----	CATTGACCAACTCTGC	1568
<i>Epichloë festucae_AR37</i>	1024	ATGTCAGTGGCACTGGCATCGTCGGATTTCGG	-----	CATTGACCAACTCTGC	1071
<i>Epichloë festucae_AR48</i>	1521	ATGTCAGTGGCACTGGCATCGTCGGATTTCGG	-----	CATTGACCAACTCTGC	1568
<i>Epichloë festucae_E2368</i>	1560	ATGTCAGTGGCACTGGCATCGTCGGAATTTCGG	-----	CATTGACCAACTCTGC	1607
<i>Epichloë festucae_Fg1</i>	1521	ATGTCAGTGGCACTGGCATCGTCGGATTTCGG	C-----	ATTGACCAACTCTGC	1568
<i>Epichloë festucae_Fl1</i>	1559	ATGTCAGTGGCACTGGCATCGTCGGATTTCGG	C-----	ATTGACCAACTCTGC	1606
<i>Epichloë gansuensis_e7080</i>					
<i>Epichloë glyceriae_ATCC_200747</i>	1627	ATGTCAGTGGCACTGGCTCGTCGGATTTCGG	C-----	ATTGATCAACTCTGC	1674
<i>Epichloë inebrians_MYA-1228</i>	1560	ATGTCAGTGGCAATTGGCATCGTCGGATTTCGG	CATTGATTTTCGT	CATTGACCAACTCTGC	1619
<i>Epichloë mollis_AL9924</i>	1588	ATGTCAGTGGCACTGGCATCGTCGGAATTTCGG	-----	CATTGACCAACTCTGC	1635
<i>Epichloë typhina_ATCC_200736</i>	1554	ATGTCAGTGGCACTGGCATCGTCGGAATTTCGG	-----	CATTGACCAACTCTGC	1601
<i>Epichloë typhina_subsp_poae</i>	1564	ATGTCAGTGGCACTGGCATCGTCGGAATTCGG	-----	CATTGATCAACTCTGC	1611
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1559	ATGTCAGTGGCACTGGCATCGTCGGAATTCGG	-----C-----	ATTGACGCAACTCTGC	1606
<i>Epichloë uncinata_CBS_102646</i>	1563	ATGTCAGTGGCACTGGCATCGTCGGAATTCGG	-----	CATTGACCAACTCTGC	1610
<i>Epichloë amarillans_E57</i>	1587	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATGAATCCGACATGAAGAAATGCCAAGTTGCTC			1646
<i>Epichloë amarillans_E4668</i>	1583	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATGAATCCGACATGAAGAAATGCCAAGTTGCTC			1642
<i>Epichloë aotearoae_MYA-1229</i>	1600	GCCAAAGCTGGTCGGCCTCTCCCTAACAGTGCAGCCGACATGAAGAACGCCGAATTTGCTC			1659
<i>Epichloë brachelytri_E4804</i>	1584	GCCAAAGCTGGTCGGCCTCTCCCTAACAGTGCAGCCGACATGAAGAACGCCGAATTTGCTC			1643
<i>Epichloë bromicola_AL0434</i>	1627	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATGAATCCGACATGAAGAAATGCCAAGTTGCTC			1686
<i>Epichloë bromicola_AL04262</i>	1630	GCCAAAGCTGGTCGGCCTCTCCCTAACAGTGAATCCGACATGAAGAAATGCCAAGTTGCTC			1689
<i>Epichloë elymi_ATCC_201551</i>	1573	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATGAATCCGACATGAAGAAATGCCAAGTTGCTC			1632
<i>Epichloë festucae_AR1</i>	1569	GCCAAAGCTGGTCGGTCTCTCCCTAACAAATCAAGCCGACATGAAGAACGCCGAGTTGCTC			1628
<i>Epichloë festucae_AR37</i>	1072	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATCAAGCCGACATGAAGAACGCCGAGTTGCTC			1131
<i>Epichloë festucae_AR48</i>	1569	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATCAAGCCGACATGAAGAACGCCGAGTTGCTC			1628
<i>Epichloë festucae_E2368</i>	1608	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATCAAGCCGACATGAAGAACGCCGTTGTTGCTC			1667
<i>Epichloë festucae_Fg1</i>	1569	GCCAAAGCTGGTCGGTCTCTCCCTAACAAATCAAGCCGACATGAAGAACGCCGAGTTGCTC			1628
<i>Epichloë festucae_Fl1</i>	1607	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATCAAGCCGACATGAAGAACGCCGTTGTTGCTC			1666
<i>Epichloë gansuensis_e7080</i>					
<i>Epichloë glyceriae_ATCC_200747</i>	1675	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATGAAGCCGACATGAGGAATGCCAGTTGTTGCTC			1734
<i>Epichloë inebrians_MYA-1228</i>	1620	GCCAAAGCTAGTCGCCCTCTCCCTAACAAATGAATCCGACATGATGAATGCCGAGTTGTTGCTC			1679
<i>Epichloë mollis_AL9924</i>	1636	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATCAAGCCGACATGAAGAACGCCGAGTTGCTC			1695
<i>Epichloë typhina_ATCC_200736</i>	1602	GCCAAAGCTGGTTGGCCTCTCCCTGACAAATGAGCCGACATGAAGAACGCCAGTTGCTC			1661
<i>Epichloë typhina_subsp_poae</i>	1612	GCCAAAGCTGGTCGGCCTCTCCCTAACAAATCAAGCCGACATGAGAACGCCGAGTTGTTGCTC			1671
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1607	GCCAAAGCTGGTTGGCCTCTCCCTAACAAATGAGCCGACATGAAGAACGCCAGTTGTTGCTC			1666
<i>Epichloë uncinata_CBS_102646</i>	1611	GCCAAAGCTGGTTGGCCTCTCCCTAACAAATGAGCCGACATGAAGAACGCCAGTTGTTGCTC			1670
<i>Epichloë amarillans_E57</i>	1647	AAGCGATGTTTGAAGATCTTCACACCAGCTACCAAGCAGCAGAGGCTTCAAGACCCATC			1706
<i>Epichloë amarillans_E4668</i>	1643	AAGCGATGTTTGAAGATCTTCACACCAGCTACCAAGCAGCAGAGGCTTCAAGACCCATC			1702
<i>Epichloë aotearoae_MYA-1229</i>	1660	AAGCGATGCTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCCATC			1719
<i>Epichloë brachelytri_E4804</i>	1644	AAGCGATGCTTGAAGATCTTCACACCAGCTACCCGAGCAGCAGGCTTCAAGACCTATC			1703
<i>Epichloë bromicola_AL0434</i>	1687	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCCATC			1746
<i>Epichloë bromicola_AL04262</i>	1690	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCCATC			1749
<i>Epichloë elymi_ATCC_201551</i>	1633	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCCATC			1692
<i>Epichloë festucae_AR1</i>	1629	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCCATC			1688
<i>Epichloë festucae_AR37</i>	1132	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGGCCATC			1191
<i>Epichloë festucae_AR48</i>	1629	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGGCCATC			1688
<i>Epichloë festucae_E2368</i>	1668	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCCATC			1727
<i>Epichloë festucae_Fg1</i>	1629	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCCATC			1688
<i>Epichloë festucae_Fl1</i>	1667	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCCATC			1726
<i>Epichloë gansuensis_e7080</i>					
<i>Epichloë glyceriae_ATCC_200747</i>	1735	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCCATC			1794
<i>Epichloë inebrians_MYA-1228</i>	1680	AAGCGATGTTTGAAGATCTTCACACCAGTTACCCAGCAGCTCAGGCTTCAAGACCCATC			1739
<i>Epichloë mollis_AL9924</i>	1696	AAGCGATGTTTGAAGATCTTCACACCAGCTACCTAGCAGCAGAGGCTTCAAGACCCATC			1755
<i>Epichloë typhina_ATCC_200736</i>	1662	AAGCGATGTTTGAAGATCTTCACACCAGCTACTAGCAGCAGAGGCTTCAAGACCAATC			1721
<i>Epichloë typhina_subsp_poae</i>	1672	AAGCATGTTTGAAGATCTTCACACCAGCTACCCAGCAAGCAATGCTTCAAGACCCATC			1731
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1667	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCAATC			1726
<i>Epichloë uncinata_CBS_102646</i>	1671	AAGCGATGTTTGAAGATCTTCACACCAGCTACCCAGCAGCAGAGGCTTCAAGACCAATC			1730
<i>Epichloë amarillans_E57</i>	1707	GGCAATATGACGCTTGAGGAGGCCGTGCGCATGCTCGAGAAAAGCACCAGAACCCACCATA			1766
<i>Epichloë amarillans_E4668</i>	1703	GGCAATATGACGCTTGAGGAGGCCGTGCGCATGCTCGAGAAAAGCACCAGAACCCACCATA			1762
<i>Epichloë aotearoae_MYA-1229</i>	1720	GGCAATATGACGCTTGAGGAGGCCGTGAGGCTGCTCGAGAAAAGCACCAGAACCCACCACA			1779
<i>Epichloë brachelytri_E4804</i>	1704	GGCAATATGACGCTTGAGGAGGCCGTGAGGCTGCTGAGAAAAGCACCAGAACCCACCACA			1763
<i>Epichloë bromicola_AL0434</i>	1747	GGCAAGATGACGCTTGAGGAGGCCGTGAGCATGCTCGAGAAAAGCACCAGAACCCACCACA			1806
<i>Epichloë bromicola_AL04262</i>	1750	GGCAAGATGACGCTTGAGGAGGCCGTGAGCATGCTCGAGAAAAGCACCAGAACCCACCACA			1809
<i>Epichloë elymi_ATCC_201551</i>	1693	GGCAATACGACGCTGGAAGGCCGTGCGCATGCTCGAGAAAAGCACCAGAACCCACCACA			1752
<i>Epichloë festucae_AR1</i>	1689	GGCAATATGACGCTTGAGGAGGCCGTGAGCATGCTCGAGAAAGCACCAGAACCCACCACA			1748
<i>Epichloë festucae_AR37</i>	1192	GGCAATATGACGCTTGAGGAGGCCGTGAGCATGCTCGAGAGAGCACCAGAACCCACCACA			1251
<i>Epichloë festucae_AR48</i>	1689	GGCAATATGACGCTTGAGGAGGCCGTGAGCATGCTCGAGAGAGCACCAGAACCCACCACA			1748
<i>Epichloë festucae_E2368</i>	1728	GGCAATATGACGCTTGAGGAGGCCGTGAGCATGCTCGAGAGAGCACCAGAACCCACCACA			1787
<i>Epichloë festucae_Fg1</i>	1689	GGCAATATGACGCTTGAGGAGGCCGTGAGCATGCTCGAGAGAGCACCAGAACCCACCACA			1748
<i>Epichloë festucae_Fl1</i>	1727	GGCAATATGACGCTTGAGGAGGCCGTGAGCATGCTCGAGAGAGCACCAGAACCCACCACA			1786
<i>Epichloë gansuensis_e7080</i>					
<i>Epichloë glyceriae_ATCC_200747</i>	1795	GGCAATATGACGCTTGAGGAGGCCGTGAGGCTGCTCGAGAAAAGCACCAGAACCCACCACA			1854
<i>Epichloë inebrians_MYA-1228</i>	1740	GGCAATGATGACGCTTGAGGAGGCCGTGAGCATACTCGAGAAAAGCACCAGAACCCACCACA			1799
<i>Epichloë mollis_AL9924</i>	1756	GGCAATATGACGCTTGAGGAGGCCGTGAGCATGCTCGAGAAAAGCACCAGAACCCACCACA			1815
<i>Epichloë typhina_ATCC_200736</i>	1722	GGCAATATGACGCTTGAGGAGGCCGTGAGGCTGCTCGAGAAAAGCACCAGAACCCACCACA			1781
<i>Epichloë typhina_subsp_poae</i>	1732	GGCAATATGACGCTTGAGGAGGCCATGAGGCTGCTCGAGAGAGCACCAGAACCCACCACA			1791
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1727	GGCAATATGACGCTTGAGGAGGCCGTGAGGCTGCTCGAGAAAAGCACCAGAACCCACCACA			1786
<i>Epichloë uncinata_CBS_102646</i>	1731	GGCAATATGACGCTTGAGGAGGCCGTGAGGCTGCTCGAGAAAAGCACCAGAACCCACCACA			1790
<i>Epichloë amarillans_E57</i>	1767	TTAGCAATGCACACAGAAGTACATTCGAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1826
<i>Epichloë amarillans_E4668</i>	1763	TTAGCAATGCACACAGAAGTACATTCGAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1822
<i>Epichloë aotearoae_MYA-1229</i>	1780	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1839
<i>Epichloë brachelytri_E4804</i>	1764	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1823
<i>Epichloë bromicola_AL0434</i>	1807	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1866
<i>Epichloë bromicola_AL04262</i>	1810	TTAGCAATGCACACAGAAGTACATGCAATGTTCTGGGCTTACAAGAATGGCAATTCA			1869
<i>Epichloë elymi_ATCC_201551</i>	1753	TTAGCAATGCACACGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1812
<i>Epichloë festucae_AR1</i>	1749	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1808
<i>Epichloë festucae_AR37</i>	1252	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1311
<i>Epichloë festucae_AR48</i>	1749	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1808
<i>Epichloë festucae_E2368</i>	1788	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1847
<i>Epichloë festucae_Fg1</i>	1749	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1808
<i>Epichloë festucae_Fl1</i>	1787	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1846
<i>Epichloë gansuensis_e7080</i>					
<i>Epichloë glyceriae_ATCC_200747</i>	1855	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1914
<i>Epichloë inebrians_MYA-1228</i>	1800	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACGAGGACTGGCAATTCA			1859
<i>Epichloë mollis_AL9924</i>	1816	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1875
<i>Epichloë typhina_ATCC_200736</i>	1782	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1841
<i>Epichloë typhina_subsp_poae</i>	1792	TTAGAGATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1851
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1787	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1846
<i>Epichloë uncinata_CBS_102646</i>	1791	TTAGCAATGCACACAGAAGTACATGCAATGTTGCTGGGCTTACAAGAATGGCAATTCA			1850

Chapter eight: Appendices

<i>Epichloë amarillans_E57_</i>	1827	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1886
<i>Epichloë amarillans_E4668_</i>	1823	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1882
<i>Epichloë aotearoae_MYA-1229_</i>	1840	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1899
<i>Epichloë brachyleytrii_E4804_</i>	1824	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1883
<i>Epichloë bromicola_AL0434_</i>	1867	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1926
<i>Epichloë bromicola_AL04262_</i>	1870	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1929
<i>Epichloë elymi_ATCC_201551_</i>	1813	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1872
<i>Epichloë festucae_AR1_</i>	1809	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1868
<i>Epichloë festucae_AR37_</i>	1312	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1371
<i>Epichloë festucae_AR48_</i>	1809	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1868
<i>Epichloë festucae_E2368_</i>	1848	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1907
<i>Epichloë festucae_Fg1_</i>	1809	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1868
<i>Epichloë festucae_F11_</i>	1847	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1906
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	1915	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1974
<i>Epichloë inebrians_MYA-1228_</i>	1860	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1919
<i>Epichloë mollis_AL9924_</i>	1876	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1935
<i>Epichloë typhina_ATCC_200736_</i>	1842	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1901
<i>Epichloë typhina_subsp_poa_</i>	1852	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1911
<i>Epichloë typhina_subsp_Poa_Ps1_</i>	1847	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1906
<i>Epichloë uncinata_CBS_102646_</i>	1851	ACCTCGTGGCATTTCTATGATCCGAACCTTCGCCATTGCCACGTTCAAGTCAGGGGAAGCG	1910
<i>Epichloë amarillans_E57_</i>	1887	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1946
<i>Epichloë amarillans_E4668_</i>	1883	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1942
<i>Epichloë aotearoae_MYA-1229_</i>	1900	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1959
<i>Epichloë brachyleytrii_E4804_</i>	1884	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1943
<i>Epichloë bromicola_AL0434_</i>	1927	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1986
<i>Epichloë bromicola_AL04262_</i>	1930	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1989
<i>Epichloë elymi_ATCC_201551_</i>	1873	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1932
<i>Epichloë festucae_AR1_</i>	1869	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1928
<i>Epichloë festucae_AR37_</i>	1372	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1431
<i>Epichloë festucae_AR48_</i>	1869	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1928
<i>Epichloë festucae_E2368_</i>	1908	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1967
<i>Epichloë festucae_Fg1_</i>	1869	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1928
<i>Epichloë festucae_F11_</i>	1907	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1966
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	1975	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	2034
<i>Epichloë inebrians_MYA-1228_</i>	1920	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1979
<i>Epichloë mollis_AL9924_</i>	1936	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1995
<i>Epichloë typhina_ATCC_200736_</i>	1902	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1961
<i>Epichloë typhina_subsp_poa_</i>	1912	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1971
<i>Epichloë typhina_subsp_Poa_Ps1_</i>	1907	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1966
<i>Epichloë uncinata_CBS_102646_</i>	1911	CTACTTTGAAGCCACCACCAAGTTTTCGAAGAGTCGGGATTTCGCCAAAGTCTACGAAGCC	1970
<i>Epichloë amarillans_E57_</i>	1947	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2006
<i>Epichloë amarillans_E4668_</i>	1943	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2002
<i>Epichloë aotearoae_MYA-1229_</i>	1960	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2019
<i>Epichloë brachyleytrii_E4804_</i>	1944	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2003
<i>Epichloë bromicola_AL0434_</i>	1987	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2046
<i>Epichloë bromicola_AL04262_</i>	1990	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2049
<i>Epichloë elymi_ATCC_201551_</i>	1933	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	1992
<i>Epichloë festucae_AR1_</i>	1929	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	1988
<i>Epichloë festucae_AR37_</i>	1432	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	1491
<i>Epichloë festucae_AR48_</i>	1929	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	1988
<i>Epichloë festucae_E2368_</i>	1968	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2027
<i>Epichloë festucae_Fg1_</i>	1929	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	1988
<i>Epichloë festucae_F11_</i>	1967	CAGGGTCAGACACCTAGTTTCGACTTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2026
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	2035	CAGGGTCAGACACCTAGTTTCGATTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2094
<i>Epichloë inebrians_MYA-1228_</i>	1980	CAGGGTCAGACACCTAGTTTCGATTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2039
<i>Epichloë mollis_AL9924_</i>	1996	CAGGGTCAGACACCTAGTTTCGATTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2055
<i>Epichloë typhina_ATCC_200736_</i>	1962	CAGGGTCAGACACCTAGTTTCGATTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2021
<i>Epichloë typhina_subsp_poa_</i>	1972	CAGGGTCAGACACCTAGTTTCGATTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2031
<i>Epichloë typhina_subsp_Poa_Ps1_</i>	1967	CAGGGTCAGACACCTAGTTTCGATTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2026
<i>Epichloë uncinata_CBS_102646_</i>	1971	CAGGGTCAGACACCTAGTTTCGATTTTTCGATATTGATCGGGAAGGGTGCTCGCATC	2029
<i>Epichloë amarillans_E57_</i>	2007	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2066
<i>Epichloë amarillans_E4668_</i>	2003	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2062
<i>Epichloë aotearoae_MYA-1229_</i>	2020	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2079
<i>Epichloë brachyleytrii_E4804_</i>	2040	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2063
<i>Epichloë bromicola_AL0434_</i>	2047	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2106
<i>Epichloë bromicola_AL04262_</i>	2050	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2109
<i>Epichloë elymi_ATCC_201551_</i>	1993	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2052
<i>Epichloë festucae_AR1_</i>	1989	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2048
<i>Epichloë festucae_AR37_</i>	1492	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	1551
<i>Epichloë festucae_AR48_</i>	1989	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2048
<i>Epichloë festucae_E2368_</i>	2028	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2087
<i>Epichloë festucae_Fg1_</i>	1989	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2048
<i>Epichloë festucae_F11_</i>	2027	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2086
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	2095	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2154
<i>Epichloë inebrians_MYA-1228_</i>	2040	ATATTGCACTACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAAACC	2099
<i>Epichloë mollis_AL9924_</i>	2056	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2115
<i>Epichloë typhina_ATCC_200736_</i>	2022	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGACCTGCTCGAGACC	2081
<i>Epichloë typhina_subsp_poa_</i>	2032	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGAGACCTGCTCGAGACC	2091
<i>Epichloë typhina_subsp_Poa_Ps1_</i>	2027	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGACCTGCTCGAGACC	2086
<i>Epichloë uncinata_CBS_102646_</i>	2030	GGATTTGACCAACAACCTTGACCGTCCGCCACCTGGTTACGCCCTGACCTGCTCGAGACC	2089
<i>Epichloë amarillans_E57_</i>	2067	ATAGCCTCCGAGCATAAATACGGCGAATTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2126
<i>Epichloë amarillans_E4668_</i>	2063	ATAGCCTCCGAGCATAAATACGGCGAATTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2122
<i>Epichloë aotearoae_MYA-1229_</i>	2080	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2139
<i>Epichloë brachyleytrii_E4804_</i>	2064	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2123
<i>Epichloë bromicola_AL0434_</i>	2107	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2166
<i>Epichloë bromicola_AL04262_</i>	2110	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2169
<i>Epichloë elymi_ATCC_201551_</i>	2053	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2112
<i>Epichloë festucae_AR1_</i>	2049	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2108
<i>Epichloë festucae_AR37_</i>	1552	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	1611
<i>Epichloë festucae_AR48_</i>	2049	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2108
<i>Epichloë festucae_E2368_</i>	2088	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2147
<i>Epichloë festucae_Fg1_</i>	2049	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2108
<i>Epichloë festucae_F11_</i>	2087	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2146
<i>Epichloë gansuensis_e7080_</i>			
<i>Epichloë glyceriae_ATCC_200747_</i>	2155	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2214
<i>Epichloë inebrians_MYA-1228_</i>	2100	GTAGCCTCTCAGCAGCAGCAGCGGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2159
<i>Epichloë mollis_AL9924_</i>	2116	ATAGCCTCCGAGCATAAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2175
<i>Epichloë typhina_ATCC_200736_</i>	2082	ATAGCCTCTGATCGTAAGACGGCGACTTTTCATACAGGATCCTGCGCAGTTGACATCTTCTCC	2141
<i>Epichloë typhina_subsp_poa_</i>	2092	ATAGCTTCCGAGCATAAATACGGCGAATTTTCATACAGGATCCTGCGCAGTTGACGCTTCTCC	2151
<i>Epichloë typhina_subsp_Poa_Ps1_</i>	2087	ATATACGCTGATCGTAAGACGGTGACTTTTCATACAGGATCCTGCGCAGTTGACATCTTCTCC	2146
<i>Epichloë uncinata_CBS_102646_</i>	2090	ATAGCCTCTGATCGTAAGACGGTGACTTTTCATACAGGATCCTGCGCAGTTGACATCTTCTCC	2149

Chapter eight: Appendices

Epichloë_amarillans_E57_	2127	CACAAC	TTTAGCGCCCAAAACCGAGCTTT	C	GGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2186	
Epichloë_amarillans_E4668_	2123	CACAAC	TTTAGCGCCCAAAACCGAGCTTT	C	GGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2182	
Epichloë_aotearoae_MYA-1229_	2140	CGCACT	TTTAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2199	
Epichloë_brachyelytri_E4804_	2124	CGCACT	TTTAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2183	
Epichloë_bromicola_AL0434_	2167	CGCACTTTT	CGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2218	
Epichloë_bromicola_AL04262_	2170	CGCACTTTT	CAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2229	
Epichloë_elymi_ATCC_201551_	2113	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGCTTGGGGAGGCAGCTTGG	2172	
Epichloë_festucaae_AR1	2109	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2168	
Epichloë_festucaae_AR37	1612	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	1671	
Epichloë_festucaae_AR48	2109	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2168	
Epichloë_festucaae_E2368	2148	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2207	
Epichloë_festucaae_Fg1	2109	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2168	
Epichloë_festucaae_Fl1	2147	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2206	
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	2215	CGCGCTTTT	CAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2274	
Epichloë_inebrians_MYA-1228_	2160	GACGCTTTT	TAGCGCCCAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2219	
Epichloë_mollis_AL9924_	2176	CGCAATTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2235	
Epichloë_typhina_ATCC_200736_	2142	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGCTTGGGGAGGCAGCTTGG	2201	
Epichloë_typhina_subsp_poae	2152	CACAGTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGCTTGGGGAGGCAGCTTGG	2211	
Epichloë_typhina_subsp_Poae_Ps1	2147	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGCTTGGGGAGGCAGCTTGG	2206	
Epichloë_uncinata_CBS_102646_	2150	CGCACTTTT	TAGCGCCCAAAACCGAGCTTT	T	TGAAATCTTGGGCTTGGGGAGGCAGCTTGG	2209	
Epichloë_amarillans_E57_	2187	CGCGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2246	
Epichloë_amarillans_E4668_	2183	CGCGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2242	
Epichloë_aotearoae_MYA-1229_	2200	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2259	
Epichloë_brachyelytri_E4804_	2184	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2243	
Epichloë_bromicola_AL0434_	2227	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2286	
Epichloë_bromicola_AL04262_	2230	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2289	
Epichloë_elymi_ATCC_201551_	2173	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2232	
Epichloë_festucaae_AR1	2169	CACGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2228	
Epichloë_festucaae_AR37	1672	CACGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	1731	
Epichloë_festucaae_AR48	2169	CACGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2228	
Epichloë_festucaae_E2368	2208	CACGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2267	
Epichloë_festucaae_Fg1	2169	CACGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2228	
Epichloë_festucaae_Fl1	2207	CACGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2266	
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	2275	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGCT	GGGTGAGCACTGGATGCCAT	2334	
Epichloë_inebrians_MYA-1228_	2220	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2279	
Epichloë_mollis_AL9924_	2236	CGCGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2295	
Epichloë_typhina_ATCC_200736_	2202	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2261	
Epichloë_typhina_subsp_poae	2212	CGCGATGCC	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2271	
Epichloë_typhina_subsp_Poae_Ps1	2207	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2266	
Epichloë_uncinata_CBS_102646_	2210	CGCGATGCT	CACAGCCAGGCTGGAAGAAAGCACT	TGGTAT	GGGTGAGCACTGGATGCCAT	2269	
Epichloë_amarillans_E57_	2247	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2306	
Epichloë_amarillans_E4668_	2243	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2302	
Epichloë_aotearoae_MYA-1229_	2260	CTTGAAACGCT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2319	
Epichloë_brachyelytri_E4804_	2244	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2303	
Epichloë_bromicola_AL0434_	2287	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2346	
Epichloë_bromicola_AL04262_	2290	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2349	
Epichloë_elymi_ATCC_201551_	2233	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2292	
Epichloë_festucaae_AR1	2229	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2288	
Epichloë_festucaae_AR37	1732	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	1791	
Epichloë_festucaae_AR48	2229	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2288	
Epichloë_festucaae_E2368	2268	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2327	
Epichloë_festucaae_Fg1	2229	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2288	
Epichloë_festucaae_Fl1	2267	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2326	
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	2335	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2394	
Epichloë_inebrians_MYA-1228_	2280	CTTGAAACGCT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2339	
Epichloë_mollis_AL9924_	2296	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2355	
Epichloë_typhina_ATCC_200736_	2262	CTTGAAACGCT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2321	
Epichloë_typhina_subsp_poae	2272	CTTGAAACGAT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2331	
Epichloë_typhina_subsp_Poae_Ps1	2267	CTTGAAACGCT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2326	
Epichloë_uncinata_CBS_102646_	2270	CTTGAAACGCT	GAAAGGAGGCGGTGAGAAAGGGT	CCTAT	GAGGTGCAATTCATCAATCT	2329	
Epichloë_amarillans_E57_	2307	AACAACAAGCAAT	GACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2366	
Epichloë_amarillans_E4668_	2303	AACAACAAGCAAT	GACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2362	
Epichloë_aotearoae_MYA-1229_	2320	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2379	
Epichloë_brachyelytri_E4804_	2304	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2363	
Epichloë_bromicola_AL0434_	2347	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2406	
Epichloë_bromicola_AL04262_	2350	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2409	
Epichloë_elymi_ATCC_201551_	2293	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2352	
Epichloë_festucaae_AR1	2289	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2348	
Epichloë_festucaae_AR37	1792	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	1851	
Epichloë_festucaae_AR48	2289	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2348	
Epichloë_festucaae_E2368	2328	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2387	
Epichloë_festucaae_Fg1	2289	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2348	
Epichloë_festucaae_Fl1	2327	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2386	
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	2395	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2454	
Epichloë_inebrians_MYA-1228_	2340	AAGAACAAGCAAT	GAGACCAAGTGGCTTACGACCA	AAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2399
Epichloë_mollis_AL9924_	2356	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2415	
Epichloë_typhina_ATCC_200736_	2322	AAGAACAAT	GAAATGAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2381	
Epichloë_typhina_subsp_poae	2332	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2391	
Epichloë_typhina_subsp_Poae_Ps1	2327	AAGAACAAT	GAAATGAGACCAAGTGGATTAGTACGGAAAGT	TCCGCT	CAAAGATTTCAAAG	2386	
Epichloë_uncinata_CBS_102646_	2330	AAGAACAAGCAAT	GAGACCAAGTGGATTAGTACGGAAAGT	CCCGCCAT	CAAAGATTTCAAAG	2389	
Epichloë_amarillans_E57_	2367	CGCGGCTCTT	GATGAGCACCTCAAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2426	
Epichloë_amarillans_E4668_	2363	CGCGGCTCTT	GATGAGCACCTCAAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2422	
Epichloë_aotearoae_MYA-1229_	2380	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2439	
Epichloë_brachyelytri_E4804_	2364	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2423	
Epichloë_bromicola_AL0434_	2407	CGCGGCTCTT	GATGAGCACCTCAAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2466	
Epichloë_bromicola_AL04262_	2410	CGCGGCTCTT	GATGAGCACCTCAAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2469	
Epichloë_elymi_ATCC_201551_	2353	CGCGGCTCTT	GATGAGCACCTCAAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2412	
Epichloë_festucaae_AR1	2349	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2408	
Epichloë_festucaae_AR37	1852	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	1911	
Epichloë_festucaae_AR48	2349	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2408	
Epichloë_festucaae_E2368	2388	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2447	
Epichloë_festucaae_Fg1	2349	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2408	
Epichloë_festucaae_Fl1	2387	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2446	
Epichloë_gansuensis_e7080_							
Epichloë_glyceriae_ATCC_200747_	2455	CGCGGCTCTT	GATGAGCACCTCGGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2514	
Epichloë_inebrians_MYA-1228_	2400	CGCGGCTCTT	GATGAGCACCTCAAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2459	
Epichloë_mollis_AL9924_	2416	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2475	
Epichloë_typhina_ATCC_200736_	2382	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2441	
Epichloë_typhina_subsp_poae	2392	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2451	
Epichloë_typhina_subsp_Poae_Ps1	2387	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2446	
Epichloë_uncinata_CBS_102646_	2390	CGCGGCTCTT	GATGAGCACCTCGAGACTCTAAGCAAAACAT	ACGAGTTT	GAGTCAGGGTCTG	2449	

Chapter eight: Appendices

Epichloë amarillans_E57_	2427	TTTATGCGGAAGGAAACCTGGC	ATACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2486
Epichloë amarillans_E4668_	2423	TTTATGCGGAAGGAAACCTGGC	ATACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2482
Epichloë aotearoae_MYA-1229_	2440	TTTATGCGGAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2499
Epichloë brachelytri_E4804_	2424	TTTATGCGGAGGAAACCTGGC	CACGCCGAAGCTATTGATGGCTTGAATGCAATGTTT	2483
Epichloë bromicola_AL0434_	2467	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2526
Epichloë bromicola_AL04262_	2470	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2529
Epichloë elymi_ATCC_201551_	2413	TTTATGCGGAGAGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2472
Epichloë festucae_AR1	2409	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2468
Epichloë festucae_AR37	1912	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	1971
Epichloë festucae_AR48	2409	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2468
Epichloë festucae_E2368	2448	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2507
Epichloë festucae_Fg1	2409	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2468
Epichloë festucae_F11	2447	TTTATGCGGAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2506
Epichloë gansuensis_e7080_				
Epichloë glyceriae_ATCC_200747_	2515	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2574
Epichloë inebrians_MYA-1228_	2460	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2519
Epichloë mollis_AL9924_	2476	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2535
Epichloë typhina_ATCC_200736_	2442	TTTATGCGGAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2501
Epichloë typhina_subsp_poa	2452	TTTATGCGGAAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2511
Epichloë typhina_subsp_Poa_Ps1	2447	TTTATGCGGAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2506
Epichloë uncinata_CBS_102646_	2450	TTTATGCGGAGGAAACCTGGC	CACGCCGAAGCCATTGATGGCTTGAATGCAATGTTT	2509
Epichloë amarillans_E57_	2487	ATTGTGAGAACATTGATAGAGCACTTTT	CCGCAAAAAGACTG-----AAGA-GAGC	2537
Epichloë amarillans_E4668_	2483	ATTGTGAGAACATTGATAGAGCACTTTT	CCGCAAAAAGACTG-----AAGA-GAGC	2533
Epichloë aotearoae_MYA-1229_	2500	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2550
Epichloë brachelytri_E4804_	2484	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2534
Epichloë bromicola_AL0434_	2527	ATTGTGAATAACTGATAGAGCACTTTT	CCGCAAAAAGACTG-----AAGA-GAGC	2577
Epichloë bromicola_AL04262_	2530	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2580
Epichloë elymi_ATCC_201551_	2473	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2523
Epichloë festucae_AR1	2469	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2519
Epichloë festucae_AR37	1972	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2022
Epichloë festucae_AR48	2469	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2519
Epichloë festucae_E2368	2508	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2558
Epichloë festucae_Fg1	2469	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2519
Epichloë festucae_F11	2507	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2557
Epichloë gansuensis_e7080_				
Epichloë glyceriae_ATCC_200747_	2575	ATTGTGAGAGCACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2625
Epichloë inebrians_MYA-1228_	2520	ATTGTGCAAACTGATAGAGCACTTTT	CCGCAAAAAGACTG-----AAGA-GAGC	2570
Epichloë mollis_AL9924_	2536	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2586
Epichloë typhina_ATCC_200736_	2502	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2561
Epichloë typhina_subsp_poa	2512	ATTGTGAGAACCTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2562
Epichloë typhina_subsp_Poa_Ps1	2507	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2557
Epichloë uncinata_CBS_102646_	2510	ATTGTGAGAACACTGATAGAGCACTTTT	CCGGCAAAAAGACTG-----AAGA-GAGC	2560
Epichloë amarillans_E57_	2538	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2595
Epichloë amarillans_E4668_	2534	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2591
Epichloë aotearoae_MYA-1229_	2551	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2608
Epichloë brachelytri_E4804_	2535	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2592
Epichloë bromicola_AL0434_	2578	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2635
Epichloë bromicola_AL04262_	2581	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2638
Epichloë elymi_ATCC_201551_	2524	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2581
Epichloë festucae_AR1	2520	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2577
Epichloë festucae_AR37	2023	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2080
Epichloë festucae_AR48	2520	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2577
Epichloë festucae_E2368	2559	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2616
Epichloë festucae_Fg1	2520	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2577
Epichloë festucae_F11	2558	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2615
Epichloë gansuensis_e7080_	1	-----ATG-GCTCAAGTAAGAGCTGCC-----	CTCTCTCTTT	32
Epichloë glyceriae_ATCC_200747_	2626	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2683
Epichloë inebrians_MYA-1228_	2571	AAGACCAACGTTGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCT--	2628
Epichloë mollis_AL9924_	2587	AAGACCAACGTTGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2644
Epichloë typhina_ATCC_200736_	2562	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2619
Epichloë typhina_subsp_poa	2563	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2620
Epichloë typhina_subsp_Poa_Ps1	2558	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2615
Epichloë uncinata_CBS_102646_	2561	AAGACCAACGCCGAGCTCGCAGACGGCGT	CAAGATACACAGCTATCTCAAGCTCACCC--	2618
Epichloë amarillans_E57_	2596	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGA	2650
Epichloë amarillans_E4668_	2592	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGA	2646
Epichloë aotearoae_MYA-1229_	2609	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGA	2663
Epichloë brachelytri_E4804_	2593	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGA	2647
Epichloë bromicola_AL0434_	2636	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2690
Epichloë bromicola_AL04262_	2639	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2693
Epichloë elymi_ATCC_201551_	2582	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2636
Epichloë festucae_AR1	2578	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2632
Epichloë festucae_AR37	2081	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2135
Epichloë festucae_AR48	2578	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2632
Epichloë festucae_E2368	2617	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2671
Epichloë festucae_Fg1	2578	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2632
Epichloë festucae_F11	2616	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2670
Epichloë gansuensis_e7080_	33	ATTTTGTG--CAGAAATTTGAC	GAATTGTTTCTCCATGATGGACTAAATC--	84
Epichloë glyceriae_ATCC_200747_	2684	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2738
Epichloë inebrians_MYA-1228_	2629	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2683
Epichloë mollis_AL9924_	2645	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2699
Epichloë typhina_ATCC_200736_	2620	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2674
Epichloë typhina_subsp_poa	2621	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2675
Epichloë typhina_subsp_Poa_Ps1	2616	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2670
Epichloë uncinata_CBS_102646_	2619	AGATGGGTACACAGACTTTG--	GGTGACGTAGAGAAGATGGTCAATCT--CGTCAAAGC	2673
Epichloë amarillans_E57_	2651	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2706
Epichloë amarillans_E4668_	2647	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2702
Epichloë aotearoae_MYA-1229_	2664	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2719
Epichloë brachelytri_E4804_	2648	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2703
Epichloë bromicola_AL0434_	2691	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2746
Epichloë bromicola_AL04262_	2694	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2749
Epichloë elymi_ATCC_201551_	2637	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2692
Epichloë festucae_AR1	2633	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2688
Epichloë festucae_AR37	2136	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2191
Epichloë festucae_AR48	2633	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2688
Epichloë festucae_E2368	2672	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2727
Epichloë festucae_Fg1	2633	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2688
Epichloë festucae_F11	2671	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2726
Epichloë gansuensis_e7080_	85	TATCTTTGCACTTACCAATCTGTC--ATTTGTCG--	AAATTTTCG--AAAGATCCC	135
Epichloë glyceriae_ATCC_200747_	2739	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2794
Epichloë inebrians_MYA-1228_	2684	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2739
Epichloë mollis_AL9924_	2700	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2755
Epichloë typhina_ATCC_200736_	2675	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2730
Epichloë typhina_subsp_poa	2676	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2731
Epichloë typhina_subsp_Poa_Ps1	2671	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2726
Epichloë uncinata_CBS_102646_	2674	TATGCTTG--AG-ACCGGGCAAGTGCCCAAATCGT	CGCTGTCAACTCTCGTCAAAGGTC--	2729

Chapter eight: Appendices

Epichloë_amarillans_E57_	2707	TTGGATATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2749
Epichloë_amarillans_E4668_	2703	TTGGATATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2745
Epichloë_aotearoae_MYA-1229_	2720	TTGGTAATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2762
Epichloë_brachelytri_E4804_	2704	TTGGTAATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2746
Epichloë_bromicola_AL0434_	2747	TTGGATATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2789
Epichloë_bromicola_AL04262_	2750	TTGGATACGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2792
Epichloë_elymi_ATCC_201551_	2693	TTGGATACGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2735
Epichloë_festucaae_AR1_	2689	TTGGTAATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2731
Epichloë_festucaae_AR37_	2192	TTGGTAATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2234
Epichloë_festucaae_AR48_	2689	TTGGTAATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2731
Epichloë_festucaae_E2368_	2728	TTGGTAATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2770
Epichloë_festucaae_Fg1_	2689	TTGGTAATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2731
Epichloë_festucaae_Fl1_	2727	TTGGTAATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2769
Epichloë_gansuensis_e7080_	136	CTTGCT--TTGATCAGGAAGCGGAACCATACTATGCCGTCTGTAGCTCTCTTTGAAATTC	193
Epichloë_glyceriae_ATCC_200747_	2795	TTGGAATGCCTCG-GAAG-GC-----T-T--CGGCGT--GCTCCTTGGCGGTGC	2837
Epichloë_inebrians_MYA-1228_	2740	TTGGAATGCATCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2782
Epichloë_mollis_AL9924_	2756	TTGGTAATGCCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2798
Epichloë_typhina_ATCC_200736_	2731	TTGGTAATGTTCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2773
Epichloë_typhina_subsp_poae_	2732	TTGGTAATGCCTCA-GAAG-GC-----T-T--CGGCGT--GCTCCTTGGCGGTGC	2774
Epichloë_typhina_subsp_Poae_Ps1_	2727	TTGGTAATGTTCTCA-GAAG-G-----CT-T--CGGCGT--GCTCCTTGGCGGTGC	2769
Epichloë_uncinata_CBS_102646_	2730	TTGGTAATGTTCTCA-GAAG-G--C-----T-T--CGGCGT--GCTCCTTGGCGGTGC	2772
Epichloë_amarillans_E57_	2750	CAACGTTGTTCTCGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCACAGAGAGCGCG	2808
Epichloë_amarillans_E4668_	2746	CAACGTTGTTCTCGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCACAGAGAGCGCG	2804
Epichloë_aotearoae_MYA-1229_	2763	CAACGTTGTTCTCGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCACAGAAAGCGCG	2821
Epichloë_brachelytri_E4804_	2747	CAACGTTATCTCTGACGCCCTTGAGCTTGCCCAAGGGACAATGATGCACAGAGAGCGCG	2805
Epichloë_bromicola_AL0434_	2790	CAACGTTATCTCTGAGCGCTACGAGCTTGCCCAAGGGACAATGATGTACAAAGAGCGCG	2848
Epichloë_bromicola_AL04262_	2793	CAACGTTGTTCTCGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCACAGAGAGCGCG	2851
Epichloë_elymi_ATCC_201551_	2736	CAACGTTGTTCTCGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCCAGAGAGCGCG	2794
Epichloë_festucaae_AR1_	2732	CAACGTTATCTCTGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCCAGAGAGCGCG	2790
Epichloë_festucaae_AR37_	2235	CAACGTTATCTCTGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCCAGAGAGCGCG	2293
Epichloë_festucaae_AR48_	2732	CAACGTTATCTCTGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCCAGAGAGCGCG	2790
Epichloë_festucaae_E2368_	2771	CAACGTTATCTCTGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCCAGAGAGCGCG	2829
Epichloë_festucaae_Fg1_	2732	CAACGTTATCTCTGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCCAGAGAGCGCG	2790
Epichloë_festucaae_Fl1_	2770	CAACGTTATCTCTGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCCAGAGAGCGCG	2828
Epichloë_gansuensis_e7080_	194	AAA-GTGGTTG---AGGTGTAACATATTGAAAGGAAGGACATTT-----CAGA-----	237
Epichloë_glyceriae_ATCC_200747_	2838	CAACGTTATCTCTGAGCGCTACGAGCTTGCCCAAGGGACAATGATGCCAGAGAGCGCG	2896
Epichloë_inebrians_MYA-1228_	2783	AGGTGTTATCTCTGAGCGCTTGAGCTTGCCCAAGGGACAATTTGCACAGAGAGCGCG	2841
Epichloë_mollis_AL9924_	2799	CAACGTTATCTCTGAGCGCTACGAGCTTGCCCAAGGGAAAATGATACACAGAGAGCGCG	2857
Epichloë_typhina_ATCC_200736_	2774	CAACGTTGTTCTCTGAGCGCTACGAGCTTGCCCAAGGGACAACGATGCACAGAAAGCGCG	2832
Epichloë_typhina_subsp_poae_	2775	CAACGTTATTTCTCGATGCTTACGAGCTTGCCCAAGGGACAATGATGCACAGAGAGCGCG	2833
Epichloë_typhina_subsp_Poae_Ps1_	2770	CAACGTTGTTCTCTGAGCGCTACGAGCTTGCCCAAGGGACAACGATGCACAGAAAGCGCG	2828
Epichloë_uncinata_CBS_102646_	2773	CAACGTTGTTCTCTGAGCGCTACGAGCTTGCCCAAGGGACAACGATGCACAGAAAGCGCG	2831
Epichloë_amarillans_E57_	2809	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2862
Epichloë_amarillans_E4668_	2805	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2858
Epichloë_aotearoae_MYA-1229_	2822	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2875
Epichloë_brachelytri_E4804_	2806	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2859
Epichloë_bromicola_AL0434_	2849	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACATTCTCTAGC-----AAGTGTGGTA	2902
Epichloë_bromicola_AL04262_	2852	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTATC-----AAGTGTGGTA	2905
Epichloë_elymi_ATCC_201551_	2795	TCTTTGGCACACAGTTAGCCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2848
Epichloë_festucaae_AR1_	2791	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2844
Epichloë_festucaae_AR37_	2294	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2347
Epichloë_festucaae_AR48_	2791	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2844
Epichloë_festucaae_E2368_	2830	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2883
Epichloë_festucaae_Fg1_	2791	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2844
Epichloë_festucaae_Fl1_	2829	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2882
Epichloë_gansuensis_e7080_	238	---TTTG---AGAGCGTGGGA---GATCCAGATACAC---CTAGCGTTTCGAAAT--CAGGTA	284
Epichloë_glyceriae_ATCC_200747_	2897	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2950
Epichloë_inebrians_MYA-1228_	2842	TCTTAGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTTGC-----AAGTGTGGTA	2895
Epichloë_mollis_AL9924_	2858	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2911
Epichloë_typhina_ATCC_200736_	2833	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2886
Epichloë_typhina_subsp_poae_	2834	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACATTCTCTAAC-----AAGTGTGGTA	2887
Epichloë_typhina_subsp_Poae_Ps1_	2829	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGCA-----AAGTGTGGTA	2882
Epichloë_uncinata_CBS_102646_	2832	TCTTTGGCACACAGTTGGCTTTTGATTTCGGTACAGTTCTCTAGC-----AAGTGTGGTA	2885
Epichloë_amarillans_E57_	2863	CTATTGGTGCCGGATTCTATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2918
Epichloë_amarillans_E4668_	2859	CTATTGGTGCCGGATTCTATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2914
Epichloë_aotearoae_MYA-1229_	2876	CTATTGGTGCCGGACTCATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2931
Epichloë_brachelytri_E4804_	2860	CTATTGGTGCCGGACTCATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2915
Epichloë_bromicola_AL0434_	2903	CTATTGGTGCCGGATTCTATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2958
Epichloë_bromicola_AL04262_	2906	CTATTGGTGCCGGCTTAATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2961
Epichloë_elymi_ATCC_201551_	2849	CTATTGGTGCCGGATTCTATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2904
Epichloë_festucaae_AR1_	2845	CGTGTGGTGCCGGACTCTTAGGAGGCACTACCGTCTGTCGCGG-----TCTGGGAGGCGT	2900
Epichloë_festucaae_AR37_	2348	CGTGTGGTGCCGGACTCTTAGGAGGCACTACCGTCTGTCGCGG-----TCTGGGAGGCGT	2403
Epichloë_festucaae_AR48_	2845	CGTGTGGTGCCGGACTCTTAGGAGGCACTACCGTCTGTCGCGG-----TCTGGGAGGCGT	2900
Epichloë_festucaae_E2368_	2884	CGTGTGGTGCCGGACTCTTAGGAGGCACTACCGTCTGTCGCGG-----TCTGGGAGGCGT	2939
Epichloë_festucaae_Fg1_	2845	CGTGTGGTGCCGGACTCTTAGGAGGCACTACCGTCTGTCGCGG-----TCTGGGAGGCGT	2900
Epichloë_festucaae_Fl1_	2883	CGTGTGGTGCCGGACTCTTAGGAGGCACTACCGTCTGTCGCGG-----TCTGGGAGGCGT	2938
Epichloë_gansuensis_e7080_	285	CGATGGATCTAGCGCT---GGCGCGGACACCGCTCTCGCGGTATTTCTGGGATA---C	336
Epichloë_glyceriae_ATCC_200747_	2951	CTATTGGTGCCGGACTCATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	3006
Epichloë_inebrians_MYA-1228_	2896	CTATTGGTGCCGGACTCATAGGAGGCACTACCGTCTGTCGCGG-----TCTGGGAGGCGT	2951
Epichloë_mollis_AL9924_	2912	CTATTGGTGCCGGATTCTATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2967
Epichloë_typhina_ATCC_200736_	2887	CTATTGGTGCCGGACTCATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2942
Epichloë_typhina_subsp_poae_	2888	CGTGTGGTGCCGGACTCATAGGAGGCACTACCGTCTGTCGCGG-----TCTGGGAGGCGT	2943
Epichloë_typhina_subsp_Poae_Ps1_	2883	CTATTGGTGCCGGACTCATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2938
Epichloë_uncinata_CBS_102646_	2886	CTATTGGTGCCGGACTCATAGGAGGCACTACCGCGTGCCTGCGG-----TCTGGGAGGCGT	2941
Epichloë_amarillans_E57_	2919	AGTGTTATTCTCGGAGGACTGCCATTGGCGTTGGCGGCTCTGTATCCGCTTTTGCAG	2976
Epichloë_amarillans_E4668_	2915	AGTGTTATTCTCGGAGGACTGCCATTGGCGTTGGCGGCTCTGTATCCGCTTTTGCAG	2972
Epichloë_aotearoae_MYA-1229_	2932	AGTGTTATTCTCGGAGGACTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2989
Epichloë_brachelytri_E4804_	2916	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2973
Epichloë_bromicola_AL0434_	2959	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCAACTTTGCAC	3016
Epichloë_bromicola_AL04262_	2962	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGCTTTGCAC	3019
Epichloë_elymi_ATCC_201551_	2905	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2962
Epichloë_festucaae_AR1_	2901	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2958
Epichloë_festucaae_AR37_	2404	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2461
Epichloë_festucaae_AR48_	2901	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2958
Epichloë_festucaae_E2368_	2940	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2997
Epichloë_festucaae_Fg1_	2901	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2958
Epichloë_festucaae_Fl1_	2939	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2996
Epichloë_gansuensis_e7080_	337	AATGG-AGGCGCGCAGGAAT---CTTGGACGCCCGCCCATATCGATATCC--CCAT--CAA	389
Epichloë_glyceriae_ATCC_200747_	3007	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	3064
Epichloë_inebrians_MYA-1228_	2952	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTATCATCCAACTATGCAC	3009
Epichloë_mollis_AL9924_	2968	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCACTTTGCAC	3025
Epichloë_typhina_ATCC_200736_	2943	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	3000
Epichloë_typhina_subsp_poae_	2944	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGTATCCGCTTTTGCAC	3001
Epichloë_typhina_subsp_Poae_Ps1_	2939	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2996
Epichloë_uncinata_CBS_102646_	2942	AGTGTTATTCTCGGAGGACTTGCCCTTTGGCGTTGGCGGCTCTGGCATCCGGCTTTGCAC	2999

