UNIVERSITY OF LIVERPOOL

Department of Evolution, Ecology and Behaviour

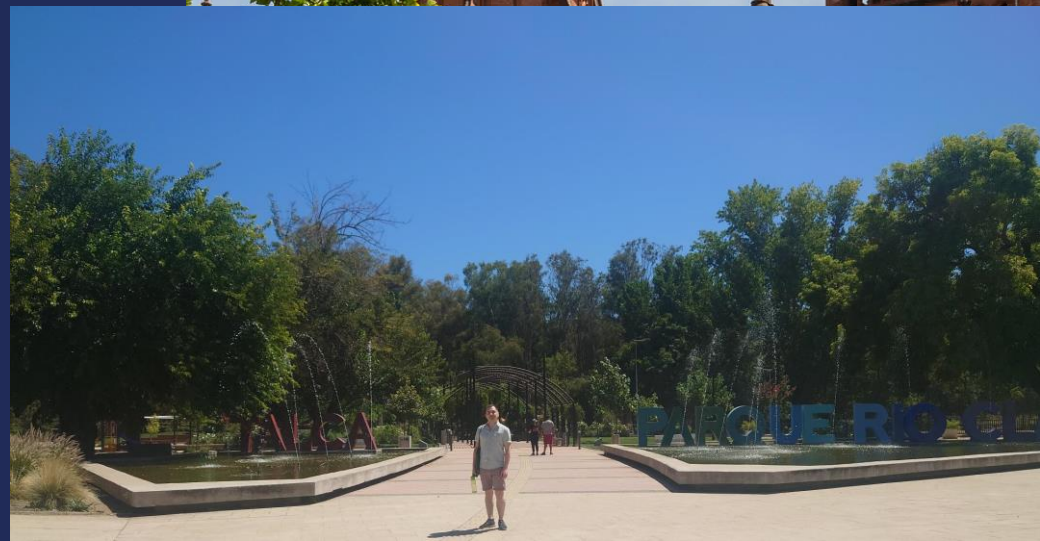


APHID RESISTANCE TRAITS AND DROUGHT STRESS:

THE PLANT RESISTANCE HYPOTHESIS

Dr Daniel Leybourne
1851 Research Fellow

Universidad de Talca, March 2024



1: Identifying aphid resistance traits

2: Drought impacts on aphid-plant interactions

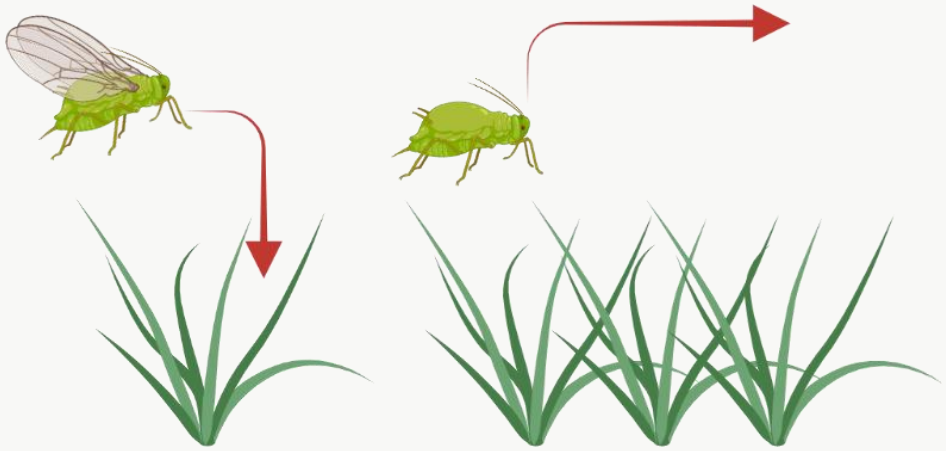
3: The plant resistance hypothesis

4: Holistic systems

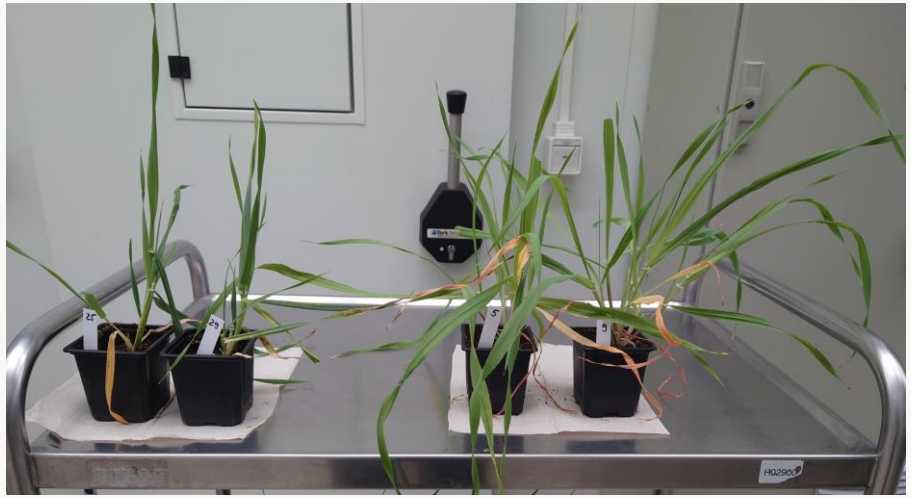




APHIDS: THE COMMON ENEMY









- Feeding damage – Reduce yields by ~ 5%
- Vectors of plant viruses – Yellow dwarf virus
- Virus infection – Reduce yields by >20%
- Insecticide resistance increasing

