

Soil tripartite interactions between host plants, viruses and the protist vectors *Polymyxa*

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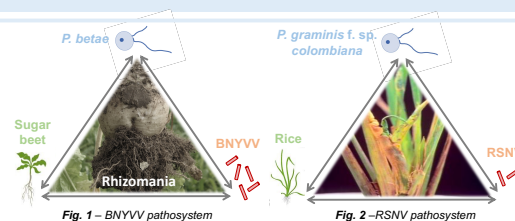


Two pathosystems

This study of host-*Polymyxa*-virus interactions mainly focuses on two host-*Polymyxa*-*Benyvirus* models, for which genomic data are available for the two vectors *P. betae* on dicotyledons and *P. graminis* f. sp. *colombiana* on monocotyledons.

The **beet necrotic yellow vein virus** (BNYVV) is a multipartite *Benyvirus* transmitted by *Polymyxa betae* on sugar beet (Fig. 1). It is the causal agent of an important disease in sugar beet : the rhizomania, which causes the proliferation of rootlets, browning of the vascular rings and wilting of leaves. This disease causes up to 60% of losses in susceptible crops [1].

The **rice stripe necrosis virus** (RSNV) is a bipartite *Benyvirus* transmitted by *P. graminis* f. sp. *colombiana* on rice (Fig. 2). It causes characteristic symptoms of crinkling yellow and deformation of rice leaves and can lead to severe deformity in plants. The incidence of the disease ranges from 37% to 80% in West-African countries and up to 40% yield losses in central and South America [2].



Polymyxa – host plant interactions

In order to achieve **successful infection** of its host, *Polymyxa* must bypass three defense barriers (Fig. 3) [1,3,4]:

- (1) **Physical barrier** (plant cell walls)
Polymyxa penetrates plant cell walls thanks to a needle-like structure, the "Stachel", regardless it is a host or non-host.
- (2) **Pattern-triggered immunity** (PTI)
Polymyxa can mitigate oxidative stressed caused by PTI with production of Glutathione-S-Transferase (GST) and enzymes ; it manipulates plant defense reaction as shown by the down-regulation of plant transcriptomic factors, resistance gene analogues and pattern-recognition receptors with **effectors**.
- (3) **Effector triggered immunity** (ETI)
Plants can specifically recognize the effectors with cytoplasmic receptors (NLRs). It is likely that the outcome of **compatible or non-compatible interaction** could be determined by this third barrier : effector triggered susceptibility (ETS) or ETI.

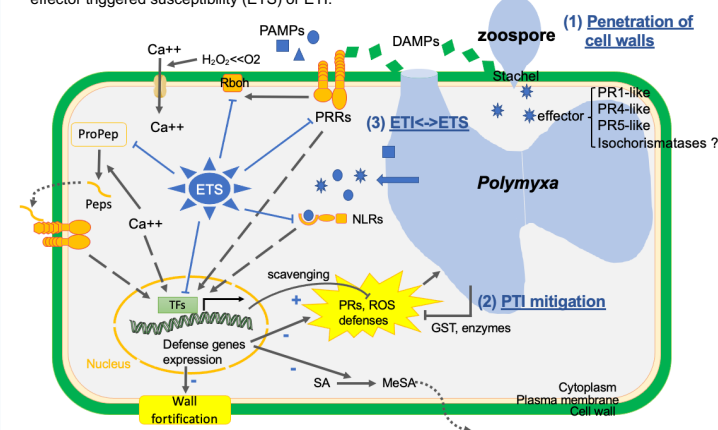


Fig. 3 – Schematic representation of sugar beet defenses manipulation by *P. betae* during compatible host infection by means of direct effector secretion, based on transcriptomic and genomic analyses [3]
ETS = effector triggered susceptibility, ETI = effector triggered immunity, PTI = PAMPs triggered immunity, PAMPs = pathogen-associated molecular patterns, DAMPs = damage-associated molecular patterns, NLRs = nucleotide-binding, leucine-rich repeat receptors, PRRs = pattern recognition receptors, TF = transcription factors, ProPep = precursor of signal peptide, Peps = signal peptides, Rboh = respiratory burst oxidase homologs, ROS = reactive oxygen species, PR = pathogenesis-related proteins, GST = Glutathione-S-Transferase, SA = Salicylic acid

Polymyxa – virus interactions

Transcriptomic analyses show that BNYVV has several impacts on *P. betae*, leading to the **acceleration of its life cycle** (Fig. 4) [1,3,5]:

- (1) **Stronger plant defense activation**
A clear **defense reaction** was observed when BNYVV was inoculated with *P. betae* (up-regulation of pathogenesis-related (PR) genes, phenylpropanoids and flavonoids pathways). This could have a negative impact on *Polymyxa* and lead to the earlier induction of resting spore stage.
- (2) **Reduction of the plant cell wall integrity**
BNYVV likely causes a **reduction of the plant cell wall integrity**. This could be a beneficial effect for the cell-to-cell movement of *P. betae*, explaining the acceleration of *P. betae* life cycle.
- (3) **Creating energy sinks in the roots**
BNYVV presence also impacts the **carbohydrate and lipid metabolism**. Creating energy reserves and transporting carbohydrates to growing lateral roots could support the protist development.