Chapter eight: Appendices

Epichloë_amarillans_E57_	2977	AAATTGGCTGCAAAAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGGGGCC	3032		
Epichloë_amarillans_E4668_	2973	AAATTGGCTGCAAAAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGGGGCC	3028		
Epichloë_aotearoae_MYA-1229_	2990	AAATTGCCGAAAAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGGGGCC	3045		
Epichloë_brachelytri_E4804_	2974	AAATTGCCGAAAAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGGGGCC	3029		
Epichloë_bromicola_AL0434_	3017	GAATTGCTGAAAAAGCAGAGGCTGT	---	TGGTTCGCTATTTC	-GGTGATGCCCATACGCC	3072		
Epichloë_bromicola_AL04262_	3020	AAATTGCTGCAAAAAGCAGAGGCTGT	---	GGGTTCGCTATTTC	-GGTGACGCCGACAGGGCC	3075		
Epichloë_elymi_ATCC_201551_	2963	AAATTGCCGAAAAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	3018		
Epichloë_festucae_AR1	2959	AAATTGCCGCCCCAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	3014		
Epichloë_festucae_AR37	2462	AAATTGCCGCCCCAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	2517		
Epichloë_festucae_AR48	2959	AAATTGCCGCCCCAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	3014		
Epichloë_festucae_E2368	2998	AAATTGCCGCCCCAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	3053		
Epichloë_festucae_Fg1	2959	AAATTGCCGCCCCAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	3014		
Epichloë_festucae_F11	2997	AAATTGCCGCCCCAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	3052		
Epichloë_gansuensis_e7080_	390	AAAC--CCGCAACATGAGTTGCTTT	T	CAGGCACTCTCTCG	GTTTGTTCCTCATAG-T	446		
Epichloë_glyceriae_ATCC_200747_	3065	AAATTGCCGCAAAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACTACGCC	3120		
Epichloë_inebrians_MYA-1228_	3010	GAATTGCCGAGGACGCAAAAGGCTGT	---	GGGTAGCTATTTC	-GGTGACGCTGACACACGCC	3065		
Epichloë_mollis_AL9924_	3026	AAATTGCCGCAAAAAGCAGAGGCTGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACACGCC	3081		
Epichloë_typhina_ATCC_200736_	3001	AAATTGCCGCAAAAAGCAAGATATGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	3056		
Epichloë_typhina_subsp_poae	3002	AAATTGCCGCAAAAAGCAGAGGCTGT	---	GGGTTCGCTATTTC	-GGTGACGCTCAACGAGGCC	3057		
Epichloë_typhina_subsp_Poae_Ps1	2997	AAATTGCCGCAAAAAGCAAGATATGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	3057		
Epichloë_uncinata_CBS_102646_	3000	AAATTGCCGCAAAAAGCAAGATATGT	---	GGGTGCGCTATTTC	-GGTGACGCCGACGAGGCC	3055		
Epichloë_amarillans_E57_	3033	TACAAAGCTGGAGGAT	-TCAAGTACGATGAGAAGGATAAGATTCT	---	TG--TTCTCT	3085		
Epichloë_amarillans_E4668_	3029	TACAAAGCTGGAGGAT	-TCAAGTACGATGAGAAGGATAAGATTCT	---	TG--TTCTCT	3081		
Epichloë_aotearoae_MYA-1229_	3046	TACAAAGCTGGAGGAT	-TCAAGTACGATGGGACCATAGGATTCT	---	TG--TTCTCT	3098		
Epichloë_brachelytri_E4804_	3030	TACAAAGCTGGAGGAT	-TCAAGTACGACGAGGACCATAGGATTCT	---	TG--TTCTCT	3082		
Epichloë_bromicola_AL0434_	3073	TACAGAGCTGGAGGAT	-TCAAGCAGCATGAGAACCATAAGATTCT	---	TG--TTCTCT	3125		
Epichloë_bromicola_AL04262_	3076	TACAGAGCTGGAGGAT	-TCAAGTACGATGAGAACCAGAGATTCT	---	TG--TTCTCT	3128		
Epichloë_elymi_ATCC_201551_	3019	TACAAAGCTGGAGGAT	-TCAAGTACGATAGGAACCATAGGATTCT	---	TG--TGCCT	3071		
Epichloë_festucae_AR1	3015	TACAAAGCTGGAGGAT	-TCAAGTACGATGAGAACCATAAGATTCT	---	TG--TTCTCT	3067		
Epichloë_festucae_AR37	2518	TACAAAGCTGGAGGAT	-TCAAGTACGATGAGAACCATAAGATTCT	---	TG--TTCTCT	2570		
Epichloë_festucae_AR48	3015	TACAAAGCTGGAGGAT	-TCAAGTACGATGAGAACCATAAGATTCT	---	TG--TTCTCT	3067		
Epichloë_festucae_E2368	3054	TACAAAGCTGGAGGAT	-TCAAGTACGATGAGAACCATAAGATTCT	---	TG--TTCTCT	3106		
Epichloë_festucae_Fg1	3015	TACAAAGCTGGAGGAT	-TCAAGTACGATGAGAACCATAAGATTCT	---	TG--TGCCT	3067		
Epichloë_festucae_F11	3053	TACAAAGCTGGAGGAT	-TCAAGTACGATGAGAACCATAAGATTCT	---	TG--TTCTCT	3105		
Epichloë_gansuensis_e7080_	447	TACGAAGCTCAATGATA	AACAGTACCGTGTCTATCAC--	GACTCTCGAA	TGATAGCTCG	504		
Epichloë_glyceriae_ATCC_200747_	3121	TACAGGCTGGAGGAT	-TCAAGTACGATGGGAACCATGACATTCT	---	TG--TTCTCT	3173		
Epichloë_inebrians_MYA-1228_	3066	TACCGACATGGAGGAT	-TCGATACGATGAAAAACAAGATTCT	---	TG--TTCTCT	3118		
Epichloë_mollis_AL9924_	3082	TACAGAGCTGGAGGAT	-TCAAGTACGATGAGAATCATAGGCTCT	---	TG--TTCTCT	3134		
Epichloë_typhina_ATCC_200736_	3057	TACAGAGCTGGAGGAT	-TCAAGTACGATGAAGAGCATGACATTCT	---	TG--TTCTCT	3109		
Epichloë_typhina_subsp_poae	3058	TACAAAGCTGGAGGAT	-TCAAGTACGATGAAGAGCATGACATTCT	---	TG--TTCTCT	3110		
Epichloë_typhina_subsp_Poae_Ps1	3053	TACAAAGCTGGAGGAT	-TCAAGTACGATAGGACCATGGATTCT	---	TG--TTCTCT	3105		
Epichloë_uncinata_CBS_102646_	3056	TACAAAGCTGGAGGAT	-TCAAGTACGATAGGACCATGGATTCT	---	TG--TTCTCT	3108		
Epichloë_amarillans_E57_	3086	GTTTGGTGC	---	TGTCATCGCGGAAATCGA	---	C-GCGGCCGTAACGT	3129	
Epichloë_amarillans_E4668_	3082	GTTTGGTGC	---	TGTCATCGCGGAAATCGA	---	C-GCGGCCGTAACGT	3125	
Epichloë_aotearoae_MYA-1229_	3099	GTTTGGTGC	---	CGTCATCAGCGAAATCGA	---	C-GCGGCCGTAACGT	3142	
Epichloë_brachelytri_E4804_	3083	GTTTGGTGC	---	TGTCATCAGCGAAATCGA	---	C-GCGGCCGTAACGT	3126	
Epichloë_bromicola_AL0434_	3126	GTTTGGTGC	---	TGTCATCAGCGAAATCGA	---	C-GCGGCCGTAACGT	3169	
Epichloë_bromicola_AL04262_	3129	GTTTGGTGC	---	TGTCATCAGCGAAATCGA	---	C-GCGGCCGTAACGT	3172	
Epichloë_elymi_ATCC_201551_	3072	GTTTGGTGC	---	TGTCATCAGCGAAATCGA	---	C-GCGGCCGTAACGT	3115	
Epichloë_festucae_AR1	3068	GTTTGGTGC	---	TGTCATCAGCGAAGTCTGA	---	C-GCGGCCGTAACGT	3111	
Epichloë_festucae_AR37	2571	GTTTGGTGC	---	TGTCATCAGCGAAGTCTGA	---	C-GCGGCCGTAACGT	2614	
Epichloë_festucae_AR48	3068	GTTTGGTGC	---	TGTCATCAGCGAAGTCTGA	---	C-GCGGCCGTAACGT	3111	
Epichloë_festucae_E2368	3107	GTTTGGTGC	---	TGTCATCAGCGAAGTCTGA	---	C-GCGGCCGTAACGT	3150	
Epichloë_festucae_Fg1	3068	GTTTGGTGC	---	TGTCATCAGCGAAGTCTGA	---	C-GCGGCCGTAACGT	3111	
Epichloë_festucae_F11	3106	GTTTGGTGC	---	TGTCATCAGCGAAGTCTGA	---	C-GCGGCCGTAACGT	3149	
Epichloë_gansuensis_e7080_	505	ATGTTGTAGGCAAT	TGTCATCTGGCAATTGACTACA	GAGACTATAAAGATAC	GCGATGTG	564		
Epichloë_glyceriae_ATCC_200747_	3174	GTTTGGTGC	---	TGTCATCAGCGAAATCGA	---	C-GCGGCCGTAACGT	3217	
Epichloë_inebrians_MYA-1228_	3119	GAGAGGTGC	---	TGTCATCAGCAATCGA	---	C-GTGGCCGTAACGT	3162	
Epichloë_mollis_AL9924_	3135	GTTTGGTGC	---	TGTCATCAGCGAAGTCTGA	---	C-GCGGCCGTAACGT	3178	
Epichloë_typhina_ATCC_200736_	3110	GTTTGGTGC	---	TGTTATCAGCGAAATCGA	---	C-GCGGCCGTAACGT	3153	
Epichloë_typhina_subsp_poae	3111	GTTTGGTGC	---	TGTCATCAGCGAAGTCTGA	---	C-GCGGCCGTAACGT	3155	
Epichloë_typhina_subsp_Poae_Ps1	3106	GTTTGGTGC	---	TGTCATCAGCGAATCGA	---	C-GCGGCCGTAACGT	3149	
Epichloë_uncinata_CBS_102646_	3109	GTTTGGTGC	---	TGTCATCAGCGAATCGA	---	C-GCGGCCGTAACGT	3152	
Epichloë_amarillans_E57_	3130	AGTTCC	---	GAGCCAAATACAT	---	CTATCGCA-CGAGGCAGGATCCACA	3175	
Epichloë_amarillans_E4668_	3126	AGTTCC	---	GAGCCAAATACAT	---	CTATCGCA-CGAGGCAGGATCCACA	3171	
Epichloë_aotearoae_MYA-1229_	3143	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3188	
Epichloë_brachelytri_E4804_	3127	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3172	
Epichloë_bromicola_AL0434_	3170	AATTCC	---	GAGCCAAATATATAGATATAGCAG	CGCT--CAC--ATC	---	3209	
Epichloë_bromicola_AL04262_	3173	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3219	
Epichloë_elymi_ATCC_201551_	3116	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3162	
Epichloë_festucae_AR1	3112	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3158	
Epichloë_festucae_AR37	2615	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	2661	
Epichloë_festucae_AR48	3112	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3158	
Epichloë_festucae_E2368	3151	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3197	
Epichloë_festucae_Fg1	3112	AATTCC	---	C--AGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3157	
Epichloë_festucae_F11	3150	AATTCC	---	C--AGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3195	
Epichloë_gansuensis_e7080_	565	AGTTCTGGGATGGCT	TGCGCATTCATCGC	CTATCGCA	---	AAGGTG--ACT	612	
Epichloë_glyceriae_ATCC_200747_	3218	GATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3263	
Epichloë_inebrians_MYA-1228_	3163	AATTCC	---	CAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACGGCTG	3211	
Epichloë_mollis_AL9924_	3179	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CGAGACAGGATCCACA	3224	
Epichloë_typhina_ATCC_200736_	3154	AATTCC	---	C--AGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3199	
Epichloë_typhina_subsp_poae	3156	ATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3200	
Epichloë_typhina_subsp_Poae_Ps1	3150	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3195	
Epichloë_uncinata_CBS_102646_	3153	AATTCC	---	GAGCCAAATACAT	---	CTATCGCA-CCTGGCAGGATCCACA	3198	
Epichloë_amarillans_E57_	3176	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTTT	CCGGAATC	-ATCCACGA	3232	
Epichloë_amarillans_E4668_	3172	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTTT	CCGGAATG	-ATCCACGA	3228	
Epichloë_aotearoae_MYA-1229_	3189	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3245	
Epichloë_brachelytri_E4804_	3173	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3229	
Epichloë_bromicola_AL0434_	3210	-TTAGGCAT	CACTCA	AATAC--CTTC	---	C--CTATTT--AAGG	3250	
Epichloë_bromicola_AL04262_	3220	-TCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTTT	CCGGAATG	-ATCCACGA	3275	
Epichloë_elymi_ATCC_201551_	3163	-TCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTTT	CCGGAATG	-ATCCACGA	3218	
Epichloë_festucae_AR1	3159	-TCGGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3214	
Epichloë_festucae_AR37	2662	-TCGGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	2717	
Epichloë_festucae_AR48	3159	-TCGGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3214	
Epichloë_festucae_E2368	3198	-TCGGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3253	
Epichloë_festucae_Fg1	3158	GTCGGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3214	
Epichloë_festucae_F11	3196	ATCGGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3252	
Epichloë_gansuensis_e7080_	613	---	AGGCTG	---	TGTTTC	---	CAGAGA	646
Epichloë_glyceriae_ATCC_200747_	3264	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3320	
Epichloë_inebrians_MYA-1228_	3212	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTTT	CCGGAATG	-ATCCACGA	3268	
Epichloë_mollis_AL9924_	3225	ATGGGGCAGAA	---	ACTACTTCTTCTGGGCGGGCATTTT	CCGGAATG	-ATCCACGA	3278	
Epichloë_typhina_ATCC_200736_	3200	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3256	
Epichloë_typhina_subsp_poae	3201	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTTT	CCGGAATG	-ATCCACGA	3257	
Epichloë_typhina_subsp_Poae_Ps1	3196	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3252	
Epichloë_uncinata_CBS_102646_	3199	GTCAGGCAG	-AATCA-	ACTACTTCTTCTGGGCGGGCATTAAG	CCGGAATG	-ATCCACGA	3255	

Chapter eight: Appendices

Epichloë_amarillans_E57_	3233	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3286
Epichloë_amarillans_E4668	3229	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3282
Epichloë_aotearoae_MYA-1229_	3246	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3299
Epichloë_brachelyytrii_E4804_	3300	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3283
Epichloë_bromicola_AL0434_	3251	TTTACCGTGGCTTATAG	CT	TACCTTTAGCACTT	AGGGCAA	--	AGACCTTCTCTGCTTTTAT	3307	
Epichloë_bromicola_AL04262_	3276	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCTCCGGCCAGC	--	GGAAA	3329
Epichloë_elymi_ATCC_201551_	3219	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3272
Epichloë_festucaae_AR1	3215	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3268
Epichloë_festucaae_AR37	2718	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	2771
Epichloë_festucaae_AR48	3215	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3268
Epichloë_festucaae_E2368	3254	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3307
Epichloë_festucaae_Fg1	3215	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3268
Epichloë_festucaae_F11	3253	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3306
Epichloë_gansuensis_e7080_	647	AAGGTACTGTCCTGTA	--	TAATTTGCGCGG	GAAGGAAACAGTAT	ACCGAACTGG	--	GCCAG	703
Epichloë_glyceriae_ATCC_200747_	3321	CAAGTCCCAGGCTAT	--	TAAGTGTGCG	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3374
Epichloë_inebrians_MYA-1228_	3269	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCAGCCAGC	--	GGAAA	3322
Epichloë_mollis_AL9924_	3279	TAAGTCCCAGGCTAT	--	TAAGTGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3332
Epichloë_typhina_ATCC_200736_	3257	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3310
Epichloë_typhina_subsp_poae	3258	TAAATCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3311
Epichloë_typhina_subsp_Poae_Ps1	3253	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3306
Epichloë_uncinata_CBS_102646_	3256	TAAGTCCCAGGCTAT	--	TAATGTGCGA	--	GAAGGCATTGGAGCCCCGGCCAGC	--	GGAAA	3309
Epichloë_amarillans_E57_	3287	ACT-TGCGAATACTAGAGACTACA	--	CCACAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3342		
Epichloë_amarillans_E4668	3283	ACT-TGCGAATACTAGAGACTACA	--	CCACAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3338		
Epichloë_aotearoae_MYA-1229_	3300	ACT-TGCGAATACTAGAGACTACA	--	CCACAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3355		
Epichloë_brachelyytrii_E4804_	3284	ACT-TGCGAATACTAGAGACTACA	--	CCACAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3339		
Epichloë_bromicola_AL0434_	3308	CCTATGCGCTTATTT	--	ATACTACATATATAAAT	--	AGCCT---AGATA-GCTAAATACAT	3359		
Epichloë_bromicola_AL04262_	3330	ACT-TGCGAATACTAGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3385		
Epichloë_elymi_ATCC_201551_	3273	ACT-TGCGAATACTAGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3328		
Epichloë_festucaae_AR1	3269	ACT-TACGAATACTCGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3324		
Epichloë_festucaae_AR37	2772	ACT-TACGAATACTCGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	2827		
Epichloë_festucaae_AR48	3269	ACT-TACGAATACTCGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3324		
Epichloë_festucaae_E2368	3308	ACT-TACGAATACTCGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3363		
Epichloë_festucaae_Fg1	3269	ACT-TACGAATACTCGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3324		
Epichloë_festucaae_F11	3307	ACT-TACGAATACTCGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3362		
Epichloë_gansuensis_e7080_	704	A---GCGCTTGAT	TGAG-CGGGAG	CCAGAATCGT	ATGATATAAATCAAGTTCAA	-TGC	757		
Epichloë_glyceriae_ATCC_200747_	3375	ACT-TGCGAATACTAGAACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3430		
Epichloë_inebrians_MYA-1228_	3323	ACT-TGCGAATACTAGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3378		
Epichloë_mollis_AL9924_	3333	ACT-TGCGAATACTAGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3388		
Epichloë_typhina_ATCC_200736_	3311	ACT-TGCGAATACTAGAGACTACA	--	CCACAATCG	--	TCTGCGCCGCCACGCCCAAATCGT	3366		
Epichloë_typhina_subsp_poae	3312	ACT-TGCGAATACTAGAGACTACA	--	CCGCAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3367		
Epichloë_typhina_subsp_Poae_Ps1	3307	ACT-TGCGAATACTAGAGACTACA	--	CCACAATC	--	ATCCTCCCCGCCACGCCCAAATCGT	3362		
Epichloë_uncinata_CBS_102646_	3310	ACT-TGCGAATACTAGAGACTACA	--	CCACAATCG	--	TCTGCGCCGCCACGCCCAAATCGT	3365		
Epichloë_amarillans_E57_	3343	T-CATCAGCTACGAT	TGGC-A	---AAC	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3398			
Epichloë_amarillans_E4668	3339	T-CATCAGCTACGAT	TGGC-A	---AAC	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3394			
Epichloë_aotearoae_MYA-1229_	3356	ACATCAGCTACGAT	TGGC-A	---AAT	ACTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3411			
Epichloë_brachelyytrii_E4804_	3340	ACATCAGCTACGAT	TGGC-A	---GAT	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3395			
Epichloë_bromicola_AL0434_	3360	T-ATTA-TTACTTTT	---ACACTA	---TCT-TATAGGTT-AT	AGCTTAGCG	3403			
Epichloë_bromicola_AL04262_	3386	ACATCAGCTACGAT	TGGC-A	---AAC	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3441			
Epichloë_elymi_ATCC_201551_	3329	ACATCAGCTACGAT	TGGC-A	---AAT	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3384			
Epichloë_festucaae_AR1	3325	ACATCAGCTACGAT	TGGC-A	---AAT	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3380			
Epichloë_festucaae_AR37	2828	ACATCAGCTACGAT	TGGC-A	---AAT	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	2883			
Epichloë_festucaae_AR48	3325	ACATCAGCTACGAT	TGGC-A	---AAT	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3380			
Epichloë_festucaae_E2368	3364	ACATCAGCTACGAT	TGGC-A	---AAT	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3419			
Epichloë_festucaae_Fg1	3325	ACATCAGCTACGAT	TGGC-A	---AAT	CCTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3380			
Epichloë_festucaae_F11	3363	ACATCAGCTACGAT	TGGC-A	---AAT	CCTTCCGTTTGTACAGGCCGCGCATGACTACGGC	3418			
Epichloë_gansuensis_e7080_	758	GTTTAAACGA-GAGTCCGAATAAG	AACCGGGAGCGCT-TGCAGGAT	---TTT	CAC-ACGAC	812			
Epichloë_glyceriae_ATCC_200747_	3431	ACATCAGCTACGAT	TGGC-A	---ATC	CTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3486			
Epichloë_inebrians_MYA-1228_	3379	ACATCAGCTACGAT	TGGC-A	---AC	CTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3434			
Epichloë_mollis_AL9924_	3389	T-CATCAGCTACGAT	TGGC-A	---AC	CTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3444			
Epichloë_typhina_ATCC_200736_	3367	T-CATCAGCTACGAT	TGGC-A	---AT	CTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3422			
Epichloë_typhina_subsp_poae	3368	T-CATCAGCTACGAT	TGGC-A	---AT	CTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3423			
Epichloë_typhina_subsp_Poae_Ps1	3363	T-CATCAGCTACGAT	TGGC-A	---AT	CTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3418			
Epichloë_uncinata_CBS_102646_	3366	T-CATCAGCTACGAT	TGGC-A	---AT	CTTCCGTTCTGTACAGGCCGCGCATGACTACGGC	3421			
Epichloë_amarillans_E57_	3399	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3452			
Epichloë_amarillans_E4668	3395	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3448			
Epichloë_aotearoae_MYA-1229_	3412	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3465			
Epichloë_brachelyytrii_E4804_	3396	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3449			
Epichloë_bromicola_AL0434_	3404	TTCC-TATTATGCTTACT	ACACTTAG	---CTATTTT	TTTACTATTAAAAAGTTATAT	3458			
Epichloë_bromicola_AL04262_	3442	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGATGAGCGGATTCGACTATGAC	---TTTTAC	3495			
Epichloë_elymi_ATCC_201551_	3385	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3436			
Epichloë_festucaae_AR1	3381	TTTCGATGTAATCCGGAG	--	ACTTGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3434			
Epichloë_festucaae_AR37	2884	TTTCGATGTAATCCGGAG	--	ACTTGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	2937			
Epichloë_festucaae_AR48	3381	TTTCGATGTAATCCGGAG	--	ACTTGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3434			
Epichloë_festucaae_E2368	3420	TTTCGATGTAATCCGGAG	--	ACTTGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3473			
Epichloë_festucaae_Fg1	3381	TTTCGATGTAATCCGGAG	--	ACTTGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3434			
Epichloë_festucaae_F11	3419	TTTCGATGTAATCCGGAG	--	ACTTGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3472			
Epichloë_gansuensis_e7080_	813	CTGGT-TTAGCGCTCG	--CT	-----ACCGAGCGTGGATAGTGAAT	---TTAT	854			
Epichloë_glyceriae_ATCC_200747_	3487	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3540			
Epichloë_inebrians_MYA-1228_	3435	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3488			
Epichloë_mollis_AL9924_	3445	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3498			
Epichloë_typhina_ATCC_200736_	3423	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3476			
Epichloë_typhina_subsp_poae	3424	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3477			
Epichloë_typhina_subsp_Poae_Ps1	3419	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3472			
Epichloë_uncinata_CBS_102646_	3422	TTTCGATGTAATCCGGAG	--	ACTCGAAGAAGACAGCGGATTCGACTATGAC	---TTTTAC	3475			
Epichloë_amarillans_E57_	3453	ATCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCACTACATCACACA-TG	-----3492			
Epichloë_amarillans_E4668	3449	ATCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCACTACATCACACA-TG	-----3488			
Epichloë_aotearoae_MYA-1229_	3466	ATCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----3505			
Epichloë_brachelyytrii_E4804_	3450	ATCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----3489			
Epichloë_bromicola_AL0434_	3459	ATAATTACACTAGAAATCT	TTAATAAATATCTAG	AGCGTAAAAATTTATATA	---ATTTAAGGG	3516			
Epichloë_bromicola_AL04262_	3496	ATCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----3535			
Epichloë_elymi_ATCC_201551_	3437	ATCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-TG	-----3476			
Epichloë_festucaae_AR1	3435	ATC-TTCC	-CTAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----3474			
Epichloë_festucaae_AR37	2938	ATC-TTCC	-CTAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----2977			
Epichloë_festucaae_AR48	3435	ATC-TTCC	-CTAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----3474			
Epichloë_festucaae_E2368	3474	ATC-TTCC	-CTAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----3513			
Epichloë_festucaae_Fg1	3435	ATC-TTCC	-CTAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----3474			
Epichloë_festucaae_F11	3473	ATC-TTCC	-CTAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----3512			
Epichloë_gansuensis_e7080_	855	TCCGTTCG	--ACA	-----AAAATGACAT	---TTAAGTCAACAACCGACGTA	-----897			
Epichloë_glyceriae_ATCC_200747_	3541	CTC-TTCC	-CTAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-CG	-----3580			
Epichloë_inebrians_MYA-1228_	3489	ATC-TTCC	-CAAG	-----TGAAT-ACGCG	---ATTCAAAAATCACACA-CG	A-----3529			
Epichloë_mollis_AL9924_	3499	ATCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCAAAAATCACACA-TG	-----3538			
Epichloë_typhina_ATCC_200736_	3477	ATTTTTTC	--TAG	-----TGAAT-ACATC	---ATTCACTAAATCACACA-CG	A-----3517			
Epichloë_typhina_subsp_poae	3478	CTCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCACTAAATCACACA-CG	-----3517			
Epichloë_typhina_subsp_Poae_Ps1	3473	ATCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCACTAAATCACACA-CG	-----3512			
Epichloë_uncinata_CBS_102646_	3476	ATCTTTTC	--TAG	-----TGAAT-ACATC	---ATTCACTAAATCACACA-CG	-----3515			

Chapter eight: Appendices

<i>Epichloë amarillans_E57_</i>	3493	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3526										
<i>Epichloë amarillans_E4668_</i>	3489	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3522										
<i>Epichloë aotearoae_MYA-1229_</i>	3506	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	G	3539										
<i>Epichloë brachelytri_E4804_</i>	3490	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	G	3525										
<i>Epichloë bromicola_AL0434_</i>	3517	GT	AGT	AAATAA	TTATGA	GGCCCCACTC	CA	AACAC	CAG	----	CGGTGACCCAC	---	G	A	3568									
<i>Epichloë bromicola_AL04262_</i>	3536	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3569										
<i>Epichloë elymi_ATCC_201551_</i>	3477	--	AGTT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3510										
<i>Epichloë festucae_AR1</i>	3475	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3508										
<i>Epichloë festucae_AR37</i>	2978	--	AGT	----	TTGTGAG	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3011										
<i>Epichloë festucae_AR48</i>	3475	--	AGT	----	TTGTGAG	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3508										
<i>Epichloë festucae_E2368</i>	3514	--	AGT	----	TTGTGAG	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3547										
<i>Epichloë festucae_Fg1</i>	3475	--	AGTT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3508										
<i>Epichloë festucae_F11</i>	3513	--	AGTT	----	TTGTGAG	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	G	A	3546										
<i>Epichloë gansuensis_e7080_</i>	898	--	AGC	----	TTATCA	-----	C	AAGCACTTA	GAGAAG	CTCTCAGAGGC	----	A	934											
<i>Epichloë glyceriae_ATCC_200747_</i>	3581	--	AGTA	----	TATGA	-----	A	AACGCCAT	----	TGCGGTCAAGCTC	---	A	3614											
<i>Epichloë inebrians_MYA-1228_</i>	3530	--	GT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	A	3562											
<i>Epichloë mollis_AL9924_</i>	3539	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	A	3572											
<i>Epichloë typhina_ATCC_200736_</i>	3518	--	GT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	A	3550											
<i>Epichloë typhina_subsp_poae</i>	3518	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	A	3551											
<i>Epichloë typhina_subsp_Poae_Ps1</i>	3513	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	A	3546											
<i>Epichloë uncinata_CBS_102646_</i>	3516	--	AGT	----	TTGTGA	-----	A	AACACCCAT	----	TGCGGTCAAGCTC	---	A	3549											
<i>Epichloë amarillans_E57_</i>	3527	CAGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3577												
<i>Epichloë amarillans_E4668_</i>	3523	CAGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3573												
<i>Epichloë aotearoae_MYA-1229_</i>	3540	CAAT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3590												
<i>Epichloë brachelytri_E4804_</i>	3526	AC	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3574												
<i>Epichloë bromicola_AL0434_</i>	3569	CCCT	--	A	GGCT	AGGGCTAGGT	CACGTGACACT	AGC	--	GAGCCACTAGCTA	TAACTA	3623												
<i>Epichloë bromicola_AL04262_</i>	3570	CAGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3620												
<i>Epichloë elymi_ATCC_201551_</i>	3511	CAGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3561												
<i>Epichloë festucae_AR1</i>	3509	CCGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3559												
<i>Epichloë festucae_AR37</i>	3012	CCGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3062												
<i>Epichloë festucae_AR48</i>	3509	CCGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3559												
<i>Epichloë festucae_E2368</i>	3548	CCGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3598												
<i>Epichloë festucae_Fg1</i>	3509	CCGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3559												
<i>Epichloë festucae_F11</i>	3547	CCGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3597												
<i>Epichloë gansuensis_e7080_</i>	935	CCAT	GAG	CGGT	AGGGTGCAGAT	GA	ACTCGGTG	--	CTGA	CTTA	A	--	TGTAC	A	983									
<i>Epichloë glyceriae_ATCC_200747_</i>	3615	CAGA	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3665												
<i>Epichloë inebrians_MYA-1228_</i>	3563	CAGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3613												
<i>Epichloë mollis_AL9924_</i>	3573	CAGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3623												
<i>Epichloë typhina_ATCC_200736_</i>	3551	CAAT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3601												
<i>Epichloë typhina_subsp_poae</i>	3552	CCGT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3602												
<i>Epichloë typhina_subsp_Poae_Ps1</i>	3547	CAAT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3597												
<i>Epichloë uncinata_CBS_102646_</i>	3550	CAAT	----	CGGTC	AGTGGCAGTT	CAAGTCGCAG	A	ACTGGA	TAA	GAGCC	TACACAA	3600												
<i>Epichloë amarillans_E57_</i>	3578	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3620									
<i>Epichloë amarillans_E4668_</i>	3574	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3616									
<i>Epichloë aotearoae_MYA-1229_</i>	3591	TGTCCT	TGAA	--	TACACCATA	TA	TGG	CGCAGGA	GCC	----	GAT	T	ACA	CC	3633									
<i>Epichloë brachelytri_E4804_</i>	3575	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3617									
<i>Epichloë bromicola_AL0434_</i>	3624	GTA	ACT	CGCAT	GTA	TAACT	ACT	--	TAG	ACTAGTA	AGGTTTAGTA	AAATAT	ATA	--	3675									
<i>Epichloë bromicola_AL04262_</i>	3621	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3663									
<i>Epichloë elymi_ATCC_201551_</i>	3562	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3604									
<i>Epichloë festucae_AR1</i>	3560	TGTCCT	TGAA	--	TACACCATA	TA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3602									
<i>Epichloë festucae_AR37</i>	3063	TGTCCT	TGAA	--	TACACCATA	TA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3105									
<i>Epichloë festucae_AR48</i>	3560	TGTCCT	TGAA	--	TACACCATA	TA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3602									
<i>Epichloë festucae_E2368</i>	3599	TGTCCT	TGAA	--	TACACCATA	TA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3641									
<i>Epichloë festucae_Fg1</i>	3560	TGTCCT	TGAA	--	TACACCATA	TA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3602									
<i>Epichloë festucae_F11</i>	3598	TGTCCT	TGAA	--	TACACCATA	TA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3640									
<i>Epichloë gansuensis_e7080_</i>	984	G	GT	CTT	GGT	G	CT	CA	GA	A	CAAGT	GGT	TT	CAG	A	GCA	--	AGA	AA	TT	CTT	AG	CCA	1037
<i>Epichloë glyceriae_ATCC_200747_</i>	3666	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3708									
<i>Epichloë inebrians_MYA-1228_</i>	3614	TGTCCT	TGAG	--	TACACCATA	CA	TGG	CGTAGGA	GCT	----	AAT	T	ACA	CC	3656									
<i>Epichloë mollis_AL9924_</i>	3624	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3666									
<i>Epichloë typhina_ATCC_200736_</i>	3602	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3644									
<i>Epichloë typhina_subsp_poae</i>	3603	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	GAT	T	ACA	CC	3645									
<i>Epichloë typhina_subsp_Poae_Ps1</i>	3598	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3640									
<i>Epichloë uncinata_CBS_102646_</i>	3601	TGTCCT	TGAA	--	TACACCATA	CA	TGG	CGCAGGA	GCC	----	AAT	T	ACA	CC	3643									
<i>Epichloë amarillans_E57_</i>	3621	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3669									
<i>Epichloë amarillans_E4668_</i>	3617	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3665									
<i>Epichloë aotearoae_MYA-1229_</i>	3634	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3682									
<i>Epichloë brachelytri_E4804_</i>	3618	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3666									
<i>Epichloë bromicola_AL0434_</i>	3676	AGT	CGCCCT	TAT	CTT	CTT	CA	AGCT	AT	CTT	TT	AT	----	TTT	AT	TA	ATT	CT	AA	AG	CGT	3728		
<i>Epichloë bromicola_AL04262_</i>	3664	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3712									
<i>Epichloë elymi_ATCC_201551_</i>	3605	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3653									
<i>Epichloë festucae_AR1</i>	3603	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3651									
<i>Epichloë festucae_AR37</i>	3106	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3154									
<i>Epichloë festucae_AR48</i>	3603	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3651									
<i>Epichloë festucae_E2368</i>	3642	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3690									
<i>Epichloë festucae_Fg1</i>	3603	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3651									
<i>Epichloë festucae_F11</i>	3641	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3689									
<i>Epichloë gansuensis_e7080_</i>	1038	G	AT	CGAT	GCT	GCT	CTT	CT	GAT	AAGT	----	AT	GAC	CA	TAT	AT	AT	AT	AT	AT	AT	AT	AT	1089
<i>Epichloë glyceriae_ATCC_200747_</i>	3709	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3757									
<i>Epichloë inebrians_MYA-1228_</i>	3657	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3705									
<i>Epichloë mollis_AL9924_</i>	3667	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3715									
<i>Epichloë typhina_ATCC_200736_</i>	3645	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3693									
<i>Epichloë typhina_subsp_poae</i>	3646	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3694									
<i>Epichloë typhina_subsp_Poae_Ps1</i>	3641	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3689									
<i>Epichloë uncinata_CBS_102646_</i>	3644	AT	CGGGCT	CAAT	CTCTG	--	CGTGGCCAT	GAC	ATT	GT	----	CTTCGAA	--	CAAGAGCA	3692									
<i>Epichloë amarillans_E57_</i>	3670	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3719											
<i>Epichloë amarillans_E4668_</i>	3666	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3715											
<i>Epichloë aotearoae_MYA-1229_</i>	3683	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3732											
<i>Epichloë brachelytri_E4804_</i>	3667	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3716											
<i>Epichloë bromicola_AL0434_</i>	3729	--	TCT	CT	ACT	AGCT	ACCTA	A	G	----	AGT	AT	AT	AT	AT	AT	AT	AT	AT	AT	AT	AT	AT	3774
<i>Epichloë bromicola_AL04262_</i>	3713	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3762											
<i>Epichloë elymi_ATCC_201551_</i>	3654	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3703											
<i>Epichloë festucae_AR1</i>	3652	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3701											
<i>Epichloë festucae_AR37</i>	3155	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3204											
<i>Epichloë festucae_AR48</i>	3652	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3701											
<i>Epichloë festucae_E2368</i>	3691	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3740											
<i>Epichloë festucae_Fg1</i>	3652	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3701											
<i>Epichloë festucae_F11</i>	3690	--	GCACAT	GTTGGGTTT	TGGA	C	----	TGCGGAAAGTT	TGACG	----	GGGAGAACAT	CGTG	3739											
<i>Epichloë gansuensis</i>																								

Chapter eight: Appendices

Epichloë_amarillans_E57_	3720	ATTGAAGG	C	---	CAG	GC	CGTCT	---	CAATC	---	TCAGGT	---	TT	CCG	GGT	3757
Epichloë_amarillans_E4668_	3716	ATTGAAGG	C	---	CAG	GC	CGTCT	---	CAATC	---	TCAGGT	---	TT	CCG	GGT	3753
Epichloë_aotearoae_MYA-1229_	3733	ATTGAGGC	C	---	CGG	GC	CGTCT	---	CAATC	---	TCAGGT	---	TT	CCG	GGT	3770
Epichloë_brachyelytri_E4804_	3717	ATTGAGGC	C	---	CGG	GC	CGTCT	---	CAATC	---	TCAGGT	---	TT	CCG	GGT	3754
Epichloë_bromicola_AL0434_	3775	ATTTA	-	---	TAGAGT	AA	TATAGATA	TA	TAAC	---	TAAGGGCT	ACC	TA	ATAA	GGT	3823
Epichloë_bromicola_AL04262_	3763	ATTGAGGCA	C	---	AGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3800	
Epichloë_elymi_ATCC_201551_	3704	ATTGAGGCC	C	---	AGG	-	CGTCT	---	CAATC	---	TCAGGT	---	TT	CCG	GGT	3741
Epichloë_festucaae_AR1_	3702	ATTGAGGC	C	---	CGGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3739	
Epichloë_festucaae_AR37_	3205	ATTGAGGC	C	---	CGGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3242	
Epichloë_festucaae_AR48_	3702	ATTGAGGC	C	---	CGGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3739	
Epichloë_festucaae_E2368_	3741	ATTGAGGC	C	---	CGGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3778	
Epichloë_festucaae_Fg1_	3702	ATTGAGGC	C	---	CGGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3739	
Epichloë_festucaae_FI1_	3740	ATTGAGGC	C	---	CGGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3777	
Epichloë_gansuensis_e7080_	1149	AG	GAGGCA	AGC	CGG	CGAA	CGTCT	CT	CCGAACAG	CGGT	TCAGG	CGC	TT	TGG	CG	1206
Epichloë_glyceriae_ATCC_200747_	3808	GTTGAGGCC	C	---	GGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3845	
Epichloë_inebrians_MYA-1228_	3756	GTTGAGGCC	C	---	AGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3793	
Epichloë_mollis_AL9924_	3766	GTTGAGGCC	C	---	GGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3803	
Epichloë_typhina_ATCC_200736_	3744	GTTGAGGCC	C	---	GGG	-	CGTCA	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3781	
Epichloë_typhina_subsp_poae	3745	GTTGAGGC	C	---	CT	GGG	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3782	
Epichloë_typhina_subsp_Poae_Ps1	3740	ATTGAGGCC	C	---	GGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3777	
Epichloë_uncinata_CBS_102646_	3743	ATTGAGGC	C	---	GGG	-	CGTCT	---	CAATC	---	TCAGG	---	TTTCCG	GGT	3780	
Epichloë_amarillans_E57_	3758	GA	AC	CTGGC	AGA	---	GCACTAC	---	TTC	---	GAATCGATGT	TCATCTGCAAACCC	---	3803		
Epichloë_amarillans_E4668_	3754	GA	AC	CTGGC	AGA	---	GCACTAC	---	TTC	---	GAATCGATGT	TCATCTGCAAACCC	---	3799		
Epichloë_aotearoae_MYA-1229_	3771	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	AGTTCATGCT	CATCTGCAAACCC	---	3816		
Epichloë_brachyelytri_E4804_	3755	GA	AC	CTGGC	AGA	---	CCTCTTA	---	TTC	---	AAATCCATGCT	CATCTGCAAACCC	---	3800		
Epichloë_bromicola_AL0434_	3824	AAT	ACTA	TAGCTA	AGAATA	CACTATA	---	TTC	TATA	GAGACTATAT	TAGAGAATAT	TACCC	---	3881		
Epichloë_bromicola_AL04262_	3801	GAATC	---	TGGC	AGA	---	CA	CTAC	---	TTC	---	GAATCGATGT	TCATCTGCAAACCC	---	3846	
Epichloë_elymi_ATCC_201551_	3742	GA	AC	CTGGC	AGA	---	GCACTAC	---	TTC	---	GAATCGATGT	TCATCTGCAAACCC	---	3787		
Epichloë_festucaae_AR1_	3740	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	GAGTCCATGCT	CATCTGCAAACCC	---	3785		
Epichloë_festucaae_AR37_	3243	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	GAGTCCATGCT	CATCTGCAAACCC	---	3288		
Epichloë_festucaae_AR48_	3740	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	GAGTCCATGCT	CATCTGCAAACCC	---	3785		
Epichloë_festucaae_E2368_	3779	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	GAGTCCATGCT	CATCTGCAAACCC	---	3824		
Epichloë_festucaae_Fg1_	3740	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	GAGTCCATGCT	CATCTGCAAACCC	---	3785		
Epichloë_festucaae_FI1_	3778	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	GAGTCCATGCT	CATCTGCAAACCC	---	3823		
Epichloë_gansuensis_e7080_	1207	CATA	---	ATG	---	AG	---	---	TT	---	TTC	AACGGGAT	CAAG	ACATATG	---	1244
Epichloë_glyceriae_ATCC_200747_	3846	GA	AC	CTGGC	AGA	---	CACTTA	---	TTC	---	AGTTCATGCT	CATCTGCAAACCC	---	3891		
Epichloë_inebrians_MYA-1228_	3794	GA	AC	CTGGC	AGA	---	CCGTAACT	---	TTC	---	GAATCCATGT	TCATCTGCAAACCC	---	3839		
Epichloë_mollis_AL9924_	3804	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	AGTTCATGCT	CATCTGCAAACCC	---	3849		
Epichloë_typhina_ATCC_200736_	3782	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	AGTTCATGCT	CATCTGCAAACCC	---	3827		
Epichloë_typhina_subsp_poae	3783	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	AGTTCATGCT	CATCTGCAAACCC	---	3828		
Epichloë_typhina_subsp_Poae_Ps1	3778	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	AGTTCATGCT	CATCTGCAAACCC	---	3823		
Epichloë_uncinata_CBS_102646_	3781	GA	AC	CTGGC	AGA	---	CACCTTA	---	TTC	---	AGTTCATGCT	CATCTGCAAACCC	---	3826		
Epichloë_amarillans_E57_	3804	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3856					
Epichloë_amarillans_E4668_	3800	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3852					
Epichloë_aotearoae_MYA-1229_	3817	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3869					
Epichloë_brachyelytri_E4804_	3801	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3853					
Epichloë_bromicola_AL0434_	3882	TAA	---	CTATA	---	TATACCTATAT	TATAGTAATAGTAAAGTAAAT	TACCTAGCT	TAAA	---	3934					
Epichloë_bromicola_AL04262_	3847	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3899					
Epichloë_elymi_ATCC_201551_	3788	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3840					
Epichloë_festucaae_AR1_	3786	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3838					
Epichloë_festucaae_AR37_	3289	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3341					
Epichloë_festucaae_AR48_	3786	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3838					
Epichloë_festucaae_E2368_	3825	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3877					
Epichloë_festucaae_Fg1_	3786	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3838					
Epichloë_festucaae_FI1_	3824	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3876					
Epichloë_gansuensis_e7080_	1245	A	---	CTGCAAAATTTTG	---	GGATACACGGATGACATGAC	ACTATC	---	TAAA	---	1288					
Epichloë_glyceriae_ATCC_200747_	3892	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3944					
Epichloë_inebrians_MYA-1228_	3840	---	AACGGCGAAATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAGA	---	3892					
Epichloë_mollis_AL9924_	3850	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3902					
Epichloë_typhina_ATCC_200736_	3828	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3880					
Epichloë_typhina_subsp_poae	3829	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3881					
Epichloë_typhina_subsp_Poae_Ps1	3824	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3876					
Epichloë_uncinata_CBS_102646_	3827	---	AACGGCGAGATCCT	GAAGTGGACTTT	GGCAAGA	---	AAACCACTTTCTCCA	---	TAAA	---	3879					
Epichloë_amarillans_E57_	3857	---	GG	AAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3905	
Epichloë_amarillans_E4668_	3853	---	GG	AAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3901	
Epichloë_aotearoae_MYA-1229_	3870	---	GG	TAGATGCT	G	CAAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3918	
Epichloë_brachyelytri_E4804_	3854	---	GG	AAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3902	
Epichloë_bromicola_AL0434_	3935	---	G	AACCTT	---	AAGCAA	---	---	ACTATAA	GAACAGAGT	AAAGCTTTA	AGACCTA	---	3979		
Epichloë_bromicola_AL04262_	3900	---	G	GAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3948	
Epichloë_elymi_ATCC_201551_	3841	---	G	GAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3889	
Epichloë_festucaae_AR1_	3839	---	G	GAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3887	
Epichloë_festucaae_AR37_	3342	---	G	GAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3390	
Epichloë_festucaae_AR48_	3839	---	G	GAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3887	
Epichloë_festucaae_E2368_	3878	---	G	GAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3926	
Epichloë_festucaae_Fg1_	3839	---	G	GAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3887	
Epichloë_festucaae_FI1_	3877	---	G	GAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3925	
Epichloë_gansuensis_e7080_	1289	T	GTTAAAGTTG	TC	CGACGAT	CT	CGACAAAGCTTGAC	CGCAAAAGCGAA	---	CAAGGAGGC	CT	---	1345			
Epichloë_glyceriae_ATCC_200747_	3945	---	GGAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3993		
Epichloë_inebrians_MYA-1228_	3893	---	GGAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3941		
Epichloë_mollis_AL9924_	3903	---	GGAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3951		
Epichloë_typhina_ATCC_200736_	3881	---	GGAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGT	CAGACTC	CACAGAGCAT	---	3929	
Epichloë_typhina_subsp_poae	3882	---	GTTAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3930		
Epichloë_typhina_subsp_Poae_Ps1	3877	---	GGAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3925		
Epichloë_uncinata_CBS_102646_	3880	---	GGAAGATGCT	GC	CAA	---	GT	---	ACCAG	---	GGAGGAAGCCAGAACTC	CACAGAGCAT	---	3928		
Epichloë_amarillans_E57_	3906	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3952			
Epichloë_amarillans_E4668_	3902	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3948			
Epichloë_aotearoae_MYA-1229_	3919	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3965			
Epichloë_brachyelytri_E4804_	3903	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3949			
Epichloë_bromicola_AL0434_	3980	T	TATAGCT	TAA	TACTAGG	---	GAAAGTAACT	AAACAGGTA	CT	TAAGAGCT	ACT	---	4034			
Epichloë_bromicola_AL04262_	3949	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3995			
Epichloë_elymi_ATCC_201551_	3890	C	---	T	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	3936			
Epichloë_festucaae_AR1_	3888	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3934			
Epichloë_festucaae_AR37_	3391	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3437			
Epichloë_festucaae_AR48_	3888	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3934			
Epichloë_festucaae_E2368_	3927	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3973			
Epichloë_festucaae_Fg1_	3888	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3934			
Epichloë_festucaae_FI1_	3926	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3972			
Epichloë_gansuensis_e7080_	1346	T	---	GCTT	CGT	CGATT	GAACT	GGC	CAGAAAGCA	---	CTTGT	TCAATGAG	TC	---	1394	
Epichloë_glyceriae_ATCC_200747_	3994	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	4040			
Epichloë_inebrians_MYA-1228_	3942	---	CT	CGACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	CGCCGAGCTCAT	---	CGT	---	3988			
Epichloë_mollis_AL9924_	3952	---	CT	CAACGATTTGAGC	GACAAGCACCT	---	GCTTG	---	GCACCGAGCTCAT	---	CGT	---	3998			
Epichlo																

