Environmentally dependent host-pathogen and vector-pathogen interactions in the *Barley yellow dwarf virus* pathosystem

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Introduction

- Climate models project future conditions that may heighten environmental stress and drive emergence of infectious diseases in both agricultural and nonmanaged ecosystems through multiple pathways (Anderson *et al.* 2004), and extreme weather events resulting in amplified abiotic stress are likely to limit plant productivity (Rosenzweig & Parry 1994).

- Understanding environmentally dependent variation in interspecific interactions is needed for evaluating how agroecosystems respond to abiotic stressors, including climate change. Both biotic and abiotic conditions shape crop responses to stress events, but interactions between environmental conditions and insect-borne plant pathogens remain poorly understood.

- We tested the hypothesis that drought stress, as applied by water deprivation, drives conditional outcomes in host-pathogen and host-vector interactions using a cereal-aphid-virus association (bird cherry-oat aphid, *Rhopalosiphum padi*; cultivated wheat, and the *Barley yellow dwarf virus;* BYDV) and controlled greenhouse experiments.

Methods and Materials

Experiment 1

Chronic water stress & BYDV

- This experiment employed a factorial design to test whether interactions between water quantity and BYDV infection impacts host plant growth and seed set when different water regimes are continued over the life of hosts.
- Experimental watering ('high' and 'low' water regime) was applied on a gravimetric basis at the soil surface every 48 for 75 d, when plants were harvested.
- We estimated plant performance by aboveground biomass (g), seed set (number of seeds/plant^{-1}), average seed weight for each plant ([total seed mass/number of seeds]/plant^{-1}), seed yield (mg seed/plant^{-1}), seed germination (total number of germinating seeds), and germination frequency (%).

Experiment 2

Short term water stress & BYDV

- The test of short-term water scarcity was designed to evaluate leaf water potentials (ψleaf) prior to and following experimental water shortage.
- Experimental water shortage was imposed 15 d after inoculation. Predawn ψleaf was measured for each plant, and we initiated a drought-watering regime that consisted of watering all plants at 0.1 g water/g soil for 7 d.
- At the end of the 7 d period, we again measured ψleaf for each plant. After the second measurement of ψleaf, we watered ad libitum until harvest (75 d).
- We estimated plant performance using the same parameters as in Experiment 1.

Experiment 3

Water deprivation & BYDV

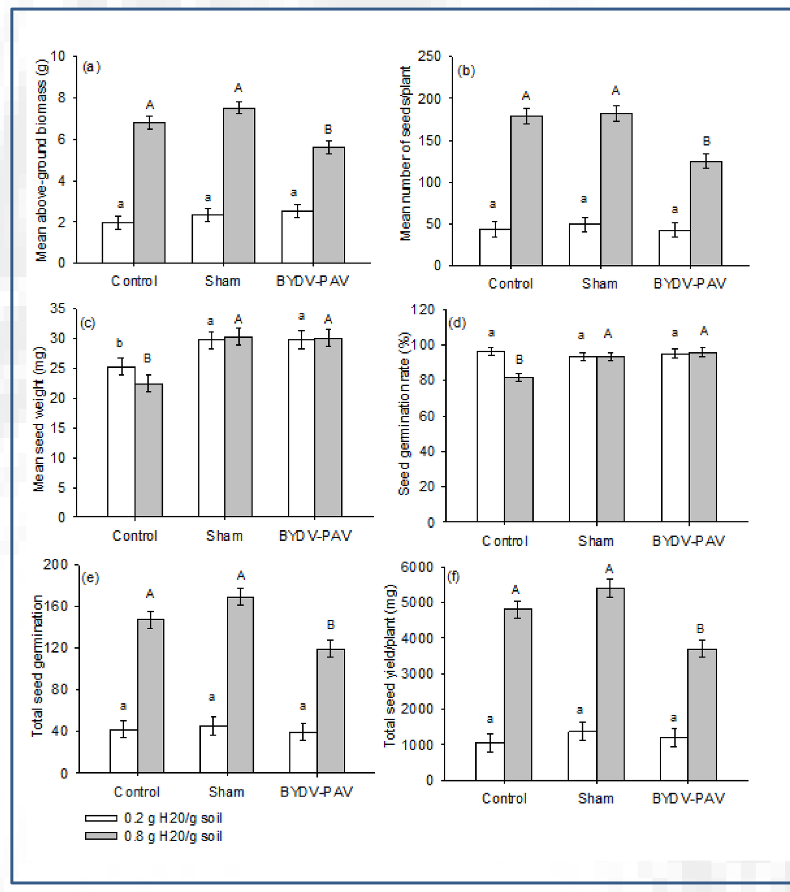
- We used a water deprivation experiment to evaluate whether plant infection status affects the onset and rapidity of drought stress symptoms.
- Experimental deprivation was imposed 15 d after inoculation procedures. Plant water stress symptoms were recorded daily for 15 d using the leaf water stress symptom index (WSI) developed by O'Toole & Cruz (1980) for graminoid crops.
- After withholding water for 15 d and recording symptoms, plants were again watered ad libitum until harvest at 75 d.
- We assessed wheat plant performance using the same variables as in the previous two experiments.