1: Identifying aphid resistance traits

2: Drought impacts on aphid-plant interactions

3: The plant resistance hypothesis

4: Holistic systems





IDENTIFYING APHID RESISTANCE

CASE STUDY: BARLEY

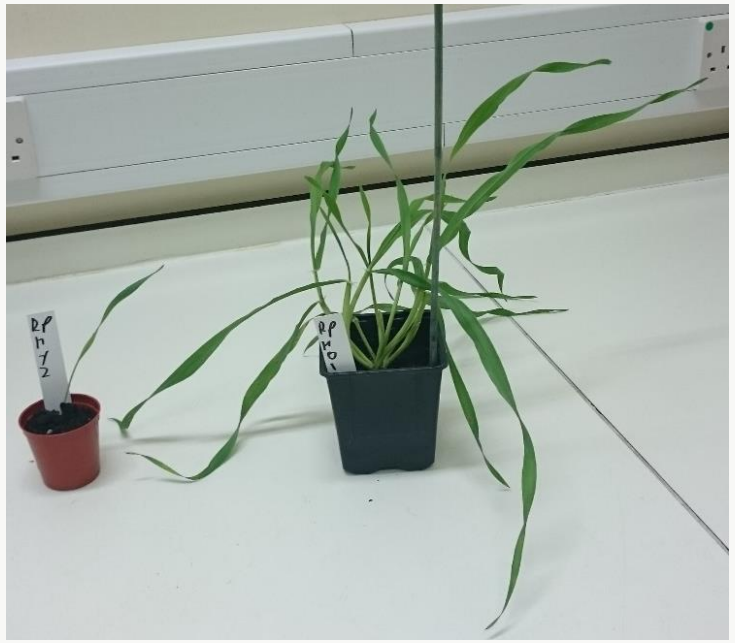
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Modern Barley: *Hordeum vulgare* cv. Concerto

- Elite cultivar
- Commercially grown
- Susceptible



Wild Relative:
Hordeum spontaneum 5 (Hsp5)

- Wild Israeli relative
- Arid conditions
- Partial-resistance against *R. padi* (Delp *et al.* 2009)



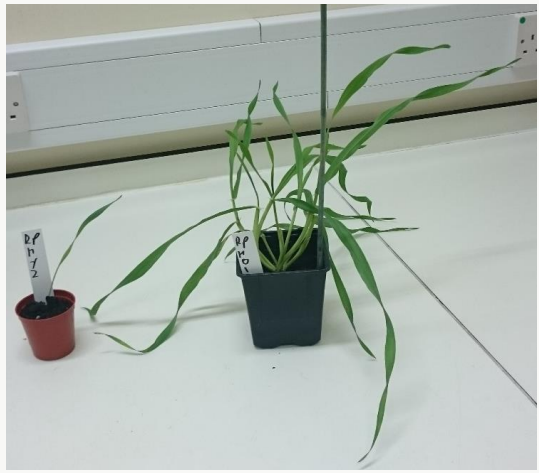
IDENTIFYING APHID RESISTANCE

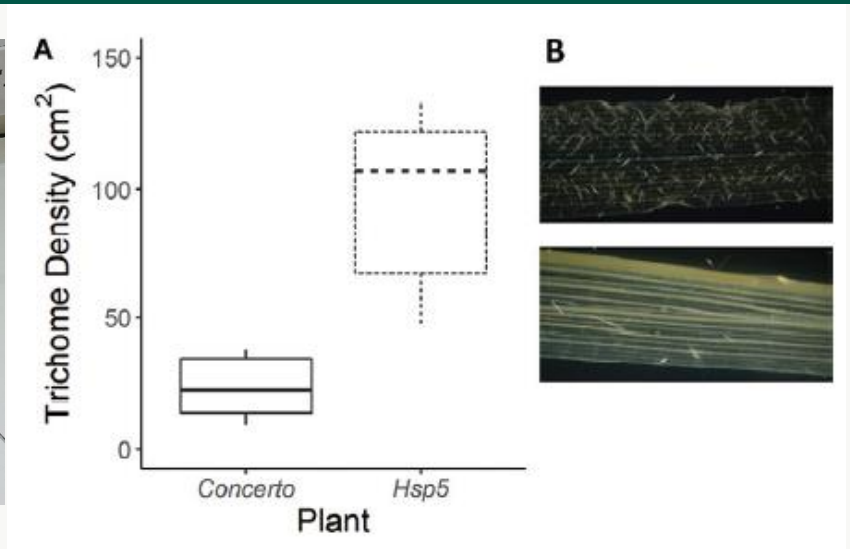
CASE STUDY: BARLEY

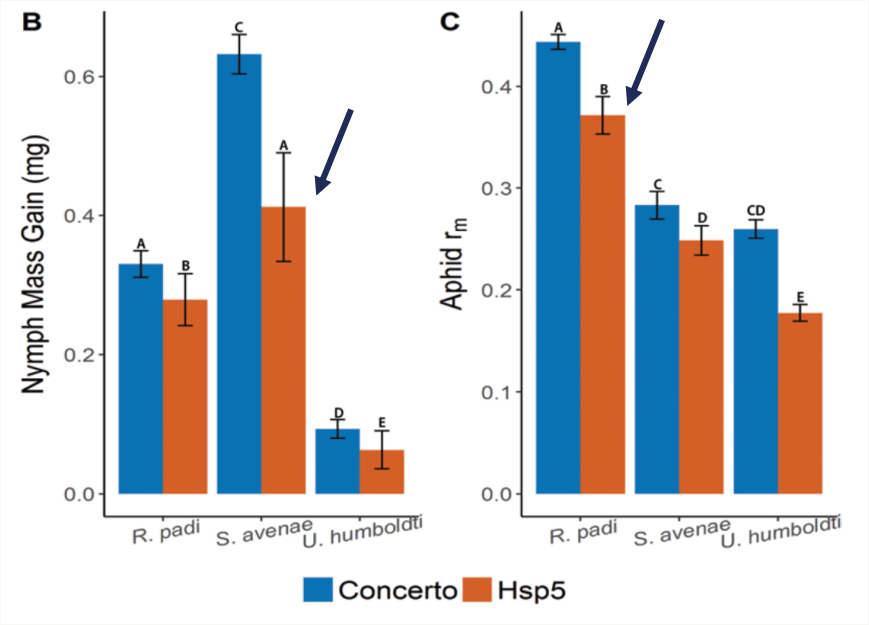
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Leybourne et al., 2019, *Journal Experimental Botany*