Chapter eight: Appendices

<i>Epichloë amarillans_E57_</i>	3953	CGTGGACAAG - TACACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTAC 4004
<i>Epichloë amarillans_E4668_</i>	3949	CGTGGACAAG - TACACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4000
<i>Epichloë aotearoae_MYA-1229_</i>	3966	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4017
<i>Epichloë brachyleytrii_E4804_</i>	3950	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4001
<i>Epichloë bromicola_AL0434_</i>	4035	CTT - - - TAACT - TATAGTA - - - - - GCTAAG - AGATTAAA - - - - - GTCTAATAATATAC 4077
<i>Epichloë bromicola_AL04262_</i>	3996	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4047
<i>Epichloë elymi_ATCC_201551_</i>	3937	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 3988
<i>Epichloë festucae_AR1</i>	3935	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 3986
<i>Epichloë festucae_AR37</i>	3438	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 3489
<i>Epichloë festucae_AR48</i>	3935	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 3986
<i>Epichloë festucae_E2368</i>	3974	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4025
<i>Epichloë festucae_Fg1</i>	3935	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 3986
<i>Epichloë festucae_F11</i>	3973	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4024
<i>Epichloë gansuensis_e7080_</i>	1395	CTGGCAGAA - - AACCAACGAGTCA TGGCA - - - TGTTCCAAGA GATGGAGGTTCTAC 1448
<i>Epichloë glyceriae_ATCC_200747_</i>	4041	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTC - - - - - GGTCGGCGCTTTTAC 4092
<i>Epichloë inebrians_MYA-1228_</i>	3989	CGTGAACGAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4040
<i>Epichloë mollis_AL9924_</i>	3999	CGTGGACAAG - TATACAACGCCAGCG - TGGCCAGTCTGTTG - - - - - GGTCGGCGCTTTTAC 4050
<i>Epichloë typhina_ATCC_200736_</i>	3977	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4028
<i>Epichloë typhina_subsp_poae</i>	3978	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4029
<i>Epichloë typhina_subsp_Poae_Ps1</i>	3973	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTTG - - - - - GGTCGGCGCTTTTAC 4024
<i>Epichloë uncinata_CBS_102646_</i>	3976	CGTGGACAAG - TATACAACGCCCGC - TGGCCAGTCTGTT - - - - - GGTCGGCGCTTTTAC 4027
<i>Epichloë amarillans_E57_</i>	4005	CAA - CCGACGAGCAAG CGCTTTCTCTACACC - ATCGATGC - - G - CCTGAAGA - ATTGACC 4058
<i>Epichloë amarillans_E4668_</i>	4001	CAA - CCGACGAGCAAG CGCTTTCTCTACACC - ATCGATGC - - G - CCTGAAGA - ATTGACC 4054
<i>Epichloë aotearoae_MYA-1229_</i>	4018	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - T - CCTGAAGA - ATTGACC 4071
<i>Epichloë brachyleytrii_E4804_</i>	4002	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - T - CCTGAAGA - ATTGACC 4055
<i>Epichloë bromicola_AL0434_</i>	4078	TAA - CGT - - - - CTAATAC - - CTATAAACCTATAGAGGT - - - - - ATAAGATATAGATT 4123
<i>Epichloë bromicola_AL04262_</i>	4048	GAA - CCGACGAGCAAGCGCTTTCTCTACACC - ATCGATGC - - G - CCTGAAGA - ATTGACC 4101
<i>Epichloë elymi_ATCC_201551_</i>	3989	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - G - CCTGAAGA - ATTGACC 4042
<i>Epichloë festucae_AR1</i>	3987	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - T - CCTGAAGA - ATTGACC 4040
<i>Epichloë festucae_AR37</i>	3490	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - T - CCTGAAGA - ATTGACC 3543
<i>Epichloë festucae_AR48</i>	3987	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - T - CCTGAAGA - ATTGACC 4040
<i>Epichloë festucae_E2368</i>	4026	GAA - CCGACGAGCAACGCTTTCTCTACGCC - ATCGATGC - - T - CCTGAAGA - ATTGACC 4079
<i>Epichloë festucae_Fg1</i>	3987	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - T - CCTGAAGA - ATTGACC 4040
<i>Epichloë festucae_F11</i>	4025	GAA - CCGACGAGCAACGCTTTCTCTAGGCC - ATCGATGC - - T - CCTGAAGA - ATTGACC 4078
<i>Epichloë gansuensis_e7080_</i>	1449	GAAACCTATGCCCAA - GAGAT - TCTTTGT - - - TCG - TGCAGTTCCCGA - - - - - TGAGC 1495
<i>Epichloë glyceriae_ATCC_200747_</i>	4093	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - G - CCTGAAGA - ATTGACC 4146
<i>Epichloë inebrians_MYA-1228_</i>	4041	GAA - CCGACTACAACAGCTTTCTCTACACC - ATCGATGC - - G - CCTGAAGA - ATTGACT 4094
<i>Epichloë mollis_AL9924_</i>	4051	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - G - CCTGAAGA - ATTGACC 4104
<i>Epichloë typhina_ATCC_200736_</i>	4029	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - G - CCTGAAGA - ATTGACC 4082
<i>Epichloë typhina_subsp_poae</i>	4030	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - T - CCTGAAGA - ATTGACC 4083
<i>Epichloë typhina_subsp_Poae_Ps1</i>	4025	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - G - CCTGAAGA - ATTGACC 4078
<i>Epichloë uncinata_CBS_102646_</i>	4028	GAA - CCGACGAGCAACGCTTTCTCTACACC - ATCGATGC - - T - CCTGAAGA - ATTGACC 4081
<i>Epichloë amarillans_E57_</i>	4059	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - - AAGGAAAAGTCTTCTCTA 4108
<i>Epichloë amarillans_E4668_</i>	4055	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - - AAGGAAAAGTCTTCTCTA 4104
<i>Epichloë aotearoae_MYA-1229_</i>	4072	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - - GAGGAAAAGTCTTCTCTA 4121
<i>Epichloë brachyleytrii_E4804_</i>	4056	AACAGTGGCGAGTTGGTGCCCT - - TACT - - GC - - TG - - - GAGGAAAAGTCTTCTCTA 4105
<i>Epichloë bromicola_AL0434_</i>	4124	AATAAC - CTAAACT - - ATACCTT - - TATAAAGG - TA - - AAGAAAAAG - - TTCTAATA 4170
<i>Epichloë bromicola_AL04262_</i>	4102	AACAGTCCGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - A - GGGAAAAGTCTTCTCTA 4151
<i>Epichloë elymi_ATCC_201551_</i>	4043	AACAGCGCGCAGTTGGTGCTTAAACAACT - - GC - - TG - - - GAGGAAAAGTCTTCTCTA 4095
<i>Epichloë festucae_AR1</i>	4041	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - G - TGGAAAAGTCTTCTCTA 4090
<i>Epichloë festucae_AR37</i>	3544	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - G - TGGAAAAGTCTTCTCTA 3593
<i>Epichloë festucae_AR48</i>	4041	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - G - TGGAAAAGTCTTCTCTA 4090
<i>Epichloë festucae_E2368</i>	4080	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - G - TGGAAAAGTCTTCTCTA 4129
<i>Epichloë festucae_Fg1</i>	4041	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - GTGGAAAAGTCTTCTCTA 4090
<i>Epichloë festucae_F11</i>	4079	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - GTGGAAAAGTCTTCTCTA 4128
<i>Epichloë gansuensis_e7080_</i>	1496	ATGCTGCGCGCGCTTGCTATCTTTGCTACGCCATGTCAGTGCATTGGGATCGT - T - 1553
<i>Epichloë glyceriae_ATCC_200747_</i>	4147	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - - GAGGAAAAGTCTTCTCTA 4196
<i>Epichloë inebrians_MYA-1228_</i>	4095	AACAGTGGCGAGTTGGTGCTCT - - GACT - - GC - - TG - - - GGGAAAAGTCTTCTCTA 4144
<i>Epichloë mollis_AL9924_</i>	4105	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - - GAGGAAAAGTCTTCTCTA 4154
<i>Epichloë typhina_ATCC_200736_</i>	4083	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - - AAGGAAAAGTCTTCTCTA 4132
<i>Epichloë typhina_subsp_poae</i>	4084	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - - GAGGAAAAGTCTTCTCTA 4133
<i>Epichloë typhina_subsp_Poae_Ps1</i>	4079	AACAGTGGCGAGTTGGTGCCCT - - GACT - - GC - - TG - - - AAGGAAAAGTCTTCTCTA 4128
<i>Epichloë uncinata_CBS_102646_</i>	4082	AACAGTGGCGAGTTGGTGCCCT - - GACC - - GC - - TG - - - AGGAAAAGTCTTCTCTA 4131
<i>Epichloë amarillans_E57_</i>	4109	CAAT - AC - - - - AGAACATTGTGCCATCTGGCGTGTGGAAGTTTCGACCGGAGTCTGCGAA 4163
<i>Epichloë amarillans_E4668_</i>	4105	CAAT - AC - - - - AGAACATTGTGCCATCTGGCGTGTGGAAGTTTCGACCGGAGTCTGCGAA 4159
<i>Epichloë aotearoae_MYA-1229_</i>	4122	CAAT - AC - - - - AGAGCATAGTGCCATTGTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4176
<i>Epichloë brachyleytrii_E4804_</i>	4106	CAAT - AC - - - - AGAACACGGCGGATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4160
<i>Epichloë bromicola_AL0434_</i>	4171	TAAAT ACTAAAAATCTTTTATCACTTAAC - TATATATATATTAATTATAGGTAAGA - 4228
<i>Epichloë bromicola_AL04262_</i>	4152	CAAT - AC - - - - AGAACATTGTGCCATCTGGCGTGTGGAAGTTTCGACTGGAGTCTGTGAA 4206
<i>Epichloë elymi_ATCC_201551_</i>	4096	CAAT - AC - - - - AGAACATTGTGCCATCTGGCGTGTGGAAGTTTCGACCGGAGTCTGTGAA 4150
<i>Epichloë festucae_AR1</i>	4091	CAAT - AC - - - - AGAGCATAGTGCCATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4145
<i>Epichloë festucae_AR37</i>	3594	CAAT - AC - - - - AGAGCATAGTGCCATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 3648
<i>Epichloë festucae_AR48</i>	4091	CAAT - AC - - - - AGAGCATAGTGCCATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4145
<i>Epichloë festucae_E2368</i>	4130	CAAT - AC - - - - AGAGCATAGTGCCATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4184
<i>Epichloë festucae_Fg1</i>	4091	CAAT - AC - - - - AGAGCATAGTGCCATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4145
<i>Epichloë festucae_F11</i>	4129	CAAT - AC - - - - AGAGCATAGTGCCATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4183
<i>Epichloë gansuensis_e7080_</i>	1554	- - - - - GGATTTCGCCAT - TGA - - TTTCTGTCATT - GACCA - ACTTTGTG - - - 1591
<i>Epichloë glyceriae_ATCC_200747_</i>	4197	CAAT - AG - - - - AGAACATAGTGCCATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4251
<i>Epichloë inebrians_MYA-1228_</i>	4145	CAAT - AG - - - - AGAACATTGTGCCATCTGGCGCTGTGGACGTTTCGACCGGAGTCTGTGAA 4199
<i>Epichloë mollis_AL9924_</i>	4155	CAAC - ACA - - - - GAGCATAGTGCCATCTGGCGTGTGGATTTTTCGACAGAGTCTGTGAA 4209
<i>Epichloë typhina_ATCC_200736_</i>	4133	CAAT - AG - - - - AGAGCATAGTGCCATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4187
<i>Epichloë typhina_subsp_poae</i>	4134	CAAT - AG - - - - AGAGCATAGTGCCATCTGGCGTGTGGACGTTTCGACAGAGTCTGTGAA 4188
<i>Epichloë typhina_subsp_Poae_Ps1</i>	4129	CAAT - ACA - - - - GAGCATAGTGCCATCTGGCGTGTGGACGTTTTCGACCGGAGTCTGTGAA 4183
<i>Epichloë uncinata_CBS_102646_</i>	4132	CAAT - AG - - - - AGAGCATAGTGCCATCTGGCGTGTGGACGTTTCGACCGGAGTCTGTGAA 4186
<i>Epichloë amarillans_E57_</i>	4164	GCAAATTACCGTGACCTATGCC - - GTCTTTTAAAAAG - - - - - AACCC - - - - T - TCAC 4208
<i>Epichloë amarillans_E4668_</i>	4160	GCAAAGTACCGTGACCTATGCC - - GTCTTTTAAAAAG - - - - - AACCC - - - - T - TCAC 4204
<i>Epichloë aotearoae_MYA-1229_</i>	4177	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - AACCC - - - - T - TCAA 4221
<i>Epichloë brachyleytrii_E4804_</i>	4161	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - AACCC - - - - T - TCAT 4205
<i>Epichloë bromicola_AL0434_</i>	4229	- TAAAAATAG - ATACGTTAAGGAATA GTAGGCTAATAGCTAGGATAACC - - - - - T - TA 4278
<i>Epichloë bromicola_AL04262_</i>	4207	GCAAAGTACCATGCCCTATGCC - - GATTTCTAAAAAG - - - - - ACCC - - - - T - TGAA 4251
<i>Epichloë elymi_ATCC_201551_</i>	4151	GCAAAGTACCATGCCCTATGCC - - GATTTCTAAAAAG - - - - - AACCC - - - - T - TGAA 4195
<i>Epichloë festucae_AR1</i>	4146	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - ACCC - - - - T - TCAA 4190
<i>Epichloë festucae_AR37</i>	3649	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - ACCC - - - - T - TCAA 3693
<i>Epichloë festucae_AR48</i>	4146	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - ACCC - - - - T - TCAA 4190
<i>Epichloë festucae_E2368</i>	4185	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - ACCC - - - - T - TCAA 4229
<i>Epichloë festucae_Fg1</i>	4146	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - AACCC - - - - T - TCAA 4190
<i>Epichloë festucae_F11</i>	4184	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - AACCC - - - - T - TCAA 4228
<i>Epichloë gansuensis_e7080_</i>	1592	- GCAAGCTGGTGCCCTATGCC - - - - TAATAATA - - - - - AATCGGACATGATGAA 1637
<i>Epichloë glyceriae_ATCC_200747_</i>	4252	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - AACCC - - - - T - TCAA 4296
<i>Epichloë inebrians_MYA-1228_</i>	4200	GCAAGTACCATGCCCTATGCC - - GTCTAATAAAAAAT - - - - - TACCC - - - - T - GCAG 4244
<i>Epichloë mollis_AL9924_</i>	4210	GCAAAGTACCATGAACTATGCC - - GTCTTCTAAAAAG - A - - - - ACCC - - - - T - TCAA 4254
<i>Epichloë typhina_ATCC_200736_</i>	4188	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - AACCC - - - - T - TCAA 4232
<i>Epichloë typhina_subsp_poae</i>	4189	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - - - - - AACCC - - - - T - TCAA 4233
<i>Epichloë typhina_subsp_Poae_Ps1</i>	4184	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - A - - - - ACCC - - - - T - TCAA 4228
<i>Epichloë uncinata_CBS_102646_</i>	4187	GCAAAGTACCATGCCCTATGCC - - GTCTTCTAAAAAG - A - - - - ACCC - - - - T - TCAA 4231

Chapter eight: Appendices

<i>Epichloë amarillans_E57_</i>	4209	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATCATT-CA-TTC--AAGT-----TAC--	4251
<i>Epichloë amarillans_E4668_</i>	4205	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATCATT-CA-TTC--AAGT-----TAC--	4247
<i>Epichloë aotearoae_MYA-1229_</i>	4222	AGCC-TCTTGG-TAGATGGTAGGT--GGA-ATTGTTTCA-TAC--AAGT-----TAC--	4265
<i>Epichloë brachelytrii_E4804_</i>	4206	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTGTTTCA-TAC--AAGT-----TAC--	4249
<i>Epichloë bromicola_AL0434_</i>	4279	AGATAACTAGGATAAATTTTAGAC--CTAGATACTTACACTACTTTTAAAG--ACCTCTACTA	4334
<i>Epichloë bromicola_AL04262_</i>	4252	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATCATTTCA-TTC--AAGTT--GCG--	4296
<i>Epichloë elymi_ATCC_201551_</i>	4196	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATCATTTCA-TTC--AAGTT--GCG--	4241
<i>Epichloë festucae_AR1_</i>	4191	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	4240
<i>Epichloë festucae_AR37_</i>	3694	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	3743
<i>Epichloë festucae_AR48_</i>	4191	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	4240
<i>Epichloë festucae_E2368_</i>	4230	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	4279
<i>Epichloë festucae_Fg1_</i>	4191	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	4240
<i>Epichloë festucae_Fl1_</i>	4229	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	4278
<i>Epichloë gansuensis_e7080_</i>	1638	TCCGAGTTG--TTGAACCGATCTTTTGG-AGATCTTCACACC--AGCTACCAAGC--	1688
<i>Epichloë glyceriae_ATCC_200747_</i>	4297	CGCG-TCTGGG-TAGACGGTAGGT--GGA-ATCATTTA-TTC--AAGCT--GCGT--	4342
<i>Epichloë inebrians_MYA-1228_</i>	4245	CGCG-TCTGGG-CAGATGGTAGGT--GGA-ATCCTTCG--TTC--AAGTTA-CGT--	4289
<i>Epichloë mollis_AL9924_</i>	4255	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	4304
<i>Epichloë typhina_ATCC_200736_</i>	4233	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	4282
<i>Epichloë typhina_subsp_poae_</i>	4234	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	4283
<i>Epichloë typhina_subsp_Poae_Ps1_</i>	4229	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCGTACCT	4278
<i>Epichloë uncinata_CBS_102646_</i>	4232	CGCG-TCTGGG-TAGATGGTAGGT--GGA-ATTATTTTCA-TAC--AAG-TAGCATACCT	4281
<i>Epichloë amarillans_E57_</i>	4252	--G--TAAATCTGTCACTAA--TTGTTTATCCAGCGGACAATCAGAT-----T--CACGC	4298
<i>Epichloë amarillans_E4668_</i>	4248	--G--TAAATCTGTCACTAA--TTGTTTATCCAGCGGACAATCAGAT-----T--CACGC	4294
<i>Epichloë aotearoae_MYA-1229_</i>	4266	--G--TACCTCTGTCACTAA--TTGATTATCCAGTGGACAATCAGAT-----T--CACGC	4312
<i>Epichloë brachelytrii_E4804_</i>	4250	--G--TACCTCTGTCACTAA--TTGTTTATCTAGTGGACAATCAGAT-----T--CACGC	4296
<i>Epichloë bromicola_AL0434_</i>	4335	ATTATAATACCTTAAAT--AGTAATAAATTAGAGAAATGTAAGTAATAAGGGCTAAAGC	4393
<i>Epichloë bromicola_AL04262_</i>	4297	-----TACCTCTGTCACTAA--TTGTTTATCCAGCGGACAATCAGAT-----TACGC	4342
<i>Epichloë elymi_ATCC_201551_</i>	4242	-----ACCTCTGTCACTAA--TTGTTTATCCAGCGGACAATCAGAT-----TACGC	4286
<i>Epichloë festucae_AR1_</i>	4241	--G--TACCTCTGTCACTAA--TTGTTTATCCAGTGGACAATCAGAT-----TACGC	4287
<i>Epichloë festucae_AR37_</i>	3744	--G--TACCTCTGTCACTAA--TTGTTTATCCAGTGGACAATCAGAT-----TACGC	3790
<i>Epichloë festucae_AR48_</i>	4241	--G--TACCTCTGTCACTAA--TTGTTTATCCAGTGGACAATCAGAT-----TACGC	4287
<i>Epichloë festucae_E2368_</i>	4280	--G--TACCTCTGTCACTAA--TTGTTTATCCAGTGGACAATCAGAT-----TACGC	4326
<i>Epichloë festucae_Fg1_</i>	4241	--GT--ACCTCTGTCACTAATTT--TTTATCCAGTGGACAATCAGAT-----TACGC	4287
<i>Epichloë festucae_Fl1_</i>	4279	--GT--ACCTCTGTCACTAATTT--TTTATCCAGTGGACAATCAGAT-----TACGC	4325
<i>Epichloë gansuensis_e7080_</i>	1689	--AG-----CCAGGCT--T--TCAGGACCGATCGG--CAAT--AT-----TACGC	1723
<i>Epichloë glyceriae_ATCC_200747_</i>	4343	-----ACCTCTGTCACTAA--TTGTTTATCCAGTGGACAATCAGAT-----TACGC	4387
<i>Epichloë inebrians_MYA-1228_</i>	4290	-----ACTTCTGTCACTAA--TTGTTTATCCAGCGGACAATCAGAT-----TACGC	4334
<i>Epichloë mollis_AL9924_</i>	4305	--G--TACCTCTGTCACTAATTT--TTTATCCAGCGGACAATCAAT--T--CAGC--	4350
<i>Epichloë typhina_ATCC_200736_</i>	4283	G-----TATCTTTTCACTAATTTTTTTCAGTGGACAATCAGAT-----TACGC	4330
<i>Epichloë typhina_subsp_poae_</i>	4284	G-----TACCTCTGTCACTAATTT--TCTATCCAGCGGACAATCAGAT-----TACGC	4330
<i>Epichloë typhina_subsp_Poae_Ps1_</i>	4279	GT-----ACCTCTGTCACTAATTTTTTATCCAGCGGACAATCAGAT-----TACGC	4326
<i>Epichloë uncinata_CBS_102646_</i>	4282	G-----TACCTCTGTCACTAATTTTTTATCCAGCGGACAATCAGAT-----TACGC	4329
<i>Epichloë amarillans_E57_</i>	4299	-----T--ATTT--TCCGCCACCAGTTAAGCAACAATTATTTTCG--GACATCTCAATTA	4346
<i>Epichloë amarillans_E4668_</i>	4295	-----T--ATTT--TCCGCCACCAGTTAAGCAACAATTATTTTCG--GACATCTCAATTA	4342
<i>Epichloë aotearoae_MYA-1229_</i>	4313	-----C--ATTT--TCCGCCACCAGTTGAGCGAGAATCATTTTCG--GAACCTCTCAATTA	4360
<i>Epichloë brachelytrii_E4804_</i>	4297	-----T--ATTT--TCCGCCACCAGTTGAGCGAGAATCATTTTCG--GAACCTCTCAATTA	4344
<i>Epichloë bromicola_AL0434_</i>	4394	CTTATTAAATTTAGTATCTTTCTTACTAGAGAAATACCTAGAAAGAGCCCTAGAA	4453
<i>Epichloë bromicola_AL04262_</i>	4343	-----T--ATTT--TCCGCCACCAGTTGAGCAACAATTATTTTCG--GACATCTCAATTA	4390
<i>Epichloë elymi_ATCC_201551_</i>	4287	T-----ATTT--TCCGCCACCAGTTGAGCAACAATTATTTTCG--GACATCTCAATTA	4334
<i>Epichloë festucae_AR1_</i>	4288	-----TC--TTT--TCCGCCACCAGTTGAGCGAGGATTATTTTCG--GAACCTCTCAACTA	4335
<i>Epichloë festucae_AR37_</i>	3791	-----TC--TTT--TCCGCCACCAGTTGAGCGAGGATTATTTTCG--GAACCTCTCAACTA	3838
<i>Epichloë festucae_AR48_</i>	4288	-----TC--TTT--TCCGCCACCAGTTGAGCGAGGATTATTTTCG--GAACCTCTCAACTA	4335
<i>Epichloë festucae_E2368_</i>	4327	-----TC--TTT--TCCGCCACCAGTTGAGCGAGGATTATTTTCG--GAACCTCTCAACTA	4374
<i>Epichloë festucae_Fg1_</i>	4288	-----TC--TTT--TCCGCCACCAGTTGAGCGAGGATTATTTTCG--GAACCTCTCAACTA	4335
<i>Epichloë festucae_Fl1_</i>	4326	-----TC--TTT--TCCGCCACCAGTTGAGCGAGGATTATTTTCG--GAACCTCTCAACTA	4373
<i>Epichloë gansuensis_e7080_</i>	1724	-----TTGAGGAGCGCTTGGCA--TACTCGAGAAAGCACAA--GACCACCACTTA	1773
<i>Epichloë glyceriae_ATCC_200747_</i>	4388	T-----CTTT--TCCGCCACCAGTTGAGCGAGGATTATTTTCG--GAACCTCTCAATTA	4435
<i>Epichloë inebrians_MYA-1228_</i>	4335	T-----GTTT--TCTTCCACCAGTTGAGCGAGAATATTTTCG--GACATCTCAATTA	4382
<i>Epichloë mollis_AL9924_</i>	4351	-----TC-ATTT--TCCGCCACCAGTTGAGCAACAATTATTTTCG--GACATCTCAATTA	4399
<i>Epichloë typhina_ATCC_200736_</i>	4331	T-----CTTT--TCCGCCACCAGTTGAGCGAGAATCACTTTCG--GAACCTCTCAACTA	4378
<i>Epichloë typhina_subsp_poae_</i>	4331	T-----ATTT--TCCGCCACCAGTTGAGCGAGAATCACTTTCG--GAAATCTCAATTA	4378
<i>Epichloë typhina_subsp_Poae_Ps1_</i>	4327	T-----CTTT--TCCGCCACCAGTTGAGCGAGAATCACTTTCG--GAACCTCTCAATTA	4374
<i>Epichloë uncinata_CBS_102646_</i>	4330	T-----CTTT--TCCGCCACCAGTTGAGCGAGAATCACTTTCG--GAACCTCTCAATTA	4377
<i>Epichloë amarillans_E57_</i>	4347	TG--TCCCTCACC GCCG--ATAGC--ATGAACCT--CATGGCATGGTTGGAGGCCCTG	4396
<i>Epichloë amarillans_E4668_</i>	4343	TG--TCCCTCACC GCCG--ATAGC--ATGAACCT--CATGGCATGGTTGGAGGCCCTG	4392
<i>Epichloë aotearoae_MYA-1229_</i>	4361	T--ATCCTCACC GCCG--ATAGC--ATGAATCT--CGTTGGCATGGTTGGAGGCCCTG	4410
<i>Epichloë brachelytrii_E4804_</i>	4345	T--ATCCTCACC GCCG--ATAGT--ATGAACCT--CGTTGGCATGGTTGGAGGCCCTG	4394
<i>Epichloë bromicola_AL0434_</i>	4454	AAGACCTATACC--CTTATTCTTTTATAAGCTACTTCTTAACCTA--TAGGA--CTA	4506
<i>Epichloë bromicola_AL04262_</i>	4391	T--ATCCTCACC GCCG--ATAGA--ATGAACCT--TGTGGCATGGTTGGAGGCCCTG	4440
<i>Epichloë elymi_ATCC_201551_</i>	4335	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--TGTGGCATGGTTGGAGGCCCTG	4384
<i>Epichloë festucae_AR1_</i>	4336	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--CGTTGCCATGGTTGGAGGCCCTG	4385
<i>Epichloë festucae_AR37_</i>	3839	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--CGTTGCCATGGTTGGAGGCCCTG	3888
<i>Epichloë festucae_AR48_</i>	4336	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--CGTTGCCATGGTTGGAGGCCCTG	4385
<i>Epichloë festucae_E2368_</i>	4375	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--CGTTGCCATGGTTGGAGGCCCTG	4424
<i>Epichloë festucae_Fg1_</i>	4336	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--CGTTGCCATGGTTGGAGGCCCTG	4385
<i>Epichloë festucae_Fl1_</i>	4374	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--CGTTGCCATGGTTGGAGGCCCTG	4423
<i>Epichloë gansuensis_e7080_</i>	1774	GCAATGCACAGAAATACAT--GCA--ATGTTGCTGAGCGTTACAAAGACTGGCAATTGA	1831
<i>Epichloë glyceriae_ATCC_200747_</i>	4436	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--TGTGGCATGGTTGGAGGCCCTG	4485
<i>Epichloë inebrians_MYA-1228_</i>	4383	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--TGTACGATGGTTGGAGGCCCTG	4432
<i>Epichloë mollis_AL9924_</i>	4400	T--GTCTCACC GCCG--ATAGC--ATGAGCCT--CGTTGGCATGGTTGGAGGCCCTG	4449
<i>Epichloë typhina_ATCC_200736_</i>	4379	C--ATTCTCACC GCCG--AAAGC--ATGAACCT--CGTTGGCATGGTTGGAGGCCCTG	4428
<i>Epichloë typhina_subsp_poae_</i>	4379	T--ATCCTCACC GCCG--ATAGC--ATGAACCT--CGTTGGCATGGTTGGAGGCCCTG	4428
<i>Epichloë typhina_subsp_Poae_Ps1_</i>	4375	T--ATTCTCACC GCCG--ATAGC--ATGAACCT--CGTTGGCATGGTTGGAGGCCCTG	4424
<i>Epichloë uncinata_CBS_102646_</i>	4378	T--ATTCTCACC GCCG--ATAGC--ATGAACCT--CGTTGGCATGGTTGGAGGCCCTG	4427
<i>Epichloë amarillans_E57_</i>	4397	CCTTG--CTTGCCAAGCTCAAT--GG--ACTAGAC-----AAGTGG--ACAG--GCGAGGCTA	4444
<i>Epichloë amarillans_E4668_</i>	4393	CCTTG--CTTGCCAAGCTCAAT--GG--ACTAGAC-----AAGTGG--ACAG--GCGAGGCTA	4440
<i>Epichloë aotearoae_MYA-1229_</i>	4411	CCTTG--CTTGCCAAGCTCAT--GA--AGAAGAC-----AAGTGG--ACAG--GTGAGGCTA	4458
<i>Epichloë brachelytrii_E4804_</i>	4395	CCTTG--CTTGCCAAGCTCAT--CA--AGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4442
<i>Epichloë bromicola_AL0434_</i>	4507	TATTAACTATATAGCTTATTACTAATAAGACTAAG--AAGAGTTTATATAGTTTGCCTA	4566
<i>Epichloë bromicola_AL04262_</i>	4441	CCTTG--CTTTCCAAGCTCAATG--GACTAGAC-----AAGTGG--ACAG--GCGAGGCTA	4488
<i>Epichloë elymi_ATCC_201551_</i>	4385	CCTTG--CTTTCCAAGCTCAATG--GACTAGAC-----AAGTGG--ACAG--GCGAGGCTA	4432
<i>Epichloë festucae_AR1_</i>	4386	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4433
<i>Epichloë festucae_AR37_</i>	3889	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	3936
<i>Epichloë festucae_AR48_</i>	4386	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4433
<i>Epichloë festucae_E2368_</i>	4425	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4472
<i>Epichloë festucae_Fg1_</i>	4386	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4433
<i>Epichloë festucae_Fl1_</i>	4424	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4471
<i>Epichloë gansuensis_e7080_</i>	1832	CTTTG--TGGC--ATTTCTATG--ATCCGA-----AATTCG--CCATTGCCAGTT--	1874
<i>Epichloë glyceriae_ATCC_200747_</i>	4486	CCTTG--CTTGCCAAGCTCATG--GTAGAC-----AAGTGG--ACAG--GCGAGGCTA	4533
<i>Epichloë inebrians_MYA-1228_</i>	4433	CCTTG--CTTGGAAGCTTAATG--GACTAGAT-----AAGTGG--ACAG--GCGAGGCTA	4480
<i>Epichloë mollis_AL9924_</i>	4450	CCTTG--CTTGCCAAGCTCAATG--GACTAGACA-----AAGTGG--ACAG--GCGAGGCTA	4497
<i>Epichloë typhina_ATCC_200736_</i>	4429	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4476
<i>Epichloë typhina_subsp_poae_</i>	4429	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4476
<i>Epichloë typhina_subsp_Poae_Ps1_</i>	4425	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4472
<i>Epichloë uncinata_CBS_102646_</i>	4428	CCTTG--CTTGCCAAGCTCATG--AAGAAGAC-----AAGTGG--ACAG--GCGAGGCTA	4475

Chapter eight: Appendices

```
Epichloë_amarillans_E57_
Epichloë_amarillans_E4668
Epichloë_aotearoae_MYA-1229_
Epichloë_brachyleytrii_E4804_
Epichloë_bromicola_AL0434_
Epichloë_bromicola_AL04262_
Epichloë_elymi_ATCC_201551_
Epichloë_festucaae_AR1
Epichloë_festucaae_AR37
Epichloë_festucaae_AR48
Epichloë_festucaae_E2368
Epichloë_festucaae_Fg1
Epichloë_festucaae_F11
Epichloë_gansuensis_e7080_
Epichloë_glyceriae_ATCC_200747_
Epichloë_inebrians_MYA-1228_
Epichloë_mollis_AL9924_
Epichloë_typhina_ATCC_200736_
Epichloë_typhina_subsp_poae
Epichloë_typhina_subsp_Poae_Ps1
Epichloë_uncinata_CBS_102646_

4445 A - ACTTCTACTGGAAGA-CTACT--A--CACTGATCCAAG-----CG-AGATGA--TTC 4489
4441 A - ACTTCTACTGGAAGA-CTACT--A--CACTAAATCCAAG-----CG-AGATGA--TTC 4485
4459 C - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAG-----CG-AGCTTA--TGC 4503
4443 C - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAG-----CG-AGCTTA--TGC 4487
4567 GTAGTTCTA--GGAGCTATACT--AAGAAATAAGCAAA-----AGCCTAAGTAA 4612
4489 A - ACTTCTACTGGAAGA-CTACT--A--CACTGATCCAAG-----CG-AGATGA--TTC 4533
4433 A - ACTTCTACTGGAAGA-CTACT--A--CACTGATCCAAG-----C-G-AGATGA--TTC 4477
4434 C - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAG-----CG-AGCTTA--TGC 4478
3937 C - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAG-----CG-AGCTTA--TGC 3981
4434 C - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAG-----CG-AGCTTA--TGC 4478
4473 C - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAG-----CG-AGCTTA--TGC 4517
4434 C - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAG-----C-G-AGCTTA--TGC 4478
4472 C - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAG-----C-G-AGCTTA--TGC 4516
1875 CAACT-C-AGGGGAAGCGTCTTGAAGCCACCA--CCAAGTTTTCGAAGACTCGGGAT 1930
4534 C - ACTTCTACTGGAAGA-CTACT--A--CACCGGGCCGAGC-----G-AGCTTA--TGC 4578
4481 C - ACTTCTACTGGAAGA-CTAC-----ACTGATACACG-----G-AGGTCA--TGC 4522
4498 A - ACTTCTACTGGAAGA-CTACT--A--CACTGATCCAAG-----CG-AGATGA--TTC 4542
4477 C - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAGC-----G-AGCTTC--TGC 4521
4477 G - ACTTCTACTGGAAGA-CTACTA-----CACTGGGCCGAGG-----G-AGCTTA--TGC 4521
4473 G - ACTTCTACTGGAAGA-CTACT--A--CACTGGGCCGAG-----CG-AGCTTC--TGC 4517
4476 G - ACTTCTACTGGAAGA-CTACTA-----CACTGGGCCGAG-----CG-AGCTTC--TGC 4520

Epichloë_amarillans_E57_
Epichloë_amarillans_E4668
Epichloë_aotearoae_MYA-1229_
Epichloë_brachyleytrii_E4804_
Epichloë_bromicola_AL0434_
Epichloë_bromicola_AL04262_
Epichloë_elymi_ATCC_201551_
Epichloë_festucaae_AR1
Epichloë_festucaae_AR37
Epichloë_festucaae_AR48
Epichloë_festucaae_E2368
Epichloë_festucaae_Fg1
Epichloë_festucaae_F11
Epichloë_gansuensis_e7080_
Epichloë_glyceriae_ATCC_200747_
Epichloë_inebrians_MYA-1228_
Epichloë_mollis_AL9924_
Epichloë_typhina_ATCC_200736_
Epichloë_typhina_subsp_poae
Epichloë_typhina_subsp_Poae_Ps1
Epichloë_uncinata_CBS_102646_

4490 TCA--AGCCCAAGCAT-TC--GGATCCCTAA--CTGG-----AGC--CGATAT----C 4530
4486 TCA--AGCCCAAGCAT-TC--GGATCCCTAG--CTGG-----AGC--CGATAT----C 4526
4504 CCA--AGCTCAAGCCAT-TC--GAATCCCTAG--CTGG-----AGC--CGATAT----C 4544
4488 TCA--AGCTCAAGCCAT-TC--GAATCCCTAG--CTGG-----AGC--CGATAT----C 4528
4613 TTAGGACATAAAGGCTTCTAAGAACCTTACACTA-T--AG--GAATAA--TTC 4663
4534 TCA--AGCCCAAGCCAT-TC--GGATCCCTAG--CTG-G--AGC--CGATATC----4574
4478 TCA--AGCCCAAGCCAT-TC--GGATCCCTAG--CTG-G--AGC--CGATATC----C 4518
4479 TCA--AGCTCAAGCCAT-TC--GAAGCCCTAG--CTG-G--AGC--CGATATC----4519
3982 TCA--AGCTCAAGCCAT-TC--GAAGCCCTAG--CTG-G--AGC--CGATATC----4022
4479 TCA--AGCTCAAGCCAT-TC--GAAGCCCTAG--CTG-G--AGC--CGATATC----4519
4518 TCA--AGCTCAAGCCAT-TC--GAAGCCCTAG--CTG-G--AGC--CGATATC----4558
4479 TCA--AGCTCAAGCCAT-TC--GAAGCCCTAG--CTG-G--AGC--CGATATC----4519
4517 TCA--AGCTCAAGCCAT-TC--GAAGCCCTAG--CTG-G--AGC--CGATATC----4557
1931 TC--GCCAAGG--TCTACGAAGCCACGGTACACACCCAGCCTTGTTTTC 1981
4579 TCA--AGCCCAAGCGCT-TC--GAATCCCTAG--CTGG-----AGC--CGATATC----4619
4523 TCA--TGCATAATTCAT-TC--GGATCCCTAG--CTGG-----AGC--CGATATC----4563
4543 TCA--AGCCCAAGCCAT-TC--GGATCCCTAG--CTGG-----AGC--CGATATC----4583
4522 CCA--AGCTCAAGCTAT-TC--GAATCCCTAG--CTGG-----AGC--CGATATC----4562
4522 TCA--AGCTCAAGCCAT-TC--GAATCCCTAG--CTGG-----AGC--CGATATC----4562
4518 CCA--AGCTCAAGCTAT-TC--GAATCCCTAG--CTGG-----AGC--CGATATC----4558
4521 CCA--AGCTCAAGCTAT-TC--GAATCCCTAG--CTGG-----AGC--GGATATC----4561

Epichloë_amarillans_E57_
Epichloë_amarillans_E4668
Epichloë_aotearoae_MYA-1229_
Epichloë_brachyleytrii_E4804_
Epichloë_bromicola_AL0434_
Epichloë_bromicola_AL04262_
Epichloë_elymi_ATCC_201551_
Epichloë_festucaae_AR1
Epichloë_festucaae_AR37
Epichloë_festucaae_AR48
Epichloë_festucaae_E2368
Epichloë_festucaae_Fg1
Epichloë_festucaae_F11
Epichloë_gansuensis_e7080_
Epichloë_glyceriae_ATCC_200747_
Epichloë_inebrians_MYA-1228_
Epichloë_mollis_AL9924_
Epichloë_typhina_ATCC_200736_
Epichloë_typhina_subsp_poae
Epichloë_typhina_subsp_Poae_Ps1
Epichloë_uncinata_CBS_102646_

4531 -GAT-GCGGCG-ATAGA--TCCTCATA-TGATTTTTG--TG--CTGGGACCAAAAGA 4577
4527 -GAT-GCGGCG-ATAGA--TCCTCATA-TGATTTTTG--TG--CTGGGACCAAAAGA 4573
4545 -GAT-GCGGCG-ATAGA--TCCTCATA-TGTTTTTTG--TA--CTGGGACCGCAAGC 4591
4529 -GAT-GCGGCG-ATAGA--TCCTCATT-TGATTTTTG--TG--CTGGGACCGAAAGG 4575
4664 CTAT-AAGGTT-ATA-A-ACCTTATAAAGATTAAAGAAATAAAGA-CTAGGA--AAAGGG 4716
4575 -GATG-GCGGCG-ATAGA--TCCTCATA-TGATTTCTG--TG--CTGGGACCAAAAGA 4621
4519 -GATG-GCGGCG-ATAGA--TCCTCATA-TGATTTCTG--TG--CTGGGACCAAAAGA 4565
4520 -GATG-GCGGCG-ATAGA--TCCTCATT-TGATTTTTG--TG--CTGGGACCGAAAGG 4566
4023 -GATG-GCGGCG-ATAGA--TCCTCATT-TGATTTTTG--TG--CTGGGACCGAAAGG 4069
4520 -GATG-GCGGCG-ATAGA--TCCTCATT-TGATTTTTG--TG--CTGGGACCGAAAGG 4566
4559 -GATG-GCGGCG-ATAGA--TCCTCATT-TGATTTTTG--TG--CTGGGACCGAAAGG 4605
4520 -GATG-GCGGCG-ATAGA--TCCTCATT-TGATTTTTG--TG--CTGGGACCGAAAGG 4566
4558 -GATG-GCGGCG-ATAGA--TCCTCATT-TGATTTTTG--TG--CTGGGACCGAAAGG 4604
1982 AGATTGACGCGAGAGAGTTTCTCGCA-TCATATTGGA-CTACAACCT--GACCGTCGCC 2037
4620 -GAT-GCGGCG-ATTGA--TCCTCATA-TTATTTTCTG--TG--CTGGGACCGAAAGG 4666
4564 -GAC-GCGGCG-ATAGA--TTCTCATA-TGATTTCTG--TG--CTGGGACCGAAAGG 4610
4584 -TAT-GCGGCG-ATAGA--TCCTCATA-TGATTTTTG--TG--ACGGGACCAAAAGA 4630
4563 -AAT-GCGGCG-ATAGA--TCCTCATT-TGATCTTTG--TG--CTGGGACCGAAAGG 4609
4563 -GAT-GCGGCG-ATAGA--TTCTCATA-TGTTTTTTG--TA--CTGGGACCGCAAGC 4609
4559 -GAT-GCGGCG-ATAGA--TCCTCATT-TGATTTTTG--TG--CTGGGACCGAAAGG 4605
4562 -GAT-GCGGCG-ATAGA--TCCTCATT-TGATTTTTG--TG--CTGGGACCGAAAGG 4608

Epichloë_amarillans_E57_
Epichloë_amarillans_E4668
Epichloë_aotearoae_MYA-1229_
Epichloë_brachyleytrii_E4804_
Epichloë_bromicola_AL0434_
Epichloë_bromicola_AL04262_
Epichloë_elymi_ATCC_201551_
Epichloë_festucaae_AR1
Epichloë_festucaae_AR37
Epichloë_festucaae_AR48
Epichloë_festucaae_E2368
Epichloë_festucaae_Fg1
Epichloë_festucaae_F11
Epichloë_gansuensis_e7080_
Epichloë_glyceriae_ATCC_200747_
Epichloë_inebrians_MYA-1228_
Epichloë_mollis_AL9924_
Epichloë_typhina_ATCC_200736_
Epichloë_typhina_subsp_poae
Epichloë_typhina_subsp_Poae_Ps1
Epichloë_uncinata_CBS_102646_

4578 CGAAGATCAATACCTTT--CACCACCGATTCT--GGATACGAATGTCCGACCGAACTGTTA 4633
4574 CGAAGATCAATACCTTT--CACCACCGATTCT--GGATACGAATGTCCGACCGAACTGTTA 4629
4592 CAAAGAT--CGATTCT--GGATACGAATGTCCGACCGAACTGTTA 4632
4576 CAAAGATCATTACTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4631
4717 CCTAGCTACCTACCTAAATAACACTAAACCTAGGGATAAG-ATAI-----AGTGTA 4767
4622 CGAAGATCGATACCTTT--CACCATCGATTCT--GGATACGAATGTCCGACCGAACTGTTA 4677
4566 CGAAGATCAATACCTTT--CACCATCGATTCT--GGATACGAATGTCCGACCGAACTGTTA 4621
4567 CAAAGATCTACTTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4622
4070 CAAAGATCGTTACTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4125
4567 CAAAGATCGTTACTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4622
4606 CAAAGATCTACTTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4661
4567 CAAAGATCGTTACTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4622
4605 CAAAGATCGTTACTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4660
2038 CGAA-----TCCATT--CACCATCGATTCT--GGATACGAATGTCCGACCGAACTGTTA 2087
4667 CAAAGATCAATTTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4722
4611 CGACGACGAATTCATT--CACCATCGATTCT--GGATACGAATGTCCGACCGAACTGTTA 4666
4631 CGAAGATCGATACCTTT--CACCATCGATTCT--GGATACGAATGTCCGACCGAACTGTTA 4686
4610 CAAAGATCATTACTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4665
4610 CAAAGATGATTACATT--CACCACCGATTCT--GGATACGAATGTCCGACCGAACTGTTA 4665
4606 CAAAGATCATTACTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4661
4609 CAAAGATCATTACTTT--TACCATCAATTCT--GGATACGAATGTCCGACCGAACTGTTA 4664

Epichloë_amarillans_E57_
Epichloë_amarillans_E4668
Epichloë_aotearoae_MYA-1229_
Epichloë_brachyleytrii_E4804_
Epichloë_bromicola_AL0434_
Epichloë_bromicola_AL04262_
Epichloë_elymi_ATCC_201551_
Epichloë_festucaae_AR1
Epichloë_festucaae_AR37
Epichloë_festucaae_AR48
Epichloë_festucaae_E2368
Epichloë_festucaae_Fg1
Epichloë_festucaae_F11
Epichloë_gansuensis_e7080_
Epichloë_glyceriae_ATCC_200747_
Epichloë_inebrians_MYA-1228_
Epichloë_mollis_AL9924_
Epichloë_typhina_ATCC_200736_
Epichloë_typhina_subsp_poae
Epichloë_typhina_subsp_Poae_Ps1
Epichloë_uncinata_CBS_102646_

4634 TCAAACCCCATCCTGACATTCACCTCG-ATTACCTGCT--TGTGGGAACGTGTCGCTTCGA 4690
4630 TCAAACCCCATCCTGACATTCACCTCG-ATTACCTGCT--TGTGGGAACGTGTCGCTTCGA 4686
4633 TCAAACCCCATCCTGACATTCACCTCG-ATTACCTGCT--TGTGGGAACCATCGCTTCGA 4689
4632 TCAAACCCCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATCGCTTCGA 4688
4768 T--AAC--TATAATAGCAT--AGATATATTATATACTATAGGAAC--CTAAGA 4817
4678 TCAAACCCCATCCTGACATTCACCTCG-ATTACCTGCT--TGTGGGAACCATCGCTTCGA 4734
4622 TCAAACCCCATCCTGACATTCACCTTG-ATTACCTGCT--TGTGGGAACCATCGCTTCGA 4678
4623 TCAAACCTCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATCGCTTCG 4679
4126 TCAAACCTCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCGA 4182
4623 TCAAACCTCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCGA 4679
4662 TCAAACCTCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCG 4718
4623 TCAAACCTCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCGA 4679
4661 TCAAACCTCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCGA 4717
2088 TCAAACCCCATCCTGACATTCACCTTG-ATTACCTGCT--CGTTGGAATTATCACTCAA 2144
4723 TCAAACCCCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCGA 4779
4667 TCAAACCCCATCCTGACATTCACCTTG-ATTACCTGCT--CGTTGGAATTCAATTCAA 4723
4687 TCAAACCCCATCCTGACATTCACCTTG-ATTACCTGCT--TGTGGGAATTATCGCTTCGA 4743
4666 TCAAACCCCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCGA 4722
4666 TCAAACCCCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCG 4722
4662 TCAAACCCCATCCTGACATTCACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCGA 4718
4665 TCAAACCCCATCCTGATATTACCTTA-ATTACCTGCT--TGTGGGAACCATTCGCTTCGA 4721
```


