Genetic diversity and plant-plant interactions as drivers of disease resistance in cereals

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Genetic diversity and plant-plant interactions as drivers of disease resistance in cereals

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Plant immunity is modulated by the environment

Water
microbiota

Defense stimulators
Ballini et al, Euphytica 2020

Plant health
Signal integration

neighbors

Huang et al, Frontiers in Plant Science 2017

Alonso et al, Env Microb 2020

nutrients

subrahmaniam et al, Plant 2018
Zhu and Morel, MPMI 2019
Henry et al, Plant Sign Behav 2020
Plants modulate immunity and susceptibility in their neighborhood

Plant-soil feedbacks and legacies

Constitutive VOCs

Inducible VOCs

Danger signalization

Kin recognition

Competition

Stranger recognition

Microbiota modification

Root Exudates, small peptides

Root exudates

Root density, nutrient foraging

SAS

Allelochemicals

Loliolide, allantoin

Markovic et al, JEBX. 2019
Wenig et al, Nature com. 2019
Orlovskis et al, New phytol. 2020
Coppola et al, Scientific reports. 2017

Sukeygawa et al. Plant journal, 2018
Venturelli et al. Plant cell, 2015
Kong et al. 2018
Li et al. JEBX, 2020
Murata et al, Plant physiology 2019
Takagi et al. JEBX, 2016

Biedrzycky et al, Plant Signaling & Behavior 2011

Wit et al, Plant Journal 2013
Cerrudo et al, Plant Physiology 2012
Ballaré, An. rev. of Plant biology 2014
Chen et al. Frontiers in P. Science, 2019

Plants modulate immunity and susceptiblity in their neighborhood
**Intraspecific competition for nutrients between conspecifics**

Intraspecific competition leads to increases in intraspecific plant density. Shade Avoidance Syndrome (SAS) increases A. thaliana susceptibility to pathogens. Root interaction with conspecifics increases accumulation of chemical defense in tobacco.

- **Shade Avoidance Syndrome**
  - Increases A. thaliana susceptibility to pathogens
  - Wit et al, Plant Journal 2013
  - Cerrudo et al, Plant Physiology 2012
  - Review in Ballaré, An. rev. of Plant biology 2014

- **Root interaction with conspecifics**
  - Increases accumulation of chemical defense in tobacco
  - Chen et al, Frontiers in Plants Science, 2019
Plants modulate immunity and susceptibility in their neighborhood

- Plant-soil feedbacks and legacies
- Microbiota modification
- Inducible VOCs
- Root Exudates, small peptides
- Root exudates
- Danger signalization
- Kin recognition
- Stranger recognition
- Constitutive VOCs
- loliolide, allantoin
- allelochemicals
- SAS
- Root density, nutrient foraging
- Competition
Stranger’s things from healthy neighbors

Constitutive VOCs

- Menthol (cVOCs)
  - Modifying histone acetylation of promoters of defense genes
  - Defense gene upregulated
  - Herbivory & pathogen resistance increased
  - Production of allelopathic molecules against parasites

DIMBOA and derivatives

- (-)-Loliolide
  - Li et al. JEBX, 2020
  - Murata et al. Plant phisiology 2019

- Allantoine
  - Takagi et al. JEBX, 2016

- Diallyl disulfide

Allelochemicals
DIMBOA hypothesis

DIMBOA derivatives → HDAC → defense

(Venturelli et al, 2015)
Intercropping rice and maize

Rice blast disease (GY11)
average lesions/ rice leaf

Maize blast disease (2 isolates)
normalized average lesions/maize leaf

~40% reduction of symptoms
**DIMBOA biosynthesis is required for protection in intercropping**

**Figure A**

- **Inole-3-glycerol phosphate**
- **Br1, Br5, Br8, Br13**
- **DIMBOA-Glc**
- **Br7, Br13**
- **DIMBOA-Glc**
- **DIMBOA-Glc**
- **HDMIROA-Glc**

**Graph**

- **Rice blast disease (on rice)**
- **Disease level (normalized)**
- **rice**, **W22**, **bx1 (W22)**, **B73**, **bx1 (B73)**

**Legend**

- **neighbor**
- **focal**

*DIMBOA is required for protection in intercropping.*
Plants modulate immunity and susceptibility in their neighborhood

Plant-soil feedbacks and legacies

danger signalization

kin recognition

constitutive VOCs

loliolide, allantoin

inducible VOCs

root exudates, small peptides

root density, nutrient foraging

SAS

Microbiota modification

Competition

Stranger recognition

allelochemicals
**Plants leave a message: plant soil feedback and legacies**

**Plant–soil feedback** is a process where plants alter the **biotic** and **abiotic** qualities of **soil** they grow in, which then alters the ability of plants to grow in that soil in the future.