IDENTIFYING APHID RESISTANCE

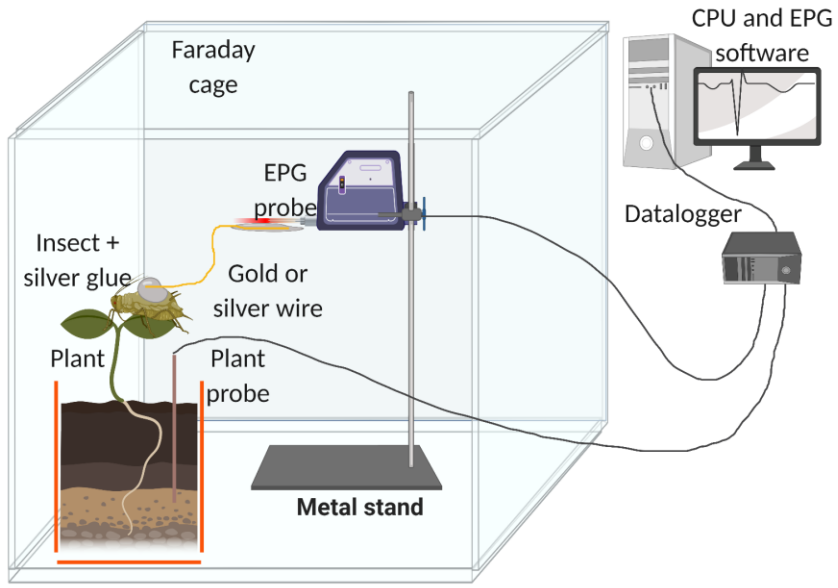
CASE STUDY: BARLEY

University of Dundee

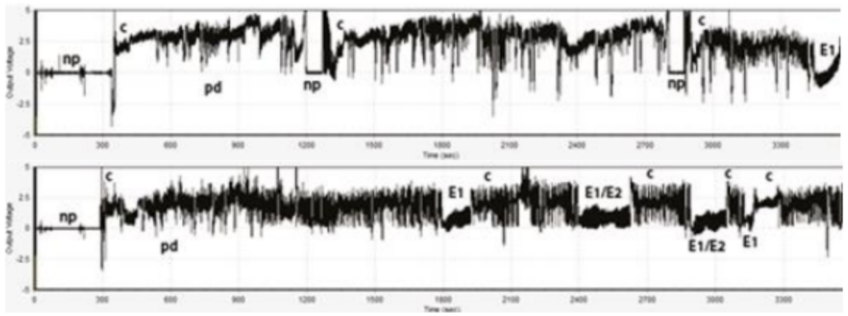
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A) Graphical representation of the EPG experimental setup

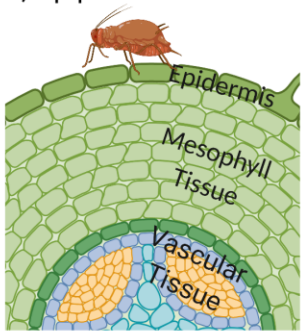


C) Example of EPG waveforms from a feeding study



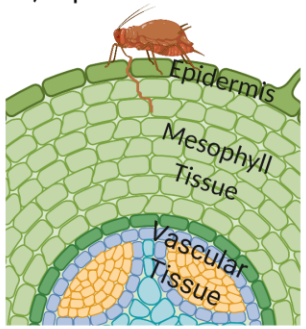
B) Overview of the main EPG phases and corresponding stylet activity in plant tissue

i) np phase



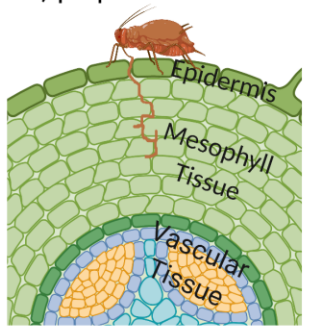
Insect stylet not in contact with plant tissue.

ii) C phase



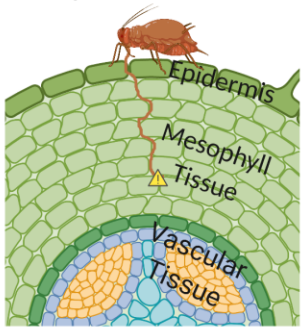
Insect stylet penetrates through epidermis tissue and into mesophyll tissue.

iii) pd phase



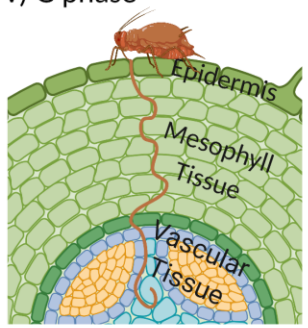
Insect stylet penetrates a mesophyll cell, leading to an observed potential drop on the electrogram.

iv) F phase



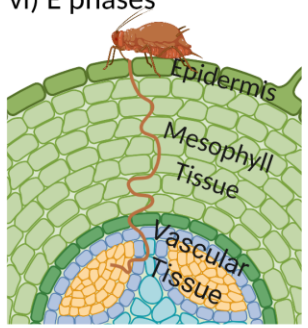
Insect stylet experiences penetration difficulties in the mesophyll tissue.

v) G phase



Insect stylet penetrates xylem tissue and xylem ingestion occurs.