Chapter eight: Appendices

Epichloë_amarillans_E57_	4691	CAGATGGCAGTGATGAACAATTTTGGCTTCTTCTCACACAAAGAA---	CACA-AGCTCGTG	4746
Epichloë_amarillans_E4668_	4687	CAGATGGCAGTGATGAACAATTTTGGCTTCTTCTCACACAAAGAA---	CACA-AGCTCGTG	4742
Epichloë_aotearoae_MYA-1229_	4690	CAGATGACAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4745
Epichloë_brachelytri_E4804_	4689	CAGGTGAAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4744
Epichloë_bromicola_AL0434_	4818	AAGAGTCTCTAAGGAGGCTAGAAAACTCTAAGGTAAAGTAAATG	CCCTTACCTCTAC	4877
Epichloë_bromicola_AL04262_	4735	CAGATGGCAGTGGTGAACAGTTTTGGCTTCTTCTCACACAAAGAA---	CACA-AGCTCGTG	4790
Epichloë_elymi_ATCC_201551_	4679	CAGATGGCAGTGGTGAACGTGTTTGGCTTCTTCTCACACAAAGAA---	CACA-AGCTCGTG	4734
Epichloë_festucae_AR1_	4680	CAGATGGCAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4735
Epichloë_festucae_AR37_	4183	CAGATGGCAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4238
Epichloë_festucae_AR48_	4680	CAGATGGCAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4735
Epichloë_festucae_E2368_	4719	CAGATGGCAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4774
Epichloë_festucae_Fg1_	4680	CAGATGGCAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4735
Epichloë_festucae_Fl1_	4718	CAGATGGCAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4773
Epichloë_gansuensis_e7080_	2145	CAGATGGTAGTGGTGAACAATTTTGGCTTCTTCTCACACAAAGAA---	CACA-AGCTCGTG	2200
Epichloë_glyceriae_ATCC_200747_	4780	CAGATGGCGTGGTGAACAGTTTTGGCTTCTTCTCATACATTCAA---	CACA-AGCTCGTG	4835
Epichloë_inebrians_MYA-1228_	4724	CAGATGGTAGTGGTGAACAGTTTTGGCTTCTTCTCACACAAAGAA---	CACA-AGCTCGTG	4779
Epichloë_mollis_AL9924_	4744	CAGATGGCAGTGATGAACAGTTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4799
Epichloë_typhina_ATCC_200736_	4723	CAGGTGAAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4778
Epichloë_typhina_subsp_poae_	4723	CAGATGGCAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4778
Epichloë_typhina_subsp_Poae_Ps1_	4719	CAGGTGAAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCAA---	CACA-AGCTCGTG	4774
Epichloë_uncinata_CBS_102646_	4722	CAGAGGACAGTGGTGAACGTGTTTGGCTTCTTCTCATACAATCGA---	TACA-AGCTCGTG	4777
Epichloë_amarillans_E57_	4747	ATCCAACAAGGAAACGGCAGACGGG-C---	AAACAAACCAAGGCCTGTACGATTTC	4801
Epichloë_amarillans_E4668_	4743	ATCCAACAAGGAAACGGCAGAAACGGG-C---	AAAAAACAAGGCCTGTACGATTTC	4800
Epichloë_aotearoae_MYA-1229_	4746	GTCCAACGAGGAAACGGCAAAACAGG-C---	AGAGGAACCAAGGCCTGTACAAATTC	4800
Epichloë_brachelytri_E4804_	4745	GTCCAACGAGGAAACGGCAAAACAGG-C---	AGAGGAACCAAGGCCTGTACAAATTC	4799
Epichloë_bromicola_AL0434_	4878	CTCTAA-TATTAAGGTGCTAATAGGGGTT	AGTTTTAG--ACACTAATTTAATTTATAG	4934
Epichloë_bromicola_AL04262_	4791	ATCCAACGAGGAATGGCAAAACAGG-C---	AAAGAAACCAAGGCCTGTACGATTGT	4845
Epichloë_elymi_ATCC_201551_	4735	ATCCAACGAGGAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACGATTTC	4879
Epichloë_festucae_AR1_	4736	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4790
Epichloë_festucae_AR37_	4239	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4293
Epichloë_festucae_AR48_	4736	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4790
Epichloë_festucae_E2368_	4775	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4829
Epichloë_festucae_Fg1_	4736	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4790
Epichloë_festucae_Fl1_	4774	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4828
Epichloë_gansuensis_e7080_	2201	ATCCAACAAGGAAACGGCAAAACAGG-C---	AAAGGAACCAAGGCCTGTACGATTGT	2255
Epichloë_glyceriae_ATCC_200747_	4836	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACGATTTC	4890
Epichloë_inebrians_MYA-1228_	4780	ATCCAACAAGGAAACGGCAAAACAGG-C---	AAAGGAACCAAGGCCTGTACGATTGT	4834
Epichloë_mollis_AL9924_	4800	ATCCAACGAGGAAACGGCAAAACAGG-C---	AAAGGAACCAAGGCCTGTACGATTTC	4855
Epichloë_typhina_ATCC_200736_	4779	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4833
Epichloë_typhina_subsp_poae_	4779	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4833
Epichloë_typhina_subsp_Poae_Ps1_	4775	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4830
Epichloë_uncinata_CBS_102646_	4778	GTCCAACGAGGAAACGGCAAAACAGG-C---	GAAGAAACCAAGGCCTGTACAAATTC	4832
Epichloë_amarillans_E57_	4802	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4848
Epichloë_amarillans_E4668_	4798	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4844
Epichloë_aotearoae_MYA-1229_	4801	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4847
Epichloë_brachelytri_E4804_	4800	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4846
Epichloë_bromicola_AL0434_	4935	GCATAAAATATAAATAGTGGTAAATCTAAATAGTTACGCTAAGATTATATAATTAAG		4994
Epichloë_bromicola_AL04262_	4846	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4892
Epichloë_elymi_ATCC_201551_	4790	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4836
Epichloë_festucae_AR1_	4791	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4837
Epichloë_festucae_AR37_	4294	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4340
Epichloë_festucae_AR48_	4791	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4837
Epichloë_festucae_E2368_	4830	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4876
Epichloë_festucae_Fg1_	4791	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4837
Epichloë_festucae_Fl1_	4829	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4875
Epichloë_gansuensis_e7080_	2256	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	2302
Epichloë_glyceriae_ATCC_200747_	4891	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4937
Epichloë_inebrians_MYA-1228_	4835	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4881
Epichloë_mollis_AL9924_	4856	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4901
Epichloë_typhina_ATCC_200736_	4834	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4880
Epichloë_typhina_subsp_poae_	4834	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4880
Epichloë_typhina_subsp_Poae_Ps1_	4831	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4876
Epichloë_uncinata_CBS_102646_	4833	CC-----GAGTTCGGAA-----CC-	ATCTCAA-ACITCTTTCTGTCTCAACAAATGACTTG	4879
Epichloë_amarillans_E57_	4849	TTTTCCAT---TACGGATACGGGTTTCATATCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4905
Epichloë_amarillans_E4668_	4845	TTTTCCAT---TACGGATACGGGTTTCATATCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4901
Epichloë_aotearoae_MYA-1229_	4848	TTTTCCAT---TACGGATACGGGTTTCATATCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4904
Epichloë_brachelytri_E4804_	4847	TTTTCCAT---TACGGATACGGGTTTCATATCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4903
Epichloë_bromicola_AL0434_	4995	TATTAAGTTATAAGAA-----		5011
Epichloë_bromicola_AL04262_	4893	TTTTCCAT---TACGGATACGGGTTTCATATCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4949
Epichloë_elymi_ATCC_201551_	4837	TTTTCCAT---TACGGATACGGGTTTCATATCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4893
Epichloë_festucae_AR1_	4838	TTTTCCAT---TACGGATACGGGTTTCATATCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4894
Epichloë_festucae_AR37_	4341	TTTTCCAT---TACGAATCGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4397
Epichloë_festucae_AR48_	4838	TTTTCCAT---TACGAATCGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4894
Epichloë_festucae_E2368_	4877	TTTTCCAT---TACGAATCGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4933
Epichloë_festucae_Fg1_	4838	TTTTCCAT---TACGAATCGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4894
Epichloë_festucae_Fl1_	4876	TTTTCCAT---TACGAATCGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4932
Epichloë_gansuensis_e7080_	2303	TTTTCCAT---TACTACTACGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	2359
Epichloë_glyceriae_ATCC_200747_	4938	TTTTCCAT---TACGAACCGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4994
Epichloë_inebrians_MYA-1228_	4882	TTTTCCAT---TACTACTACGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4938
Epichloë_mollis_AL9924_	4902	TTTTCCAT---TACGGATACGGGTTTCATATCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4958
Epichloë_typhina_ATCC_200736_	4881	TTTTCCAT---TACGGATACGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4937
Epichloë_typhina_subsp_poae_	4881	TTTTCCAT---TACGAATCGGGTTTCATTCTCCGCTTGACAAAACACTGTACACTT	GCT	4937
Epichloë_typhina_subsp_Poae_Ps1_	4877	TTTTCCAT---TACGGATACGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4933
Epichloë_uncinata_CBS_102646_	4880	TTTTCCAT---TACGGATACGGGTTTCATTCTCCGCTTGACAACGCAGCTGTACACTT	GCT	4936
Epichloë_amarillans_E57_	4906	CTGGAAGCGCTAAATCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4965
Epichloë_amarillans_E4668_	4902	CTGGAAGCGCTAAATCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4961
Epichloë_aotearoae_MYA-1229_	4905	TTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4964
Epichloë_brachelytri_E4804_	4904	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4963
Epichloë_bromicola_AL0434_				
Epichloë_bromicola_AL04262_	4950	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	5009
Epichloë_elymi_ATCC_201551_	4894	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4953
Epichloë_festucae_AR1_	4895	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4954
Epichloë_festucae_AR37_	4398	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4457
Epichloë_festucae_AR48_	4895	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4954
Epichloë_festucae_E2368_	4934	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4993
Epichloë_festucae_Fg1_	4895	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4954
Epichloë_festucae_Fl1_	4933	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4992
Epichloë_gansuensis_e7080_	2360	CTGGAAGCTGTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	2416
Epichloë_glyceriae_ATCC_200747_	4995	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	5054
Epichloë_inebrians_MYA-1228_	4939	CTGGAAGCTGTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4995
Epichloë_mollis_AL9924_	4959	CTGGAAGCGCTAAATCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	5018
Epichloë_typhina_ATCC_200736_	4938	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4997
Epichloë_typhina_subsp_poae_	4938	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4997
Epichloë_typhina_subsp_Poae_Ps1_	4934	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4993
Epichloë_uncinata_CBS_102646_	4937	CTGGAAGCGCTCAACCATCAGTGGCTCGAGCACTGCGGAAAGGACGTAGAT	GGCGGCCCC	4996

Chapter eight: Appendices

<i>Epichloë amarillans_E57_</i>	4966	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCGGCAATTGTCTCCATAGTT	5025
<i>Epichloë amarillans_E4668_</i>	4962	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCGGCAATTGTCTCCATAGTT	5021
<i>Epichloë aotearoae_MYA-1229_</i>	4965	TGGTGGACTGCACTATCAAAGCTCGCCAAAGACCACGCGCGCAGCAATTGTCTCCATAGTT	5024
<i>Epichloë brachelyltri_E4804_</i>	4964	TGGTGGACTGCACTATCAAAGCTCGCCAAAGACCACGCGCGCAGCAATTGTCTCCATAGTT	5023
<i>Epichloë bromicola_AL0434_</i>			
<i>Epichloë bromicola_AL04262_</i>	5010	TGGTGGACTGCACTACCAAAGCTCGTCAAAGACCACGACCCAGCAATTGTCTCCATAGTT	5069
<i>Epichloë elymi_ATCC_201551_</i>	4954	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGACCCAGCAATTGTCTCCATAGTT	5013
<i>Epichloë festucae_AR1_</i>	4955	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	5014
<i>Epichloë festucae_AR37_</i>	4458	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	4517
<i>Epichloë festucae_AR48_</i>	4955	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	5014
<i>Epichloë festucae_E2368_</i>	4994	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	5053
<i>Epichloë festucae_Fg1_</i>	4955	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	5014
<i>Epichloë festucae_Fl1_</i>	4993	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCGCAATTGTCTCCATAGTT	5052
<i>Epichloë gansuensis_e7080_</i>	2417	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCTTATAGTT	2476
<i>Epichloë glyceriae_ATCC_200747_</i>	5055	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCGCAATTGTCTCCATAGTT	5114
<i>Epichloë inebrians_MYA-1228_</i>	4996	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCTTATAGTT	5055
<i>Epichloë mollis_AL9924_</i>	5019	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	5078
<i>Epichloë typhina_ATCC_200736_</i>	4998	TGGTGGACTGCACTATCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	5057
<i>Epichloë typhina_subsp_poae</i>	4998	TGGTGGACTGCACTACCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	5057
<i>Epichloë typhina_subsp_Poae_Ps1</i>	4994	TGGTGGACTGCACTATCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	5053
<i>Epichloë uncinata_CBS_102646_</i>	4997	TGGTGGACTGCACTATCAAAGCTCGCCAAAGACCACGCGCAGCAATTGTCTCCATAGTT	5056
<i>Epichloë amarillans_E57_</i>	5026	GGCCTTTGCGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5085
<i>Epichloë amarillans_E4668_</i>	5022	GGCCTTTGCGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5081
<i>Epichloë aotearoae_MYA-1229_</i>	5025	GGCCTTTGCGGATACCGAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5084
<i>Epichloë brachelyltri_E4804_</i>	5024	GGCCTTTGCGGATACCGAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5083
<i>Epichloë bromicola_AL0434_</i>			
<i>Epichloë bromicola_AL04262_</i>	5070	GGCCTTTGCGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5129
<i>Epichloë elymi_ATCC_201551_</i>	5014	GGCCTTTGCGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5073
<i>Epichloë festucae_AR1_</i>	5015	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5074
<i>Epichloë festucae_AR37_</i>	4518	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	4577
<i>Epichloë festucae_AR48_</i>	5015	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5074
<i>Epichloë festucae_E2368_</i>	5054	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5113
<i>Epichloë festucae_Fg1_</i>	5015	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5074
<i>Epichloë festucae_Fl1_</i>	5053	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5112
<i>Epichloë gansuensis_e7080_</i>	2477	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	2536
<i>Epichloë glyceriae_ATCC_200747_</i>	5115	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5174
<i>Epichloë inebrians_MYA-1228_</i>	5056	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5115
<i>Epichloë mollis_AL9924_</i>	5079	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5138
<i>Epichloë typhina_ATCC_200736_</i>	5058	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5117
<i>Epichloë typhina_subsp_poae</i>	5058	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5117
<i>Epichloë typhina_subsp_Poae_Ps1</i>	5054	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5113
<i>Epichloë uncinata_CBS_102646_</i>	5057	GGCCTTTGCGGATGCCAGGGCTCCCCGTTCAAGCTTGGCTCTGCAGTAAACCGATTGTGTC	5116
<i>Epichloë amarillans_E57_</i>	5086	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5145
<i>Epichloë amarillans_E4668_</i>	5082	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5141
<i>Epichloë aotearoae_MYA-1229_</i>	5085	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5144
<i>Epichloë brachelyltri_E4804_</i>	5084	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5143
<i>Epichloë bromicola_AL0434_</i>			
<i>Epichloë bromicola_AL04262_</i>	5130	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5189
<i>Epichloë elymi_ATCC_201551_</i>	5074	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5133
<i>Epichloë festucae_AR1_</i>	5075	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5134
<i>Epichloë festucae_AR37_</i>	4578	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	4637
<i>Epichloë festucae_AR48_</i>	5075	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5134
<i>Epichloë festucae_E2368_</i>	5114	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5173
<i>Epichloë festucae_Fg1_</i>	5075	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5134
<i>Epichloë festucae_Fl1_</i>	5113	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5172
<i>Epichloë gansuensis_e7080_</i>	2537	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	2596
<i>Epichloë glyceriae_ATCC_200747_</i>	5175	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5234
<i>Epichloë inebrians_MYA-1228_</i>	5116	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5175
<i>Epichloë mollis_AL9924_</i>	5139	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5198
<i>Epichloë typhina_ATCC_200736_</i>	5118	GTTGCAGGATCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5177
<i>Epichloë typhina_subsp_poae</i>	5118	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGTACATGGCAGGACTGACAGAAGGGGA	5177
<i>Epichloë typhina_subsp_Poae_Ps1</i>	5114	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5173
<i>Epichloë uncinata_CBS_102646_</i>	5117	GTTGCAGGACCCCTCTCTACGTGAAAAACCGGGGCACATGGCAGGACTGACAGAAGGGGGA	5176
<i>Epichloë amarillans_E57_</i>	5146	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----A-----	5178
<i>Epichloë amarillans_E4668_</i>	5142	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----A-----	5174
<i>Epichloë aotearoae_MYA-1229_</i>	5145	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----A-----	5177
<i>Epichloë brachelyltri_E4804_</i>	5144	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----A-----	5176
<i>Epichloë bromicola_AL0434_</i>			
<i>Epichloë bromicola_AL04262_</i>	5190	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5223
<i>Epichloë elymi_ATCC_201551_</i>	5134	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5165
<i>Epichloë festucae_AR1_</i>	5135	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5168
<i>Epichloë festucae_AR37_</i>	4638	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	4671
<i>Epichloë festucae_AR48_</i>	5135	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5168
<i>Epichloë festucae_E2368_</i>	5174	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5207
<i>Epichloë festucae_Fg1_</i>	5135	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5168
<i>Epichloë festucae_Fl1_</i>	5173	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5206
<i>Epichloë gansuensis_e7080_</i>	2597	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----A-----	2629
<i>Epichloë glyceriae_ATCC_200747_</i>	5235	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5268
<i>Epichloë inebrians_MYA-1228_</i>	5176	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGAAGGCAGCGGCCACCTTGAAGTTGAGCCT	5235
<i>Epichloë mollis_AL9924_</i>	5199	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5231
<i>Epichloë typhina_ATCC_200736_</i>	5178	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5210
<i>Epichloë typhina_subsp_poae</i>	5178	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5211
<i>Epichloë typhina_subsp_Poae_Ps1</i>	5174	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5206
<i>Epichloë uncinata_CBS_102646_</i>	5177	TCCAAGGCTTGGCTGTGGCATTATCGAGTCGGA-----G-----	5209
<i>Epichloë amarillans_E57_</i>	5179	-----GACAGCGGCCACGTTTACGCTCAGCCTACT	5208
<i>Epichloë amarillans_E4668_</i>	5175	-----GACAGCGGCCACGTTTACGCTCAGCCTACT	5204
<i>Epichloë aotearoae_MYA-1229_</i>	5178	-----GACAGCGGCCACGTTTACGCTCAGCCTACT	5207
<i>Epichloë brachelyltri_E4804_</i>	5177	-----GACAGCGGCCACGTTTACGCTCAGCCTACT	5206
<i>Epichloë bromicola_AL0434_</i>			
<i>Epichloë bromicola_AL04262_</i>	5224	-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5252
<i>Epichloë elymi_ATCC_201551_</i>	5166	-----A-----GACAGCGGCCACGTTTACGCTCAGCCTACT	5196
<i>Epichloë festucae_AR1_</i>	5169	-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5197
<i>Epichloë festucae_AR37_</i>	4672	-----ACAGCGGCCACGTTTACGCTCAGCCTACT	4700
<i>Epichloë festucae_AR48_</i>	5169	-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5197
<i>Epichloë festucae_E2368_</i>	5208	-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5236
<i>Epichloë festucae_Fg1_</i>	5169	-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5197
<i>Epichloë festucae_Fl1_</i>	5207	-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5235
<i>Epichloë gansuensis_e7080_</i>	2630	-----GACAGCGGCCACGTTTACGCTCAGCCTACT	2659
<i>Epichloë glyceriae_ATCC_200747_</i>	5269	-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5297
<i>Epichloë inebrians_MYA-1228_</i>	5236	ATTGTACGGGTCCAGGAATCGAGACAGTAGACAGCGGCCACTATACGCTCAGCCTACT	5295
<i>Epichloë mollis_AL9924_</i>	5232	G-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5261
<i>Epichloë typhina_ATCC_200736_</i>	5211	G-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5240
<i>Epichloë typhina_subsp_poae</i>	5212	G-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5240
<i>Epichloë typhina_subsp_Poae_Ps1</i>	5207	G-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5236
<i>Epichloë uncinata_CBS_102646_</i>	5210	G-----ACAGCGGCCACGTTTACGCTCAGCCTACT	5239

Chapter eight: Appendices

<i>Epichloë amarillans_E57_</i>	5209	GTACGGGA	GAGGA	AACTCGAGACAGTATTT	GA	TCCCAAT	GCTCCATT	TGTCAAAGCTGAA	5268
<i>Epichloë amarillans_E4668_</i>	5205	GTACGGGA	GAGGA	AACTCGAGACAGTATTT	GA	TCCCAAT	GCTCCATT	TGTCAAAGCTGAA	5264
<i>Epichloë aotearoae_MYA-1229_</i>	5208	GTACGGGG	CAAGGA	ACTCGAGACAGTATTT	CTGT	CAAGGCTCCATT	TGTCAAAGCTGAA		5267
<i>Epichloë brachelytrii_E4804_</i>	5207	GTACGGGG	CAAGGA	ACTCGAGACAGTATTT	CTGT	CAAGGCTCCATT	TGTCAAAGCTGAA		5266
<i>Epichloë bromicola_AL0434_</i>									
<i>Epichloë bromicola_AL04262_</i>	5253	GTACGGGA	CAAGGA	ACTCGAGACAGTATTT	GTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5312
<i>Epichloë elymi_ATCC_201551_</i>	5197	GTACGGGA	CAAGGA	ACTCGATATTT	GTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5256
<i>Epichloë festucae_AR1</i>	5198	GTACGGGG	CAAGGA	ACTCGAGACAGTATTT	AGTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5257
<i>Epichloë festucae_AR37</i>	4701	GTACGGAG	CAAGGA	ACTCGAGACTGTATTT	AGTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		4760
<i>Epichloë festucae_AR48</i>	5198	GTACGGGG	CAAGGA	ACTCGAGACAGTATTT	AGTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5257
<i>Epichloë festucae_E2368</i>	5237	GTACGGAG	CAAGGA	ACTCGAGACTGTATTT	AGTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5296
<i>Epichloë festucae_Fg1</i>	5198	GTACGGAG	CAAGGA	ACTCGAGACTGTATTT	AGTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5257
<i>Epichloë festucae_FI1</i>	5236	GTACGGAG	CAAGGA	ACTCGAGACTGTATTT	AGTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5295
<i>Epichloë gansuensis_e7080_</i>	2660	GTACGGGT	CAAGGA	ACTCGAGACAGTATTT	GTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		2719
<i>Epichloë glyceriae_ATCC_200747_</i>	5298	GTACGGGG	CAAGGA	ACTCGAGACTGTATTT	AGTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5357
<i>Epichloë inebrians_MYA-1228_</i>	5296	GTACGGAG	CAAGGA	ACTCGAGACTGTATTT	GTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5355
<i>Epichloë mollis_AL9924_</i>	5262	GTACGGGG	CAAGGA	ACTCGAGACAGTATTT	GTCC	CAAGGCTCCATT	TGTCAAAGCTGAA		5321
<i>Epichloë typhina_ATCC_200736_</i>	5241	GTACGGGG	CAAGGA	ACTCGAGACAGTATTT	CTGT	CAAGGCTCCATT	TGTCAAAGCTGAA		5300
<i>Epichloë typhina_subsp_poae</i>	5241	GTACAGGA	CAAGGA	ACTCGAGACAGTATTT	GTCC	CAAT	GCTGCAAT	GCTGCAAT	5300
<i>Epichloë typhina_subsp_Poae_Ps1</i>	5237	GTACGGGG	CAAGGA	ACTCGAGACAGTATTT	CTGT	CAAGGCTCCATT	TGTCAAAGCTGAA		5296
<i>Epichloë uncinata_CBS_102646_</i>	5240	GTACGGGG	CAAGGA	ACTCGAGACAGTATTT	CTGT	CAAGGCTCCATT	TGTCAAAGCTGAA		5299
<i>Epichloë amarillans_E57_</i>	5269	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5325		
<i>Epichloë amarillans_E4668_</i>	5265	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5321		
<i>Epichloë aotearoae_MYA-1229_</i>	5268	GCCGTGCCAGATGGCGTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5324		
<i>Epichloë brachelytrii_E4804_</i>	5267	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5323		
<i>Epichloë bromicola_AL0434_</i>									
<i>Epichloë bromicola_AL04262_</i>	5313	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5369		
<i>Epichloë elymi_ATCC_201551_</i>	5257	GCCGTGCCAGATGGTCTG	AGCGTACTCGTAGAGCACCATT	CAAGATAGTAGCTTT	---	G	5313		
<i>Epichloë festucae_AR1</i>	5258	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5314		
<i>Epichloë festucae_AR37</i>	4761	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	4817		
<i>Epichloë festucae_AR48</i>	5258	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5314		
<i>Epichloë festucae_E2368</i>	5297	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5353		
<i>Epichloë festucae_Fg1</i>	5258	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5314		
<i>Epichloë festucae_FI1</i>	5296	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5352		
<i>Epichloë gansuensis_e7080_</i>	2720	GCCGTGCCAGATGGTCTG	AGCGTACTCGTAGAGCACCATT	CAAGACAGTAGCTTT	GAT	G	2779		
<i>Epichloë glyceriae_ATCC_200747_</i>	5358	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5414		
<i>Epichloë inebrians_MYA-1228_</i>	5356	GCCGTGCCAGATGGTCTG	AGCGTACTCGTAGAGCACCATT	CAAGACAGTAGCTTT	GAT	G	5415		
<i>Epichloë mollis_AL9924_</i>	5322	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5378		
<i>Epichloë typhina_ATCC_200736_</i>	5301	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5357		
<i>Epichloë typhina_subsp_poae</i>	5301	GCCGTGCCATGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5357		
<i>Epichloë typhina_subsp_Poae_Ps1</i>	5297	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5353		
<i>Epichloë uncinata_CBS_102646_</i>	5300	GCCGTGCCAGATGGTCTG	GCGTGCTCGTAGAGCACCATT	CAAGACAGTAGCTTT	---	G	5356		
<i>Epichloë amarillans_E57_</i>	5326	ACAGAGGGCGGATT	GCGGTACACCACCAAGAT	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5385
<i>Epichloë amarillans_E4668_</i>	5322	ACAGAGGGCGGATT	GCGGTACACCACCAAGAT	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5381
<i>Epichloë aotearoae_MYA-1229_</i>	5325	ACAGAGGGCGGATT	ACGGTACACCACCAAGAT	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5384
<i>Epichloë brachelytrii_E4804_</i>	5324	ACAGAGGGCGGATT	ACGGTACACCACCAAGAT	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5383
<i>Epichloë bromicola_AL0434_</i>									
<i>Epichloë bromicola_AL04262_</i>	5370	ACAGAGGGCGGATT	ACGGTACACCACCAAGAT	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5429
<i>Epichloë elymi_ATCC_201551_</i>	5314	ACAGAGGGCGGATT	ACGGTACACCACCAAGAT	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5373
<i>Epichloë festucae_AR1</i>	5315	ACAGAGAGCGGACT	GCGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5374
<i>Epichloë festucae_AR37</i>	4818	ACAGAGAGCGGATT	GCGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			4877
<i>Epichloë festucae_AR48</i>	5315	ACAGAGAGCGGACT	GCGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5374
<i>Epichloë festucae_E2368</i>	5354	ACAGAGAGCGGATT	GCGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5413
<i>Epichloë festucae_Fg1</i>	5315	ACAGAGAGCGGATT	GCGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5374
<i>Epichloë festucae_FI1</i>	5353	ACAGAGAGCGGATT	GCGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5412
<i>Epichloë gansuensis_e7080_</i>	2780	ACGGATGGTGGATAAAGGTAT	ACCACATAAGAT	GGAGTTGTCT	TAACCTCTT	CAAGCGAA			2839
<i>Epichloë glyceriae_ATCC_200747_</i>	5415	ACGGAGGGCGGATT	GCGGTACACCACCAAGAT	GGAGTTGTCT	TAACCTCTT	CAAGCGAA			5474
<i>Epichloë inebrians_MYA-1228_</i>	5416	ACGGATGGCGGATT	AAAGTACACCACCAAGAT	GGAGTTGTCT	TAACCTCTT	CAAGCGAA			5475
<i>Epichloë mollis_AL9924_</i>	5379	ACAGAGGGCGGATT	ACGGTACACCACCAAGAT	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5438
<i>Epichloë typhina_ATCC_200736_</i>	5358	ACAGAGGGCGGATT	ACGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5417
<i>Epichloë typhina_subsp_poae</i>	5358	ACAGAGGGCGGATT	ACGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5417
<i>Epichloë typhina_subsp_Poae_Ps1</i>	5354	ACAGAGGGCGGATT	ACGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5413
<i>Epichloë uncinata_CBS_102646_</i>	5357	ACAGAGGGCGGATT	ACGGTACACCACCAAGAA	GGAGTTGTCT	GATTCTT	GCAAGCGAG			5416
<i>Epichloë amarillans_E57_</i>	5386	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5445
<i>Epichloë amarillans_E4668_</i>	5382	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5441
<i>Epichloë aotearoae_MYA-1229_</i>	5385	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5441
<i>Epichloë brachelytrii_E4804_</i>	5384	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5440
<i>Epichloë bromicola_AL0434_</i>									
<i>Epichloë bromicola_AL04262_</i>	5430	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5486
<i>Epichloë elymi_ATCC_201551_</i>	5374	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5418
<i>Epichloë festucae_AR1</i>	5375	AGAAGTATCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5431
<i>Epichloë festucae_AR37</i>	4878	AGAAGTATCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				4934
<i>Epichloë festucae_AR48</i>	5375	AGAAGTATCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5431
<i>Epichloë festucae_E2368</i>	5414	AGAAGTATCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5470
<i>Epichloë festucae_Fg1</i>	5375	AGAAGTATCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5431
<i>Epichloë festucae_FI1</i>	5413	AGAAGTATCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5469
<i>Epichloë gansuensis_e7080_</i>	2840	CGCAGTGCAGACTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				2896
<i>Epichloë glyceriae_ATCC_200747_</i>	5475	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5531
<i>Epichloë inebrians_MYA-1228_</i>	5476	CGCAGTGCAGACTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5532
<i>Epichloë mollis_AL9924_</i>	5439	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5495
<i>Epichloë typhina_ATCC_200736_</i>	5418	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5474
<i>Epichloë typhina_subsp_poae</i>	5418	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5474
<i>Epichloë typhina_subsp_Poae_Ps1</i>	5414	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5470
<i>Epichloë uncinata_CBS_102646_</i>	5417	AGAAGTGCAGGCTCTACGGT	CTCGACAAAGTCTGGCAGAA	TAA	CGGGGCATCTTCT				5473
<i>Epichloë amarillans_E57_</i>	5446	AGTGCGAGAACTCGCGACTTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5505
<i>Epichloë amarillans_E4668_</i>	5442	AGTGCGAGAACTCGCGACTTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5501
<i>Epichloë aotearoae_MYA-1229_</i>	5442	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5501
<i>Epichloë brachelytrii_E4804_</i>	5441	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5500
<i>Epichloë bromicola_AL0434_</i>									
<i>Epichloë bromicola_AL04262_</i>	5487	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5546
<i>Epichloë elymi_ATCC_201551_</i>	5419	TCCAGGCTAGTCCGCTGAT	ACTGTATATAATG	CCATCG	-----	TAATG			5466
<i>Epichloë festucae_AR1</i>	5432	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5477
<i>Epichloë festucae_AR37</i>	4935	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				4994
<i>Epichloë festucae_AR48</i>	5432	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5491
<i>Epichloë festucae_E2368</i>	5471	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5530
<i>Epichloë festucae_Fg1</i>	5432	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5491
<i>Epichloë festucae_FI1</i>	5470	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5529
<i>Epichloë gansuensis_e7080_</i>	2897	AATGCAGACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				2956
<i>Epichloë glyceriae_ATCC_200747_</i>	5532	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5591
<i>Epichloë inebrians_MYA-1228_</i>	5533	AATGCAGACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5592
<i>Epichloë mollis_AL9924_</i>	5496	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5555
<i>Epichloë typhina_ATCC_200736_</i>	5475	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5534
<i>Epichloë typhina_subsp_poae</i>	5475	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5534
<i>Epichloë typhina_subsp_Poae_Ps1</i>	5471	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5530
<i>Epichloë uncinata_CBS_102646_</i>	5474	AGTGCGAGAACTCGCGACTTT	GTAAGACATGGAGCCAT	GGAGAAACCGT	CGTCATGTTG				5533

Chapter eight: Appendices

Epichloë amarillans_E57_
Epichloë amarillans_E4668_
Epichloë aotearoae_MYA-1229_
Epichloë brachelytri_E4804_
Epichloë bromicola_AL0434_
Epichloë bromicola_AL04262_
Epichloë elymi_ATCC_201551_
Epichloë festucae_AR1
Epichloë festucae_AR37
Epichloë festucae_AR48
Epichloë festucae_E2368
Epichloë festucae_Fg1
Epichloë festucae_F11
Epichloë gansuensis_e7080_
Epichloë glyceriae_ATCC_200747_
Epichloë inebrians_MYA-1228_
Epichloë mollis_AL9924_
Epichloë typhina_ATCC_200736_
Epichloë typhina_subsp_poa
Epichloë typhina_subsp_Poa_Ps1
Epichloë uncinata_CBS_102646_

Epichloë amarillans_E57_
Epichloë amarillans_E4668_
Epichloë aotearoae_MYA-1229_
Epichloë brachelytri_E4804_
Epichloë bromicola_AL0434_
Epichloë bromicola_AL04262_
Epichloë elymi_ATCC_201551_
Epichloë festucae_AR1
Epichloë festucae_AR37
Epichloë festucae_AR48
Epichloë festucae_E2368
Epichloë festucae_Fg1
Epichloë festucae_F11
Epichloë gansuensis_e7080_
Epichloë glyceriae_ATCC_200747_
Epichloë inebrians_MYA-1228_
Epichloë mollis_AL9924_
Epichloë typhina_ATCC_200736_
Epichloë typhina_subsp_poa
Epichloë typhina_subsp_Poa_Ps1
Epichloë uncinata_CBS_102646_

Epichloë amarillans_E57_
Epichloë amarillans_E4668_
Epichloë aotearoae_MYA-1229_
Epichloë brachelytri_E4804_
Epichloë bromicola_AL0434_
Epichloë bromicola_AL04262_
Epichloë elymi_ATCC_201551_
Epichloë festucae_AR1
Epichloë festucae_AR37
Epichloë festucae_AR48
Epichloë festucae_E2368
Epichloë festucae_Fg1
Epichloë festucae_F11
Epichloë gansuensis_e7080_
Epichloë glyceriae_ATCC_200747_
Epichloë inebrians_MYA-1228_
Epichloë mollis_AL9924_
Epichloë typhina_ATCC_200736_
Epichloë typhina_subsp_poa
Epichloë typhina_subsp_Poa_Ps1
Epichloë uncinata_CBS_102646_

Epichloë amarillans_E57_
Epichloë amarillans_E4668_
Epichloë aotearoae_MYA-1229_
Epichloë brachelytri_E4804_
Epichloë bromicola_AL0434_
Epichloë bromicola_AL04262_
Epichloë elymi_ATCC_201551_
Epichloë festucae_AR1
Epichloë festucae_AR37
Epichloë festucae_AR48
Epichloë festucae_E2368
Epichloë festucae_Fg1
Epichloë festucae_F11
Epichloë gansuensis_e7080_
Epichloë glyceriae_ATCC_200747_
Epichloë inebrians_MYA-1228_
Epichloë mollis_AL9924_
Epichloë typhina_ATCC_200736_
Epichloë typhina_subsp_poa
Epichloë typhina_subsp_Poa_Ps1
Epichloë uncinata_CBS_102646_

Epichloë amarillans_E57_
Epichloë amarillans_E4668_
Epichloë aotearoae_MYA-1229_
Epichloë brachelytri_E4804_
Epichloë bromicola_AL0434_
Epichloë bromicola_AL04262_
Epichloë elymi_ATCC_201551_
Epichloë festucae_AR1
Epichloë festucae_AR37
Epichloë festucae_AR48
Epichloë festucae_E2368
Epichloë festucae_Fg1
Epichloë festucae_F11
Epichloë gansuensis_e7080_
Epichloë glyceriae_ATCC_200747_
Epichloë inebrians_MYA-1228_
Epichloë mollis_AL9924_
Epichloë typhina_ATCC_200736_
Epichloë typhina_subsp_poa
Epichloë typhina_subsp_Poa_Ps1
Epichloë uncinata_CBS_102646_

5506 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAAAG 5565
5502 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAAAG 5561
5502 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAAAG 5561
5501 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAAAG 5560
5547 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAAAG 5606
5467 C-CTCTT-AGCTTCAATTTGTCCTC-CACGACCTGACAG--CGCTCTAAAC-CATGC 5516
5478 -----CCGCCCAATGGTATCTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAG 5528
4995 GGTTC GAACCGCCGAATGGTATCTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAG 5054
4992 GGTTC GAACCGCCGAATGGTATCTGATGTCTTCTAGAAAGATTCTCGCGCAGCAAG 5551
5531 GGTTC GAACCGCCGAATGGTATCTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAG 5590
4992 GGTTC GAACCGCCGAATGGTATCTGATGTCTTCTAGAAAGATTCTCGCGCAGCAAG 5551
5530 GGTTC GAACCGCCGAATGGTATCTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAG 5589
2957 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAAAC 3016
5592 GGTTC GAGCCGCCAATGGTATTTGCGCTCTTCTAGAAAGATTCTCGCGCAGCAAAAC 5651
5593 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAAAC 5652
5556 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAAAC 5615
5535 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAATATTGCTCAGCAGCAAAAG 5594
5535 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCGCGCAGCAAAAG 5594
5531 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAATATTGCTCAGCAGCAAAAG 5590
5534 GGTTC GAACCGCCGAATGGTATTTGACGTCTTCTAGAAAGATTCTCTCAGCAGCAAAAG 5593

5566 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5618
5562 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5614
5562 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5614
5561 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5613

5607 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5659
5517 GTCAC--CCCGCGCGCACTCGATGCCCTA-G-GCCTAGGCTCGATGACCTAGCGA 5570
5529 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5581
5055 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGTGG 5107
5552 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5604
5591 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5643
5552 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5604
5590 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5642
3017 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 3069
5652 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5704
5653 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5705
5616 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5668
5595 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5647
5595 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5647
5591 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGCTTGGTGC-CG--ATCCCAGCGG 5643
5594 GCG-ACCTTTTACTTGG--CTCGATGCCCCACGTGGATTTGATGCG-CG--ATCCCAGCGG 5646

5619 TGCAAGAG-GATACGCCCTACCTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5677
5615 TGCAAGAG-GATACGCCCTACCTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5673
5615 TGCAAGAG-GATACGCCCTACCTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5673
5614 TGCAAGAG-GATACGCCCTACCTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5672

5660 TGCAAGAG-GATACGCCCTACCTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5718
5571 GCACTAGCTATAAGCCAGCAATG-CGACGTACAACACACTTAGACCTAGCA-AG--- 5624
5582 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5640
5108 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5166
5605 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5663
5644 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5702
5605 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5663
5643 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5701
3070 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 3128
5705 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5763
5706 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5764
5669 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5727
5648 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5706
5648 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5706
5644 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5702
5647 TGCAAGAG-GATACGCCCTATGTCGCGCCACAGAGTAATCTACGAATTGGAGAGAGATT 5705