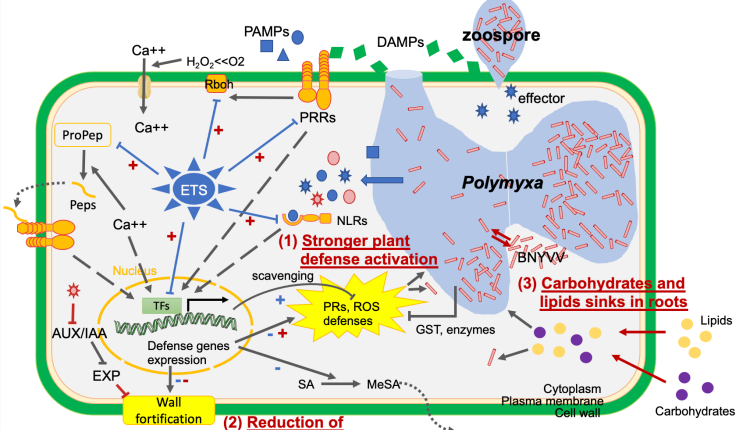


Fig. 4 – Schematic representation of the impact of BNYVV on sugar beet roots and the subsequent *P. betae* development
ETS = effector triggered susceptibility, PAMPs = pathogen-associated molecular patterns, DAMPs = damage-associated molecular patterns, NLRs = nucleotide-binding, leucine-rich repeat receptors, PRRs = pattern recognition receptors, TF = transcription factors, ProPep = precursor of signal peptide, Peps = signal peptides, Rboh = respiratory burst oxidase homologs, ROS = reactive oxygen species, PR = pathogenesis-related proteins, GST = Glutathione-S-Transferase, SA = Salicylic acid, EXP = expansin, BNYVV = beet necrotic yellow vein virus

Polymyxa, an ancient pathogen, now commensalist

Polymyxa

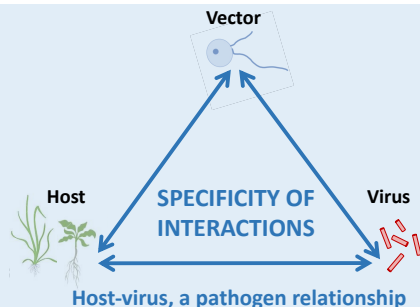
+ Carbohydrates and nutrients from host cytoplasm

Host

0 No deleterious effect, except few specific cases (specific isolate, host, life stage, infection pressure, etc.)

-> Manipulation of plant defenses with effectors

-> Compensation of *Polymyxa* energy sink ? (Systemic acquired resistance activation ?)



Carbohydrates and lipid sink in lateral roots -

Primary defense compromised - **Host**

Better drought resistance with lateral roots proliferation +

Virus + Energy from host cytoplasm

Polymyxa-virus, a win-win relationship

Polymyxa

Plant cell wall integrity reduction induced by BNYVV +
BNYVV suppressors of RNA silencing +
Proliferation of rootlets induced by BNYVV +

BNYVV

+ Earlier production resting spores
Infection, spread and conservation +
Alleviation of plant defenses +

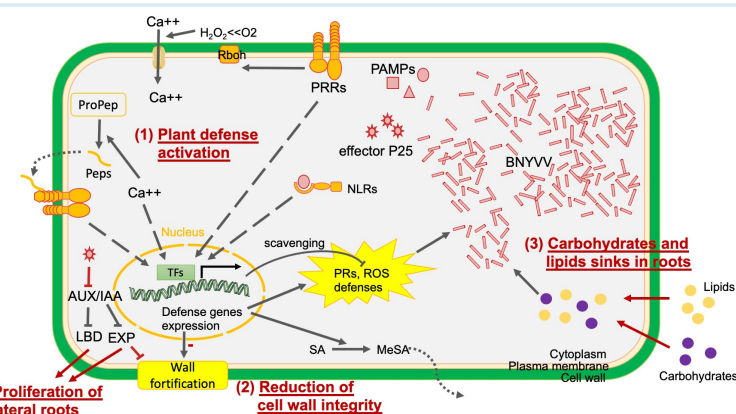
Host – virus interactions

BNYVV has several impacts on the host plant it colonizes [1,3,5,6]:

- (1) **Plant defense activation**
A clear **defense reaction** was observed when BNYVV is inoculated, with the up-regulation of defense-related transcriptomic factors (TF), genes involved in secondary metabolite biosynthesis pathways (phenylpropanoids and flavonoids pathways) and pathogenesis-related (PR) proteins, such as chitinase, protease, glucanase, peroxidase and defensin.
- (2) **Reduction of host cell wall integrity**
Expansins (EXP), which are cell-wall loosening proteins were expressed in BNYVV-infected roots. BNYVV likely causes a **reduction of the cell walls integrity**.
- (3) **Creating energy sinks in the roots**
BNYVV presence also impacts the **carbohydrate and lipid metabolism** by creating energy reserves and transporting carbohydrates to growing lateral roots.
- (4) **Proliferation of lateral roots**
BNYVV P25 is thought to act as an effector protein, which represses the AUX/IAA protein, an inhibitor of EXP, TF and lateral organ boundary domain (LBD) genes involved in **formation of lateral roots**.

Fig. 5 – Schematic representation of the impact of BNYVV alone on sugar beet roots

PAMPs = pathogen-associated molecular patterns, NLRs = nucleotide-binding, leucine-rich repeat receptors, PRRs = pattern recognition receptors, TF = transcription factors, ProPep = precursor of signal peptide, Peps = signal peptides, Rboh = respiratory burst oxidase homologs, ROS = reactive oxygen species, PR = pathogenesis-related proteins, SA = Salicylic acid, EXP = expansin, LBD = lateral organ boundary domain, BNYVV = beet necrotic yellow vein virus



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