vi) E phases



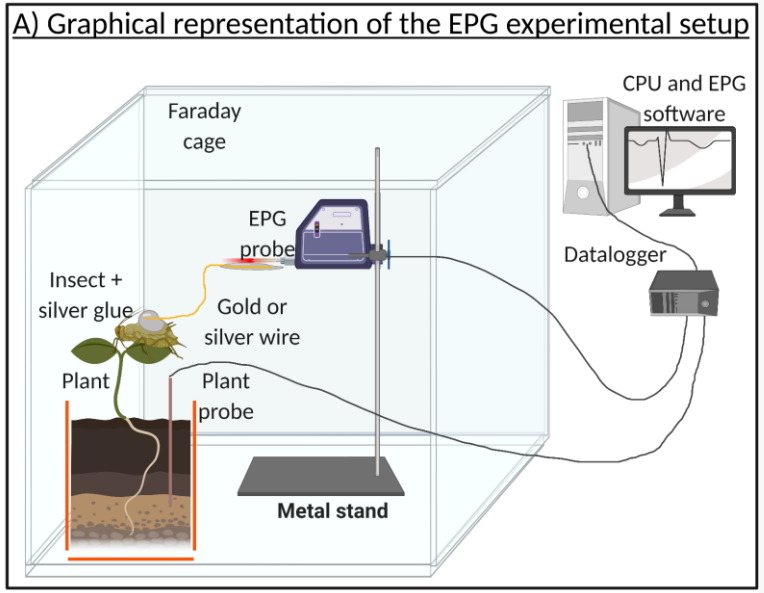
Insect stylet penetrates the phloem tissue. Three possible phases:
E1 - salivation into the phloem sap
E2 - ingestion of phloem sap
sE2 - >10 minutes ingestion of phloem sap

IDENTIFYING APHID RESISTANCE

CASE STUDY: BARLEY

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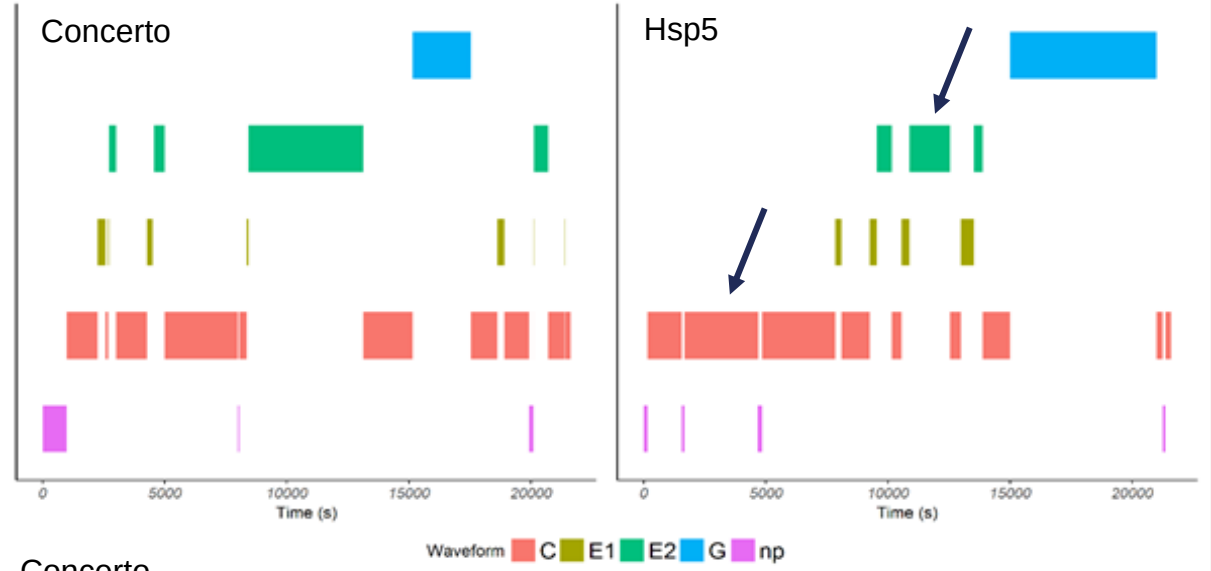
Xylem Ingestion

Phloem: Ingestion

Phloem: Salivation

Penetrating Mesophyll

Not Probing



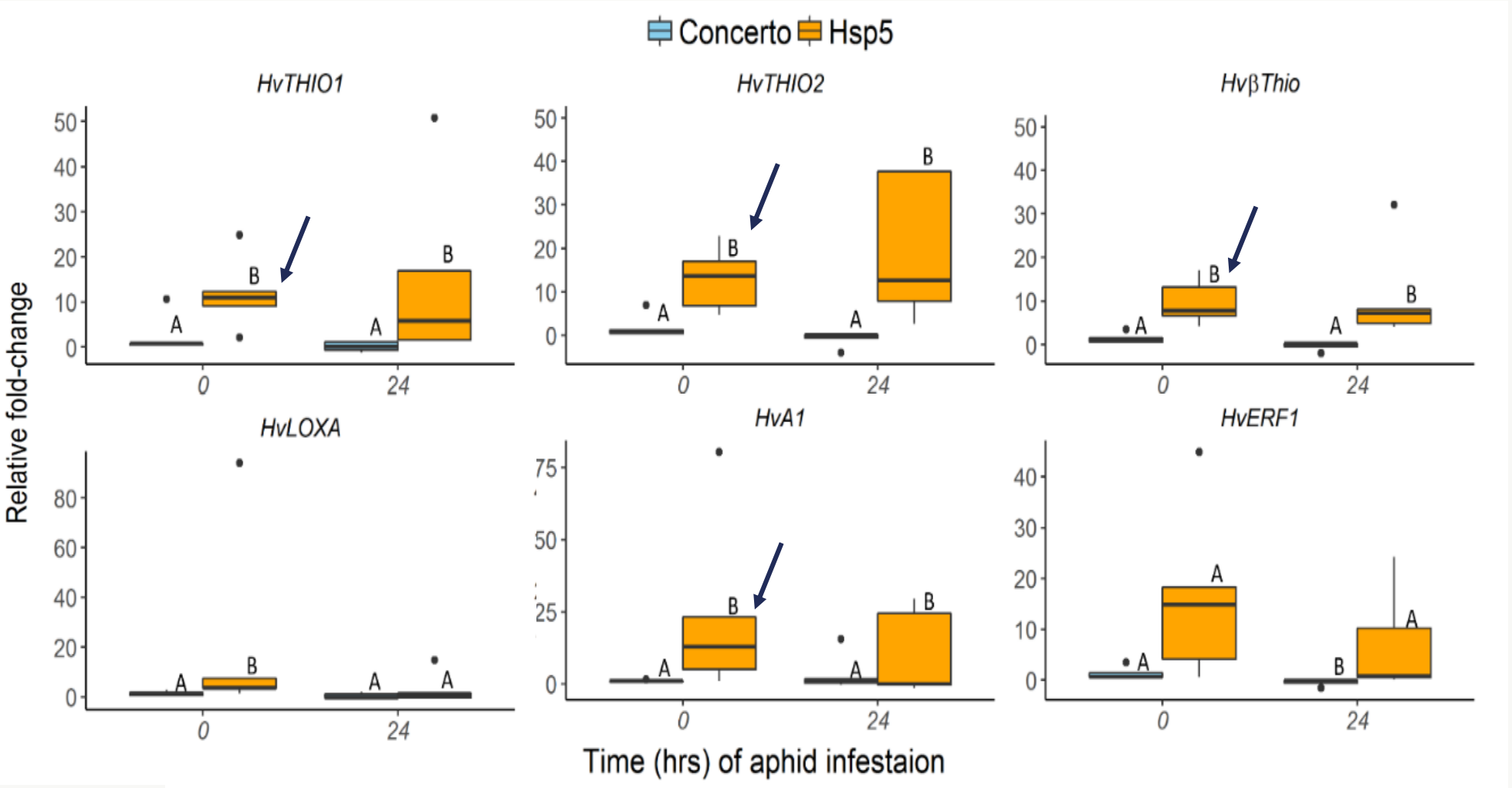
- Increase in time spent probing mesophyll tissue (mesophyll-resistance)
- Decrease in phloem ingestion (phloem-resistance)