5678 CTGCAGAGGAAGAAAAGTCGGCCCGCTCCAGGAAGTCGCTTCGCTCAGCCT-TGCAG 5736
5674 CTGCAGAGGAAGAAAAGTCGGCCCGCTCCAGGAAGTCGCTTCGCTCAGCCT-TGCAG 5732
5674 CTGCAGAGG---AAAAGTCGGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5729
5673 CTGCAGAGG---AAAAGTCGGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5728

5719 CTGCAGAGG---AAAAGTCGGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5774
5625 CTTCAGTT---AATATACGAGTGC---CCCATACCTC---TTGCC-TA-GCTATCCAT 5672
5641 CTGCAGAGGAAGAAAAGTCGGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5699
5167 CTGCAGAGGAAGAAAAGTCGGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5225
5664 CTGCAGAGGAAGAAAAGTCGGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5722
5703 CTGCAGAGGAAGAAAAGTCGGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5761
5664 CTGCAGAGGAAGAAAAGTCGGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5722
5702 CTGCAGAGGAAGAAAAGTCGGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5760
3129 CTGCAGAGG---AAGAGTCGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TGCAT 3184
5764 CTGCAGAGG---AAGAGTCGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5819
5765 CTGCAGAGG---AAGAGTCGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TGCAT 5820
5728 CTGCAGAGGAAGAAAAGTCGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAA 5786
5707 CTGCAGAGGACAAGAGTCGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5765
5707 CTGCAGAGGAAGAAAAGTCGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TTCAG 5765
5703 CTGCAGAGGAAGAAAAGTCGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5761
5706 CTGCAGAGGAAGAAAAGTCGCTGCTCCAGGAAGTCGCTTCGCTCAGCCT-TCCAG 5764

5737 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5794
5733 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5790
5730 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5787
5729 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5786

5775 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5832
5673 --TGTTCTCACA-TGGG--CAGCCATAAGGATTTTCAGCGGAAACGGTTCCCGA 5726
5700 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5757
5226 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5283
5723 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5780
5762 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5819
5723 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5780
5761 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5818
3185 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 3242
5820 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5877
5821 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5878
5787 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5844
5766 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5823
5762 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5819
5765 GATGTTCTGGCTGTCAAGCCCAAGCCG---GGGAGCAAGCTTCGTCAGTTTGGCTTGAGA 5822

Chapter eight: Appendices

Epichloë_amarillans_E57_	5795	ATGTCCTGTATACCA--TACTG-TCTCATTTTGAGGGCGATACTAGC----	T-----	5839
Epichloë_amarillans_E4668_	5791	ATGTCTCTGTATACCA--TACTG-TCTCATTTTGAGGGCGATACTAGC----	T-----	5835
Epichloë_aotearoae_MYA-1229_	5788	ATGTCCTTTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	T-----	5832
Epichloë_brachelytri_E4804_	5787	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGCAGC----	T-----	5831
Epichloë_bromicola_AL0434_				
Epichloë_bromicola_AL04262_	5833	ATGTCCTGTATACCA--TACTG-TCCAGTTTGAGGGCGATACTAGC----	CT-----	5877
Epichloë_elymi_ATCC_201551_	5727	AATATTAATAATAACAAATAATGCCCTCCAACTCCGAATGAATCTAGACTAGACT		5778
Epichloë_festucaae_AR1_	5758	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5802
Epichloë_festucaae_AR37_	5284	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5328
Epichloë_festucaae_AR48_	5781	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5825
Epichloë_festucaae_E2368_	5820	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5864
Epichloë_festucaae_Fg1_	5781	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5825
Epichloë_festucaae_FI1_	5819	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5863
Epichloë_gansuensis_e7080_	3243	ATGTCCTGTATACCA--TACTG-TCTCAAGTTAAGGGCGATACTAGC----	CT-----	3287
Epichloë_glyceriae_ATCC_200747_	5878	ATGTCCTGTATACCA--TACTG-TCCCAATTTGAGGGCGATGCTAGC----	CT-----	5922
Epichloë_inebrians_MYA-1228_	5879	ATGTCCTGTATACCA--TACTG-TCTCAAGTTGAGGGCGATACTAGC----	CT-----	5923
Epichloë_mollis_AL9924_	5845	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5889
Epichloë_typhina_ATCC_200736_	5824	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5868
Epichloë_typhina_subsp_poae_	5824	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGAGCAATACTAATCTCTGGGGCATG		5880
Epichloë_typhina_subsp_Poae_Ps1_	5820	ATGTCCTGTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5864
Epichloë_uncinata_CBS_102646_	5823	ATGTCCTTTATACCA--TACTG-TCTCAATTTGAGGGCGATACTAGC----	CT-----	5867
Epichloë_amarillans_E57_	5840	---TCATGGAGTCTGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGGCA--GG--	AATTGT	5891
Epichloë_amarillans_E4668_	5836	---TCATGGAGTCTGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGGCA--GG--	AATTGT	5887
Epichloë_aotearoae_MYA-1229_	5833	---TCATGGAGTATGGTGTTCGAGCTCCAGCTGGGAGTCTTTGAGT--GG--	ACTTGT	5884
Epichloë_brachelytri_E4804_	5832	---TCATGGAGAAATGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGAGT--GG--	ACTTGT	5883
Epichloë_bromicola_AL0434_				
Epichloë_bromicola_AL04262_	5878	---TCATGGAGTATGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGGAT--GG--	ACTTGT	5929
Epichloë_elymi_ATCC_201551_	5779	---T--TGATCGATCTTGT--CGGATTTCGGCCGGGA--CATTGATTTCGGCTGTCTGGC		5830
Epichloë_festucaae_AR1_	5803	---TCATGGAGTCTGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGACA--GG--	ACTTGT	5854
Epichloë_festucaae_AR37_	5329	---TCATGGAGTCTGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGACA--GG--	ACTTGT	5380
Epichloë_festucaae_AR48_	5826	---TCATGGAGTCTGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGACA--GG--	ACTTGT	5877
Epichloë_festucaae_E2368_	5865	---TCATGGAGTCTGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGACA--GG--	ACTTGT	5916
Epichloë_festucaae_Fg1_	5826	---TCATGGAGTCTGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGACA--GG--	ACTTGT	5877
Epichloë_festucaae_FI1_	5864	---TCATGGAGTCTGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGACA--GG--	ACTTGT	5915
Epichloë_gansuensis_e7080_	3288	---TTATACAGTACGTTATTTCCAGCTCCAGCTGGGAGTCTTTGGAT--GG--	ACTTGT	3339
Epichloë_glyceriae_ATCC_200747_	5923	---TCATGGAGTATGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGCAT--GG--	ACTTGT	5974
Epichloë_inebrians_MYA-1228_	5924	T--T--ATGGAGTACGTTATTTCCAGCTCCAGCTGGGAGTCTTTGGAT--GG--	ACTTGT	5975
Epichloë_mollis_AL9924_	5890	---TCATGGAGTCTGTTATTCGAGCTCCAGCTGGGAGTCTTTGAAAT--GG--	ACTTGT	5941
Epichloë_typhina_ATCC_200736_	5869	TC--TC--ATGGATATATGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGAGT--GG--	AGTTGT	5920
Epichloë_typhina_subsp_poae_	5881	ACATTAATGAAGTCTGTTGTTCCGAGCTCCAGCTGGGAGTCTTTGAAAT--GG--	ACTTGT	5935
Epichloë_typhina_subsp_Poae_Ps1_	5865	---TCATGGATATAGTGTTCGAGCTCCAGCTGGGAGTCTTTGAGT--GG--	ACTTGT	5916
Epichloë_uncinata_CBS_102646_	5868	---TCATGGATATAGTGTTCGAGCTCCGTTGGGAGTCTTTGAGT--GG--	ACTTGT	5919
Epichloë_amarillans_E57_	5892	CATTG--AGTG-GAAGGATCAGG-GT-C-A-AGTTCA--GATTGAGGGTTCCACGAGGC		5941
Epichloë_amarillans_E4668_	5888	CATTG--AGTG-GAAGGATCAGG-GT-C-A-AGTTCA--GATTGAGGGTTCCACGAGGC		5937
Epichloë_aotearoae_MYA-1229_	5885	CATTG--AGTG-GAAGGATCAGG-GT-C-A-AGTTGA--GATTGAGGGTTCCACGAGGC		5934
Epichloë_brachelytri_E4804_	5884	CATTG--AGTG-GAAGGATCAGG-GT-C-G-AGTTGA--GATTGAGGGTTCCACGAGGC		5933
Epichloë_bromicola_AL0434_				
Epichloë_bromicola_AL04262_	5930	CATTG--AGTG-GAAGGATCAGG-GT-C-GAGTTGA--GATTGAGGGTTCCACGAGGC		5979
Epichloë_elymi_ATCC_201551_	5831	CTCGATAGCTCCGCAACATCTGGTGTCTGGTGTTCGCCCGCATAAGTGT--CA--GACCT		5887
Epichloë_festucaae_AR1_	5855	CATTG--AGTG-GAAGGATCAGG-GT-C-AAGTTCA--GATTGAGGGTTCTACGAGGC		5904
Epichloë_festucaae_AR37_	5381	CATTG--AGTG-GAAGGATCAGG-GT-C-AAGTTCA--GATTGAGGGTTCTACGAGGC		5430
Epichloë_festucaae_AR48_	5878	CATTG--AGTG-GAAGGATCAGG-GT-C-AAGTTCA--GATTGAGGGTTCTACGAGGC		5927
Epichloë_festucaae_E2368_	5917	CATTG--AGTG-GAAGGATCAGG-GT-C-AAGTTCA--GATTGAGGGTTCTACGAGGC		5966
Epichloë_festucaae_Fg1_	5878	CATTG--AGTG-GAAGGATCAGG-GT-C-AAGTTCA--GATTGAGGGTTCTACGAGGC		5927
Epichloë_festucaae_FI1_	5916	CATTG--AGTG-GAAGGATCAGG-GT-C-AAGTTAA--GATTGAGGGTTCCACGAGGC		5965
Epichloë_gansuensis_e7080_	3340	TGTTA--AGTG-GAAGGATCAGG-GT-C-GAGTTGA--GATTGAGGGTTCCACGAGGC		3389
Epichloë_glyceriae_ATCC_200747_	5975	CATTG--AGTG-GAAGGATCAGG-GT-C-GAGTTGA--GATTGAGGGTTCCACGAGGC		6024
Epichloë_inebrians_MYA-1228_	5976	TGTTA--AGTG-GAAGGATCAGG-GT-CG--AGTTGA--GATTGAGGGTTCCACGAGGC		6025
Epichloë_mollis_AL9924_	5942	CATTG--AGTG-GAAGGATCAGG-GT-C-AAGTTGA--GATTGAGGGTTCCACGAGGC		5991
Epichloë_typhina_ATCC_200736_	5921	CATTG--AGTG-GAAGGATCAGG-GT-C-GAGTTGA--GATTGAGGGTTCCACGAGGC		5970
Epichloë_typhina_subsp_poae_	5936	CATTG--AGTG-GAAGGATCAGG-GTTC--ACTTCT--GATTGAGGGTTCCACGAGGC		5985
Epichloë_typhina_subsp_Poae_Ps1_	5917	CATTG--AGTG-GAAGGATCAGG-GT-C-GAGTTGA--GATTGAGGGTTCCACGAGGC		5966
Epichloë_uncinata_CBS_102646_	5920	CATTG--AGTG-GAAGGATCAGG-GT-C-GAGTTGA--AATGAGGGTTCCACGAGGC		5969
Epichloë_amarillans_E57_	5942	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GGCGACGATCTCATAATGA		5988
Epichloë_amarillans_E4668_	5938	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GGCGACGATCTCATAATGA		5994
Epichloë_aotearoae_MYA-1229_	5935	ATCCGAGACCGGCTGGCTCGTTTCTCG--GAAAGAGATTG--GGCGACGATCTAATAATGA		5991
Epichloë_brachelytri_E4804_	5934	ATCCGAGACCGGCTGGCTCGTTTATCG--GAAAGAGATTG--GGCGACGATCTAATAATGA		5990
Epichloë_bromicola_AL0434_				
Epichloë_bromicola_AL04262_	5980	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GGCGACGATCTCATAATGA		6036
Epichloë_elymi_ATCC_201551_	5888	ATCCGAGGCT--GCTC--CCCGTTCTCGAGGAAAGA-ATCGTGGGCGCTGT--GTGA		5939
Epichloë_festucaae_AR1_	5905	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GACGACGATCTCATAATGA		5961
Epichloë_festucaae_AR37_	5431	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GACGACGATCTCATAATGA		5487
Epichloë_festucaae_AR48_	5928	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GACGACGATCTCATAATGA		5984
Epichloë_festucaae_E2368_	5967	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GACGACGATCTCATAATGA		6023
Epichloë_festucaae_Fg1_	5928	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GACGACGATCTCATAATGA		5984
Epichloë_festucaae_FI1_	5966	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GACGACGATCTCATAATGA		6022
Epichloë_gansuensis_e7080_	3390	ATCCGAGACCGGCTGGCTCGTTTCTCG--GAAATAGATTG--GACGACGATCTCATAATGA		3446
Epichloë_glyceriae_ATCC_200747_	6025	ATCCGAGACCGGCTGGCTCGTTTCTCG--GAAAGAGATTG--GGCGACGATCTCATAATGA		6081
Epichloë_inebrians_MYA-1228_	6026	ATCCGAGACCGGCTGGCTCGTTTCTCG--GAAATCGATTG--GACGACGATCTCATAATGA		6082
Epichloë_mollis_AL9924_	5992	ATCCGAGACCGGCTGACTCGTTTCTCG--GAAAGAGATTG--GGCGACGATCTCATAATGA		6048
Epichloë_typhina_ATCC_200736_	5971	ATCCGGACCGCTGGCTTGTCTCTCA--CAAAGAGATTG--GGCGACGATCTCATACTGA		6027
Epichloë_typhina_subsp_poae_	5986	GACCGACCGGCTGACTTGTCTCTCG--GAAGGAGATCG--GGTACGATCTCATAATGA		6042
Epichloë_typhina_subsp_Poae_Ps1_	5967	ATCCGGACCGCTGGCTGTTATCTCGC--AAAGAGATTG--GGCGACGATCTCATAATGA		6023
Epichloë_uncinata_CBS_102646_	5970	ATCCGGACCGCTGGCTGCTTCTCTCGC--AAAGAGATTG--GGCGACGATCTCATAATGA		6026
Epichloë_amarillans_E57_	5999	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGA--C--TC--GTTATG		6048
Epichloë_amarillans_E4668_	5995	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGA--C--TC--GTTATG		6044
Epichloë_aotearoae_MYA-1229_	5992	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGA--C--TC--GTTATG		6041
Epichloë_brachelytri_E4804_	5991	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGA--C--TC--GTTATG		6040
Epichloë_bromicola_AL0434_				
Epichloë_bromicola_AL04262_	6037	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGA--C--TC--GTTATG		6086
Epichloë_elymi_ATCC_201551_	5940	CTTCCAAGG--GATCTGAGGCTTCTTAAGTCTGGTTACATTGGAGCTTATGCTAGATA		5997
Epichloë_festucaae_AR1_	5962	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGAC--TC--GTTATG		6011
Epichloë_festucaae_AR37_	5488	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGAC--TC--GTTATG		5537
Epichloë_festucaae_AR48_	5985	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGAC--TC--GTTATG		6034
Epichloë_festucaae_E2368_	6024	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGAC--TC--GTTATG		6073
Epichloë_festucaae_Fg1_	5985	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGACT--TC--GTTATG		6034
Epichloë_festucaae_FI1_	6023	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGACT--TC--GTTATG		6072
Epichloë_gansuensis_e7080_	3447	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGCA--TTCTCTATG		3496
Epichloë_glyceriae_ATCC_200747_	6082	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGACT--TC--GTTATG		6131
Epichloë_inebrians_MYA-1228_	6083	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGCA--TTCTCTATG		6132
Epichloë_mollis_AL9924_	6049	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGAC--TC--GTTATG		6098
Epichloë_typhina_ATCC_200736_	6028	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGCAAT--TC--GTTATG		6077
Epichloë_typhina_subsp_poae_	6043	--TGGAATTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGGACT--TC--GTTATG		6092
Epichloë_typhina_subsp_Poae_Ps1_	6024	--TGGAAGTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGCAAT--TC--GTTATG		6073
Epichloë_uncinata_CBS_102646_	6027	--TGGAAGTTTCA--CTGGTCGCTTCTTAAAAAT--TTCCAGAGCAAT--TC--GTTATG		6076

Chapter eight: Appendices

<i>Epichloë amarillans_E57_</i>	6049	GATCC-TTCG---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	6097
<i>Epichloë amarillans_E4668_</i>	6045	GATCC-TTCG---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	6093
<i>Epichloë aotearoae_MYA-1229_</i>	6042	GATCC-TTCG---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	6090
<i>Epichloë brachyelytri_E4804_</i>	6041	GATCC-TTCG---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	6089
<i>Epichloë bromicola_AL0434_</i>			
<i>Epichloë bromicola_AL04262_</i>	6087	GATCC-TTCG---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	6135
<i>Epichloë elymi_ATCC_201551_</i>	5998	GATTCATACGGATTACTTGCTTGCATTTTACTGCCATTTTGCTGCTCCGAGGTGGTCC	6057
<i>Epichloë festucae_AR1</i>	6012	GATCC-TTCG---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	6060
<i>Epichloë festucae_AR37</i>	5538	GATCC-TTCG---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	5586
<i>Epichloë festucae_AR48</i>	6035	GATCC-TTCG---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	6083
<i>Epichloë festucae_E2368</i>	6074	GATCC-TTCG---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	6122
<i>Epichloë festucae_Fg1</i>	6035	GATCC-TTCG---TGTGTGATT-CGGTTCACGTGA---TAAGCTACT---GACCGTGGGCA	6083
<i>Epichloë festucae_FI1</i>	6073	GATCC-TTCG---TGTGTGATT-CGGTTCACGTGA---TAAGCTACT---GACCGTGGGCA	6121
<i>Epichloë gansuensis_e7080_</i>	3497	AATCC-TTTC---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACTGTGGGCA	3545
<i>Epichloë glyceriae_ATCC_200747_</i>	6132	GATCC-TTCG---TGTGTGATT-CGGTTCACGTGA---TAAGCTACT---GACCGTGGGCA	6180
<i>Epichloë inebrians_MYA-1228_</i>	6133	AATCC-TTTC---TGTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACTGTGGGCA	6181
<i>Epichloë mollis_AL9924_</i>	6099	GATCC-TTCT---TTTGTGATT-CGGTTCACGTG---A-TAAGCTACT---GACCGTGGGCA	6147
<i>Epichloë typhina_ATCC_200736_</i>	6078	GATCC-TTCG---TGTAC-ATTTCCGTTCCGTGG---TAAGCTACT---GACTGTGAGCA	6126
<i>Epichloë typhina_subsp_poa</i>	6093	AATCC-TTCG---TGTGTGATT-CAGTCTTTT---A-TAGCTAAT---GACCGTGACCA	6141
<i>Epichloë typhina_subsp_Poa_Ps1</i>	6074	GATCC-TACG---TGTATGATT-CATATGACTG---G-TAAGCTACT---GACCGTGGGCA	6122
<i>Epichloë uncinata_CBS_102646_</i>	6077	GATCC-TACG---TGTATGATT-CGGTTCGACTG---G-TAAGCTACT---GACCGTGGGCA	6125
<i>Epichloë amarillans_E57_</i>	6098	ATGGGACGGCTGGAAATCGGT-AG	6120
<i>Epichloë amarillans_E4668_</i>	6094	ATGGGACGGCTGGAAATCGGT-AG	6116
<i>Epichloë aotearoae_MYA-1229_</i>	6091	ATGGGACGGCTGGAAATCGGT-AG	6113
<i>Epichloë brachyelytri_E4804_</i>	6090	ATGGGACGGCTGGAAATCGGT-AG	6112
<i>Epichloë bromicola_AL0434_</i>			
<i>Epichloë bromicola_AL04262_</i>	6136	ATGGGACGGCTGGAAATAGGT-AG	6158
<i>Epichloë elymi_ATCC_201551_</i>	6058	AACCAAGGTATGGTCCCTGGATGAG	6081
<i>Epichloë festucae_AR1</i>	6061	ATGGGACCAATGAAATTCAGT-AG	6083
<i>Epichloë festucae_AR37</i>	5587	ATGGGACCAATGAAATTCAGT-AG	5609
<i>Epichloë festucae_AR48</i>	6084	ATGGGACCAATGAAATTCAGT-AG	6106
<i>Epichloë festucae_E2368</i>	6123	ATGGGACCAATGAAATTCAGT-AG	6145
<i>Epichloë festucae_Fg1</i>	6084	ATGGGACCAATGAAATTCAGT-AG	6106
<i>Epichloë festucae_FI1</i>	6122	ATGGGACGGCTGGAAATCAGT-AG	6144
<i>Epichloë gansuensis_e7080_</i>	3546	ATGAGAGTGGAGGAAATCAGT-AG	3568
<i>Epichloë glyceriae_ATCC_200747_</i>	6181	ATGGGACGGCAGGAAATCGGT-AG	6203
<i>Epichloë inebrians_MYA-1228_</i>	6182	ATGAGAGTGCAGGAAATCAGT-AG	6204
<i>Epichloë mollis_AL9924_</i>	6148	ATGGGACGGCTGGAAATCGGT-AG	6170
<i>Epichloë typhina_ATCC_200736_</i>	6127	ATGGGACGGCTGGAAATCAGT-AG	6149
<i>Epichloë typhina_subsp_poa</i>	6142	GATCCGCGTTGGAAATGACA-AG	6164
<i>Epichloë typhina_subsp_Poa_Ps1</i>	6123	ATGGGACGGCTGGAAATCAGT-AG	6145
<i>Epichloë uncinata_CBS_102646_</i>	6126	ATGGGACGGCTGGAAATCAGT-AG	6148

Appendix 20: Alignment of makes caterpillars floppy (*mcf*) genes from a range of *Epichloë* strains across multiple species using the alignment function of Geneious. The *E. gansuensis* sequence is cut short due to loss of sequence identity.

Chapter eight: Appendices

<i>Epichloë typhina_subsp_Poae_Ps1</i>	1 MAHNTDEAFIVEFSKDP LAFITKGEKGYAVISSDNIP-GRPDIRIGDNGHFRFESVGNPDQ	60
<i>Epichloë_festuca_AR48</i>	1 MAHNAETSIVEFSKDP LGFITKGEKGYAVISSDNIPGRRPNVF IGDEGHFRFDSVGNLDQ	61
<i>Epichloë_festuca_Fg1</i>	1 MAHNAETSIVEFSKDP LGFITKGEKGYAVISSDNIPGRRPNVF IGDEGHFRFDSVGNLDQ	61
<i>Epichloë_festuca_F11</i>	-----	
<i>Epichloë_festuca_E2368</i>	-----	
<i>Epichloë_festuca_AR37</i>	1 MAHNAETSIVEFSKDP LGFITKGEKGYAVISSDNIPGRRPNVF IGDEGHFRFDSVGNLDQ	61
<i>Epichloë_festuca_AR1</i>	1 MAHNAETSIVEFSKDP LGFITKGEKGYAVISSDNVAGKMPKVFGGDEGHFRFDSVGNLDE	61
<i>Epichloë_amarillans_E57</i>	1 MAHNAETSIVEFSKDP LGFITKGEKGYAVISSDNVAGKMPKVFGGDEGHFRFDSVGNLDE	61
<i>Epichloë_amarillans_E4668</i>	1 MAHNTDESSIVEFSKDP LDFITKGEKGYAVISSDNIP-GGPSILIGDNGHFRFESVGNPDQ	60
<i>Epichloë_aotearoae</i>	1 MAHNTDESSIVEFSKNP LDFITKGEKGYAVISSDNIP-GGPSILIGDNGHFRFESVGNPDQ	60
<i>Epichloë_brachyelytri</i>	1 MAHNADESSILEFSKDP LDFITKGEKGYAVISSDNIP-GGSGFVGDGEGHFRFESVGNLQ	60
<i>Epichloë_bromicola_AL0434</i>	1 MAHNADESSIVEFSKDP LDFITKGEKGYAVISSDNIP-GGPSIFIGDEGHFRFESVGNLYQ	60
<i>Epichloë_bromicola_AL04262</i>	1 MAHNADESSIVEFSKNP LDFITKGEKGYAVISSDNIP-GGVSFVIGDEGHFRFESVGNLQ	60
<i>Epichloë_elymi_ATCC_201551</i>	1 MAHNTDESSIVEFSKDP LAFITKREPYYAVVSSFEIQ-SGSGVNI GNEGHRFESVGDPDH	60
<i>Epichloë_gansuensis_e7080</i>	1 MAHNADESSIVEFSKDP LGFITKGEQGYAVISSDNIP-GGVSVLIGDDGHFRFKSVGDADQ	60
<i>Epichloë_glyceriae_ATCC_200747</i>		
<i>Epichloë_inebrians_MYA-1228</i>		
<i>Epichloë_mollis_AL9924</i>	1 MAHNADESSIVEFSKDP LDFITKGEQDHAVVSSDNITGHKVPV IK-DYGHFRFESVGNPNH	60
<i>Epichloë_typhina_ATCC_200736</i>		
<i>Epichloë_typhina_subsp_poa_e5819</i>	1 MAHNTDES FIVEFSNDP LAFITKGEKSYAVISSNHI P-----	37
<i>Epichloë_uncinata_CBS_102646</i>	1 MAHNTDEAFIVEFSKDP LDFITKGEKDYAVIISDRIPGGGHSIDIGDNGHFRFESVGNPDQ	61
<i>Epichloë typhina_subsp_Poae_Ps1</i>	61 PAFEIRYYGSEAGADTISAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	121
<i>Epichloë_festuca_AR48</i>	62 PAFEIRYHAGADAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	122
<i>Epichloë_festuca_Fg1</i>	62 PAFEIRYHAGADAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	122
<i>Epichloë_festuca_F11</i>	-----	
<i>Epichloë_festuca_E2368</i>	-----	
<i>Epichloë_festuca_AR37</i>	62 PAFEIRYHAGADAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	122
<i>Epichloë_festuca_AR1</i>	62 PVFEIRYHGRNAGADTVSAYHLRYDGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	122
<i>Epichloë_amarillans_E57</i>	62 PVLEIRYHGRNAGADTVSAYHLRYDGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	122
<i>Epichloë_amarillans_E4668</i>	61 PAFEIRYYGPDAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	121
<i>Epichloë_aotearoae</i>	61 PAFEIRYYGPDAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	121
<i>Epichloë_brachyelytri</i>	61 PAFEIRYYGPDAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	121
<i>Epichloë_bromicola_AL0434</i>	61 PAFEIRYHGPDAAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHKL LFTGSLSGCSVIV	121
<i>Epichloë_bromicola_AL04262</i>	61 PAFEIRYHGPDAAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHKL LFTGSLSGCSVIV	121
<i>Epichloë_elymi_ATCC_201551</i>	61 PAFEIRYHGPDAAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	121
<i>Epichloë_gansuensis_e7080</i>	61 LAFEIRYHGSAGADTVSAYFLGYNGGAQTSWTPAHIDIPKINPQHELLFTGTLSGCSVIV	121
<i>Epichloë_glyceriae_ATCC_200747</i>	61 PAFAIKYHGPDAAGADTVSAYHLGYNGGAQTSWTPAQIDIPKINPQHKLLFTGSLSGCSVIV	121
<i>Epichloë_inebrians_MYA-1228</i>	-----	
<i>Epichloë_mollis_AL9924</i>	61 PAFEIRYHGS EAGANTVSAYYLG YKGAQTSWTPAQIDIPKINPQHKLLFTGSLSGCSVIV	121
<i>Epichloë_typhina_ATCC_200736</i>	-----	
<i>Epichloë_typhina_subsp_poa_e5819</i>	38 -----GG-----	39
<i>Epichloë_uncinata_CBS_102646</i>	62 PAFEIRYYGPEAGADTVSAYHLGYKGGGPTSWTPAQIDIPKINPEHNLLFTGSLSGCSVIV	122
<i>Epichloë typhina_subsp_Poae_Ps1</i>	122 TNLNDQYRVYHDSRQDSSLLYDDVVMADVDRDYKHRDASTGFASTFMHYREGRWSLCFQR	182
<i>Epichloë_festuca_AR48</i>	123 TNLNDQYRVYHDTQRDSSLLYDDVVMADVDRDYKHRDASTGYACAFMHYREGRWSLCFQR	183
<i>Epichloë_festuca_Fg1</i>	123 TNLNDQYRVYHDTQRDSSLLYDDVVMADVDRDYKHRDASTGYACAFMHYREGRWSLCFQR	183
<i>Epichloë_festuca_F11</i>	1 -----MAVDYRDYKHRDASTGYACAFMHYREGRWSLCFQR	35
<i>Epichloë_festuca_E2368</i>	1 -----MAVDYRDYKHRDASTGYACAFMHYREGRWSLCFQR	35
<i>Epichloë_festuca_AR37</i>	1 -----MTSSWQLTETINHRDASTGYACAFMHYREGRWSLCFQR	39
<i>Epichloë_festuca_AR1</i>	123 TNLNDQYRVYHDTQRDSSLLYDDVVMADVDRDYKHRDASTGYACAFMHYREGRWSLCFQR	183
<i>Epichloë_amarillans_E57</i>	123 TNLNDQYRVYHDSRQDSSLLYKVVMAVDYRDYKHRYENTGYACAFMHYREGRWSLCFQR	183
<i>Epichloë_amarillans_E4668</i>	123 TNLNDQYRVYHDSRQDSSLLYKVVMAVDYRDYKHRYENTGYACAFMHYREGRWSLCFQR	183
<i>Epichloë_aotearoae</i>	122 TNLNDQYRVYHDSRQDSSLLYDDVVMADVDRDYKHRDASTGFAYAFMHYREGRWSLCFQR	182
<i>Epichloë_brachyelytri</i>	122 TNLNDQYRVYHDSRQDSSLLYDDVVMADVDRDYKHRDASTGFACAFMHYREGRWSLCFQR	182
<i>Epichloë_bromicola_AL0434</i>	122 TNLNDQYRVYHDSRLDSSLLYDDVVMADVDRDYKHRRVSTGYACAFMHYREGRWSLCFQR	182
<i>Epichloë_bromicola_AL04262</i>	122 TNLNDQYRVYHDSRQDSSLLYDDVVMADVDRDYKHWPSTGFACAFMHYREGRWLYFKQ	182
<i>Epichloë_elymi_ATCC_201551</i>	122 TNLNDQYRVYHDSRQDI SLLYDDVVMADVDRDYKHRDASTGFACAFMHYREGRWTLRFQR	182
<i>Epichloë_gansuensis_e7080</i>	122 TNLNDQYRVYHDSRQDSSMLYDNVIMADYRDYKHSVSSGMAFCFMR YKRGDWR LCFQR	182
<i>Epichloë_glyceriae_ATCC_200747</i>	122 TNLNDSQYRVYHDSRLDSSLLYDDVVMADVDRDYKHRDASTGLACAFMHYREGRWSLYFKQ	182
<i>Epichloë_inebrians_MYA-1228</i>	1 -----MDSMLYDNVIMADVDRDYKLR EDGGGLACAFMHYREGLWSLYFKQ	46
<i>Epichloë_mollis_AL9924</i>	122 KNLNENQYRVYHDSRLDSSLLYDDVVMADVDRDYKHFEPTGFACAFMHYREGLWSLCFQR	182
<i>Epichloë_typhina_ATCC_200736</i>	1 -----MHYREGRWSFCFQR	14
<i>Epichloë_typhina_subsp_poa_e5819</i>	40 -----ASIVYR-----RQWIFQICERR	56
<i>Epichloë_uncinata_CBS_102646</i>	123 TNLNDQYRVYHDPRLDSSLLYDDVVMADVDRDYKHRDASTGFASTFMHYREGRWSLCFQR	183
<i>Epichloë typhina_subsp_Poae_Ps1</i>	183 QTIIVANARI-VLYEPAPRDGPSILGAEP LIEMVPGSYNRELQVSRFEQSREKCLERLRDAR	242
<i>Epichloë_festuca_AR48</i>	184 QTLQONARV-VLYDPLPRDGPISVGT EPLIEMVPKSYNRELQVSRFDESREKCLERLRDAR	243
<i>Epichloë_festuca_Fg1</i>	184 QTLQONARV-VLYDPLPRDGPISVGT EPLIEMVPKSYNRELQVSRFDESREKCLERLRDAR	243
<i>Epichloë_festuca_F11</i>	36 QTLQONARV-VLYDPLPRDGPISVGT EPLIEMVPE SYNRELQVSRFDESREKCLERLRDAR	95
<i>Epichloë_festuca_E2368</i>	36 QTLQONARV-VLYDPLPRDGPISVGT EPLIEMVPE SYNRELQVSRFDESREKCLERLRDAR	95
<i>Epichloë_festuca_AR37</i>	40 QTLQONARV-VLYDPLPRDGPISVGT EPLIEMVPE SYNRELQVSRFDESREKCLERLRDAR	99
<i>Epichloë_festuca_AR1</i>	184 QTLQONARV-VLYDPLPRDGPISVGT EPLIEMVPKSYNRELQVSRFDESREKCLERLRDAR	243
<i>Epichloë_amarillans_E57</i>	184 QTLQNGAV-RLYDPLPRDGFIVGQEP LIEILPQSYNRELQVSRFDESROKCLERLRDAL	243
<i>Epichloë_amarillans_E4668</i>	184 QTLQNGAV-RLYDPLPRDGFIVGQEP LIEILPQSYNRELQVSRFDESROKCLERLRDAL	243
<i>Epichloë_aotearoae</i>	183 QTLVNTNARI-VLYDPPPRDAPISVGAEP LIEMVPE SYNRELQVSRFEESREKCLERLRDAR	242
<i>Epichloë_brachyelytri</i>	183 QTIIVANARI-VLYDPPPRDAPISVGAEP LIEMVPE SYNRELQVSRFDESREKCLERLRDAR	242
<i>Epichloë_bromicola_AL0434</i>	183 QTPVGNRIVLYIPLLEKDPPIYI GAEP LIEMVPKSYNRELQVSRFDKNREKCLERLRDAR	243
<i>Epichloë_bromicola_AL04262</i>	183 QTLGTNGRI-VLYNPPPKYI LTTAGPVL IEQ--KLYDPEIQWR FDDSR EKNREQLQIL	240
<i>Epichloë_elymi_ATCC_201551</i>	183 QTI AANARI-VLYDPPPRGAPISVGAEP LIEMVPKSYNRELQVSRFDESREKCLERLRDAR	242
<i>Epichloë_gansuensis_e7080</i>	183 QNL SVKGTV--LYLNRKKETVHRTGAEP LIEREPESYDINQVSRFDES RNKNERLQDFH	241
<i>Epichloë_glyceriae_ATCC_200747</i>	183 QTLGT DGR I-VLYNPLPRDTPSIYI GAEP LIELVPSYNDLVQSRFDESREKSRERLQDAH	242
<i>Epichloë_inebrians_MYA-1228</i>	47 QNQTKNGAFRTLYNARPKDTPYI I GAEP LIKLAPKSYNPNLVQSRFDES RNKNERLQDFH	107
<i>Epichloë_mollis_AL9924</i>	183 QTLAENGR I-VLYNPLPRNGPYI I GAEP LIVLGP KSYDPERVSRFDESROKCLERLQDAR	242
<i>Epichloë_typhina_ATCC_200736</i>	15 QTIIVANARV-VLYEP PPRGCPISILGAEP LIEMVPGSYNRELQVSRFEQSREKCLERLRDVR	74
<i>Epichloë_typhina_subsp_poa_e5819</i>	57 KSRSTS VRN-----QVPWTR S-----	72
<i>Epichloë_uncinata_CBS_102646</i>	184 QVMLGILRF-GLYEP PPRDAPISILGAEP LIEMVPGSYNRELQVSRFEQSREKCLERLRDAR	243
<i>Epichloë typhina_subsp_Poae_Ps1</i>	243 TKLSNDP FQGEDGDFQPF EENHISLDNEAVRYSQRLRADLHLMKDRRHDRDHPGDDO---	300
<i>Epichloë_festuca_AR48</i>	244 TKLSNDP FHYEDGEFQPF EENHISLDNEAVGYSQGLRTEL DGI LRDR-PYPT EPN-----	297
<i>Epichloë_festuca_Fg1</i>	244 TKLSNDP FHYEDGEFQPF EENHISLDNEAVGYSQGLRTEL DGI LRDR-PYPT EPN-----	297
<i>Epichloë_festuca_F11</i>	96 TKLSNDP FHYEDGEFQPF EENHISLDNEAVGYSQGLRTEL DGI LRDR-PYPT EPN-----	149
<i>Epichloë_festuca_E2368</i>	96 TKLSNDP FHYEDGEFQPF EENHISLDNEAVGYSQGLRTEL DGI LRDR-PYPT EPN-----	149
<i>Epichloë_festuca_AR37</i>	100 TKLSNDP FHYEDGEFQPF EENHISLDNEAVGYSQGLRTEL DGI LRDR-PYPT EPN-----	153
<i>Epichloë_festuca_AR1</i>	244 TKLSNDP FHYEDGEFQPF EENHISLDNEAVGYSQGLRTEL DGI LRDR-PYPT EPN-----	297
<i>Epichloë_amarillans_E57</i>	244 TKLSHDP FHYEDGEFQPF EENRISLDNEAVRYSQGLRTEL DGI LNNRGPYP AELN-----	298
<i>Epichloë_amarillans_E4668</i>	244 TKLSNDP FHYEDGEFQPF EENRISLDNEAVRYSQGLRTEL DGI LNNRGPYP AELN-----	298
<i>Epichloë_aotearoae</i>	243 TKLSDDP FHGDEGDFQPF EENHISLDNEAVRYSQRLRADLNDI LGNRRP---YPAEPD---	297
<i>Epichloë_brachyelytri</i>	243 TKLSNDP FHGDEGDFQPF EENHISLDNEAVRYSQRLRADLHGI LENRRP-----KPD---	294
<i>Epichloë_bromicola_AL0434</i>	244 TKLSKDP PKGVGDGKFP FKDNISLDNEAVGYSGLRKDL DVI KKNKRNSS THHAELI---	301
<i>Epichloë_bromicola_AL04262</i>	241 TKLSNNAP EGMGDGDFQPF KFNHISLDNEAVRYSQGLRKYL RGI IK----NKRD SNRDSKMD	297
<i>Epichloë_elymi_ATCC_201551</i>	243 TKLSKDP SHYKDGDFQPF EENHISLDNEAVRYSQGLRTEL DGI LKNRRPYPAKPI I----	297
<i>Epichloë_gansuensis_e7080</i>	242 TWF SRRYQGVDS EFI PF EKNDI-----	264
<i>Epichloë_glyceriae_ATCC_200747</i>	243 TKLSDDP PKGVDRGFQPF EENSILANEAVGYSGLRKDL RGI IKKKRDSITDPAET----	199
<i>Epichloë_inebrians_MYA-1228</i>	108 MTLFGHR YQGVGDGFEFTPF ENNHI KLNPN AVSLSQGLREALKGN T S---WPAELG----	158
<i>Epichloë_mollis_AL9924</i>	75 TKLSDDP FHGDEGDFQPF EENHISLDNEAVRYSQRLRADLHGL LEDRKDPDNDPVED----	131
<i>Epichloë_typhina_ATCC_200736</i>	-----	
<i>Epichloë_typhina_subsp_poa_e5819</i>	244 TKLSNDP FHGDEGDFQPF EENHISLDNEAVRYSQRLRADLIGFLRDRSYDPDHPGDND---	301
<i>Epichloë_uncinata_CBS_102646</i>		

Chapter eight: Appendices

*Epichloë typhina*_subsp_Poae_Ps1
*Epichloë festucae*_AR48
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë festucae*_E2368
*Epichloë festucae*_AR37
*Epichloë festucae*_AR1
*Epichloë amarillans*_E57
*Epichloë amarillans*_E4668
Epichloë aotearoae
Epichloë brachyelytri
*Epichloë bromicola*_AL0434
*Epichloë bromicola*_AL04262
*Epichloë elymi*_ATCC_201551
*Epichloë gansuensis*_e7080
*Epichloë glyceriae*_ATCC_200747
*Epichloë inebrians*_MYA-1228
*Epichloë mollis*_AL9924
*Epichloë typhina*_ATCC_200736
*Epichloë typhina*_subsp_poae_E5819
*Epichloë uncinata*_CBS_102646

*Epichloë typhina*_subsp_Poae_Ps1
*Epichloë festucae*_AR48
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë festucae*_E2368
*Epichloë festucae*_AR37
*Epichloë festucae*_AR1
*Epichloë amarillans*_E57
*Epichloë amarillans*_E4668
Epichloë aotearoae
Epichloë brachyelytri
*Epichloë bromicola*_AL0434
*Epichloë bromicola*_AL04262
*Epichloë elymi*_ATCC_201551
*Epichloë gansuensis*_e7080
*Epichloë glyceriae*_ATCC_200747
*Epichloë inebrians*_MYA-1228
*Epichloë mollis*_AL9924
*Epichloë typhina*_ATCC_200736
*Epichloë typhina*_subsp_poae_E5819
*Epichloë uncinata*_CBS_102646

*Epichloë typhina*_subsp_Poae_Ps1
*Epichloë festucae*_AR48
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë festucae*_E2368
*Epichloë festucae*_AR37
*Epichloë festucae*_AR1
*Epichloë amarillans*_E57
*Epichloë amarillans*_E4668
Epichloë aotearoae
Epichloë brachyelytri
*Epichloë bromicola*_AL0434
*Epichloë bromicola*_AL04262
*Epichloë elymi*_ATCC_201551
*Epichloë gansuensis*_e7080
*Epichloë glyceriae*_ATCC_200747
*Epichloë inebrians*_MYA-1228
*Epichloë mollis*_AL9924
*Epichloë typhina*_ATCC_200736
*Epichloë typhina*_subsp_poae_E5819
*Epichloë uncinata*_CBS_102646

*Epichloë typhina*_subsp_Poae_Ps1
*Epichloë festucae*_AR48
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë festucae*_E2368
*Epichloë festucae*_AR37
*Epichloë festucae*_AR1
*Epichloë amarillans*_E57
*Epichloë amarillans*_E4668
Epichloë aotearoae
Epichloë brachyelytri
*Epichloë bromicola*_AL0434
*Epichloë bromicola*_AL04262
*Epichloë elymi*_ATCC_201551
*Epichloë gansuensis*_e7080
*Epichloë glyceriae*_ATCC_200747
*Epichloë inebrians*_MYA-1228
*Epichloë mollis*_AL9924
*Epichloë typhina*_ATCC_200736
*Epichloë typhina*_subsp_poae_E5819
*Epichloë uncinata*_CBS_102646

*Epichloë typhina*_subsp_Poae_Ps1
*Epichloë festucae*_AR48
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë festucae*_E2368
*Epichloë festucae*_AR37
*Epichloë festucae*_AR1
*Epichloë amarillans*_E57
*Epichloë amarillans*_E4668
Epichloë aotearoae
Epichloë brachyelytri
*Epichloë bromicola*_AL0434
*Epichloë bromicola*_AL04262
*Epichloë elymi*_ATCC_201551
*Epichloë gansuensis*_e7080
*Epichloë glyceriae*_ATCC_200747
*Epichloë inebrians*_MYA-1228
*Epichloë mollis*_AL9924
*Epichloë typhina*_ATCC_200736
*Epichloë typhina*_subsp_poae_E5819
*Epichloë uncinata*_CBS_102646

*Epichloë typhina*_subsp_Poae_Ps1
*Epichloë festucae*_AR48
*Epichloë festucae*_Fg1
*Epichloë festucae*_F11
*Epichloë festucae*_E2368
*Epichloë festucae*_AR37
*Epichloë festucae*_AR1
*Epichloë amarillans*_E57
*Epichloë amarillans*_E4668
Epichloë aotearoae
Epichloë brachyelytri
*Epichloë bromicola*_AL0434
*Epichloë bromicola*_AL04262
*Epichloë elymi*_ATCC_201551
*Epichloë gansuensis*_e7080
*Epichloë glyceriae*_ATCC_200747
*Epichloë inebrians*_MYA-1228
*Epichloë mollis*_AL9924
*Epichloë typhina*_ATCC_200736
*Epichloë typhina*_subsp_poae_E5819
*Epichloë uncinata*_CBS_102646

301 -----MAFSAQWLVSLLGDQLFLNER-----FVGRAVASRRNYDFTYLWLK 341
298 -----ADLNPNQELVLSLSDQLLLSER-----FVRRRTMTSSRRNYDFTYLWLK 337
298 -----ADLNAQELVLSLSDQLLLSER-----FVRRRTVTSRRNYDFTYLWLK 337
150 -----ADLNAQELVLSLSDQLFLSER-----FVRRRTVTSRRNYDFTYLWLK 189
150 -----ADLNAQELVLSLSDQLFLSER-----FVRRRTVTSRRNYDFTYLWLK 189
154 -----ADLNAQELVLSLSDQLFLSER-----FVRRRTVTSRRNYDFTYLWLK 193
298 -----ADLNAQELVLSLSDQLLLSER-----FVRRRTVTSRRNYDFTYLWLK 337
299 -----GELNVQELVLSLSDQLFLSKN-----FITRIVKSSRRNYDCTFLWLQ 338
299 -----GELNVQELVLSLSDQLFLSKN-----FITRIMKSSRRNYDFTFLWLQ 338
298 -----AELDQAQVLSLSDQLFLSER-----FVRRRTMASRRYDFTYLWLK 337
295 -----AELNAQDLVLSLSDQRFLSKK-----FVRRRTMTSSRRNYDFTYLWLK 334
302 -----AELNAQDLVLSLSDQLFLSKN-----FVRRRTMTSSRRNYDFTYLWLK 335
298 SNTFPAELKLDQFLSHS-DEMEVSDMSLRAD-SSRKYDYGYANRTMTSSSEKYDYTYLWLK 356
298 -----AELNAQESLLLS-NQLLLSER-----FVRRRTMTSSRRNYDFTYLWLK 337

300 -----IAELNAQDLVLSLSDQLFLSKN-----FVRRRTMTSSRRNYDFTYLWLK 355
159 -----AELNVQVLPVLT-DRWLQSDRFLKLF-ASK-----YFDDQIKKSSSEKYDYTYLWLK 208
299 KTYHLAELKQDLVSHS-EELLVSDMSLRAD-SRQYDYGYVTRTMTASSEKHDFTYLWLK 358
132 -----RELNAQ-LLEFMSDQLFLTER-----FVRRRTVTSRRNYDFTYLWLK 171

