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**How does *Epichloë festucae* avoid the host defence response?**

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

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**2018**

## Abstract

*Epichloë festucae* is a filamentous fungus, which forms symbiotic associations with aerial tissues of *Lolium* and *Festuca* grass species. Chitin, a polymer of N-acetyl-D-glucosamine, is an important component of the fungal cell wall and a well-known pathogen associated molecular pattern (PAMP). Chitin promotes pathogen-triggered immunity (PTI) upon hydrolysis with plant chitinases and release of chitin oligomers. Therefore, to establish a stable and successful symbiosis, the endophyte needs to remain 'hidden' from the host immune system or actively suppress it. Confocal laser scanning microscopy (CLSM)-based analysis of leaf tissue infected with the *E. festucae* wild type strain and infiltrated with the chitin-specific molecular probe, WGA-Alexa Fluor-488, showed that only the septa of endophytic hyphae bound this probe while the entire cell wall was labelled in epiphyllous hyphae confirming previous observations that hyphal cell wall chitin is either masked or remodelled in endophytic hyphae. The aims of this project were (i) to test whether *E. festucae* LysM-containing proteins have a role in binding to or sequestering cell wall chitin oligomers and thereby preventing PAMP-triggered immunity and (ii) to analyse the composition of the cell wall of endophytic and epiphytic hyphae. An analysis of the *E. festucae* genome identified seven genes encoding proteins with LysM domains. Expression of two of these genes, *lymA* and *lymB*, increased *in planta* compared to in culture. Interestingly, both are divergently transcribed from chitinase encoding genes (*chiA* and *chiB* respectively), which also have increased expression *in planta*. Single gene deletion mutants of *lymA*, *lymB*, *chiA* and *chiB* as well as a double gene deletion  $\Delta$ *lymA/B* were generated, and their plant interaction phenotype analysed. Plants infected with  $\Delta$ *lymA*,  $\Delta$ *lymB* or  $\Delta$ *chiA* had the same plant-interaction phenotype as wild type whereas  $\Delta$ *chiB* and  $\Delta$ *lymA/B* mutants had defects in hyphal growth within the leaves. Analysis of hyphal cell wall structure using Chitin Binding Protein (CBP) and chitosan (CAP (Chitosan Affinity Protein) and OGA-488)-specific eGFP-based biosensors suggest that cell wall chitin is converted to chitosan in endophytic hyphae. This structural change is consistent with a lack of a defence response when *E. festucae* forms a mutualistic symbiotic association with *L. perenne*. Three *E. festucae* chitin deacetylase genes were identified (*cdaA*, *cdaB* and *cdaC*), and gene expression analysis showed *cdaA* expression is significantly increased *in planta* compare to in culture. Functional analysis of *cdaA* revealed that although plants infected with the  $\Delta$ *cdaA* mutant had a similar whole plant interaction phenotype as wild type, they had an abnormal

cellular phenotype. Patches of chitin were exposed along the endophytic hyphae confirming this mutant was unable to convert chitin to chitosan. However, hyphae in these plants still labelled with the chitosan biosensor OGA-488 demonstrating that despite the deletion of the *cdaA*, the hyphal cell wall of endophytic hyphae still contain chitosan suggesting that another chitin deacetylase, possibly CdaB has a redundant function in *E. festucae*. Collectively these results show that *lymA*, *lymB* and *chiB* are required for establishment of the symbiosis between *E. festucae* and *L. perenne*. In addition, this study shows that chitin is converted to chitosan in the hyphal cell wall of endophytic hyphae during the infection and colonisation of the host. The *E. festucae* chitin deacetylase gene *cdaA* is also essential for proper hyphal growth *in planta* and the symbiotic interaction.

## **Acknowledgments**

My deepest sense of gratitude to my main supervisor Professor Barry Scott for the patient guidance, encouragement and advice he has provided throughout the period of my doctoral study as his student. I have been extremely lucky to have a knowledgeable and experienced supervisor who cared so much about my work and who responded to my questions and queries so promptly. It was a rewarding experience to work under his supervision. I would like to thank my co-supervisor Dr Matthew Savoian for his technical training, constant support, availability and constructive suggestions which were determinant for the accomplishment of the work presented in this thesis.

A big thank you to our lab manager Arvina Ram, the first person who gave me technical training in the lab and whom throughout these years had always gave encouraging words and always stood with me and ready to help me specially during the hard time of writing. It was a wonderful time being with her and to work with her in the lab. She is like a sister to me far away from home.

A warm thank you to all Scottbase members, past and present, Alex, Kim, Daniel, Yonathan, Berit and Taryn for providing so pleasurable and friendly working atmosphere I am truly thankful for all the help, discussions and ideas whenever I needed them and a big thank you to Elli and Alyesha for helping me taking care of the plant room and their help whenever I needed them.