Leybourne et al., 2019, *Journal Experimental Botany*

IDENTIFYING APHID RESISTANCE

CASE STUDY: BARLEY

- *HvThionin*: Defensive genes (antimicrobial)
- *HvA1*: ABA-responsive gene (drought tolerance?)



Leybourne et al., 2019, *Journal Experimental Botany*

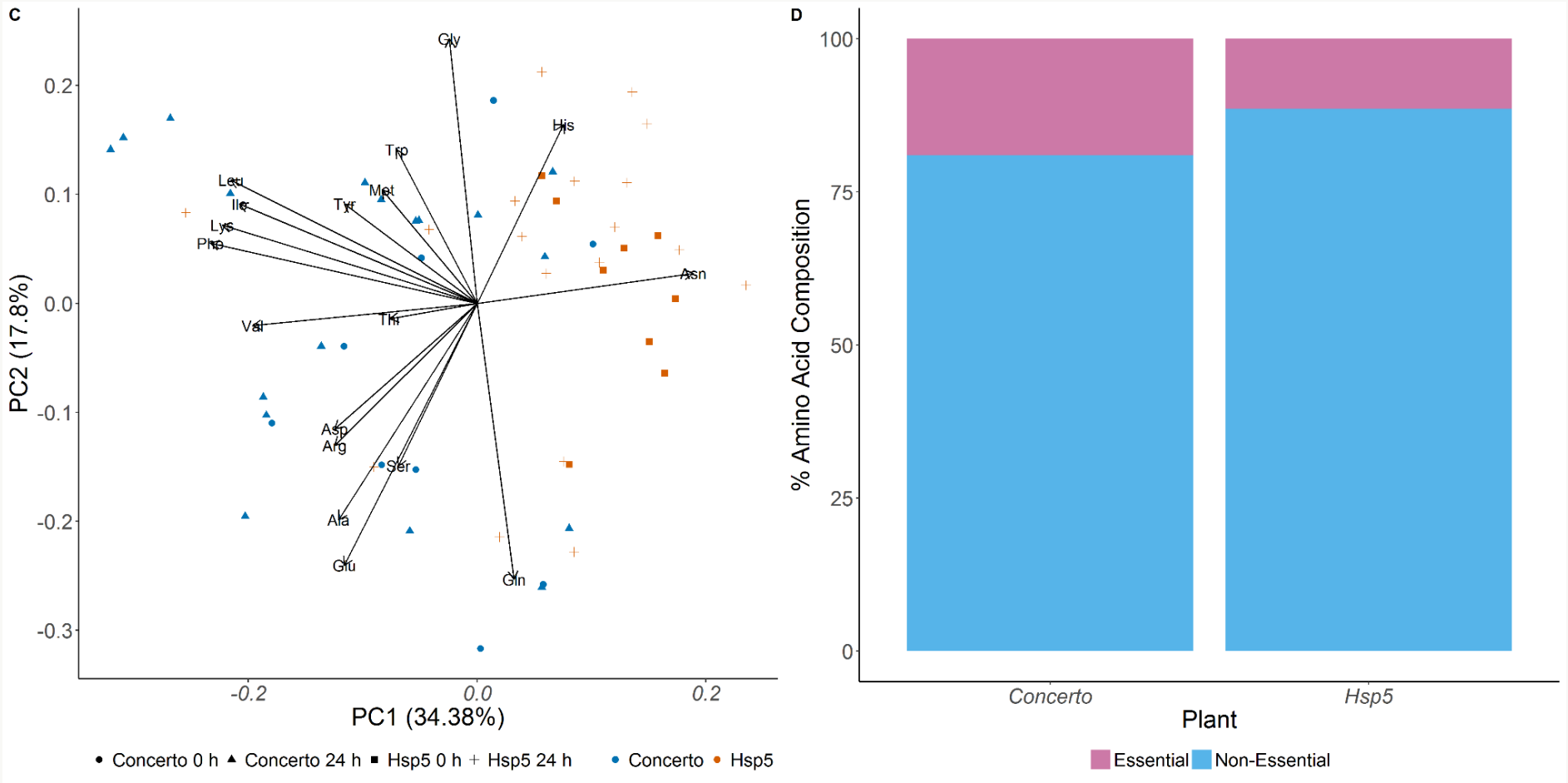
IDENTIFYING APHID RESISTANCE

CASE STUDY: BARLEY

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- Differences in amino acid compositions (more Asn, His in Hsp5)
- Increase in non-essential amino acid in resistant plant