Experiment 4

Aphid response to drought x virus interactions

- The purpose of this experiment was to determine whether interactions between water stress and BYDV infection have significant consequences for the life history of aphid virus vectors.
- One mature apterous aphid was enclosed in a small clip cage on a single leaf. After 24 h, all new nymphs except for one (foundress) and the initial aphid were removed to yield a starting density of one aphid per plant. Foundresses were checked daily thereafter, and new nymphs were recorded and removed.
- We compared pre-reproductive period, lifetime fecundity, and longevity of foundress aphids; and we determined age-specific survivorship and fecundity, and tested for differences in age-specific fecundity using repeated-measures ANOVA.

Results

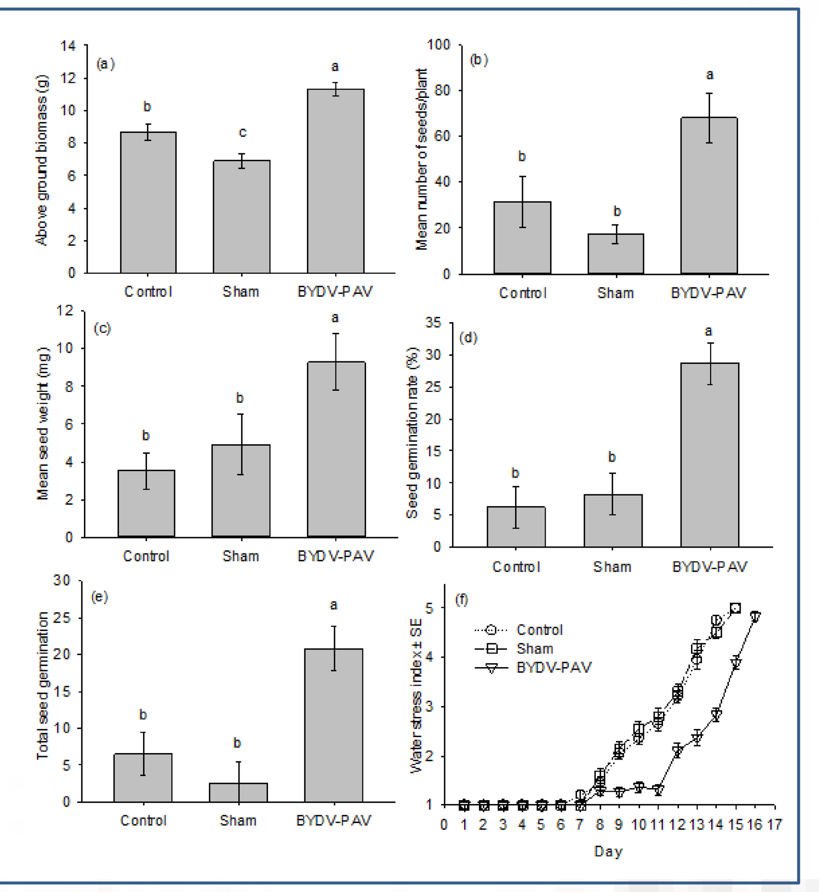


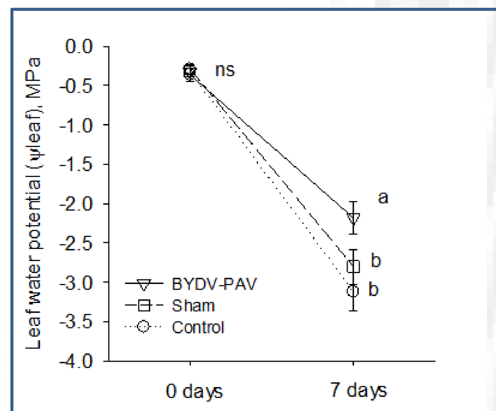
Experiment 1: Chronic water stress & BYDV

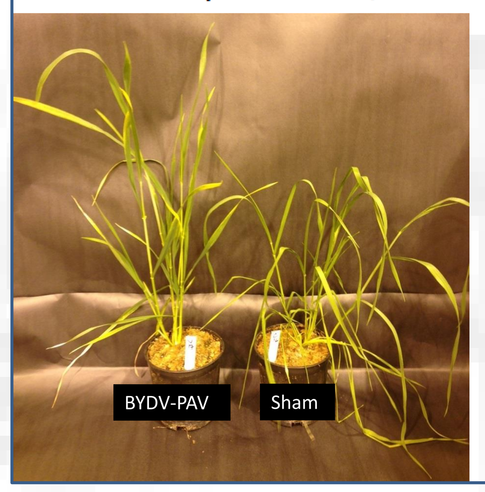
- When water was chronically limiting, wheat infected with *Barley yellow dwarf virus* (BYDV) did not exhibit significantly more injury than plants exposed to noninfected (nonviruliferous) aphids, or control plants not subjected to aphid infestation.
- However, under conditions of ample water, BYDV-infected plants suffered injury resulting in reduced aboveground growth, seed set, seed yields, and seed germination compared to noninfected plants.