302 -----AGLSAQWLVSLSLSDQLFLSKN-----FVRRRTVTSRRNYDFTYLWLK 341

342 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 402
338 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 398
338 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 398
190 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 250
190 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 250
194 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 254
338 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 398
339 QKIRKGF EAVVVKQGISLQAP LGGTAGERLSEQRFSSELLVGDNEFSTGYKDYGSVEIPGYEH 399
339 QKIRKGF EAVVVKQGISLQAP LGGTAGERLSEQRFSSELLVGDNEFSTGYKDYGSVEIPGYEH 399
338 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 398
335 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 395
356 QKEAKGFAAVVREGEHRQAP LGGTAGERLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 416
357 QKERKGIKAVVREGEHRQAP LGGTAGERLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 417
338 QKAVKGF AAVVVRACRRQAP LGGTAGERLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 398

356 QKEAKGFAAVVREGEHRQAP LGGTAGERLSEQRFRRLLAGDNDFSSGGYNAYESVEIPGYEH 416
209 QKEERGFAAVVREGEHRQAP LGGTAGERLSEQRFRASLAGDNDFSSGGYNAYESVEIPGYEH 269
359 QKIRKGF EAVVVRGIGLQAP LGGTAGERLSEQRFSDDLAGDNDFSSGGYNAYESVEIPGYEH 419
172 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 232

342 QKEERGFAAVVREGEHRQTP LGGTAGQRLSEQRFRELLAGDNDFSSGGYNAYESVEIPGYEH 402

403 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 463
399 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 459
399 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 459
251 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 311
251 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 311
255 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 315
399 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 459
400 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 460
400 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 460
399 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 459
396 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 456
417 DMTLSQMIQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 477
418 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 478
399 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI ELTRKELFNE IWQMTNDV VAMFQEMGGYTK 459

417 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 477
270 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 330
420 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 480
233 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 293

403 DMTLSEIVQLFDRSSTSLTQT EQGALLRRI DLARKKLFNES IWQMTNDV VAMFQEMGGYTK 463

464 PMPQDILLNAIPDKYGGGRCYPLVYAMSVALLASS----NFAIDQLCAKLVGLSPNNAADMK 520
460 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 516
460 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 516
312 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 368
312 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----NFAIDQLCAKLVGLSPNNAADMK 368
316 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 372
460 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 516
461 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----EFAIDQLCAKLVGLSPNNAADMK 517
461 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----EFAIDQLCAKLVGLSPNNAADMK 517
460 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 516
457 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 513
478 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 534
479 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 535
460 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 516

478 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----DFAIDQLCAKLVGLSPNNAADMK 534
331 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASSDFAIDFVIDQLCAKLVGLSPNNAADMK 391
481 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----EFAIDQLCAKLVGLSPNNAADMK 537
294 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----NFAIDQLCAKLVGLSPNNAADMK 350

464 PMPQDILLNAIPDEYGGGRCYPLVYAMSVALLASS----NFAIDQLCAKLVGLSPNNAADMK 520

521 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 581
517 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 577
517 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 577
369 NAVLLKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 429
369 NAVLLKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 429
373 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 433
517 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 577
518 NAKLLKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 578
517 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 577
514 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 574
535 NSKLLKRCLEDLHTSYPAAEASRP IGMNTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 595
536 NAKLLKRCLEDLHTSYPAAEASRP IGMNTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 596
517 NAKLLKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 577

535 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 595
392 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 452
538 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 598
351 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 411

521 NAEELKRCLEDLHTSYPAAEASRP IGNMTLEAAVSLEKSTETTTLAMHTEVHAMLGLGTRK 581

Epichloë typhina_subsp_Poa_Ps1
Epichloë festucae_AR48
Epichloë festucae_Fg1
Epichloë festucae_FI1
Epichloë festucae_E2368
Epichloë festucae_AR37
Epichloë festucae_AR1
Epichloë amarillans_E57
Epichloë amarillans_E4668
Epichloë aotearoae
Epichloë brachyleytrii
Epichloë bromicola_AL0434
Epichloë bromicola_AL04262
Epichloë elymi_ATCC_201551
Epichloë gansuensis_e7080
Epichloë glyceriae_ATCC_200747
Epichloë inebrians_MYA-1228
Epichloë mollis_AL9924
Epichloë typhina_ATCC_200736
Epichloë typhina_subsp_poa_E5819
Epichloë uncinata_CBS_102646

Epichloë typhina_subsp_Poa_Ps1
Epichloë festucae_AR48
Epichloë festucae_Fg1
Epichloë festucae_FI1
Epichloë festucae_E2368
Epichloë festucae_AR37
Epichloë festucae_AR1
Epichloë amarillans_E57
Epichloë amarillans_E4668
Epichloë aotearoae
Epichloë brachyleytrii
Epichloë bromicola_AL0434
Epichloë bromicola_AL04262
Epichloë elymi_ATCC_201551
Epichloë gansuensis_e7080
Epichloë glyceriae_ATCC_200747
Epichloë inebrians_MYA-1228
Epichloë mollis_AL9924
Epichloë typhina_ATCC_200736
Epichloë typhina_subsp_poa_E5819
Epichloë uncinata_CBS_102646

Epichloë typhina_subsp_Poa_Ps1
Epichloë festucae_AR48
Epichloë festucae_Fg1
Epichloë festucae_FI1
Epichloë festucae_E2368
Epichloë festucae_AR37
Epichloë festucae_AR1
Epichloë amarillans_E57
Epichloë amarillans_E4668
Epichloë aotearoae
Epichloë brachyleytrii
Epichloë bromicola_AL0434
Epichloë bromicola_AL04262
Epichloë elymi_ATCC_201551
Epichloë gansuensis_e7080
Epichloë glyceriae_ATCC_200747
Epichloë inebrians_MYA-1228
Epichloë mollis_AL9924
Epichloë typhina_ATCC_200736
Epichloë typhina_subsp_poa_E5819
Epichloë uncinata_CBS_102646

Epichloë typhina_subsp_Poa_Ps1
Epichloë festucae_AR48
Epichloë festucae_Fg1
Epichloë festucae_FI1
Epichloë festucae_E2368
Epichloë festucae_AR37
Epichloë festucae_AR1
Epichloë amarillans_E57
Epichloë amarillans_E4668
Epichloë aotearoae
Epichloë brachyleytrii
Epichloë bromicola_AL0434
Epichloë bromicola_AL04262
Epichloë elymi_ATCC_201551
Epichloë gansuensis_e7080
Epichloë glyceriae_ATCC_200747
Epichloë inebrians_MYA-1228
Epichloë mollis_AL9924
Epichloë typhina_ATCC_200736
Epichloë typhina_subsp_poa_E5819
Epichloë uncinata_CBS_102646

Chapter eight: Appendices

Epichloe_typhina_subsp_Poae_Ps1	884	EGFGVLLGGANVVLDAYELAHTDNDQAQKAVFGTQLAFDSVTF	FLASAGTI	IAGLIGATTAVA	944			
Epichloe_festucae_AR48	880	EGFGVLLGGANVILDAYELAHTDNDQAQRAVFGTQLAFDSVTF	FLASVGT	VGAGLLGATTVA	940			
Epichloe_festucae_Fg1	880	EGFGVLLGGANVILDAYELAHTDNDQAQRAVFGTQLAFDSVTF	FLASVGT	VGAGLLGATTVA	940			
Epichloe_festucae_F11	732	EGFGVLLGGANVILDAYELAHTDNDQAQRAVFGTQLAFDSVTF	FLASVGT	VGAGLLGATTVA	792			
Epichloe_festucae_E2368	732	EGFGVLLGGANVILDAYELAHTDNDQAQRAVFGTQLAFDSVTF	FLASVGT	VGAGLLGATTVA	792			
Epichloe_festucae_AR37	736	EGFGVLLGGANVILDAYELAHTDNDQAQRAVFGTQLAFDSVTF	FLASVGT	VGAGLLGATTVA	796			
Epichloe_festucae_AR1	880	EGFGVLLGGANVILDAYELAHTDNDQAQRAVFGTQLAFDSVTF	FLASVGT	VGAGLLGATTVA	940			
Epichloe_amarillans_E57	881	EGFGVLLGGANVVLDAYELAHRDNDQAQRAVFGTQLAFDSVTF	FLASVGT	IAGFIGATTAVA	941			
Epichloe_amarillans_E4668	881	EGFGVLLGGANVVLDAYELAHRDNDQAQRAVFGTQLAFDSVTF	FLASVGT	IAGFIGATTAVA	941			
Epichloe_aotearoae	880	EGFGVLLGGANVVLDAYELAHTDNDQAQKAVFGTQLAFDSVTF	FLASAGTI	IAGLIGATTAVV	940			
Epichloe_brachyelytri	877	EGFGVLLGGANVILDAYELAHTDNDQAQRAVFGTQLAFDSVTF	FLASAGTI	IAGLIGATTAVA	937			
Epichloe_bromicola_AL0434	898	EGFGVLLGGANVILDAYELAHTDNDVQRAVFGTQLAFDSVTF	FLASVGT	IAGFIGATTAVT	958			
Epichloe_bromicola_AL04262	899	EGFGVLLGGANVVLDAYELAHRDNDQAQRAVFGTQLAFDSVTF	FLSSVGT	IAGLIGATTAVA	959			
Epichloe_elymi_ATCC_201551	880	EGFGVLLGGANVVLDAYELAHAGNDAQRAVFGTQLAFDSVTF	FLASVGT	IAGFIGATTAVA	940			
Epichloe_gansuensis_e7080								
Epichloe_glyceriae_ATCC_200747	898	EGFGVLLGGANVILDAYELAHTDNDQAQRAVFGTQLAFDSVTF	FLASAGA	IAGLIGATTAVA	958			
Epichloe_inebrians_MYA-1228	755	EGFGVLLGGASVILDAFELAHVDNSAQRAVLTGTLAFDSATF	FLASVGT	IAGLIGATTAVA	815			
Epichloe_mollis_AL9924	901	EGFGVLLGSANVILDAYELAHTENDTQRAVFGTQLAFDSVTF	FLASVGT	IAGFIGATTAVA	961			
Epichloe_typhina_ATCC_200736	717	EGFGVLLGGANVVLDAYELAHTDNDQAQKAVFGTQLAFDSATF	FLASAGTI	IAGLIGATTAVA	777			
Epichloe_typhina_subsp_poae_E5819								
Epichloe_uncinata_CBS_102646								
Epichloe_typhina_subsp_Poae_Ps1	945	VMGGVSVILGGLAVGVGALASGFAQIAEKAKYVGRYFGDAEAYKAGGFKYDRDHGI	LVP	L	1005			
Epichloe_festucae_AR48	941	VVGGVSVILGGLAFGVGALASGFAQIAAKAQAVGRYFGDAEAYKAGGFKYDENHKL	LVP	L	1001			
Epichloe_festucae_Fg1	941	VVGGVSVILGGLAFGVGALASGFAQIAAKAEAVGRYFGDAEAYKAGGFKYDENHKL	LVP	L	1001			
Epichloe_festucae_F11	793	VVGGVSVILGGLAFGVGALASGFAQIAAKAEAVGRYFGDAEAYKAGGFKYDENHKL	LVP	L	853			
Epichloe_festucae_E2368	793	VVGGVSVILGGLAFGVGALASGFAQIAAKAEAVGRYFGDAEAYKAGGFKYDENHKL	LVP	L	853			
Epichloe_festucae_AR37	797	VVGGVSVILGGLAFGVGALASGFAQIAAKAEAVGRYFGDAEAYKAGGFKYDENHKL	LVP	L	857			
Epichloe_festucae_AR1	941	VVGGVSVILGGLAFGVGALASGFAQIAAKAEAVGRYFGDAEAYKAGGFKYDENHKL	LVP	L	1001			
Epichloe_amarillans_E57	942	VLLGGVSVILGGLAIGVGALSSAFIAAKAEAVGRYFGDADGAYKAGGFKYDEKDKI	LVP	L	1002			
Epichloe_amarillans_E4668	942	VLLGGVSVILGGLAIGVGALSSAFIAAKAEAVGRYFGDADGAYKAGGFKYDEKDKI	LVP	L	1002			
Epichloe_aotearoae	941	VMGGVSVILGGLAFGVGALASGFAQIAEKAKAVGRYFGDAEAYKAGGFKYDGDHRI	LVP	L	1001			
Epichloe_brachyelytri	938	VMGGVSVILGGLAFGVGALASGFAQIAEKAKAVGRYFGDAEAYKAGGFKYDRDHRI	LVP	L	998			
Epichloe_bromicola_AL0434	959	VMGGVSVILGGLGFGVGALASNFARIAEKAAVGRYFGDADYAYRAGGFKHDEHKL	LVP	L	1019			
Epichloe_bromicola_AL04262	960	VLLGGVSVILGGLAFGVGALASAFQIAEKAQAVGCYFGDADKAYRAGGFKYDENQKI	LVP	L	1020			
Epichloe_elymi_ATCC_201551	941	VLLGGVSVILGGLAFGVGALASGFAQIAEKAAVGRYFGDAEAYKAGGFKYDRNHRI	LVP	L	1001			
Epichloe_gansuensis_e7080								
Epichloe_glyceriae_ATCC_200747	959	VVGGVSVILGGLAFGVGALASGFAQIAEKAKAVGRYFGEADYAYRAGGFKYDGNHIE	LVP	L	1019			
Epichloe_inebrians_MYA-1228	816	VLLGGVSVIFGGLAFGVGALSSNYARIAEDAKAVGSYFGDVHDYRHHGDFKDNKI	LVP	L	876			
Epichloe_mollis_AL9924	962	VLLGASVILGGLAFGVGALASTFAQIAEKAAVGRYFGDADNAYRAGGFKYDENHVKI	LVP	L	1022			
Epichloe_typhina_ATCC_200736	778	VMGGVSVILGGLAIGVGALASGFAQIAEKAKYVGRYFGDAEAYRAGGFKYDEEHEI	LVP	L	838			
Epichloe_typhina_subsp_poae_E5819								
Epichloe_uncinata_CBS_102646								
Epichloe_typhina_subsp_Poae_Ps1	1006	FGAVISSEIDAAGNVKFDQSRIYRTWHGST-GSGRINYFFWVGDKPRMIQDKSQA	INVR	REGI	1065			
Epichloe_festucae_AR48	1002	SGAVISSEVDAAGNVKFDQSRIYRTWHGAT-GSGRINYFFWVGDKPRMIHDKSQA	INVR	REGI	1061			
Epichloe_festucae_Fg1	1002	FGAVISSEVDAAGNVKFDQSRIYRTWHGAT-GSGRINYFFWVGDKPRMIHDKSQA	INVR	REGI	1061			
Epichloe_festucae_F11	854	FGAVISSEVDAAGNVKFDQSRIYRTWHGAT-GSGRINYFFWVGDKPRMIHDKSQA	INVR	REGI	913			
Epichloe_festucae_E2368	854	FGAVISSEVDAAGNVKFDQSRIYRTWHGAT-GSGRINYFFWVGDKPRMIHDKSQA	INVR	REGI	913			
Epichloe_festucae_AR37	858	FGAVISSEVDAAGNVKFDQSRIYRTWHGAT-GSGRINYFFWVGDKPRMIHDKSQA	INVR	REGI	917			
Epichloe_festucae_AR1	1002	FGAVISSEVDAAGNVKFDQSRIYRTWHGAT-GSGRINYFFWVGDKPRMIHDKSQA	INVR	REGI	1061			
Epichloe_amarillans_E57	1003	FGAVIGEIDAAGNVKFDQSRIYRTRHGST-GSGRINYFFWAGDFFPRIHDKSQA	INVR	REGI	1062			
Epichloe_amarillans_E4668	1003	FGAVIGEIDAAGNVKFDQSRIYRTRHGST-GSGRINYFFWAGDFFPRIHDKSQA	INVR	REGI	1062			
Epichloe_aotearoae	1002	FGAVISSEIDAAGNVKFDQSRIYRTWHGST-GSGRINYFFWVGDKPRMIQDKSQA	INVR	REGI	1061			
Epichloe_brachyelytri	999	FGAVISSEIDAAGNVKFDQSRIYRTWHGST-GSGRINYFFWVGDKPRMIQDKSQA	INVR	REGI	1058			
Epichloe_bromicola_AL0434	1020	FGAVISSEIDAAGDVKFDQSRIYRSSLTSS- - - - -			1048			
Epichloe_bromicola_AL04262	1021	FGAVISSEIDAAGDVKFDQSRIYRTRHGST-GSGRSNYFFWAGHFFPRMIHDKSQA	IHM	REGI	1080			
Epichloe_elymi_ATCC_201551	1002	FGAVISSEIDAASDVKFDQSRIYRTRHGST-GSGRINYFFWAGDFFPRMIHDKSQA	INVR	REGI	1061			
Epichloe_gansuensis_e7080								
Epichloe_glyceriae_ATCC_200747	1020	FGAVISSEIDAAGNVKFDQSRIYRTWHGST-GSGRINYFFWAGDKPRMIHDKSQA	INVR	REGI	1079			
Epichloe_inebrians_MYA-1228	877	RGAVITSEIDVAGDVKFDQTYIYRTWHGSTRWSGRDNYFFWAGDFFPKLIHDKSQA	INVR	REGI	937			
Epichloe_mollis_AL9924	1023	FGAVISSEVDAAGNVKFDQSRIYRTRHGST-KWGR-NYFFWAGDFFEMIDDKSQA	IKVR	REGI	1081			
Epichloe_typhina_ATCC_200736	839	FGAVISSEIDAAGNVKFDQSRIYRTWHGST-GSGRINYFFWVGDKPRMIQDKSQA	INVR	REGI	898			
Epichloe_typhina_subsp_poae_E5819								
Epichloe_uncinata_CBS_102646								
Epichloe_typhina_subsp_Poae_Ps1	1066	GAPASGKLANTGDYTTIVLPATPKSFI	SYEWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	1126	
Epichloe_festucae_AR48	1062	RAPASGKLNTDRDYTAIILPATPKSYI	SYEWQILP	FCTGRHDYGF	FDVIRRL	EEDKRF	FDYDF	1122
Epichloe_festucae_Fg1	1062	RAPASGKLNTDRDYTAIILPATPKSYI	SYEWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	1122	
Epichloe_festucae_F11	914	RAPASGKLNTDRDYTAIILPATPKSYI	SYEWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	974	
Epichloe_festucae_E2368	914	RAPASGKLNTDRDYTAIILPATPKSYI	SYEWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	974	
Epichloe_festucae_AR37	918	RAPASGKLNTDRDYTAIILPATPKSYI	SYEWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	978	
Epichloe_festucae_AR1	1062	RAPASGKLNTDRDYTAIILPATPKSYI	SYEWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	1122	
Epichloe_amarillans_E57	1063	GAPASGKLANTRDYTTIILPATPKSFI	SYDWQTL	LPCTGRHDYGF	FDVIRRL	EEDKRF	FDYDF	1123
Epichloe_amarillans_E4668	1063	GAPASGKLANTRDYTTIILPATPKSFI	SYDWQTL	LPCTGRHDYGF	FDVIRRL	EEDKRF	FDYDF	1123
Epichloe_aotearoae	1062	GAPASGKLANTGDYTTIVLPATPKSFI	SYDWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	1122	
Epichloe_brachyelytri	1059	GAPASGKLANTGNYTAIILPATPKSYI	SYEWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	1119	
Epichloe_bromicola_AL0434								
Epichloe_bromicola_AL04262	1081	GAPASGKLANTQDYTAIILPTTPKSYI	SYDWQTL	LPCTGRHDYGF	FDVIRRL	EEDERFDYDF	1141	
Epichloe_elymi_ATCC_201551	1062	GAPASGKLANTRDYTAIILPATPKSYI	SYDWQILP	FCTGRHDYGF	FDVI	QTRR	- - - - -	1113
Epichloe_gansuensis_e7080								
Epichloe_glyceriae_ATCC_200747	1080	GAPASGKLANTRNYTAIILPATPKSYI	SYDWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	1140	
Epichloe_inebrians_MYA-1228	938	GAPASGKLANTQDYTAIILPATPKSYI	SYSQWTF	PGCTTRHDYGF	FDVIRRL	EEDKRF	FDYDF	998
Epichloe_mollis_AL9924	1082	GAPASGKLANTRDYTAIILPATPKSFI	SYDWQTL	LPCTGRHDYGF	FDVIRRL	EEDKRF	FDYDF	1142
Epichloe_typhina_ATCC_200736	899	GAPASGKLANTGDYTTIVLPATPKSFI	SYEWQILP	FCTGRHDYGF	FDVIRRL	EEDERFDYDF	959	
Epichloe_typhina_subsp_poae_E5819								
Epichloe_uncinata_CBS_102646								
Epichloe_typhina_subsp_Poae_Ps1	1127	YIFPSEYIIHQITHEFVKPTIAVRLGNRSVRVQVAELDES	LHNVLEYTI	HGAGANYTI	IGLN			1187
Epichloe_festucae_AR48	1123	YIFPSEYIIHKITHEFVRTPIAVRLDRRSVRVQVAELDES	LHNVLEYTI	HGAGANYTI	IGLN			1183
Epichloe_festucae_Fg1	1123	YIFPSEYIIHKITHEFVRTPIAVRLDRRSVRVQVAELDES	LHNVLEYTI	HGAGANYTI	IGLN			1183
Epichloe_festucae_F11	975	YIFPSEYIIHKITHEFVRTPIAVRLDRRSVRVQVAELDES	LHNVLEYTI	HGAGANYTI	IGLN			1035
Epichloe_festucae_E2368	975	YIFPSEYIIHKITHEFVRTPIAVRLDRRSVRVQVAELDEN	LHNVLEYTI	HGAGANYTI	IGLN			1035
Epichloe_festucae_AR37	979	YIFPSEYIIHKITHEFVRTPIAVRLDRRSVRVQVAELDES	LHNVLEYTI	HGAGANYTI	IGLN			1039
Epichloe_festucae_AR1	1123	YIFPSEYIIHKITHEFVKPTIAVRLDRRSVRVQVAELDES	LHNVLEYTI	HGAGANYTI	IGLN			1183
Epichloe_amarillans_E57	1124	YIFPSEYIIHYITHEFVKPTIAVRLDRRSVRVQVAELDKS	LHNVLEYTI	HGAGANYTI	IGLN			1184
Epichloe_amarillans_E4668	1124	YIFPSEYIIHYITHEFVKPTIAVRLDRRSVRVQVAELDKS	LHNVLEYTI	HGAGANYTI	IGLN			1184
Epichloe_aotearoae	1123	YIFPSEYIIHKITHEFVKPTIAVRLGNRSVRVQVTELDKS	LHNVLEYTI	HGAGADYTI	IGLN			1183
Epichloe_brachyelytri	1120	YIFPSEYIIHKITHEFVKPTIAVRLGNRSVRVQVAELDES	LHNVLEYTI	HGAGANYTI	IGLN			1180
Epichloe_bromicola_AL0434								
Epichloe_bromicola_AL04262	1142	YIFPSGYIIHKITHEFVKPTIAVKLDRSVRVQVAELDKS	LHNVLEYTI	HGAGANYTI	IGLN			1202
Epichloe_elymi_ATCC_201551	1114	YIFPSGYIIHKITHEFVKPTIAVKLDRSVRVQVAELDKS	LHNVLEYTI	HGAGANYTI	IGLN			1119
Epichloe_gansuensis_e7080								
Epichloe_glyceriae_ATCC_200747	1141	YVFPSEYIIHKITHEYMKPTIAVRLDRRSVRVQVAELDKS	LHNVLEYTI	HGAGANYTI	IGLN			1201
Epichloe_inebrians_MYA-1228	999	YIFPSEYIIHKITHEFVKPTIAVKLDRSVRVQVAELDKS	LHNVLEYTI	HGAGANYTI	IGLN			1059
Epichloe_mollis_AL9924	1143	YIFPSEYIIHKITHEFVKPTIAVKLDRSVRVQVAELDKS	LHNVLEYTI	HGAGANYTI	IGLN			1203
Epichloe_typhina_ATCC_200736	960	YIFPSEYIIHQITHEFVKPTIAVSLGNRSVRVQVAELDES	LHNVLEYTI	HGAGANYTI	IGLN			1020
Epichloe_typhina_subsp_poae_E5819								
Epichloe_uncinata_CBS_102646								

Chapter eight: Appendices

<i>Epichloë typhina_subsp_Poae_Ps1</i>	1493 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGSSELFCFFSYNQHKLVVQRNGNGTQAEKPR	1553
<i>Epichloë festucae_AR48</i>	1489 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGSSELFCFFSYNQHKLVVQRNGNGKQAEER	1549
<i>Epichloë festucae_Fg1</i>	1489 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGSSELFCFFSYNQHKLVVQRNGNGKQAEER	1549
<i>Epichloë festucae_F11</i>	1341 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGSSELFCFFSYNQHKLVVQRNGNGKQAEER	1401
<i>Epichloë festucae_E2368</i>	1340 FWIRMSDRTVIKPHPDHILNLYLLVGTIASADGSSELFCFFSYNQHKLVVQRNGNGKQAEER	1400
<i>Epichloë festucae_AR37</i>	1345 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGSSELFCFFSYNQHKLVVQRNGNGKQAEER	1405
<i>Epichloë festucae_AR1</i>	1489 FWIRMSDRTVIKPHPDHILNLYLLVGTIASADGSSELFCFFSYNQHKLVVQRNGNGKQAEER	1549
<i>Epichloë amarillans_E57</i>	1490 FWIRMSDRTVIKPHPDHILNLYLLVGTIVASTDGSDEQFCFFSHKEHKLVIQQNGNRANKPR	1550
<i>Epichloë amarillans_E4668</i>	1490 FWIRMSDRTVIKPHPDHILNLYLLVGTIVASTDGSDEQFCFFSHKEHKLVIQQNGNRANKPR	1550
<i>Epichloë aotearoae</i>	1484 FWIRMSDRTVIKPHPHIQLDLYLLVGTIASTDGSSELFCFFSYNQHKLVVQRNGNGKQAEER	1544
<i>Epichloë brachyelytri</i>	1486 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGSSELFCFFSYNQHKLVVQRNGNGKQAEER	1546
<i>Epichloë bromicola_AL0434</i>	-----	-----
<i>Epichloë bromicola_AL04262</i>	1508 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGSSELFCFFSHKEHKLVIQRNGNGKQAEER	1568
<i>Epichloë elymi_ATCC_201551</i>	-----	-----
<i>Epichloë gansuensis_e7080</i>	-----	-----
<i>Epichloë glyceriae_ATCC_200747</i>	1507 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGRGEQFCFFSYIQHKLVVQRNGNGKQAEER	1567
<i>Epichloë inebrians_MYA-1228</i>	1364 FWIRMSDRTVIKAHPDHLNLYLLVGTILNSTDGSSELFCFFSHKEHKLVIQQNGNGKQAEER	1424
<i>Epichloë mollis_AL9924</i>	1509 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGSSELFCFFSYNQHKLVVQRNGNGKQAEER	1569
<i>Epichloë typhina_ATCC_200736</i>	1326 FWIRMSDRTVIKPHPDHILNLYLLVGTIASTDGSSELFCFFSYNQHKLVVQRNGNGTQAEKPR	1386
<i>Epichloë typhina_subsp_poae_E5819</i>	-----	-----
<i>Epichloë uncinata_CBS_102646</i>	-----	-----
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1554 PVTISP ELGTISNFFSANNLFSITDAGFILRLTTHCTLAL EAVNHQWLEHREKDV DGGPW	1614
<i>Epichloë festucae_AR48</i>	1550 PVTISP ELGTISNFFCANNLFSITNAGFILRLTSHCTLAL EAVNHQWLEHYEKDV DGGPW	1610
<i>Epichloë festucae_Fg1</i>	1550 PVTISP ELGTISNFFCANNLFSITNAGFILRLTSHCTLAL EAVNHQWLEHYEKDV DGGPW	1610
<i>Epichloë festucae_F11</i>	1402 PVTISP ELGTISNFFCANNLFSITNAGFILRLTSHCTLAL EAVNHQWLEHYEKDV DGGPW	1462
<i>Epichloë festucae_E2368</i>	1401 PVTISP ELGTISNFFCANNLFSITNAGFILRLTTHCTLAL EAVNHQWLEHYEKDV DGGPW	1461
<i>Epichloë festucae_AR37</i>	1406 PVTISP ELGTISNFFCANNLFSITNAGFILRLTSHCTLAL EAVNHQWLEHYEKDV DGGPW	1466
<i>Epichloë festucae_AR1</i>	1550 PVTISP ELGTISNFFCANNLFSITNAGFILRLTSHCTLAL EAVNHQWLEHYEKDV DGGPW	1610
<i>Epichloë amarillans_E57</i>	1551 PVTISP EFGTISNFFCVNNDLFSITDTGFI LRLTTHCTLAL EAVNHQWLEHCEKDV DGGPW	1611
<i>Epichloë amarillans_E4668</i>	1551 PVTISP EFGTISNFFCVNNDLFSITDTGFI LRLTTHCTLAL EAVNHQWLEHCEKDV DGGPW	1611
<i>Epichloë aotearoae</i>	1545 PVTIPDPLDGTISNFFCANNLFSITDAGFILRLTTHCTLAL EAVNHQWLEHCEKDV DGGPW	1605
<i>Epichloë brachyelytri</i>	1547 PVTISP ELGTISNFFCANNLFSITDAGFILRLTTHCTLAL EAVNHQWLEHCEKDV DGGPW	1607
<i>Epichloë bromicola_AL0434</i>	-----	-----
<i>Epichloë bromicola_AL04262</i>	1569 PVTMSPELGTISNFFCANNLFSITDAGFILRLTTHCTLAL EAVNHQWLEHCEKDV DGGPW	1629
<i>Epichloë elymi_ATCC_201551</i>	-----	-----
<i>Epichloë gansuensis_e7080</i>	-----	-----
<i>Epichloë glyceriae_ATCC_200747</i>	1568 PVRISP EFGTISNFFSANDNLF AITNTGFI LRLTTHCTLAL EAVNHQWLEHCEKDV DGGPW	1628
<i>Epichloë inebrians_MYA-1228</i>	1425 PVTMSPEFGTISNFFCVNNDLFSITTTGFI LRLTTHCTLAL EAVNHQWLEHCEKDV DGGPW	1484
<i>Epichloë mollis_AL9924</i>	1570 PVTISP EFGTISNFFCVNNDLFSITDTGFI LRLTTHCTLAL EAVNHQWLEHCEKDV DGGPW	1630
<i>Epichloë typhina_ATCC_200736</i>	1387 PVTISP ELGTISNFFSANNLFSITDAGFILRLTTHCTLAL EAVNHQWLEHREKDV DGGPW	1447
<i>Epichloë typhina_subsp_poae_E5819</i>	-----	-----
<i>Epichloë uncinata_CBS_102646</i>	-----	-----
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1615 WTALSK LAKDHAAIVSVI GLRDAEGSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1675
<i>Epichloë festucae_AR48</i>	1611 WTALPK LAKDHAAIVSVI GLRDAEGSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1671
<i>Epichloë festucae_Fg1</i>	1611 WTALPK LAKDHAAIVSVI GLRDAEGSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1671
<i>Epichloë festucae_F11</i>	1463 WTALPK LAKDHAAIVSVI GLRDAEGSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1523
<i>Epichloë festucae_E2368</i>	1462 WTALPK LAKDHAAIVSVI GLRDAEGSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1522
<i>Epichloë festucae_AR37</i>	1467 WTALPK LAKDHAAIVSVI GLRDAEGSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1527
<i>Epichloë festucae_AR1</i>	1611 WTALPK LAKDHAAIVSVI GLRDAEGSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1671
<i>Epichloë amarillans_E57</i>	1612 WTALPK LAKDHAAIVSVI GLCDAQSPVQAWLCSNR FV VAGPSLRGKPRH MAGLTEGGSK	1672
<i>Epichloë amarillans_E4668</i>	1612 WTALPK LAKDHAAIVSVI GLCDAQSPVQAWLCSNR FV VAGPSLRGKPRH MAGLTEGGSK	1672
<i>Epichloë aotearoae</i>	1606 WTALSK LAKDHAAIVSVI GLRDT EGSVPQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1666
<i>Epichloë brachyelytri</i>	1608 WTALSK LAKDHAAIVSVI GLRDAEGSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1668
<i>Epichloë bromicola_AL0434</i>	-----	-----
<i>Epichloë bromicola_AL04262</i>	1630 WTALPK LVKDHDAAVSVI GLRDAEGSPVQAWLCSGR FV VAGPSLRGEP RH IAGLTEGGSK	1690
<i>Epichloë elymi_ATCC_201551</i>	-----	-----
<i>Epichloë gansuensis_e7080</i>	-----	-----
<i>Epichloë glyceriae_ATCC_200747</i>	1629 WTALPK LAKDHAAIVSVI GLRDAEGSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1689
<i>Epichloë inebrians_MYA-1228</i>	1485 WTALPK LAKDHAAIVSVI GLCDAQSPVQAWLCSNR FV VAGPSLRGKPRH MAGLTEGGSK	1545
<i>Epichloë mollis_AL9924</i>	1631 WTALPK LAKDHAAIVSVI GLCDAQSPVQAWLCSDRFV VAGPSLRGKPRH MAGLTEGGSK	1691
<i>Epichloë typhina_ATCC_200736</i>	1448 WTALSK LAKDHAAIVSVI GLRDT EGSVPQAWLCSDRFV VAGPSLRGKPRH MAGLAE RGSK	1508
<i>Epichloë typhina_subsp_poae_E5819</i>	-----	-----
<i>Epichloë uncinata_CBS_102646</i>	-----	-----
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1676 AWLWHMETE-----DSGHLYAQPTVRGKELETVFRLKAPFVNAEAVP	1717
<i>Epichloë festucae_AR48</i>	1672 AWLWHIESE-----DSGHVYAQPTVRGKELETVFSPKAPFVKA EAVP	1713
<i>Epichloë festucae_Fg1</i>	1672 AWLWHIESE-----DSGHVYAQPTVRGKELETVFSPKAPFVKA EAVP	1713
<i>Epichloë festucae_F11</i>	1524 AWLWHIESE-----DSGHVYAQPTVRGKELETVFSPKAPFVKA EAVP	1565
<i>Epichloë festucae_E2368</i>	1523 AWLWHIESE-----DSGHVYAQPTVRGKELETVFSPKAPFVKA EAVP	1564
<i>Epichloë festucae_AR37</i>	1528 AWLWHIESE-----DSGHVYAQPTVRGKELETVFSPKAPFVKA EAVP	1569
<i>Epichloë festucae_AR1</i>	1672 AWLWHIESE-----DSGHVYAQPTVRGKELETVFSPKAPFVKA EAVP	1713
<i>Epichloë amarillans_E57</i>	1673 AWLWHIESE-----DSGHVYAQPTVRDELETVFDPNAPFVKA EAVP	1714
<i>Epichloë amarillans_E4668</i>	1673 AWLWHIESE-----DSGHVYAQPTVRNEELETVFDPNAPFVKA EAVP	1714
<i>Epichloë aotearoae</i>	1667 AWLWHIESE-----DSGHVYAQPTVRGKELETVFRLKAPFVKA EAVP	1708
<i>Epichloë brachyelytri</i>	1669 AWLWHIESE-----DSGHVYAQPTVRGKELETVFRLRAPFVKA EAVP	1710
<i>Epichloë bromicola_AL0434</i>	-----	-----
<i>Epichloë bromicola_AL04262</i>	1691 AWLWHIESE-----DSGHVYAQPTVRGKELETVFCKAPFVKA EAVP	1732
<i>Epichloë elymi_ATCC_201551</i>	-----	-----
<i>Epichloë gansuensis_e7080</i>	-----	-----
<i>Epichloë glyceriae_ATCC_200747</i>	1690 AWLWHIESE-----DSGHVYAQPTVRGKELETVFSPKAPFVKA EAVP	1731
<i>Epichloë inebrians_MYA-1228</i>	1546 AWLWYIESKSGHLEVEPIVRVQELETVD SGHLYAQPTVRDELETVFSPKAPFVKA EAVP	1606
<i>Epichloë mollis_AL9924</i>	1692 AWLWHIESE-----DSGHVYAQPTVRGKELETVFCKAPFVKA EAVP	1733
<i>Epichloë typhina_ATCC_200736</i>	1509 AWLWHMETE-----DSGHLYAQPTVRGKELETVFRLKAPFVNAEAVP	1550
<i>Epichloë typhina_subsp_poae_E5819</i>	-----	-----
<i>Epichloë uncinata_CBS_102646</i>	-----	-----
<i>Epichloë typhina_subsp_Poae_Ps1</i>	1718 DGRGVLEKHPFKTVALT-EGGLRYTTKEGVVLI LASER SARLYGV DKVWQNRSDLS-GEI	1776
<i>Epichloë festucae_AR48</i>	1714 DGRGVLEHPFKTVALT-ESGLRYTTKEGVVLI LASER SMRLYGV DKVWQNRGDL S-AEL	1772
<i>Epichloë festucae_Fg1</i>	1714 DGRGVLEHPFKTVALT-ESGLRYTTKEGVVLI LASER SMRLYGV DKVWQNRGDL S-AEL	1772
<i>Epichloë festucae_F11</i>	1566 DGRGVLEHPFKTVALT-ESGLRYTTKEGVVLI LASER SMRLYGV DKVWQNRGDL S-AEL	1624
<i>Epichloë festucae_E2368</i>	1565 DGRGVLEHPFKTVALT-ESGLRYTTKEGVVLI LASER SMRLYGV DKVWQNRGDL S-AEL	1623
<i>Epichloë festucae_AR37</i>	1570 DGRGVLEHPFKTVALT-ESGLRYTTKEGVVLI LASER SMRLYGV DKVWQNRGDL S-AEL	1628
<i>Epichloë festucae_AR1</i>	1714 DGRGVLEHPFKTVALT-ESGLRYTTKEGVVLI LASER SMRLYGV DKVWQNRGDL S-AEL	1772
<i>Epichloë amarillans_E57</i>	1715 DGRRLVLEHPFKTVALT-EGGLRYTTKDG VVLI LASER SARLYGV DKVWQNRGHL SAE L	1774
<i>Epichloë amarillans_E4668</i>	1715 DGRRLVLEHPFKTVALT-EGGLRYTTKDG VVLI LASER SARLYGV DKVWQNRGHL SAE L	1774
<i>Epichloë aotearoae</i>	1709 DGRGVLEHPFKTVALT-EGGLRYTTNDG VVLI LASER SARLYGV DKVWQNRSDLS-AEL	1767
<i>Epichloë brachyelytri</i>	1711 DGRGVLEHPFKTVALT-EGGLRYTTNDG VVLI LASER SARLYGV DKVWQNRSDLS-AEL	1769
<i>Epichloë bromicola_AL0434</i>	-----	-----
<i>Epichloë bromicola_AL04262</i>	1733 DGRGVLEKHPFKTVALT-EGGLRYTTKDG VVLI LASER SARLYGV DKVWRQNRGDL S-AEL	1791
<i>Epichloë elymi_ATCC_201551</i>	-----	-----
<i>Epichloë gansuensis_e7080</i>	-----	-----
<i>Epichloë glyceriae_ATCC_200747</i>	1732 DGRGVLEKHPFKTVALT-EGGLRYTTKDG VVLI LASER SARLYGV DKVWQNRSDLS-AEL	1790
<i>Epichloë inebrians_MYA-1228</i>	1607 DGRSVPLEHPFKTVALT DGLRYTTKDG VVLT LSSER SARLYGV DKVWQNRSDVN-AAL	1666
<i>Epichloë mollis_AL9924</i>	1734 DGRGVLEHPFKTVALT-EGGLRYTTKDG VVLI LASER SARLYGV DKVWQNRSDLS-AEL	1792
<i>Epichloë typhina_ATCC_200736</i>	1551 DGRGVLEHPFKTVALT-EGGLRYTTKEGVVLI LASER SARLYGV DKVWQNRSDLS-GEL	1609
<i>Epichloë typhina_subsp_poae_E5819</i>	-----	-----
<i>Epichloë uncinata_CBS_102646</i>	-----	-----