Leybourne et al., 2019, *Journal Experimental Botany*

IDENTIFYING APHID RESISTANCE

CASE STUDY: BARLEY

University of Dundee

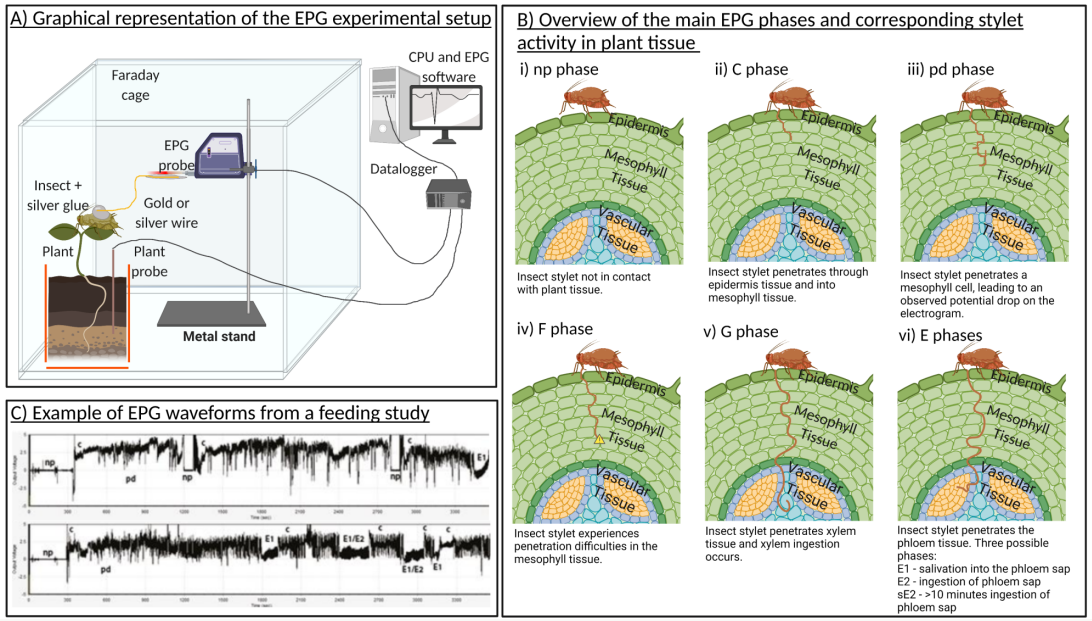
The James Hutton Institute

- Wild barley relative partially-resistant to three cereal aphid species
- EPG indicated mesophyll and phloem mediated resistance
- Associated with up-regulation of “defence” genes (Thionin family important)
- Decrease in essential amino acid composition (differences in nutritional quality)

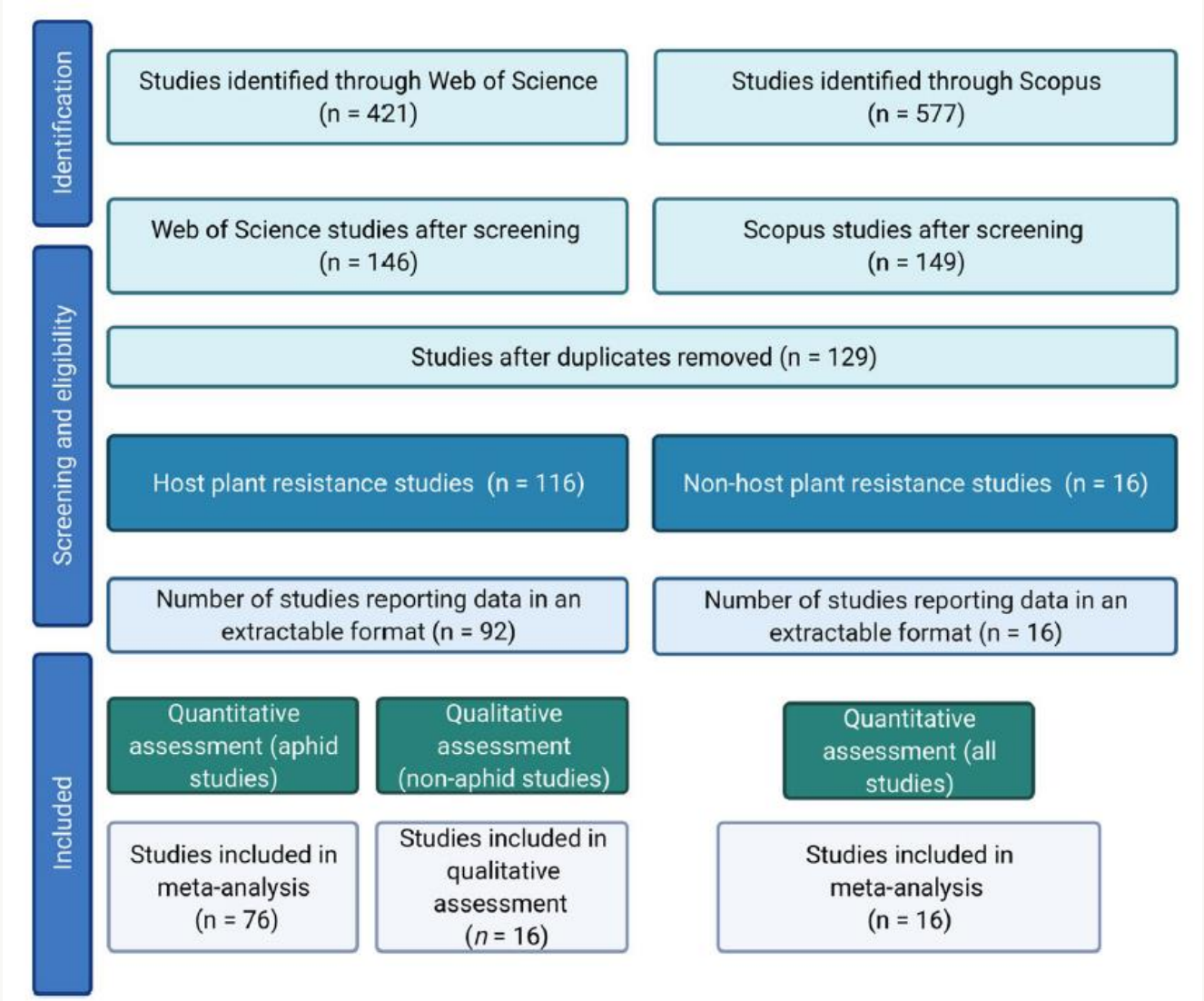


IDENTIFYING APHID RESISTANCE

COMMON MECHANISMS?