Thanks also to Dr Yvonne Becker, Dr Mathias Becker, Dr Carla Eaton and Dr David Winter for their valuable discussion and advice on microscopy and bioinformatic aspects. I also want to thank present and past members of MMIC for providing such a high-quality level of help and guidance.

I would like to thank members of the microscopy centre at Fontera in Palmerston North for kindly helping me to analyse the plant samples in the second part of the project.

I would like to thank Professor Bruno Moerschbacher and Professor William Willats for providing chitin and chitosan biosensors which made the second part of this work possible. I would also like to acknowledge the BioProtection Research Centre for funding this PhD project.

Thanks to all my friends back home in Iran and all here in New Zealand. I express my gratitude for their unconditional friendship, support and patience throughout these years. A special thanks to my family, my grandmother, my parents, my sister, Nazila, my brother, Navid and my sister in law, Parisa, for their unconditional love, support, encouragement

and all the sacrifice you have made for me. Words cannot express how grateful I am to have you all in my life. Your prayers for me were what sustained me thus far. I consider myself the luckiest in the world to have such a lovely and caring family, standing beside me with their love and unconditional support.

And last but not the least my eternal gratitude goes to my husband, Naser, for his continued and unfailing love, support and understanding during my pursuit of PhD degree that made the completion of this thesis possible. He is always around at times when I thought that it is impossible to continue.

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## **Abbreviations**

aa Amino acid

Amp Ampicillin

AmpR Ampicillin resistant

ap appressorium

Avr Avirulence

BLAST Basic local alignment search tool

BLASTn Nucleotide database search using a nucleotide query

BLASTp Protein database search using a protein query

bp Base pair(s)

*cda* chitin deacetylase

cDNA Complementary DNA

*chi* chitinase

cf conidiophore

CFW Calcofluor white

CLSM Confocal Laser Scanning Microscopy

CWI Cell wall integrity

cu cuticle

DIC Differential interference contrast

DIG Digoxigenin

dir direction

DNA Deoxyribonucleic acid

dNTP Deoxynucleotide triphosphate

EDTA Ethylene diamine tetra-acetic acid

eGFP Enhanced green fluorescent protein

en endophytic hyphae

ep epiphyllous hyphae

ETI effector-triggered immunity

ETS effector-triggered susceptibility

g Gram

gDNA Genomic DNA

Gen Geneticin

GenR Geneticin resistant  
GH18 glycoside hydrolase family 18  
GFP Green fluorescent protein  
GPI Glycosylphosphatidylinositol  
gt germ tube  
h Hour(s)  
Hph Hygromycin  
HR hypersensitive response  
HygR Hygromycin resistant  
IDC Impaired development of crippled growth  
ih infection hyphae  
kb Kilobase(s)  
KO Knock-out  
L Litre  
LB Lysogeny broth  
LysM lysin motif  
M Molar  
MAPK(K/K) Mitogen activated protein kinase (kinase/kinase)  
MAMP Microbe associated molecular pattern  
Mb millions of base pairs  
mg Milligram  
 $\mu\text{g}$  Microgram  
min Minute(s)  
 $\mu\text{L}$  Microlitre  
mL Millilitre  
 $\mu\text{m}$  Micrometre  
 $\mu\text{M}$  Micromolar  
mm Millimeter  
mM Millimolar  
Mo *Magnaporthe oryzae*  
MOB monopolar spindle-one-binder  
mRNA Messenger ribonucleic acid  
Nc *Neurospora crassa*  
NCBI National Centre for Biotechnology Information

*ntpII* Geneticin  
Nox NADPH oxidase  
PAMP Pathogen associated molecular pattern  
PCR Polymerase chain reaction  
PD Potato dextrose  
PEG Polyethylene glycol  
*pro* protoperithecia mutant  
PTI PAMP-triggered immunity  
PRR Pattern recognition receptors  
RG Regeneration  
RNA Ribonucleic acid  
RNase Ribonuclease  
RNA-seq Ribonucleic acid sequencing  
rpm Revolutions per minute  
RT Reverse transcriptase  
RT-PCR Reverse transcriptase-polymerase chain reaction  
SAK Stress-activated kinase  
SAM Shoot apical meristem  
SDS Sodium dodecyl sulfate  
Sp spore  
STRIPAK Striatin interacting phosphatase and kinase  
sv substomatal vesicle  
sym Symbiosis mutant  
TBE Tris-boric acid-EDTA  
tBLASTn Translated nucleotide database search using a protein query  
T-DNA Transfer-deoxyribonucleic acid  
TEM Transmission electron microscopy  
TMD Transmembrane domain  
Um *Ustilago maydis*  
UV Ultraviolet  
V Volts  
v/v Volume/volume ratio  
WT Wild-type  
w/v Weight/volume ratio

YE Yeast extract

°C Degrees Celsius