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**→ Intraspecific & Interspecific**

Ma et al, Frontier in plant science. 2017

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**→ Inductible or constitutive**

Beredsen et al, ISME journal. 2018
Yuan et al, Microbiome. 2018

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**→ Induces defense genes, pathogen and herbivory resistance**

Hu et al, Nature com. 2018

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**→ Depend on specific species of fungi, bacteria or combinaison**

Wang et al. New phytol, 2019
Plants modulate immunity and susceptibility in their neighborhood

- **Plant-soil feedbacks and legacies**
  - Microbiota modification
  - Inducible VOCs
  - Root exudates, small peptides
  - Danger signalization

- **Kin recognition**
  - Root density, nutrient foraging

- **Stranger recognition**
  - Constitutive VOCs
  - Loliolide, allantoin
  - Allelochemicals

- **Competition**
  - SAS
The neighbor watch, Signalisation of danger between plant

Disease / attack plant

Inducible VOCs
Markovic et al, JEBX. 2019

Can be triggered by touch in maize

Monoterpenes
Wenig et al, Nature com. 2019

Propagation of SAR (Systemic acquired Resistance) between neighbor plants

Unknown root signal
Orlovskis et al, New phytol. 2020

Systemin
Coppola et al, Scientific reports. 2017

Excreted soil peptide (18 AA) by tomato roots

Inducible Root exudates, small peptides ...

...
Plants modulate immunity and susceptibility in their neighborhood

Pelissier, Violle and Morel, review submitted

Can kins/conspecifics modulate susceptibility in their neighborhood?
Kin recognition: when plants recognize conspecifics

Kin recognition is an organism's ability to distinguish between close genetic kin and non-kin

Only one example to our knowledge shows that Kin recognition can trigger the expression of immunity (kin relations known to affect response to insects)

Wikipedia

Biedrzycki et al, Plant Signaling & Behavior 2011
Screening for Neighbor-modulated susceptibility

Specific ability of a given neighbor to modulate susceptibility of focal A (« good » or « bad » neighbor)
Neighbor-modulated susceptibility (NMS) in rice and wheat

Pelissier et al, submitted

Some kins can modulate susceptibility in their neighborhood (NMS)
Localization of intra-specific plant-plant interactions leading to NMS

NMS takes place in the soil and does not require microbiome (nor an infected neighbor)

Pelissier et al, submitted
Mapping rice ability to modulate susceptibility in its neighborhood

Focal plant = Kitaake

Neighbor plant = 280 genotypes of temperate japonica

CO-CULTURE

Blast susceptibility on Kitaake X 3 replicates

Diversity of NMS?
Rice loci involved in NMS emission?

GWAS (Genome Wide Association Study) of NMS emission

Pelissier et al, unpublished
Neighbors can reduce but also increase disease susceptibility of Kitaake cultivated with 280 different neighbors.
GWAS of the emission of NMS

One region on rice chromosome 3 controls NMS emission

LD block = 250kb
9 coding sequences, incl. 6 genes

Pelissier et al, unpublished
Test of GWAS prediction for emission of NMS

GWAS predicts that neighbors with haplotype 3 reduce susceptibility in focal kitaake

Susceptibility data from GWAS

20% reduction of susceptibility

Independent validation (6 haplotype 3 vs 6 haplotypes 1 or 2)

Neighbor haplotype

Pelissier et al, unpublished
NMS at the species level: the case of temperate japonica rice

Rice Blast fungus

Temperate japonica rice

More R
More S

Susceptibility (norm.)

Japonica rice

P = 0.063

+ 14%

Pure Mix

Intra-specific interactions are not favorable to rice blast resistance

Pelissier et al, unpublished
NMS: good neighbor and good focal plants

Wheat X leaf rust

Cultivated durum wheat

Rice X Blast fungus

Japonica Rice

EPO Wheat

Acuce rice

Pelissier et al, unpublished
Historical within-field co-existence

NMS and breeding

Wheat (leaf rust)

Rice (Blast fungus)

Pelissier et al, unpublished
QUESTIONS?

+ projet thèse (Inrae-ANR Mobidiv)
Génétique et physiologie des interactions blé-blé modulant la sensibilité aux agents pathogènes (Sept 2021-2024)