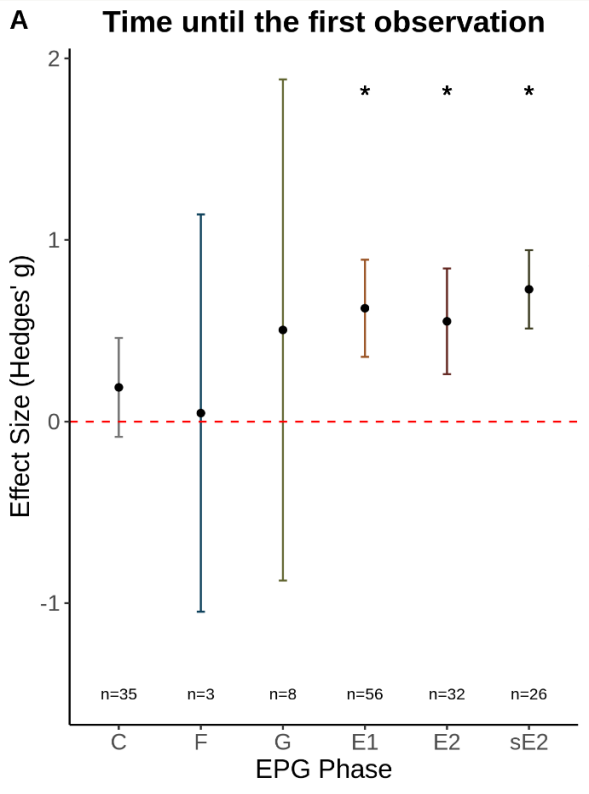
How common are resistance traits?

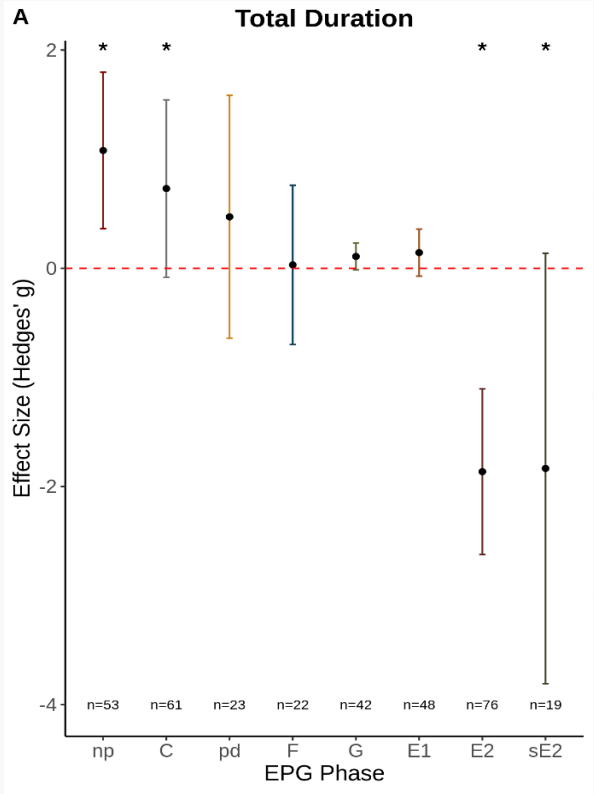


Leybourne & Aradottir, 2022, Scientific Reports

IDENTIFYING APHID RESISTANCE

COMMON MECHANISMS?





Insect feeding behaviour	Chinch bug *n* = 1	Leafhopper *n* = 3	Planthopper *n* = 4	Psyllid *n* = 1	Whitefly *n* = 7	Aphid *n* = 77
Non-probing	Duration ↑	Duration ↑	Duration ↑	Duration ↑	Duration ↑	Duration ↑
Tissue probing	Duration ↑	Duration ↓	Duration ↑	Duration ↑	Time to First ↑ Duration ↓	Time to First — Duration ↑
Salivation into the phloem	Duration —	Duration ↑	Time to First ↑ Duration —	Time to First ↑	Time to First ↑ Duration ↓	Time to First ↑ Duration —
Sap ingestion from phloem	Duration ↓	Duration ↓	Time to First ↑ Duration ↓	Time to First ↑ Duration ↓	Time to First ↑ Duration ↓	Time to First ↑ Duration ↓
Sap ingestion from Xylem	Duration ↓		Duration —	Time to First ↑ Duration ↓	Duration ↑	Time to First — Duration —