Chapter eight: Appendices

<i>Epichloë typhina_subsp_Poa_Ps1</i>	1777	ATLVKTWDHGESVVMLGSEPPQWYLTSSGNI	VSAAKATFTWLDAPTWL	GADP	SGARGYAYV	1837
<i>Epichloë festucae_AR48</i>	1773	ATLVNTWRHGETVVMLGSEPPQWYLMSSGKI	LAAAEATFTWLDAPTWL	GADP	SGARGYAYV	1833
<i>Epichloë festucae_Fg1</i>	1773	ATLVNTWSHGGETVVMLGSEPPQWYLMSSGKI	LAAAEATFTWLDAPTWL	GADP	SGARGYAYV	1833
<i>Epichloë festucae_F11</i>	1625	ATLVNTWSHGGETVVMLGSEPPQWYLTSSGKI	LAAAEATFTWLDAPTWL	GADP	SGARGYAYV	1685
<i>Epichloë festucae_E2368</i>	1624	ATLVNTWSHGGETVVMLGSEPPQWYLTSSGKI	LAAAEATFTWLDAPTWL	GADP	SGARGYAYV	1684
<i>Epichloë festucae_AR37</i>	1629	ATLVNTWSHGGETVVMLGSEPPQWYLTSSGKI	LAAAEATFTWLDAPTWL	GADP	SGARGYAYV	1689
<i>Epichloë festucae_AR1</i>	1773	ATLVNTWRHGETAAMVS-----	DVFWKDS-----	RGSRGDFYL		1805
<i>Epichloë amarillans_E57</i>	1775	ATLLKTWSHGGETVVMLGSEPPQWYLTSSRKI	LAAAKATFTWLDAPTWL	GADP	SGARGYAYV	1835
<i>Epichloë amarillans_E4668</i>	1775	ATLLKTWSHGGETVVMLGSEPPQWYLTSSRKI	LAAAKATFTWLDAPTWL	GADP	SGARGYAYV	1835
<i>Epichloë aotearoae</i>	1768	ATLVNAWSHGGETVVMLGSEPPQWYLTSSGKI	LAAAKATFTWLDAPTWL	GADP	SGARGYAYV	1828
<i>Epichloë brachyelytri</i>	1770	ATLVNAWSHGGETVVMLGSEPPQWYLTSSGKI	LAAAKATFTWLDAPTWL	GADP	SGARGYAYV	1830
<i>Epichloë bromicola_AL0434</i>						
<i>Epichloë bromicola_AL04262</i>	1792	ATLVNTWSHGGETVVMLGSEPPQWYLTSSGKI	LAAAKATFTWLDAPTWL	GADP	SGARGYAYV	1852
<i>Epichloë elymi_ATCC_201551</i>						
<i>Epichloë gansuensis_e7080</i>						
<i>Epichloë glyceriae_ATCC_200747</i>	1791	ATLANTWSHGGETVVMLGSEPPKWYLASSGKI	LAAAKATFTWLDAPTWL	GADP	SGARGYAYV	1851
<i>Epichloë inebrians_MYA-1228</i>	1667	ATLVNTWSHGELVVMLGSEPPQWYLTSSGKI	LAAATNATFTWLDAPTWL	GADL	LSGAKGYAYV	1727
<i>Epichloë mollis_AL9924</i>	1793	ATLVKTWSHGGETVVMLGSEPPQWYLTSSGKI	LAAAKATFTWLDAPTWL	GADP	SGARGYAYV	1853
<i>Epichloë typhina_ATCC_200736</i>	1610	ATLVKTWDHGESVVMLGSEPPQWYLTSSGNI	VSAAKATFTWLDAPTWL	GADP	NGARGYAYV	1670
<i>Epichloë typhina_subsp_poa_E5819</i>						
<i>Epichloë uncinata_CBS_102646</i>						
<i>Epichloë typhina_subsp_Poa_Ps1</i>	1838	AGQGR IYELGEGSAEEKKSAASQEVAFASRFQDVLAVKP	SPGASFRQFALENVHYT	ILSQF		1898
<i>Epichloë festucae_AR48</i>	1834	AAHRR IYELGESSAEGKSSAASQEVAFASRFQDVLAVKP	SPGASFRQFALENVLYT	ILSQF		1894
<i>Epichloë festucae_Fg1</i>	1834	AAHRR IYELGESSAEGKSSAASQEVAFASRFQDVLAVKP	SPGASFRQFALENVLYT	ILSQF		1894
<i>Epichloë festucae_F11</i>	1686	AAHRR IYELGESSAEEKSSAASQDVAFAFRQDVLAVKP	SPGASFRQFALENVLYT	ILSQF		1746
<i>Epichloë festucae_E2368</i>	1685	AAHRR IYELGESSAEGKSSAASQEVAFASRFQDVLAVKP	SPGASFRQFALENVLYT	ILSQF		1745
<i>Epichloë festucae_AR37</i>	1690	AAHRR IYELGESSAEGKSSAASQEVAFASRFQDVLAVKP	SPGASFRQFALENVLYT	ILSQF		1750
<i>Epichloë festucae_AR1</i>	1806	ARCPHVAWCR-----	SQRCKRIRLCRRPQKNLRIR-----	REFCRG-----		1841
<i>Epichloë amarillans_E57</i>	1836	AAHRR IYELGESSAEEKSSAASQEVAFASRLQDVLAVRP	SPGASFRQFALENVLYT	ILSHF		1896
<i>Epichloë amarillans_E4668</i>	1836	AAHRR IYELGESSAEEKSSAASQEVAFASRLQDVLAVRP	SPGASFRQFALENVLYT	ILSHF		1896
<i>Epichloë aotearoae</i>	1829	AAHRR IYELGESSAEE- KSAVSQEVAFASRFQDVLAVKP	SPGASFRQFALENVLYT	ILSQF		1888
<i>Epichloë brachyelytri</i>	1831	AAHRR IYELGESSAEE- KSAASQEVAFASRFQDVLAVKP	SPGASFRQFALENVLYT	ILSQF		1890
<i>Epichloë bromicola_AL0434</i>						
<i>Epichloë bromicola_AL04262</i>	1853	AAHGR IYELGESSAEE- KSAASQEVAFASRFQDVLAVKP	SPGARFRQFALDNVLYT	ILSQF		1912
<i>Epichloë elymi_ATCC_201551</i>						
<i>Epichloë gansuensis_e7080</i>						
<i>Epichloë glyceriae_ATCC_200747</i>	1852	AAHRR IYEVGEGSAEE- ESAASQEVAFASRFQDVLAVKP	SPGASFRQFALGNVLYT	ILSQF		1911
<i>Epichloë inebrians_MYA-1228</i>	1728	SAHRR IYELRQSSAEE- TSAASREDAFASRLHDVLAVEP	SPGASFRPFALENVLYT	ILSQV		1787
<i>Epichloë mollis_AL9924</i>	1854	AGQGR IYELGEGSAEEKKSAASQEVAFASRFQDVLAVKP	SPGAGFRQFALENVLYT	ILSQF		1914
<i>Epichloë typhina_ATCC_200736</i>	1671	AGQGR IYELGEGSAEENKSAASQEVAFASRFQDVLAVKP	SPGASFRQFALENVHFT	ILSQF		1731
<i>Epichloë typhina_subsp_poa_E5819</i>						
<i>Epichloë uncinata_CBS_102646</i>						
<i>Epichloë typhina_subsp_Poa_Ps1</i>	1899	EGDTS FMDY SVP SASWESLSGLV I EWKDQGRVEMEGSTMHPGP	LGWY LAKRLGDDLI	IMEG		1959
<i>Epichloë festucae_AR48</i>	1895	EGDTS FMECVVP SSSWESLTGLV I EWKDQGGQVQ I EGSTRHPRPADS	FLGKRLDDDL	IMMEI		1955
<i>Epichloë festucae_Fg1</i>	1895	EGDTS FMECVVP SSSWESLTGLV I EWKDQGGQVQ I EGSTRHPRPADS	FLGKRLDDDL	IMMEI		1955
<i>Epichloë festucae_F11</i>	1747	EGDTS FMECVVP SSSWESLTGLV I EWKDQGGQVQ I EGSTRHPRPADS	FLGKRLDDDL	IMMEI		1807
<i>Epichloë festucae_E2368</i>	1746	EGDTS FMECVVP SSSWESLTGLV I EWKDQGGQVQ I EGSTRHPRPADS	FLGKRLDDDL	IMMEI		1806
<i>Epichloë festucae_AR37</i>	1741	EGDTS FMECVVP SSSWESLTGLV I EWKDQGGQVQ I EGSTRHPRPADS	FLGKRLDDDL	IMMEI		1811
<i>Epichloë festucae_AR1</i>	1842	-----	RKVGCVPSRLCLTLPG-----	CSGCQAQPRSK-----	LS SV	1873
<i>Epichloë amarillans_E57</i>	1897	EGDTS FMECVVP SSSWESLAGIV I EWKDQGGQVQ I EGSTRHPRPADS	FLGKRLGDDLI	IMMEI		1957
<i>Epichloë amarillans_E4668</i>	1897	EGDTS FMECVVP SSSWESLAGIV I EWKDQGGQVQ I EGSTRHPRPADS	FLGKRLGDDLI	IMMEI		1957
<i>Epichloë aotearoae</i>	1889	EGDTS FMEYGVPS SSSWESLSGLV I EWKDQGGQVE I EGSTRHPRPAGS	FFGKRLGDDLI	IMMEI		1949
<i>Epichloë brachyelytri</i>	1891	EGDTS FMENVVP SSSWESLSGLV I EWKDQGRVE I EGSTRHPRPAGS	F I GKR LGDDLI	IMMEI		1951
<i>Epichloë bromicola_AL0434</i>						
<i>Epichloë bromicola_AL04262</i>	1913	EGDTS FMEYVVP SASWESVDGLV I EWKDQGRVE I EGSTRHPRPADS	FLGKRLGDDLI	IMMEI		1973
<i>Epichloë elymi_ATCC_201551</i>						
<i>Epichloë gansuensis_e7080</i>						
<i>Epichloë glyceriae_ATCC_200747</i>	1912	EGDAS FMEYVVP SSSWESLHGLA I EWKDQGRVE I EGSTRHPRPAGS	FFGKRLGDDLI	IMMEI		1972
<i>Epichloë inebrians_MYA-1228</i>	1788	EGDTS FMEYVIP SSSWESLDGLVVKWNDQGRVE I EGSTRHPRRAGS	FLGNRLDDDL	IMMEI		1848
<i>Epichloë mollis_AL9924</i>	1915	EGDTS FMECVIP SSSWESSNGLV I EWKNQGGQVE I EGSTRHPRPADS	FLGKRLGDDLI	IMMEM		1975
<i>Epichloë typhina_ATCC_200736</i>	1732	EGDTS FMDY IVP SSSWESLSGVV I EWKDQGRVEMEGSTMHPGP	LGLFLT KRLGDDI	ILMEG		1792
<i>Epichloë typhina_subsp_poa_E5819</i>						
<i>Epichloë uncinata_CBS_102646</i>						
<i>Epichloë typhina_subsp_Poa_Ps1</i>	1960	STGR FMK I SRAMVMDP TCM I HMTGKLLTVGNCSAGNQ-				1996
<i>Epichloë festucae_AR48</i>	1956	STGR FLK I SRGLVMDP SCV I RFTDKLLTVGNCSNEIQ-				1992
<i>Epichloë festucae_Fg1</i>	1956	STGR FLK I SRGLVMDP SCV I RFTDKLLTVGNCSNEIQ-				1992
<i>Epichloë festucae_F11</i>	1808	STGR FLK I SRGLVMDPWCVTRFTDKLLTVGNCSAGNQ-				1844
<i>Epichloë festucae_E2368</i>	1807	STGR FLK I SRGLVMDP SCV I RFTDKLLTVGNCSNEIQ-				1843
<i>Epichloë festucae_AR37</i>	1812	STGR FLK I SRGLVMDP SCV I RFTDKLLTVGNCSNEIQ-				1848
<i>Epichloë festucae_AR1</i>	1874	CPG-----	ECPVYHTVSI-----			1886
<i>Epichloë amarillans_E57</i>	1958	LTGR FLK I SRGLVMDP SCV I RFTDKLLTVGNCSAGNR-				1994
<i>Epichloë amarillans_E4668</i>	1958	STGR FLK I SRGLVMDP SCV I RFTDKLLTVGNCSAGNR-				1994
<i>Epichloë aotearoae</i>	1950	STGR FLK I SRGLVMDP SCV I RFTDKLLTVGNCSAGNR*				1987
<i>Epichloë brachyelytri</i>	1952	STGR FLRI SRGLVMDP SCV I RFTDKLLTVGNCSAGNR-				1988
<i>Epichloë bromicola_AL0434</i>						
<i>Epichloë bromicola_AL04262</i>	1974	STGR FLK I SRGLVMDP SCV I RFTDKLLTVGNCSAGNR-				2010
<i>Epichloë elymi_ATCC_201551</i>						
<i>Epichloë gansuensis_e7080</i>						
<i>Epichloë glyceriae_ATCC_200747</i>	1973	STGR FLRVSRGLVMDP SCVVRFTDKLLTVGNCSAGNR-				2009
<i>Epichloë inebrians_MYA-1228</i>	1849	STGR FLRVSKAFAMNP LCV I RFTDKLLTVGNCSAGNQ-				1885
<i>Epichloë mollis_AL9924</i>	1976	STGR FLQ I SRGLVMDP SFV I RFTDKLLTVGNCSAGNR-				2012
<i>Epichloë typhina_ATCC_200736</i>	1793	STGR FLK I SRAMVMDP SCTFRFAGKLLTVSNGSAGNQ-				1829
<i>Epichloë typhina_subsp_poa_E5819</i>						
<i>Epichloë uncinata_CBS_102646</i>						

Appendix 21: Alignment of makes caterpillars floppy (Mcf) proteins from a range of *Epichloë* strains across multiple species using the alignment function of Geneious.

Chapter eight: Appendices

<i>Etyphina_subsp_Poae_Ps1</i>	1-----MAHNTDEAFV F SKD F LA F ITKGEKGYAV30
<i>N_ditissima</i>	1MSLLYVPFLDPPDSVTNYSLPSPYKVITKKTGDLNKKD H QLLS P IA F LRTSP I GSNN60
<i>P_gigantea</i>	1-----MSNIPADPA L S F VDD P Q K LTPATVATA30
<i>Etyphina_subsp_Poae_Ps1</i>	31IS-----SDNIPGRPDIRIGDN G H F RF--ESVGNPDQPA F IRY G SEAGAD I SAY H L--82
<i>N_ditissima</i>	61LLD--FHEQ R E A RKDGRVLP R KV F AK-LDKCQNP L N L --VTWYQ I KARLSDDGSH L L114
<i>P_gigantea</i>	31VSTYQMFSG I NAR P GG-V P REG Y Q F VVNPTGKQGV I SYD I KWAGAT P SANTVW A YN L --88
<i>Etyphina_subsp_Poae_Ps1</i>	83-GYNGGAQTSWT P AI D IP--KIN P EH N LL F TGS L GC S VI V T N ND D OY R VY H DSRQ D S139
<i>N_ditissima</i>	115HSYLLQSPSNKE P TY V DIPVHPAKDE P RL L VTEELGCS V VVRR L DE T TY R VY H D R GL N T174
<i>P_gigantea</i>	89-DYAGAAQTSK P AF L DIP--KT V AE K T L L F TGA L TGCS V IT S LDANTY R V F HDSR L ES145
<i>Etyphina_subsp_Poae_Ps1</i>	140 S LLYDDV V MAVDY R DYK H RDA S TG F A S TF M HY--REGR W S L CF R Q R T I VA N AR I V L Y E PA197
<i>N_ditissima</i>	175 S ICYPDV V MA I D H FRY G ML P HEG D LAT V LM H YDP E ARQ W S L LV R --LKR N LKV W S R EA--231
<i>P_gigantea</i>	146 S LFYDN V MAVD W SDY S VS F S R E-GL A LA F MQ F --RDG Q WR L I T QL T NS P TGA I L P R S SV202
<i>Etyphina_subsp_Poae_Ps1</i>	198PRDGP S ILGA E P LIEMV P GS Y NREL V QSR F EQ S RE K CL R L-RDART K LSND P FQ G E- D G255
<i>N_ditissima</i>	232--NAERYCAP V LN I HT E TY P QLAL R P G NMRD R --VRR K MT W INAY A PE E FT V E- D G285
<i>P_gigantea</i>	203LRTALQD T Y F P P --SVDS P GS Y DHAARR A AFDS S RT E SG R LIRVAT E AF L ST V P N Q P D G261
<i>Etyphina_subsp_Poae_Ps1</i>	256D F Q P - P FEENR I S L D N EAV R YSQ R L R -ADLHLMKDRRH D R D HPGD D MA F SAQ W LV S LG313
<i>N_ditissima</i>	286D F V H PGL K E K ATLAN D AV K STQ V M R N-YLQGV L AD I KSD K L K P---EL I QL R D W CQ D SG G 341
<i>P_gigantea</i>	262A F V- P F-GET I S L N P AV N HNT A I R NAVE H E I IV-MD D ER L -----AVMD K V P AL W Q V LN313
<i>Etyphina_subsp_Poae_Ps1</i>	314D Q L F LN R EF V GRA V AS S R N Y D FT Y L W L K Q K E E RG F T A V R E G EH R Q T LC G TAG Q R L SEQ373
<i>N_ditissima</i>	342KEAMSR H --LS D L I Q E SK D ED F TY L RCR R ELID R E K GV F ND L VQ S GL L GD T AG R FAD L 399
<i>P_gigantea</i>	314 T QHR P I H DL V EP V AL D SK L D Y T Y L W L K Q K E A R G ID A IV V LD G R L RAP L GD T AG R MT S Q373
<i>Etyphina_subsp_Poae_Ps1</i>	374R F RE L LAGDN D FS S GY N AY E SV E IP G --YEH D MT L SE I VQ L FDR S ST S L T Q T EQ Q ALL R R431
<i>N_ditissima</i>	400HSRL L EL S NQ D LAQ Q YLMD T AL V LP E DIV P RD M AIV D M K EL L TD G VE T LD V Q K ALL R V459
<i>P_gigantea</i>	374EL E ML--SG N AD F AS G Y D TY K T V A I IG--FT S DM D AK A MT L L F --DS A QL L DA E K G ALL V HY428
<i>Etyphina_subsp_Poae_Ps1</i>	432 I DLARK K LF N ES I WQ M TND V AM F Q E MG Y T K MP Q DI L NA I P K Y G GG R C P LV Y AMS491
<i>N_ditissima</i>	460 I DD E CL R LY R DE I WT E ADA V RR F Q D AQ I VT G AP Q VAL F ES A T D VAA G GR C Y P LV R AA519
<i>P_gigantea</i>	429 I SDANAQ E Y R AS V W D K T ND V LG V FQ D S A ST K MP Q DL L HA I P E Y--GG R C P LV R AMA487
<i>Etyphina_subsp_Poae_Ps1</i>	492 V AL-AS S NF A I D AL C AK L V G LS P NNA D M K NA E LL K R C LED L HT S YP A AE S RP I -GN M T549
<i>N_ditissima</i>	520 V ALDEQ G PR A ME D IM A K I VS M ERR T TND---G E LL R G L HR L GN E D A RA S NR L E G Q F T576
<i>P_gigantea</i>	488 V AL-SQ S MF S V D QL M V K L T ALT--TD A D L WN A T L F M R C L D L S SY P AA E SK H I-- K ME543
<i>Etyphina_subsp_Poae_Ps1</i>	550 L AE A VS V LE--K S T E TT T L A M H T E V H AM L LG V R K TR N ST--SW H FY D PN F A I V T FN S GE A 605
<i>N_ditissima</i>	577 L ED A ME L -----T L GD G Q S GA Q L--Q Y H F Y D PN F ALL T LO S GE A 614
<i>P_gigantea</i>	544 L RDA I S L LD V SK P G A K V V A L N T E TH A ML A AND N GP T LP A S F H F Y D PN L L A T D S S EV603
<i>Etyphina_subsp_Poae_Ps1</i>	606 L EAAT K FF E ES G FA K V Y EA Q --G Q TP S FO F F Q I D A E RV S R I GF D HN L TV A D L VE P DT L 663
<i>N_ditissima</i>	615 L AMV R QH L V D NG A E K YS A AG T Q D HT T LV E MD A PR M AA V D I GH L T V GD L GA H RS L R674
<i>P_gigantea</i>	604 L AST V SK H LL T GS V YGA E GA E GS Q L T TV V EL D PN Q LA I TS D FO Q DC A P E SL N 663
<i>Etyphina_subsp_Poae_Ps1</i>	664 E IT A DR K TV T LY H DP A QL T S R TF S AQ T EL L ET L R L GE A AW R D A TAR L ES L G I GE H W M 723
<i>N_ditissima</i>	675 E SV T L A VSD P FSS R LP R LS S S A DA F SG-----AL R LA E -CW R SV A VP R LQ N E A G D AH W M727
<i>P_gigantea</i>	664 E S I T I K S AP E FN L PS P DR F T Q GT L A A TS A L D GF C LA E -CW R RA T ED L ETS L GL Q GN W M722
<i>Etyphina_subsp_Poae_Ps1</i>	724 P I L ET L KE G GE E GS V EQ F I N L K N M NET K W I ST E SS A - I K D FK A R L DE H ET L SK T HE F E782
<i>N_ditissima</i>	728 P IL S TMER Q PE G --L Q VR F LN L NP G ES R VAT V TE L DV L ERN L H D EQ L R L GG V AT V E782
<i>P_gigantea</i>	723 P V L ES L ED L G--GG H Y Q I Q F V N L DD P NE K R I V S T D DER-- I Q F K Q Y I SD Q LD A L R K V Y D L Q 780
<i>Etyphina_subsp_Poae_Ps1</i>	783 S GS F MR--E E N L A H A E A I D G L N AM F I M RT L I E H F AG K K-----T E ES K T N AE L AD A L K I834
<i>N_ditissima</i>	786EG T V K L H EP K EV S CE P ID G LN A ME P LD G N A ME P LV Q M V FE L NP S K P P V DD S PP S ET K T L E K AL Q A845
<i>P_gigantea</i>	781G T F V E--K E N V PE G EG I D G L N AM E V V K T V I DM Y SG H A-----GG A NS N LA M AL K V831
<i>Etyphina_subsp_Poae_Ps1</i>	835 H SY L N L T Q MG Q TL G D V G K MV N LV K DM L ET G Q V AK S LT---T L VER L GN V SE G F V LL890
<i>N_ditissima</i>	846 H SY F N MA Q I TY S TT Q D V G K M I SL T REL I VA E Q A GA K TLS R FS T LGR V LS V GE A L V I905
<i>P_gigantea</i>	832 Q SY F N LA QM R T T LG D V S H V Y L QA S L I K N EQ V AF A EL S ---T I G K AF R AS D GL T LL887
<i>Etyphina_subsp_Poae_Ps1</i>	891GG A NV L DAY E LA H TND D AQ K AV F GT Q LA F DS V TF L AS A CT I G A L I G A T A V A VM G VS950
<i>N_ditissima</i>	906A G SV V LD I IEL A NS E DS A Q K AV L TT Q LV F D G V N LG V AT G CT V AS L MG A AT V G A ML G A G 965
<i>P_gigantea</i>	888 S AS S V V FD A Y E LS N AQ D DD V RA V FG T QL G FD S AS L L I GV A SL G AG L IG A ST A AA L GG A C947
<i>Etyphina_subsp_Poae_Ps1</i>	951 V IL G GL A V G Y G AL A SG F QA I AE K AK Y V G R Y FG D AD E AY K AG G F K Y D R D H G I L VP L FG A V I 1010
<i>N_ditissima</i>	966 V LL A CV G IG V CA L V Q AF G EV A HA K AE A V G K Y F A DA Q ES Y R A GG Y K Y DA E KK W LP L P G AV I 1025
<i>P_gigantea</i>	948A V V A GL A V G FM G L A D A FG Q VA E DA K T V G K Y F GD A E K AY L AG G Y K Y D S A NE A L I P L AY A V I 1007
<i>Etyphina_subsp_Poae_Ps1</i>	1011 S E I D--A A GN V K F DS Q R I Y R T W H G ST G SG R IN Y FF V WG D K P RM I Q D K S QA T IN V RE G IG A P--1068
<i>N_ditissima</i>	1026R Q LD L G A NT V T F DS Q Y L Y R ---AP D K G R I ---WP W N F PS V D H R K EL A I H VR E AL Y AP N 1077
<i>P_gigantea</i>	1008 S SV N L A T G T V S F DS Q Y I Y R TH S GS T GS G AL N Y F W A GD Y PT V V Y D L TV V Y D LS Q LA I NR A G I G A P--1066
<i>Etyphina_subsp_Poae_Ps1</i>	1069A S CK L ANT G --DY T TI--V L P A TP K S F I S Y E W Q I L P F CT G R H D Y G F D V IR R LE D E--R F D1123
<i>N_ditissima</i>	1078V E GT L PP E GER D L T AV I IL P SV L K S Y I AV D W N Q L P F SL H R H DR G FD L LR Q IE K D N D P N W L1137
<i>P_gigantea</i>	1067A T GT L PR G Y--NN S T I F V L P AT P K S Y I SY G W Q ML P G A TT A CD Y G F D V IR R LE D E K --R F D1122
<i>Etyphina_subsp_Poae_Ps1</i>	1124 Y DFY I FP S EY I I H Q I THE F V K TP I AV R LG N RS V R V Q V AE L DES L HN V LE Y T I H G AG A NY T 1183
<i>N_ditissima</i>	1138 Y NFY S W P AEY I V H K L H Q RY A TT P V D V Y LS Q RS V R L AMP P LL K AQ E NY L EY T L H G A Q A H V 1197
<i>P_gigantea</i>	1123 Y DFY I FP A ERT I NT L S H EY G T S VT I QL S R N A I R V Q V PE F SV M G K M N Y L Q G AG A Y T 1182
<i>Etyphina_subsp_Poae_Ps1</i>	1184 I GL N P V AI T LS G W S N T C W V L DC G KL D GEN I V I ----E A RA V ST I SG F R V N L AD T --L F 1236
<i>N_ditissima</i>	1198 V DL R RG S SL T IT T TH A DR W Y L D G RE L P S DS V T F GD A PT D GR E ML R IG S V T DS T R N K D 1257
<i>P_gigantea</i>	1183 V GL E T G AS I T L GS T NA S TS W IL D CT H LS F TT A SV-----DS N GV T VG G VR V NI A D H N--F1235
<i>Etyphina_subsp_Poae_Ps1</i>	1237 S S M L I Y K P N GE I LE V DF A N K TT F IK E D G D K Y Q --GS Q K L TD H ND L SD K H L LT A L I V1294
<i>N_ditissima</i>	1258 S LL V LA S N K AT L A I D L ES Q T I EP C E I PA D K W Y G ED D G Q TL E QH L HD L HS R N L HS S Y I 1317
<i>P_gigantea</i>	1236 A SM I IA T PT N DM L K N W F NT P HT S IV S ED A SN F SG---S A AL Q AQ L DK L ND S QL L DS A F V L1292
<i>Etyphina_subsp_Poae_Ps1</i>	1295 V D K Y T TP--A Q Q S V G RA F Y E PT S K R LL Y T I DA P EE L T N SA Q V G AL T A E G V Y F Y--N T E H 1350
<i>N_ditissima</i>	1318 V DD Y TA P Y D SN Q EV G RA F Y E VS R ER M LY S VG V PL D LT K EA Q LG G V F GD D -Y F Y F CA T KE H 1376
<i>P_gigantea</i>	1293 L K K Y T TP--S G EA V GD A Y E AS R RR F LY S T G L P QT L QQ G NG I V V AT D DD E Y F Y--N L GA1348

Chapter eight: Appendices

```

Etyphina_subsp_Poae_Ps1      1351 SA IWRVDVSTGVCEAKYHALCPFSKR TQRVWVDADNQIHAL--FRHQLSEN--HFGT LN 1406
N_ditissima                  1377 HALWRVDAPTGTLAQYCP LFNSPEVTLKR VV-QHSHVLYATYFYRYADDDKGDQTAELT 1435
P_gigantea                   1349 QA IWRVNP IDG SCTAKYRAYYP SAMR TLVQVWLEDDN-VFAT--YRHVLGFTGLYHSDLT 1405

Etyphina_subsp_Poae_Ps1      1407 Y I LTADSMN LVGMVGGPALLAK LHQEDKWTGEVRLLED-Y YTGPS ELLPKLKL FESLAG 1465
N_ditissima                  1436 CVVHADSMVLATITDQHLFEKLI SEKLI KGGDVESLLKET YQSTKSSSALNFITGQRV IK 1495
P_gigantea                   1406 Y I LCKDSM I LVS I IGDPP L LRQ I SFLDHVDYPLDQMIAD-YALQET SADVSAPTSGPTGG 1464

Etyphina_subsp_Poae_Ps1      1466 AD I DAA I DPH I I FVLGP KGDHYF-----YHQFWIRMS DRTVIKP-HPDIHLN YLLVGT 1518
N_ditissima                  1496 A I IQGA I ---LT VNNGNDNHDEAVNASNSQRF CWLR LQDGMV INP WDKWLSNDYGFVGS 1552
P_gigantea                   1465 SDVQAS I DAK LTA VLGK EDDGTA-----RCFWIRTDGTVITP-NFTPTPD IAYAGS 1515

Etyphina_subsp_Poae_Ps1      1519 I--ASTGDSGE-----LFCFFSYNQHKLVVQRNGTQAEKPRPVTISP ELGTISNFFSA 1570
N_ditissima                  1553 VP I AASEESGEQNAQDQELI FYNPKMH- I LRR LVDI HGDFTCKEVDIPPQFSGLDHV IQQ 1611
P_gigantea                   1516 TPTTSSGPEE-----FYFYS I KHQT I TFQAGSGTKAGPQT VNFPSDFGNLANLLS L 1567

Etyphina_subsp_Poae_Ps1      1571 NNNLFSITDAGF I LRLTTHCTLA LEAVNHQWLEHREK-DVDGGPWWTALSK LAKDHCAAI 1629
N_ditissima                  1612 ADRF I LTTKAGY I MQ LMPGGAPALVAVSRDWLS SQQDPSTSLSSWWDLTGLAKQHNA P 1671
P_gigantea                   1568 EGRMFAI SDSGVVLR LTTGGGVFFLEAVNQTIANLKN-SADHLPWWTKLQALADSHSA TI 1626

Etyphina_subsp_Poae_Ps1      1630 VS I VGL-----S---DAEGSP-VQAWLCSDFEV-VAGPSLRGKPRHMACL TEG--GSKA 1676
N_ditissima                  1672 LAYMGL-----CVGAPPAEKS-VPVWCHDDR I I- IASAE LHGRFLQLLGLSPD--GESA 1721
P_gigantea                   1627 VAVLGLTATSS SAPAD SASAPAPVWY I DGKFI I VVSPSLDNKR LDV LGLSKGPVGDVA 1686

Etyphina_subsp_Poae_Ps1      1677 WLWHMETEDSGHLYAQPTVRGKELET VFR LKAPFVNAE--AVPDGRGVLVKHPFKT VALT 1734
N_ditissima                  1722 L L CDYGVPGDCK I FQQL I PRGHVPKV LQNLY I NGT I ADGAVPKAQAKFTKLTLSAVASV 1781
P_gigantea                   1687 W I AYKDG DGSGLHYAQPLATGA-VTDLFSPTDPTVNLAT I SPAQ I L TSMQSVPFKDVKMT 1745

Etyphina_subsp_Poae_Ps1      1735 EGG LRYTTKEGVVLI LASE-RSARLYGV DKVWQO-NRSDLSGEIATLV-KT-WDHGESV V 1790
N_ditissima                  1782 GNRVECDVHEGCVGLRLRGNFSSATVVGVTRAWQKPVQASLESSLFWLQ-RRRGGLSPVLV 1840
P_gigantea                   1746 EDGLQYTALDGR I F I ITDT-QVTLLGV DKTWQAANAANLEATLVTLATQT EWNHGEVFI 1804

Etyphina_subsp_Poae_Ps1      1791 MLC----SEPPQWYLTSSGNIVSAAKATFTWLDAP--TWLGADP SGARGYAYV-----AG 1839
N_ditissima                  1841 VEADETQSSGPAWYNLETNRIYRFTADNKDAMIDPYHAWLG V HATDAT-IAYV---HSSG 1896
P_gigantea                   1805 LQGD--P SDPPAWYHIVLGKAVRPTNIPVTWADQP--VWLGVS I EAIMGWFFIPVKNTAS 1860

Etyphina_subsp_Poae_Ps1      1840 QGR I YELGEGSAEEKS SAASQEVAFASRFQDV I AVKPSPGASFQRF-ALENVHYTILSQF 1898
N_ditissima                  1897 NKVLVQV-----TSSGSRPLWRSPFITRLDNTLAF-S I PAQTNANLPV I AGADHCLVT-F 1949
P_gigantea                   1861 VGVTYTV-RVDVP GGS SAPVDGLSFTKRLDDI I I LVPSPGNSFSYLPGLWGVRTAV I LQC 1919

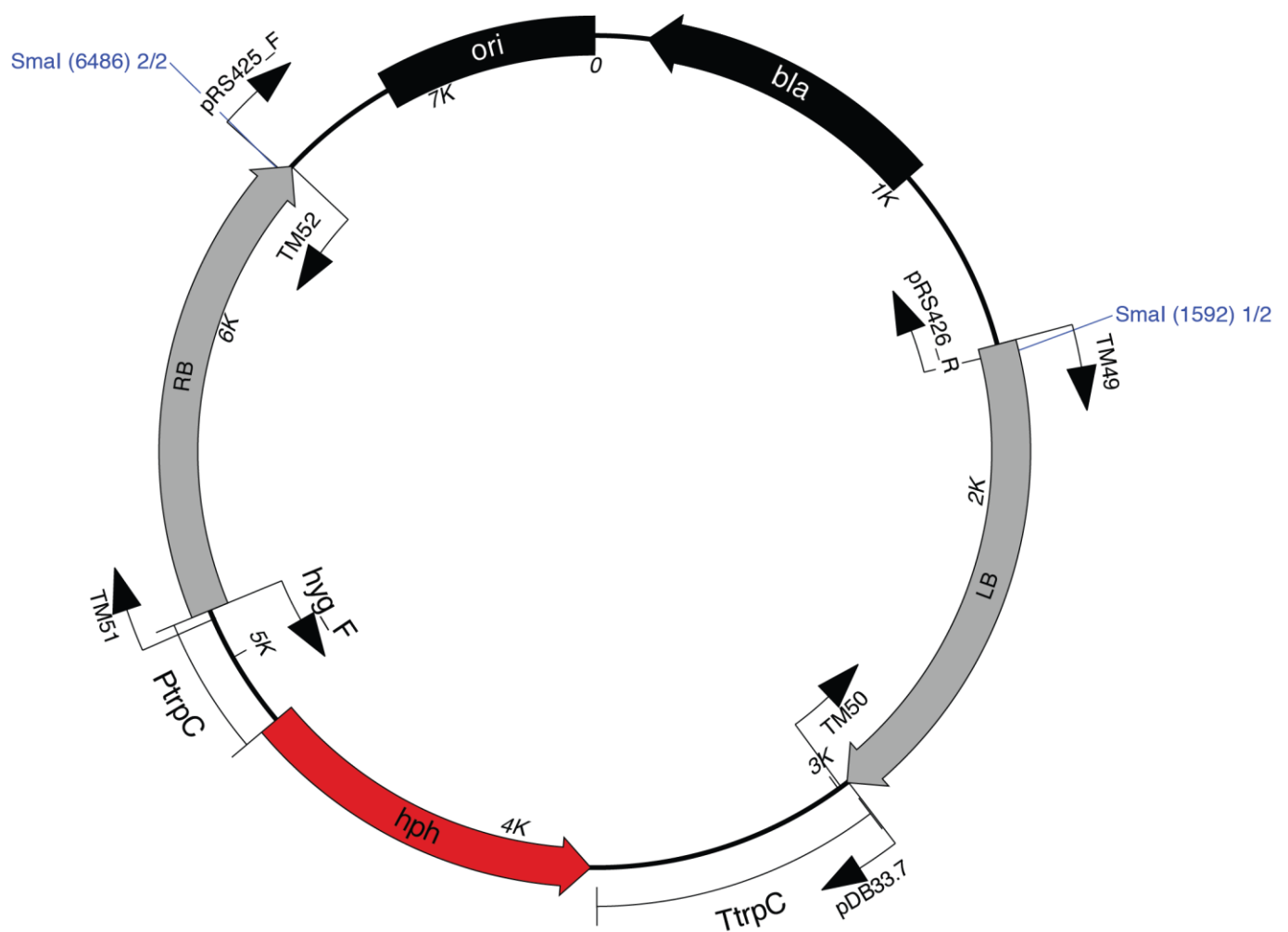
Etyphina_subsp_Poae_Ps1      1899 EGDTSFMDYSVP SASWESLSGLV I-EWKDQGRVEMEGSTMHPGPLGWY LAKRLGDDLI IM 1957
N_ditissima                  1950 DSTQGGGVLS I SKE SWEYKAITVANYEAM--EERNAI YLETDHLASFMAVE SNCA LMF I 2007
P_gigantea                   1920 AG--ALMGYRVP EASWDYYES I VVQDHNASVRTQPD SVYLDVTNP GVL LAKK I GEDLVVA 1977

Etyphina_subsp_Poae_Ps1      1958 EGS TGRFMK I SRAMVMDPTCM I HMTGKLLTVGNCSAGNQ-----1996
N_ditissima                  2008 DPR T SRS I ALDNACSLPQVAKDDDTSF I I SSSSGPSRGRAS TTDEWQ I WELRR I HEKRLQ 2067
P_gigantea                   1978 DTTNGHSLT L RKA F GADPAYANVAVNTRLGV DVTVQTMMAHQWLQKV TGSSTPADVT LQ 2037

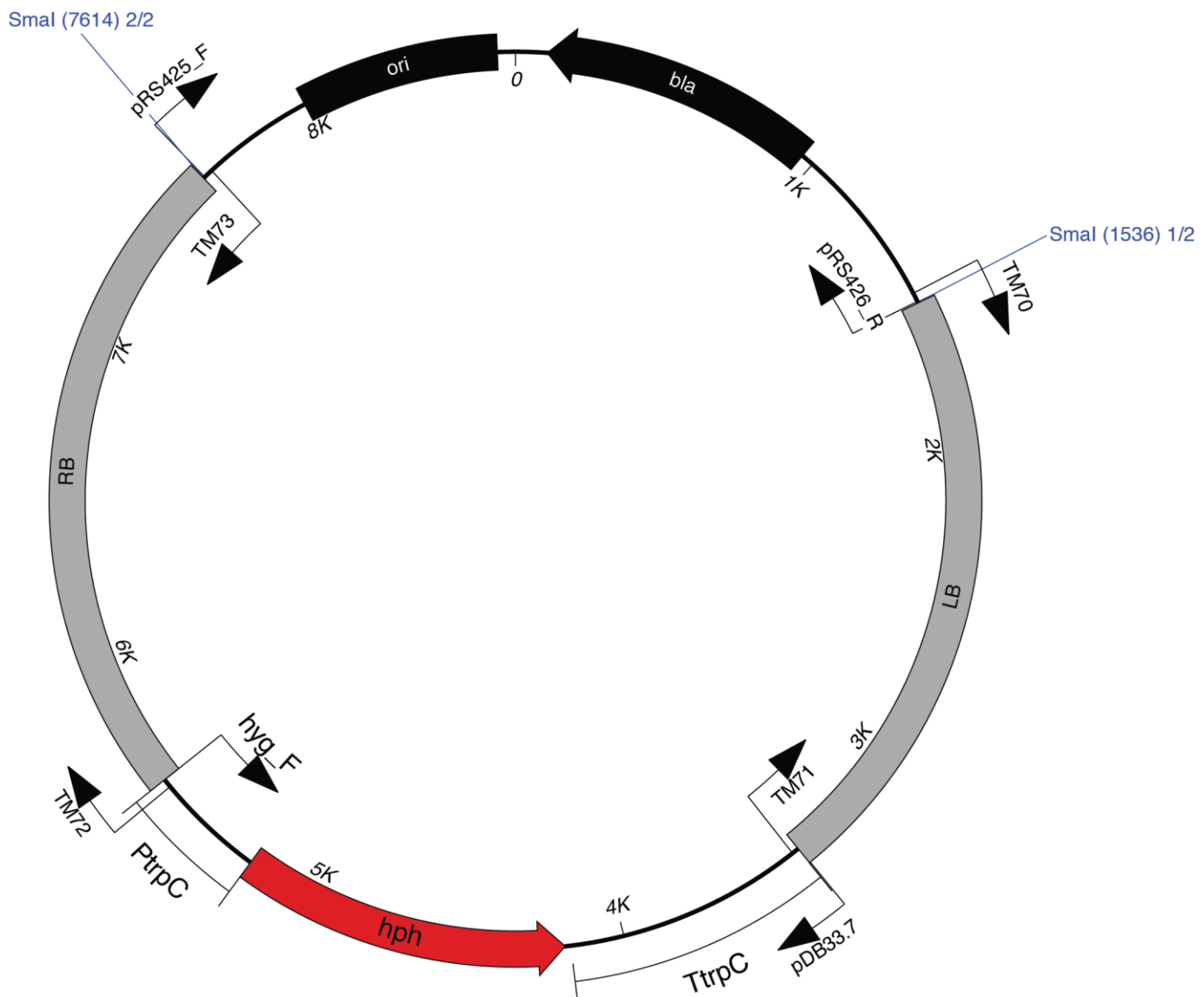
Etyphina_subsp_Poae_Ps1      -----
N_ditissima                  2068 LMETWLPQRVLMVLDQVPR S I F P                                     2090
P_gigantea                   2038 T I AYAVTQPSS-----                                         2048

```

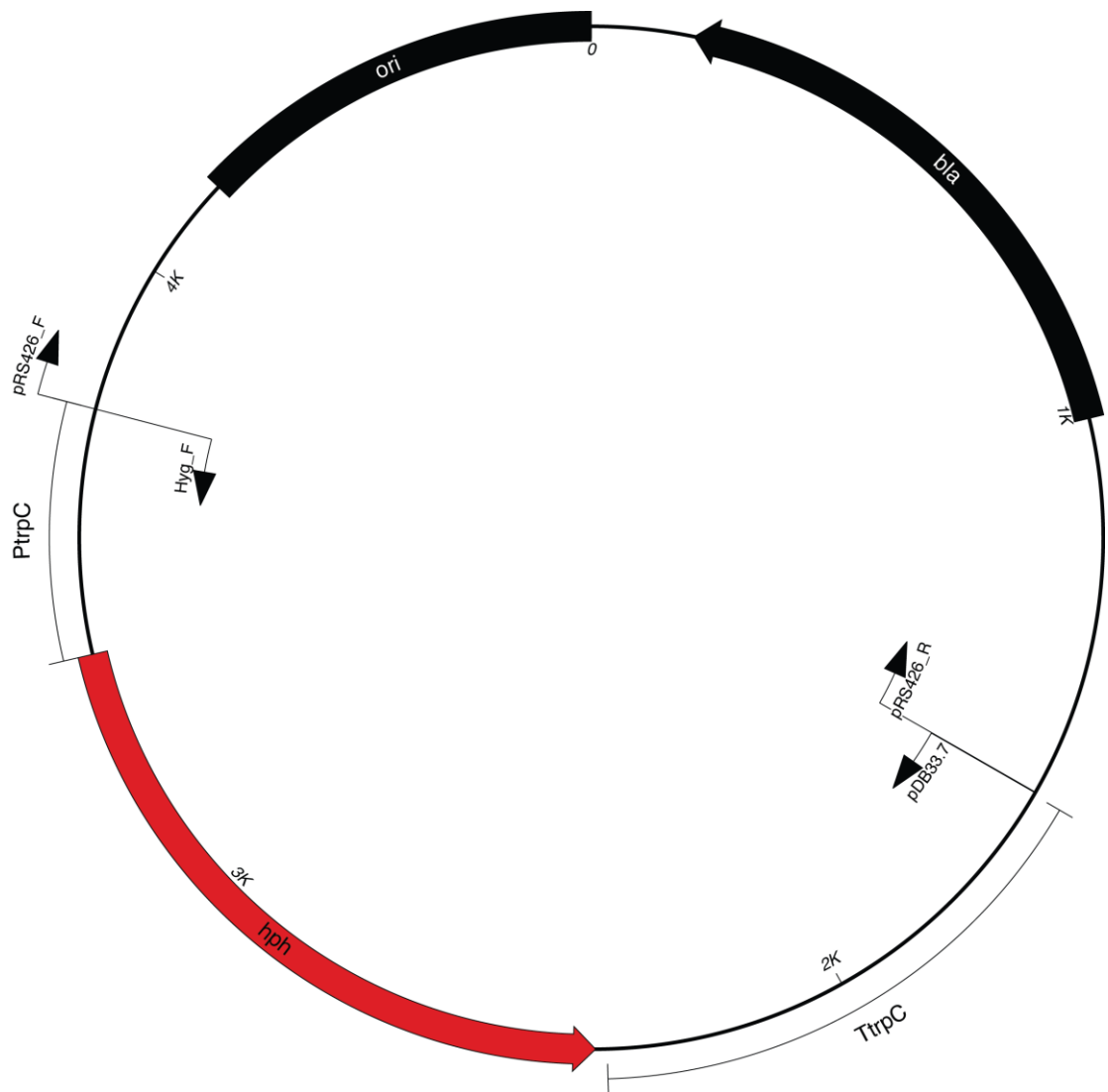
Appendix 22: Alignment of makes caterpillars floppy (Mcf) proteins from a range of fungal species across multiple species using the alignment function of Geneious.



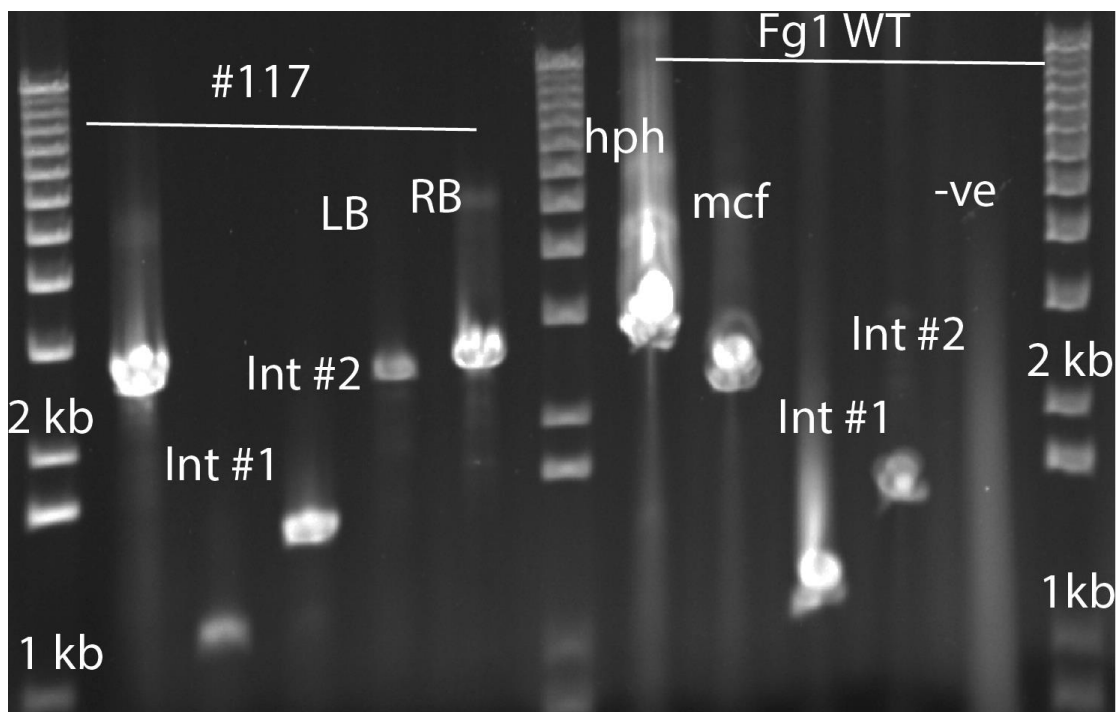
Appendix 23: Whole *Epichloë festucae* makes caterpillars floppy (*mcf*) gene deletion construct (pTM03, 7489 bp). Hph (hygromycin resistance gene). LB (left-border). RB (right-border). Ori (*E. coli* origin of replication point). Bla (ampicillin resistance gene). PptrC (promoter). TtrpC (terminator). Primers used to make plasmid are indicated by black arrows (all). SmaI cut sites used to excise knock-out insert.



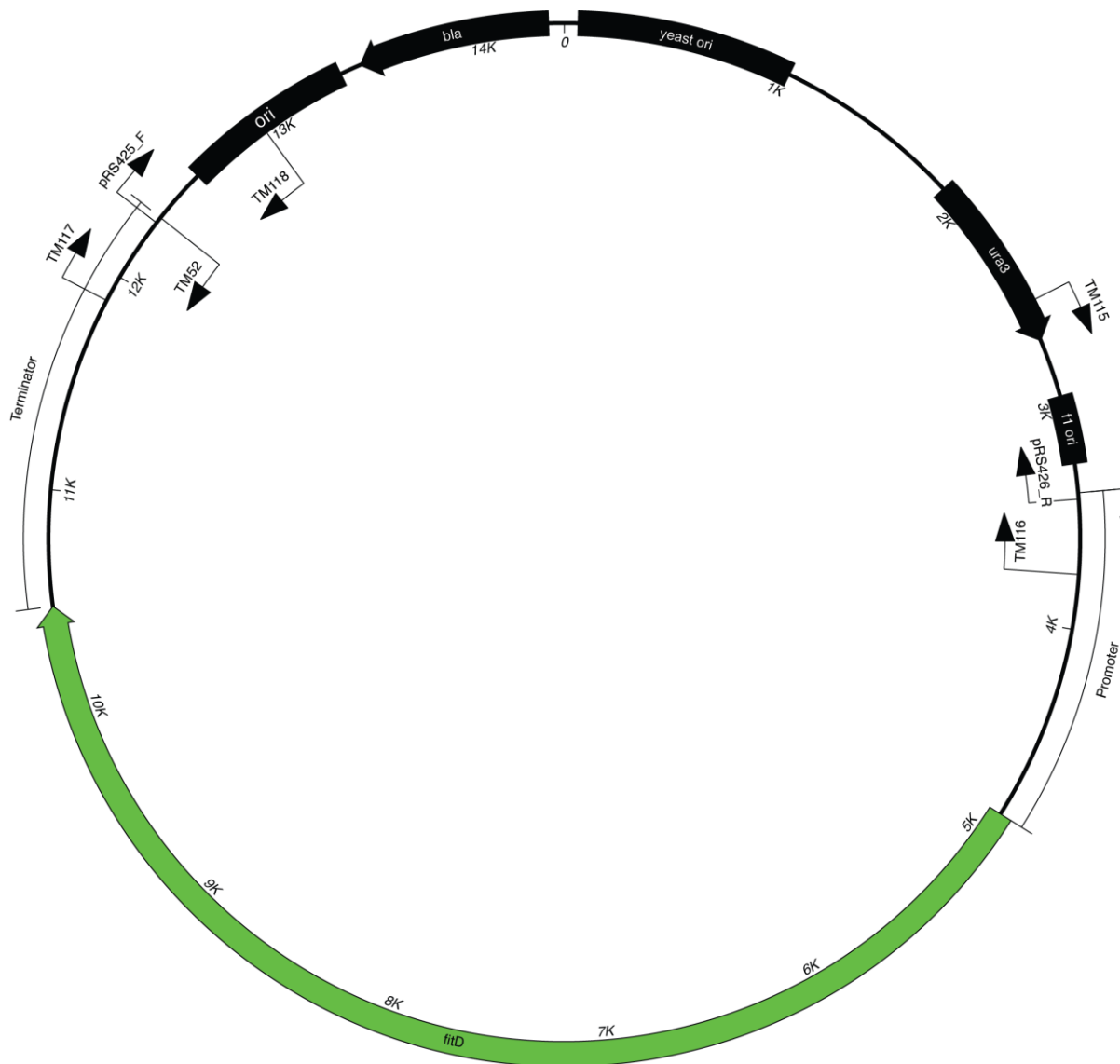
Appendix 24: 2 kb *Epichloë festucae* Fg1 5' of makes caterpillars floppy (*mcf*) gene deletion construct (pTM05, 8673 bp). Hph (hygromycin resistance gene). LB (left-border). RB (right-border). Ori (*E. coli* origin of replication point). Bla (ampicillin resistance gene). P_{trpC} (promoter). T_{trpC} (terminator). Primers used to make plasmid are indicated by black arrows (all). SmaI cut sites used to excise knock-out insert.