Experiment 3:Water deprivation & BYDV

- When water was withheld outright, the onset and rapidity of visual drought stress symptoms was delayed in BYDV-infected plants.
- Although water withholding caused significant injury to all plants, BYDV-infected plants exhibited greater biomass growth, seed set, seed yields, and germination than noninfected plants at harvest.





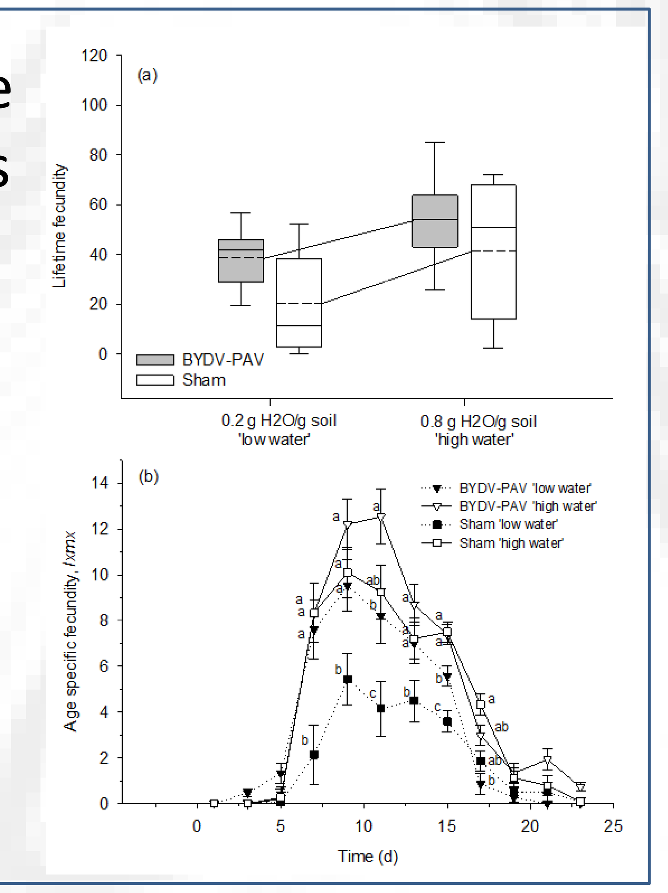


Experiment 2:Short term water stress & BYDV

- Prior to initiating short term water stress, leaf water potentials were equivalent regardless of infection status.
- After 7 d of water scarcity, wheat infected with BYDV-PAV had significantly higher leaf water potentials (see picture).
- At harvest (75 d post-sowing), there were no significant differences in measurements of plant performance.

Experiment 4: Aphid response to drought x virus interactions

- Our feeding experiments confirmed a pattern of vector-pathogen mutualism.
- Feeding experiments with aphid vectors (*Rhopalosiphum padi*) and subsequent life table analysis revealed that aphid fecundity was improved by 47% when feeding on BYDV-infected plants when water inputs were chronically low.
- However, when plants received ample water, aphid fecundity was enhanced by only 23% from feeding on BYDV-infected plants.



Conclusions

- Collectively, our experiments suggest that wheat-BYDV interactions shift relative to water stress severity and duration.
- When BYDV infection precedes water deprivation, infected wheat may not suffer additional injury from virus infection, and tolerates severe stress events more readily than noninfected plants.
- However, vector-pathogen mutualism resulting in enhanced reproduction of aphids on virus-infected plants is likely to amplify direct plant injury from herbivory in the field.
- The results of this study have implications for pest and disease management in cereal production systems. If BYDV infection is relatively non-injurious to wheat under chronic water stress and beneficial under acute water stress, then there may be a reduced need for virus or aphid vector management during drought years.
- Field studies and modeling may be able to assess whether any such approach could be viable. Longer term, elucidating the physiological mechanisms responsible for virus- conditioned resistance to drought stress could reveal novel targets for genetic improvement of drought tolerance traits in wheat crops. Both of these applications could help contribute to sustaining cropland productivity in future climates.

References

Anderson, P.K., Cunningham, A.A., Patel, N.G., Morales, F.J., Epstein, P.R., & Daszak, P. (2004) Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers. Trends in Ecology and Evolution, 10, 535–544.

Rosenzweig, C. & Parry, M.L. (1994) Potential impact of climate change on world food supply. Nature, 367, 133–138.