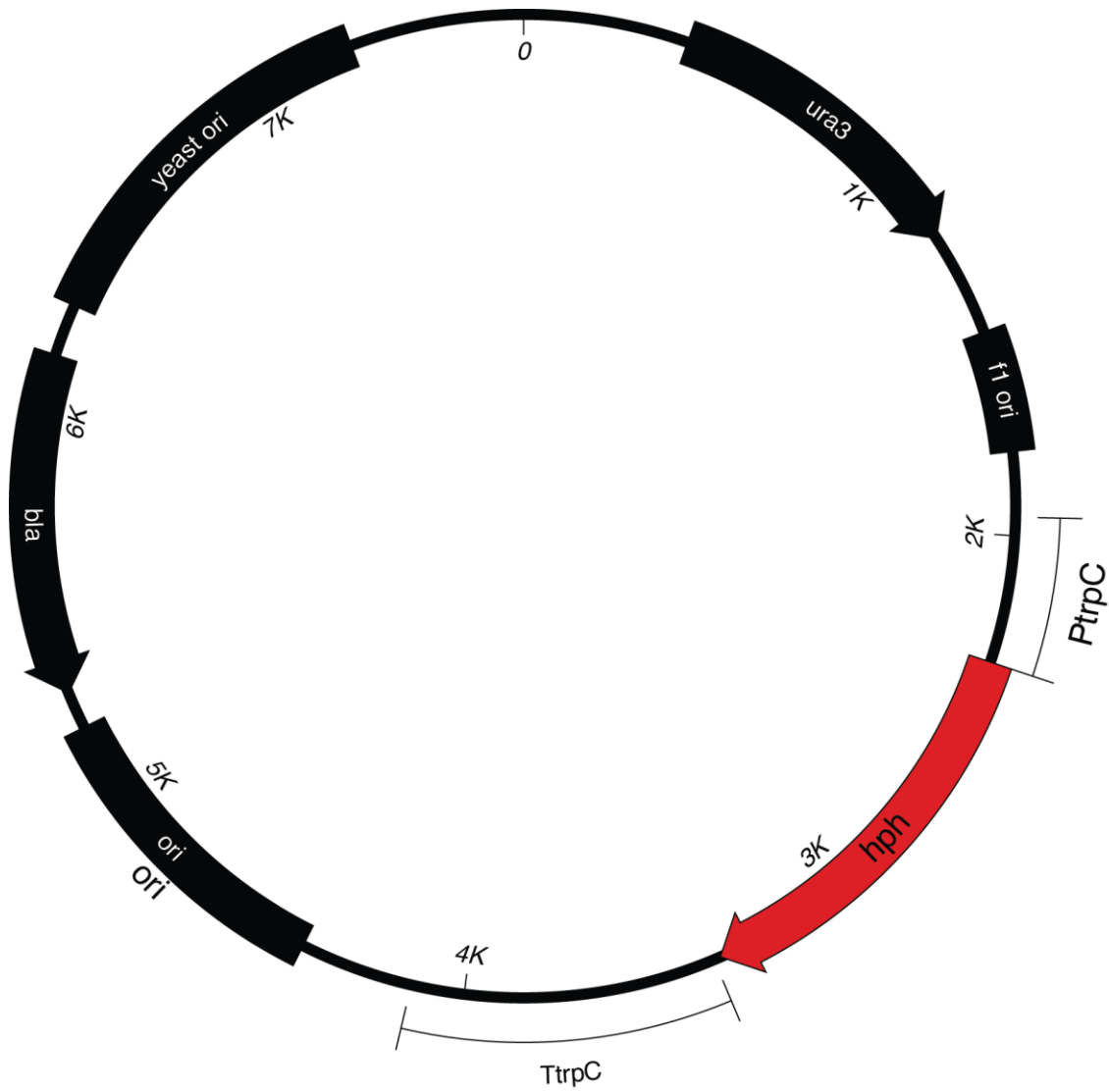
Appendix 25: Hygromycin resistant gene construct (pANS7-1, 4777 bp). Hph (hygromycin resistance gene). Ori (*E. coli* origin of replication point). Bla (ampicillin resistance gene). PtrpC (promoter). TtrpC (terminator). Primers used to amplify backbone (pANS425_F/pANS425_R) and resistant gene (Hyg_F/DB33.7) are indicated by back arrows.



Appendix 26: PCR confirmation of #117 transformant (Δmcf Fg1/pTM05). DNA from either Fg1 Δmcf mycelia or Fg1 wild type (WT) mycelia was subject to primers that amplify across the hygromycin gene (*hph*) (TM86/87), in the deleted region (int #1 and int #2) (TM111/112 and TM113/114), across the left border (LB) (TM89/109), and across the right border (RB) (TM90/110). -ve is water instead of primer



Appendix 27: *Epichloë festucae* var *lolii* AR48 makes caterpillars floppy (*mcf*) gene complementation construct (pTM04, 14377 bp). Hph (hygromycin resistance gene). LB (left-border). RB (right-border). Ori (origin of replication point). Bla (ampicillin resistance gene). PtrpC (promoter). TtrpC (terminator). Primers used to make plasmid are (TM49/TM52) and (pRS426_F/pRS426_R) indicated by black arrows. Primers used screen the transformants are (TM117/TM118) and (TM115/TM116) are indicated by black arrows



Appendix 28: Hygromycin construct (pDB48, 7702 bp). Hph (hygromycin resistance gene). Ori (*E.coli* origin of replication point). Bla (ampicillin resistance gene). PtrpC (promoter). TtrpC (terminator).

9.0 Reference

- Agpest, (2018) Greasy cutworm. Scientific name: *Agrotis ipsilon*. In.: AgResearch pp.
- Allan, D.J., (1984) Greasy cutworm, *Agrotis ipsilon* (Hufnagel), life cycle. In. New Zealand Department of Scientific and Industrial Research, pp.
- Ambrose, K.V., A.M. Koppenhöfer & F.C. Belanger, (2014) Horizontal gene transfer of a bacterial insect toxin gene into the *Epichloë* fungal symbionts of grasses. *Scientific Reports* **4**: 5562.
- Ball, O.-P., G. Barker, R. Prestidge & D. Lauren, (1997) Distribution and accumulation of the alkaloid peramine in *Neotyphodium lolii*-infected perennial ryegrass. *Journal of Chemical Ecology* **23**: 1419-1434.
- BAMONA, M.W.a., (2018) Butterflies and Moths of North America: collecting and sharing data about Lepidoptera. In., Butterflies and Moths of North America pp.
- Bastias, D.A., M.A. Martínez-Ghersa, C.L. Ballaré & P.E. Gundel, (2017) *Epichloë* fungal endophytes and plant defenses: not just alkaloids. *Trends in plant science*.
- Bayram, Ö., S. Krappmann, M. Ni, J.W. Bok, K. Helmstaedt, O. Valerius, S. Braus-Stromeier, N.-J. Kwon, N.P. Keller & J.-H. Yu, (2008) VelB/VeA/LaeA complex coordinates light signal with fungal development and secondary metabolism. *Science* **320**: 1504-1506.
- Becker, Y., C.J. Eaton, E. Brasell, K.J. May, M. Becker, B. Hassing, G.M. Cartwright, L. Reinhold & B. Scott, (2015) The fungal cell-wall integrity MAPK cascade is crucial for hyphal network formation and maintenance of restrictive growth of *Epichloe festucae* in symbiosis with *Lolium perenne*. *Molecular Plant-Microbe Interactions* **28**: 69-85.
- Berry, D., (2011) Molecular and bioinformatic analysis of the perA locus in *Epichloë*: this thesis is presented as a partial fulfilment of the requirements for the degree of Master of Science (M. Sc.) in Genetics at Massey University, Palmerston North, New Zealand. In.: Massey University, pp.
- Berry, D., J.E. Takach, C.L. Schardl, N.D. Charlton, B. Scott & C.A. Young, (2015) Disparate independent genetic events disrupt the secondary metabolism gene perA in certain symbiotic *Epichloë* species. *Applied and environmental microbiology* **81**: 2797-2807.
- Blancard, D., (2012) Tomato diseases: identification, biology and control: A Colour Handbook. CRC Press.
- Blankenship, J.D., M.J. Spiering, H.H. Wilkinson, F.F. Fannin, L.P. Bush & C.L. Schardl, (2001) Production of loline alkaloids by the grass endophyte, *Neotyphodium uncinatum*, in defined media. *Phytochemistry* **58**: 395-401.

- Bloomquist, J.R., (1996) Ion channels as targets for insecticides. *Annual review of entomology* **41**: 163-190.
- Blythe, L., A. Craig, C. Estill & C. Cebra, (2007) Clinical manifestations of tall fescue (*Festuca arundinacea*) and perennial ryegrass (*Lolium perenne*) toxicosis in Oregon and Japan. In: 6th International Symposium on Fungal Endophytes of Grasses. New Zealand Grassland Association. pp. 369-372.
- Boquet, P., (2001) The cytotoxic necrotizing factor 1 (CNF1) from *Escherichia coli*. *Toxicon* **39**: 1673-1680.
- Bouton, J., (2009) Deployment of novel endophytes in the tall fescue commercial seed trade. *Tall Fescue for the Twenty-first Century*: 367-375.
- Brakhage, A.A., (2013) Regulation of fungal secondary metabolism. *Nature Reviews Microbiology* **11**: 21.
- Byrd, A.D., C.L. Schardl, P.J. Songlin, K.L. Mogen & M.R. Siegel, (1990) The β -tubulin gene of *Epichloë typhina* from perennial ryegrass (*Lolium perenne*). *Current genetics* **18**: 347-354.
- CABI, (2018) Invasive Species Compendium: *Agrotis ipsilon* (black cutworm). In. Wallingford UK: Fallopia japonica, pp.
- Capinera, J.L., (2015) common name: black cutworm, scientific name: *Agrotis ipsilon* (Hufnagel) (Insecta: Lepidoptera: Noctuidae). In. University of Florida, pp.
- Casabuono, A.C. & A.B. Pomilio, (1997) Alkaloids from endophyte-infected *Festuca argentina*. *Journal of ethnopharmacology* **57**: 1-9.
- Cepeda-García, C., R. Domínguez-Santos, R.O. García-Rico, C. García-Estrada, A. Cajiao, F. Fierro & J.F. Martín, (2014) Direct involvement of the CreA transcription factor in penicillin biosynthesis and expression of the pcbAB gene in *Penicillium chrysogenum*. *Applied microbiology and biotechnology* **98**: 7113-7124.
- Charlton, N.D., J.-Y. Shoji, S.R. Ghimire, J. Nakashima & K.D. Craven, (2012) Deletion of the fungal gene soft disrupts mutualistic symbiosis between the grass endophyte *Epichloë festucae* and the host plant. *Eukaryotic cell* **11**: 1463-1471.
- Christensen, M., O.-P. Ball, R. Bennett & C. Schardl, (1997) Fungal and host genotype effects on compatibility and vascular colonization by *Epichloë festucae*. *Mycological research* **101**: 493-501.
- Christensen, M., A. Leuchtmann, D. Rowan & B. Tapper, (1993) Taxonomy of Acremonium endophytes of tall fescue (*Festuca arundinacea*), meadow

- fescue (*F. pratensis*) and perennial ryegrass (*Lolium perenne*). *Mycological research* **97**: 1083-1092.
- Christensen, M.J., R.J. Bennett, H.A. Ansari, H. Koga, R.D. Johnson, G.T. Bryan, W.R. Simpson, J.P. Koolaard, E.M. Nickless & C.R. Voisey, (2008) *Epichloë* endophytes grow by intercalary hyphal extension in elongating grass leaves. *Fungal Genetics and Biology* **45**: 84-93.
- Chujo, T. & B. Scott, (2014) Histone H 3 K 9 and H 3 K 27 methylation regulates fungal alkaloid biosynthesis in a fungal endophyte–plant symbiosis. *Molecular microbiology* **92**: 413-434.
- Chung, K.-R. & C. Schardl, (1997) Sexual cycle and horizontal transmission of the grass symbiont, *Epichloë typhina*. *Mycological Research* **101**: 295-301.
- Clay, K., (1990) Fungal endophytes of grasses. *Annual Review of Ecology and Systematics*: 275-297.
- Clay, K. & C. Schardl, (2002) Evolutionary origins and ecological consequences of endophyte symbiosis with grasses. *The American Naturalist* **160**: S99-S127.
- CSIRO, (2018) NOCTUIDAE: Noctuids, Cutworms, Armyworms or Semi-Loopers. In., Commonwealth Scientific and Industrial Research Organisation pp.
- Daborn, P., N. Waterfield, C. Silva, C. Au & S. Sharma, (2002) A single *Photorhabdus* gene, makes caterpillars floppy (mcf), allows *Escherichia coli* to persist within and kill insects. *Proceedings of the National Academy of Sciences* **99**: 10742-10747.
- Demain, A.L. & A. Fang, (2000) The natural functions of secondary metabolites. In: History of modern biotechnology I. Springer, pp. 1-39.
- Dong, K., (2007) Insect sodium channels and insecticide resistance. *Invertebrate Neuroscience* **7**: 17.
- Dowling, A. & N.R. Waterfield, (2007) Insecticidal toxins from *Photorhabdus* bacteria and their potential use in agriculture. *Toxicon* **49**: 436-451.
- Dowling, A.J., P. Daborn, N. Waterfield, P. Wang, C. Streuli & R. Ffrench-Constant, (2004) The insecticidal toxin Makes caterpillars floppy (Mcf) promotes apoptosis in mammalian cells. *Cellular microbiology* **6**: 345-353.
- Dowling, A.J., N.R. Waterfield, M.C. Hares, G. Le Goff, C.H. Streuli & R.H. Ffrench-Constant, (2007) The Mcf1 toxin induces apoptosis via the mitochondrial pathway and apoptosis is attenuated by mutation of the BH3-like domain. *Cellular microbiology* **9**: 2470-2484.
- Downs, J.R., M. Clearfield, S. Weis, E. Whitney, D.R. Shapiro, P.A. Beere, A. Langendorfer, E.A. Stein, W. Kruyer & A.M. Gotto Jr, (1998) Primary prevention of acute coronary events with lovastatin in men and women

- with average cholesterol levels: results of AFCAPS/TexCAPS. *Jama* **279**: 1615-1622.
- Dupont, P.-Y. & M.P. Cox, (2017) Genomic data quality impacts automated detection of lateral gene transfer in fungi. *G3: Genes, Genomes, Genetics* **7**: 1301-1314.
- Eaton, C.J., M.P. Cox, B. Ambrose, M. Becker, U. Hesse, C.L. Schardl & B. Scott, (2010) Disruption of signaling in a fungal-grass symbiosis leads to pathogenesis. *Plant Physiology* **153**: 1780-1794.
- Eaton, C.J., P.-Y. Dupont, P. Solomon, W. Clayton, B. Scott & M.P. Cox, (2015) A core gene set describes the molecular basis of mutualism and antagonism in *Epichloë* spp. *Molecular Plant-Microbe Interactions* **28**: 218-231.
- Eaton, C.J., I. Jourdain, S.J. Foster, J.S. Hyams & B. Scott, (2008) Functional analysis of a fungal endophyte stress-activated MAP kinase. *Current genetics* **53**: 163-174.
- Faeth, S.H., L.P. Bush & T. Sullivan, (2002) Peramine alkaloid variation in *Neotyphodium*-infected Arizona fescue: effects of endophyte and host genotype and environment. *Journal of chemical ecology* **28**: 1511-1526.
- Ferguson, C.M., B.I.P. Barratt, N. Bellc, S.L. Goldson, S. Hardwick, M. Jackson, T.A. Jackson, C.B. Phillips, A.J. Popay, G. Rennie, S. Sinclair, R. Townsend & M. Wilson, (2018) Quantifying the economic cost of invertebrate pests to New Zealand's pastoral industry. In: New Zealand Journal of Agricultural Research MPI, pp.
- Finch, S., A. Wilkins, A. Popay, J. Babu, B. Tapper & G. Lane, (2010) The isolation and bioactivity of *epoxy-janthitrems* from AR37 endophyte-infected perennial ryegrass. Poster 80. In: Proceedings of the 7th international symposium of fungal endophytes of grasses'. (Ed. C Schardl) Available at <http://www.ars.usda.gov/research/publications/Publications.htm>.
- Fleetwood, D.J., A.K. Khan, R.D. Johnson, C.A. Young, S. Mittal, R.E. Wrenn, U. Hesse, S.J. Foster, C.L. Schardl & B. Scott, (2011) Abundant degenerate miniature inverted-repeat transposable elements in genomes of epichloid fungal endophytes of grasses. *Genome biology and evolution* **3**: 1253-1264.
- Fleetwood, D.J., B. Scott, G.A. Lane, A. Tanaka & R.D. Johnson, (2007) A complex ergovaline gene cluster in *Epichloë* endophytes of grasses. *Applied and Environmental Microbiology* **73**: 2571-2579.
- Fleming, A., (1943) Streptococcal Meningitis treated With Penicillin. Measurement of Bacteriostatic Power of Blood and Cerebrospinal Fluid. *Lancet*: 434-438.
- Fletcher, L., C. Young, G. Aiken, R. McCulley, J. Strickland & C. Schardl, (2012) Novel endophytes in New Zealand grazing systems: The perfect solution or a

- compromise? In: *Epichloae*, endophytes of cool season grasses: implications, utilization and biology. Proceedings of the 7th International Symposium on Fungal Endophytes of Grasses, Lexington, Kentucky, USA, 28 June to 1 July 2010.: Samuel Roberts Noble Foundation, pp. 5-13.
- Forester, N.T., (2014) Role of Iron, Siderophores and Iron Regulation in the *Epichloë Festucae-Lolium Perenne* Symbiosis: A Thesis Submitted for the Degree of Doctor of Philosophy at the University of Otago, Dunedin, New Zealand. In.: University of Otago, pp.
- Forst, S., B. Dowds, N. Boemare & E. Stackebrandt, (1997) *Xenorhabdus* and *Photorhabdus* spp.: bugs that kill bugs. *Annual Reviews in Microbiology* **51**: 47-72.
- Freed, B.M., T.G. Rosano & N. Lempert, (1987) In vitro immunosuppressive properties of cyclosporine metabolites. *Transplantation* **43**: 123-127.
- Gallagher, R., E. White & P. Mortimer, (1981) Ryegrass staggers: isolation of potent neurotoxins lolitrem A and lolitrem B from staggers-producing pastures. *New Zealand veterinary journal* **29**: 189-190.
- Gallagher, R.T., A.D. Hawkes, P.S. Steyn & R. Vleggaar, (1984) Tremorgenic neurotoxins from perennial ryegrass causing ryegrass staggers disorder of livestock: structure elucidation of lolitrem B. *Journal of the Chemical Society, chemical communications*: 614-616.
- Georgia, U.o., (2018) Leafminers (Order: Diptera, Family: Agromyzidae) Vegetable leafminer (*Liriomyza sativae* (Blanchard)) *Liriomyza trifolii* (*Liriomyza trifolii* (Burgess)). In. University of Georgia, pp.
- Gerhards, N., L. Neubauer, P. Tudzynski & S.-M. Li, (2014) Biosynthetic pathways of ergot alkaloids. *Toxins* **6**: 3281-3295.
- Giordana, B., P. Parenti, G.M. Hanozet & V.F. Sacchi, (1985) Electrogenic K⁺-basic amino-acid cotransport in the midgut of lepidopteran larvae. *The Journal of Membrane Biology* **88**: 45-53.
- Harris, C., J. Mazurek & G. White, (1962) The life history of the black cutworm, *Agrotis ipsilon* (Hufnagel), under controlled conditions. *The Canadian Entomologist* **94**: 1183-1187.
- Harrison, R.A., (1976) The Arthropoda of the southern islands of New Zealand (9) Diptera. *Journal of the Royal Society of New Zealand* **6**: 107-152.
- Hennessy, L.M., A.J. Popay, S.C. Finch, M.J. Clearwater & V.M. Cave, (2016) Temperature and plant genotype alter alkaloid concentrations in ryegrass infected with an *Epichloë* endophyte and this affects an insect herbivore. *Frontiers in plant science* **7**: 1097.

Chapter nine: Reference

- Hondo, T., A. Koike & T. Sugimoto, (2006) Comparison of thermal tolerance of seven native species of parasitoids (Hymenoptera: Eulophidae) as biological control agents against *Liriomyza trifolii* (Diptera: Agromyzidae) in Japan. *Applied entomology and zoology* **41**: 73-82.
- Huang, L.-H., C.-Z. Wang & L. Kang, (2009) Cloning and expression of five heat shock protein genes in relation to cold hardening and development in the leafminer, *Liriomyza sativa*. *Journal of insect physiology* **55**: 279-285.
- Imlach, W.L., S.C. Finch, Y. Zhang, J. Dunlop & J.E. Dalziel, (2011) Mechanism of action of lolitrem B, a fungal endophyte derived toxin that inhibits BK large conductance Ca²⁺-activated K⁺ channels. *Toxicon* **57**: 686-694.
- Jackson, G., (2013) Pacific Pests and Pathogens - Fact Sheets - Black cutworm. In.: Pestnet, pp.
- Jank, T. & K. Aktories, (2008) Structure and mode of action of clostridial glucosylating toxins: the ABCD model. *Trends in microbiology* **16**: 222-229.
- Jensen, J. & A. Popay, (2004) Perennial ryegrass infected with AR37 endophyte reduces survival of porina larvae. *New Zealand Plant Protection* **57**: 323.
- Johnson, L., (2008) Iron and siderophores in fungal–host interactions. *Mycological research* **112**: 170-183.
- Johnson, L., M. Steringa, A. Koulman, M. Christensen, R. Johnson, C. Voisey, G. Bryan, I. Lamont & S. Rasmussen, (2007) Biosynthesis of an extracellular siderophore is essential for maintenance of mutualistic endophyte-grass symbioses. In: Proceedings of the sixth international symposium on fungal endophytes of grasses grassland research and practice series. pp. 177-179.
- Johnson, L.J., A.C. de Bonth, L.R. Briggs, J.R. Caradus, S.C. Finch, D.J. Fleetwood, L.R. Fletcher, D.E. Hume, R.D. Johnson & A.J. Popay, (2013a) The exploitation of *epichloae* endophytes for agricultural benefit. *Fungal Diversity* **60**: 171-188.
- Johnson, L.J., A. Koulman, M. Christensen, G.A. Lane, K. Fraser, N. Forester, R.D. Johnson, G.T. Bryan & S. Rasmussen, (2013b) An extracellular siderophore is required to maintain the mutualistic interaction of *Epichloë festucae* with *Lolium perenne*. *PLoS pathogens* **9**: e1003332.
- Jovicich, E., (2009) Leafminer pest-generic incursion management plan for the Australian vegetable industry.
- Kalish, R. & K. Johnson, (1990) Enrichment and function of urushiol (poison ivy)-specific T lymphocytes in lesions of allergic contact dermatitis to urushiol. *The Journal of Immunology* **145**: 3706-3713.
- Keller, N.P., G. Turner & J.W. Bennett, (2005) Fungal secondary metabolism—from biochemistry to genomics. *Nature Reviews Microbiology* **3**: 937-947.

- Khattab, M. & A. Azazy, (2013) Efficacy of Entomopathogenic Nematodes as Bait Formulations for Controlling the Black Cutworm *Agrotis ipsilon* (Hufnagel)(Lepidoptera: Noctuidae). *Egyptian Journal of Biological Pest Control* **23**: 255.
- Knaus, H.-G., O.B. McManus, S.H. Lee, W.A. Schmalhofer, M. Garcia-Calvo, L.M. Helms, M. Sanchez, K. Giangiacomo & J.P. Reuben, (1994) Tremorgenic indole alkaloids potently inhibit smooth muscle high-conductance calcium-activated potassium channels. *Biochemistry* **33**: 5819-5828.
- Kohlmeyer, J. & E. Kohlmeyer, (1974) Distribution of *Epichloë typhina* (Ascomycetes) and its parasitic fly. *Mycologia*: 77-86.
- Landcare, (2018) Notes on families and subfamilies of larger moths included in this guide. In., Landcare pp.
- Lane, G.A., M.J. Christensen & C.O. Miles, (2000) Coevolution of fungal endophytes with grasses: the significance of secondary metabolites. *Microbial endophytes* **2000**: 341-388.
- Leuchtmann, A., D. Schmidt & L. Bush, (2000) Different levels of protective alkaloids in grasses with stroma-forming and seed-transmitted *Epichloë/Neotyphodium* endophytes. *Journal of Chemical Ecology* **26**: 1025-1036.
- Litzka, O., P. Papagiannopolous, M.A. Davis, M.J. Hynes & A.A. Brakhage, (1998) The penicillin regulator PENR1 of *Aspergillus nidulans* is a HAP-like transcriptional complex. *The FEBS Journal* **251**: 758-767.
- Liu, R., L. Chen, Y. Jiang, Z. Zhou & G. Zou, (2015) Efficient genome editing in filamentous fungus *Trichoderma reesei* using the CRISPR/Cas9 system. *Cell Discovery* **1**: 15007.
- Lukito, Y., (2017) Epigenetic regulation of *Epichloë festucae* secondary metabolite biosynthesis and symbiotic interaction with *Lolium perenne*: a thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Genetics at Massey University, Palmerston North, New Zealand. In.: Massey University, pp.
- Luo, Z., H. Ren, J.J. Mousa, D.E. Rangel, Y. Zhang, S.D. Bruner & N.O. Keyhani, (2017) The PacC transcription factor regulates secondary metabolite production and stress response, but has only minor effects on virulence in the insect pathogenic fungus *Beauveria bassiana*. *Environmental microbiology* **19**: 788-802.
- Mantle, P.G. & C.M. Weedon, (1994) Biosynthesis and transformation of tremorgenic indolediterpenoids by *Penicillium paxilli* and *Acremonium lolii*. *Phytochemistry* **36**: 1209-1217.

Chapter nine: Reference

- McMillan, L., R. Carr, C. Young, J. Astin, R. Lowe, E. Parker, G. Jameson, S. Finch, C. Miles & O. McManus, (2003) Molecular analysis of two cytochrome P450 monooxygenase genes required for paxilline biosynthesis in *Penicillium paxilli*, and effects of paxilline intermediates on mammalian maxi-K ion channels. *Molecular genetics and genomics* **270**: 9-23.
- Mihlan, M., V. Homann, T.W.D. Liu & B. Tudzynski, (2003) AREA directly mediates nitrogen regulation of gibberellin biosynthesis in *Gibberella fujikuroi*, but its activity is not affected by NMR. *Molecular microbiology* **47**: 975-991.
- Miles, C.O., A.L. Wilkins, R.T. Gallagher, A.D. Hawkes, S.C. Munday & N.R. Towers, (1992) Synthesis and tremorgenicity of paxitriols and lolitriol: possible biosynthetic precursors of lolitrem B. *Journal of agricultural and food chemistry* **40**: 234-238.
- Milne, G., (2007) Technology transfer of novel ryegrass endophytes in New Zealand. In: 6th international symposium on fungal endophytes of grasses, Christchurch, New Zealand. New Zealand Grassland Association, Dunedin. pp. 237-239.
- Mishra, H. & C. Das, (2003) A review on biological control and metabolism of aflatoxin.
- Motoyama, T., T. Hayashi, H. Hirota, M. Ueki & H. Osada, (2012) Terpendole E, a kinesin Eg5 inhibitor, is a key biosynthetic intermediate of indole-diterpenes in the producing fungus *Chaunopycnis alba*. *Chemistry & biology* **19**: 1611-1619.
- Munday-Finch, S.C., A.L. Wilkins & C.O. Miles, (1996) Isolation of paspaline B, an indole-diterpenoid from *Penicilium paxilli*. *Phytochemistry* **41**: 327-332.
- Nasmith, C.G., S. Walkowiak, L. Wang, W.W. Leung, Y. Gong, A. Johnston, L.J. Harris, D.S. Guttman & R. Subramaniam, (2011) Tri6 is a global transcription regulator in the phytopathogen *Fusarium graminearum*. *PLoS pathogens* **7**: e1002266.
- Olcott, M.H., M.D. Henkels, K.L. Rosen, F.L. Walker, B. Sneh, J.E. Loper & B.J. Taylor, (2010) Lethality and developmental delay in *Drosophila melanogaster* larvae after ingestion of selected *Pseudomonas fluorescens* strains. *PloS one* **5**: e12504.
- Panaccione, D.G., (2005) Origins and significance of ergot alkaloid diversity in fungi. *FEMS Microbiology Letters* **251**: 9-17.
- Parker, E.J. & D.B. Scott, (2004) Indole-diterpene biosynthesis in ascomycetous fungi. Marcel Dekker: New York, NY, USA.
- Péchy-Tarr, M., D.J. Bruck, M. Maurhofer, E. Fischer, C. Vogne, M.D. Henkels, K.M. Donahue, J. Grunder, J.E. Loper & C. Keel, (2008) Molecular analysis of a

- novel gene cluster encoding an insect toxin in plant-associated strains of *Pseudomonas fluorescens*. *Environmental microbiology* **10**: 2368-2386.
- Pennell, C. & P. Rolston, (2011) AVANEX™ endophyte-infected grasses for the aviation industry now a reality.
- Philpson, M.N. & M.C. Christey, (1986) The relationship of host and endophyte during flowering, seed formation, and germination of *Lolium perenne*. *New Zealand Journal of Botany* **24**: 125-134.
- Popay, A. & P. Gerard, (2007) Cultivar and endophyte effects on a root aphid, *Aploneura lentisci*, in perennial ryegrass. *New Zealand Plant Protection* **60**: 223.
- Popay, A., B. Tapper & C. Podmore, (2009) Endophyte-infected meadow fescue and loline alkaloids affect Argentine stem weevil larvae. *NZ Plant Prot* **62**: 19-27.
- Popay, A.J., D.E. Hume, J.G. Baltus, G.C.M. Latch, B.A. Tapper, T.B. Lyons, B.M. Cooper, P. C.G. J.P.J. Eerens & S.L. Marshall, (1999) Field performance of perennial ryegrass (*Lolium perenne*) infected with toxin-free fungal endophytes (*Neotyphodium spp.*). **7**: 113-122.
- Potter, D.A., J. Tyler Stokes, C.T. Redmond, C.L. Schardl & D.G. Panaccione, (2008) Contribution of ergot alkaloids to suppression of a grass-feeding caterpillar assessed with gene knockout endophytes in perennial ryegrass. *Entomologia Experimentalis et Applicata* **126**: 138-147.
- Qa'Dan, M., L.M. Spyres & J.D. Ballard, (2000) pH-induced conformational changes in *Clostridium difficile* Toxin B. *Infection and immunity* **68**: 2470-2474.
- Qi, M. & E.A. Elion, (2005) MAP kinase pathways. *Journal of cell science* **118**: 3569-3572.
- Rahnama, M., (2016) Analysis of the role of velvet and laeA in the molecular interactions between grass and *Epichloë* fungal symbionts. In.: ResearchSpace Auckland, pp.
- Rahnama, M., R. Johnson, C.R. Voisey, W. Simpson & D.J. Fleetwood, (2018) The Global Regulatory Protein VelA Is Required for Symbiosis Between the Endophytic Fungus *Epichloë festucae* and *Lolium perenne*. *Molecular Plant-Microbe Interactions* **31**: 591-604.
- Ran, F.A., P.D. Hsu, J. Wright, V. Agarwala, D.A. Scott & F. Zhang, (2013) Genome engineering using the CRISPR-Cas9 system. *Nature protocols* **8**: 2281.
- Reineke, J., S. Tenzer, M. Rupnik, A. Koschinski, O. Hasselmayer, A. Schrattenholz, H. Schild & C. von Eichel-Streiber, (2007) Autocatalytic cleavage of *Clostridium difficile* toxin B. *Nature* **446**: 415.

- Richmond, D.S. & D.J. Shetlar, (2001) Black cutworm (Lepidoptera: Noctuidae) larval emigration and biomass in mixtures of endophytic perennial ryegrass and Kentucky bluegrass. *Journal of economic entomology* **94**: 1183-1186.
- Rowan, D.D., J.J. Dymock & M.A. Brimble, (1990) Effect of fungal metabolite peramine and analogs on feeding and development of Argentine stem weevil (*Listronotus bonariensis*). *Journal of chemical ecology* **16**: 1683-1695.
- Ruffner, B., M. Péchy-Tarr, M. Höfte, G. Bloemberg, J. Grunder, C. Keel & M. Maurhofer, (2015) Evolutionary patchwork of an insecticidal toxin shared between plant-associated pseudomonads and the insect pathogens *Photorhabdus* and *Xenorhabdus*. *BMC genomics* **16**: 609.
- Saikia, S., M.J. Nicholson, C. Young, E.J. Parker & B. Scott, (2008) The genetic basis for indole-diterpene chemical diversity in filamentous fungi. *Mycological research* **112**: 184-199.
- Saikia, S., E.J. Parker, A. Koulman & B. Scott, (2006) Four gene products are required for the fungal synthesis of the indole-diterpene, paspaline. *FEBS letters* **580**: 1625-1630.
- Saikia, S., E.J. Parker, A. Koulman & B. Scott, (2007) Defining paxilline biosynthesis in *Penicillium paxilli* functional characterization of two cytochrome P450 monooxygenases. *Journal of Biological Chemistry* **282**: 16829-16837.
- Saikia, S., D. Takemoto, B.A. Tapper, G.A. Lane, K. Fraser & B. Scott, (2012) Functional analysis of an indole-diterpene gene cluster for lolitrem B biosynthesis in the grass endosymbiont *Epichloë festucae*. *FEBS letters* **586**: 2563-2569.
- Sauerborn, M., P. Leukel & C. von Eichel-Streiber, (1997) The C-terminal ligand-binding domain of *Clostridium difficile* toxin A (TcdA) abrogates TcdA-specific binding to cells and prevents mouse lethality. *FEMS microbiology letters* **155**: 45-54.
- Schardl, C.L., R. Balestrini, S. Florea, D. Zhang & B. Scott, (2009) *Epichloë* endophytes: clavicipitaceous symbionts of grasses. In: Plant Relationships. Springer, pp. 275-306.
- Schardl, C.L., S. Florea, J. Pan, P. Nagabhyru, S. Bec & P.J. Calie, (2013a) The *epichloae*: alkaloid diversity and roles in symbiosis with grasses. *Current opinion in plant biology* **16**: 480-488.
- Schardl, C.L., R.B. Grossman, P. Nagabhyru, J.R. Faulkner & U.P. Mallik, (2007) Loline alkaloids: currencies of mutualism. *Phytochemistry* **68**: 980-996.
- Schardl, C.L. & A. Leuchtmann, (2005) The *Epichloë* endophytes of grasses and the symbiotic continuum. *Mycology series* **23**: 475.

Chapter nine: Reference

- Schardl, C.L., A. Leuchtmann & M.J. Spiering, (2004) Symbioses of grasses with seedborne fungal endophytes. *Annu. Rev. Plant Biol.* **55**: 315-340.
- Schardl, C.L., D.G. Panaccione & P. Tudzynski, (2006) Ergot alkaloids-biology and molecular biology. *Alkaloids* **63**: 45.
- Schardl, C.L., C.A. Young, J.R. Faulkner, S. Florea & J. Pan, (2012) Chemotypic diversity of *epichloae*, fungal symbionts of grasses. *fungal ecology* **5**: 331-344.
- Schardl, C.L., C.A. Young, U. Hesse, S.G. Amyotte, K. Andreeva, P.J. Calie, D.J. Fleetwood, D.C. Haws, N. Moore & B. Oeser, (2013b) Plant-symbiotic fungi as chemical engineers: multi-genome analysis of the Clavicipitaceae reveals dynamics of alkaloid loci. *PLoS Genet* **9**: e1003323.
- Schardl, C.L., C.A. Young, U. Hesse, S.G. Amyotte, K. Andreeva, P.J. Calie, D.J. Fleetwood, D.C. Haws, N. Moore & B. Oeser, (2013c) Plant-symbiotic fungi as chemical engineers: multi-genome analysis of the Clavicipitaceae reveals dynamics of alkaloid loci. *PLoS genetics* **9**: e1003323.
- Scott, B., Y. Becker, M. Becker & G. Cartwright, (2012) Morphogenesis, growth, and development of the grass symbiont *Epichloë festucae*. In: Morphogenesis and Pathogenicity in Fungi. Springer, pp. 243-264.
- Scott, B. & C.J. Eaton, (2008) Role of reactive oxygen species in fungal cellular differentiations. *Current opinion in microbiology* **11**: 488-493.
- Scott, P., (2012) Recent research on fumonisins: a review. *Food Additives & Contaminants: Part A* **29**: 242-248.
- Simpson, W., J. Schmid, J. Singh, M. Faville & R. Johnson, (2012) A morphological change in the fungal symbiont *Neotyphodium lolii* induces dwarfing in its host plant *Lolium perenne*. *Fungal biology* **116**: 234-240.
- Smith III, A.B. & R. Mewshaw, (1985) Total synthesis of (-)-paspaline. *Journal of the American Chemical Society* **107**: 1769-1771.
- Smith, M.M., V.A. Warren, B.S. Thomas, R.M. Brochu, E.A. Ertel, S. Rohrer, J. Schaeffer, D. Schmatz, B.R. Petuch & Y.S. Tang, (2000) Nodulisporic acid opens insect glutamate-gated chloride channels: identification of a new high affinity modulator. *Biochemistry* **39**: 5543-5554.
- Song, Q.-Y., H.-T. Yu, X.-X. Zhang, Z.-B. Nan & K. Gao, (2016) Dahurelmusin A, a Hybrid Peptide–Polyketide from *Elymus dahuricus* infected by the *Epichloë bromicola* Endophyte. *Organic letters* **19**: 298-300.
- Spencer, K.A., (1973) Agromyzidae (Diptera) of economic importance. *Springer Science & Business Media*.

Chapter nine: Reference

- Spencer, K.A., (1976) The Agromyzidae of New Zealand (Insecta: Diptera). *Journal of the Royal Society of New Zealand* **6**: 153-211.
- Spencer, K.A., (2012) Host specialization in the world Agromyzidae (Diptera). *Springer Science & Business Media*.
- Spiering, M.J., C.D. Moon, H.H. Wilkinson & C.L. Schardl, (2005) Gene clusters for insecticidal loline alkaloids in the grass-endophytic fungus *Neotyphodium uncinatum*. *Genetics* **169**: 1403-1414.
- Spiering, M.J., H.H. Wilkinson, J.D. Blankenship & C.L. Schardl, (2002) Expressed sequence tags and genes associated with loline alkaloid expression by the fungal endophyte *Neotyphodium uncinatum*. *Fungal Genetics and Biology* **36**: 242-254.
- Studt, L., F. Schmidt, L. Jahn, C. Sieber, L. Connolly, E.-M. Niehaus, M. Freitag, H.-U. Humpf & B. Tudzynski, (2013) Two histone deacetylases, FfHda1 and FfHda2, are important for *Fusarium fujikuroi* secondary metabolism and virulence. *Applied and environmental microbiology* **79**: 7719-7734.
- Tagami, K., C. Liu, A. Minami, M. Noike, T. Isaka, S. Fueki, Y. Shichijo, H. Toshima, K. Gomi & T. Daiji, (2013) Reconstitution of biosynthetic machinery for indole-diterpene paxilline in *Aspergillus oryzae*. *Journal of the American Chemical Society* **135**: 1260-1263.
- Takach, J.E. & C.A. Young, (2014) Alkaloid genotype diversity of tall fescue endophytes. *Crop Science* **54**: 667-678.
- Takeda, M., (2012) Structures and functions of insect midgut: The regulatory mechanisms by peptides, proteins and related compounds. *Hemolymph Proteins and Functional Peptides: Recent Advances in Insects and Other Arthropods* **1**: 94-110.
- Takemoto, D., A. Tanaka, Y. Kayano, S. Saikia, R. Wrenn, B. Scott, C. Young, G. Aiken, R. McCulley & J. Strickland, (2012) Reactive oxygen as a signal in grass-Epichloë symbiosis. In: *Epichloae*, endophytes of cool season grasses: implications, utilization and biology. Proceedings of the 7th International Symposium on Fungal Endophytes of Grasses, Lexington, Kentucky, USA, 28 June to 1 July 2010.: Samuel Roberts Noble Foundation, pp. 109-112.
- Takemoto, D., A. Tanaka & B. Scott, (2006) A p67Phox-like regulator is recruited to control hyphal branching in a fungal-grass mutualistic symbiosis. *The Plant Cell Online* **18**: 2807-2821.
- Tanaka, A., M.J. Christensen, D. Takemoto, P. Park & B. Scott, (2006) Reactive oxygen species play a role in regulating a fungus-perennial ryegrass mutualistic interaction. *The Plant Cell Online* **18**: 1052-1066.

Chapter nine: Reference

- Tanaka, A., D. Takemoto, T. Chujo & B. Scott, (2012) Fungal endophytes of grasses. *Current opinion in plant biology* **15**: 462-468.
- Tanaka, A., D. Takemoto, G.S. Hyon, P. Park & B. Scott, (2008) NoxA activation by the small GTPase RacA is required to maintain a mutualistic symbiotic association between *Epichloë festucae* and perennial ryegrass. *Molecular microbiology* **68**: 1165-1178.
- Tanaka, A., B.A. Tapper, A. Popay, E.J. Parker & B. Scott, (2005) A symbiosis expressed non-ribosomal peptide synthetase from a mutualistic fungal endophyte of perennial ryegrass confers protection to the symbiotum from insect herbivory. *Molecular microbiology* **57**: 1036-1050.
- Taranaki Educational Resource: Research, A.a.I.N., (2018) *Agrotis ipsilon* (Greasy Cutworm). In. New Zealand pp.
- TePaske, M.R., J.B. Gloer, D.T. Wicklow & P.F. Dowd, (1992) Aflavarin and β -Aflatrem: new anti-insectan metabolites from the sclerotia of *Aspergillus flavus*. *Journal of natural products* **55**: 1080-1086.
- Tian, Z., R. Wang, K.V. Ambrose, B.B. Clarke & F.C. Belanger, (2017) The *Epichloë festucae* antifungal protein has activity against the plant pathogen *Sclerotinia homoeocarpa*, the causal agent of dollar spot disease. *Scientific Reports* **7**: 5643.
- Tor-Agbidye, J., L. Blythe & A. Craig, (2001) Correlation of endophyte toxins (ergovaline and lolitrem B) with clinical disease: fescue foot and perennial ryegrass staggers. *Veterinary and human toxicology* **43**: 140-146.
- Van de Bittner, K.C., M.J. Nicholson, L.Y. Bustamante, S.A. Kessans, A. Ram, C.J. van Dolleweerd, B. Scott & E.J. Parker, (2018) Heterologous biosynthesis of nodulisporic acid F. *Journal of the American Chemical Society* **140**: 582-585.
- Voisey, C.R., (2010) Intercalary growth in hyphae of filamentous fungi. *Fungal Biology Reviews* **24**: 123-131.
- Voth, D.E. & J.D. Ballard, (2005) *Clostridium difficile* toxins: mechanism of action and role in disease. *Clinical microbiology reviews* **18**: 247-263.
- Waterfield, N.R., P.J. Daborn, A.J. Dowling, G. Yang, M. Hares & R.H. ffrench-Constant, (2003) The insecticidal toxin makes caterpillars floppy 2 (Mcf2) shows similarity to HrmA, an avirulence protein from a plant pathogen. *FEMS microbiology letters* **229**: 265-270.
- Watt, M., (1924) The Leaf-mining Insects of New Zealand. Part v. The Genus *Nepticula* (Lepidoptera) and the Agromyzidae (Diptera) continued, and *Gracilaria selenitis*, Meyr.(Lepidoptera). *Transactions & Proc. New Zealand Inst.* **55**.

- Weedon, C.M. & P.G. Mantle, (1987) Paxilline biosynthesis by *Acremonium loliae*; a step towards defining the origin of lolitrem neurotoxins. *Phytochemistry* **26**: 969-971.
- Weintraub, P.G., S.J. Scheffer, D. Visser, G. Valladares, A. Soares Correa, B.M. Shepard, A. Rauf, S.T. Murphy, N. Mujica & C. MacVean, (2017) The invasive *Liriomyza huidobrensis* (Diptera: Agromyzidae): understanding its pest status and management globally. *Journal of Insect Science* **17**.
- Wikipedia, (2018) Morphology of Diptera. In.: Wikipedia, pp.
- Winter, D.J., A. Ganley, C. Young, I. Liachko, C. Schardl, P.-y. Dupont, D. Berry, A. Ram, B. Scott & M. Cox, (2018) Repeat elements organize 3D genome structure and mediate transcription in the filamentous fungus *Epichloë festucae*. *bioRxiv*: 339010.
- Wolstenholme, A.J., (2012) Glutamate-gated chloride channels. *Journal of Biological Chemistry* **287**: 40232-40238.
- Xu, Y., R. Orozco, E.K. Wijeratne, P. Espinosa-Artiles, A.L. Gunatilaka, S.P. Stock & I. Molnár, (2009) Biosynthesis of the cyclooligomer depsipeptide bassianolide, an insecticidal virulence factor of *Beauveria bassiana*. *Fungal Genetics and Biology* **46**: 353-364.
- Young, C., M. Bryant, M. Christensen, B. Tapper, G. Bryan & B. Scott, (2005) Molecular cloning and genetic analysis of a symbiosis-expressed gene cluster for lolitrem biosynthesis from a mutualistic endophyte of perennial ryegrass. *Molecular Genetics and Genomics* **274**: 13-29.
- Young, C., L. McMillan, E. Telfer & B. Scott, (2001) Molecular cloning and genetic analysis of an indole-diterpene gene cluster from *Penicillium paxilli*. *Molecular microbiology* **39**: 754-764.
- Young, C.A., S. Felitti, K. Shields, G. Spangenberg, R.D. Johnson, G.T. Bryan, S. Saikia & B. Scott, (2006) A complex gene cluster for indole-diterpene biosynthesis in the grass endophyte *Neotyphodium lolii*. *Fungal Genetics and Biology* **43**: 679-693.
- Young, C.A., B.A. Tapper, K. May, C.D. Moon, C.L. Schardl & B. Scott, (2009) Indole-diterpene biosynthetic capability of *Epichloë* endophytes as predicted by ltm gene analysis. *Applied and environmental microbiology* **75**: 2200-2211.
- Yu, J., P.-K. Chang, K.C. Ehrlich, J.W. Cary, D. Bhatnagar, T.E. Cleveland, G.A. Payne, J.E. Linz, C.P. Woloshuk & J.W. Bennett, (2004) Clustered pathway genes in aflatoxin biosynthesis. *Applied and environmental microbiology* **70**: 1253-1262.