Leybourne & Aradottir, 2022, Scientific Reports

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DROUGHT AND WATER STRESS

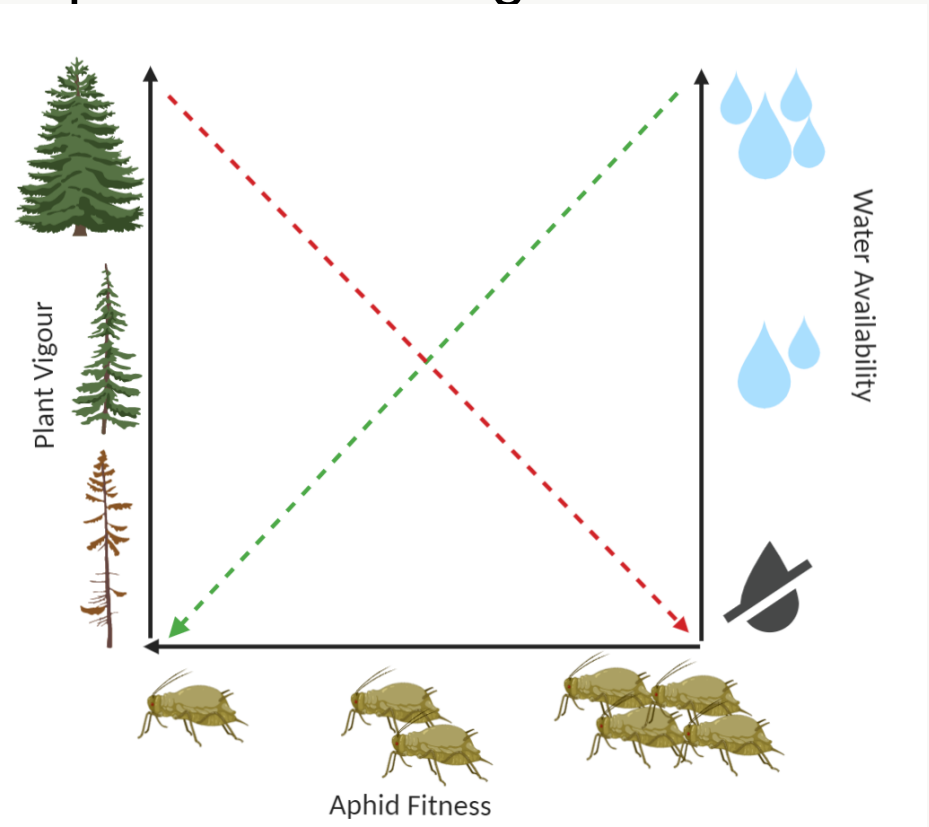
- Increasing drought: 40% reduction in precipitation by 2070
- Direct effect on plant growth and productivity
- Indirect effect on aphid biology: mediated by plant responses to drought

Plant Stress Hypothesis: insect numbers increase

- Water stress results in altered plant physiology
- N availability increases making plants better hosts

Plant Vigour Hypothesis: insect numbers decrease

- N increases
- Defensive compounds increase in abundance
- Cell turgour is reduced

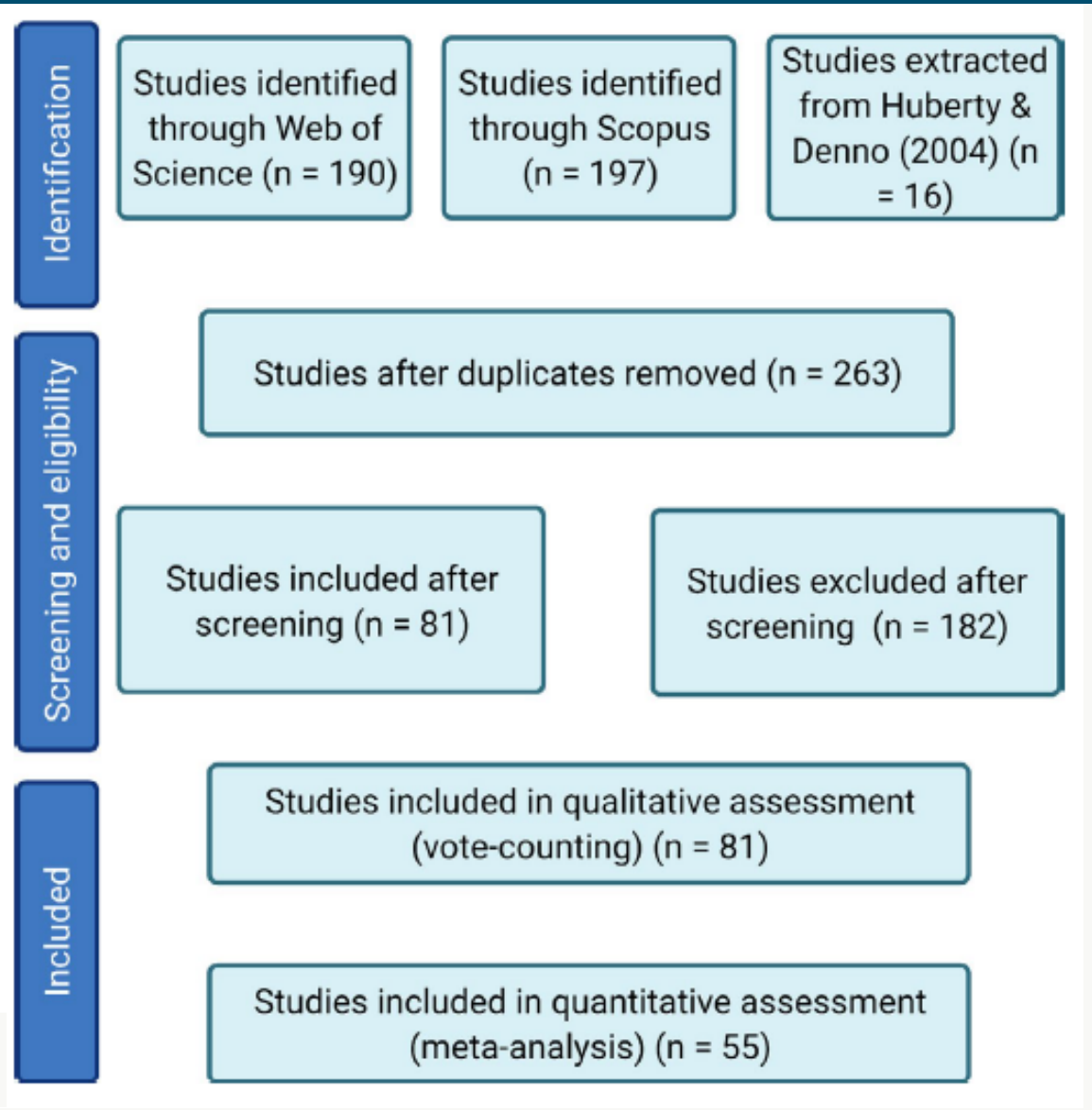


NEGATIVE EFFECTS OF DROUGHT ON APHIDS

University of Dundee

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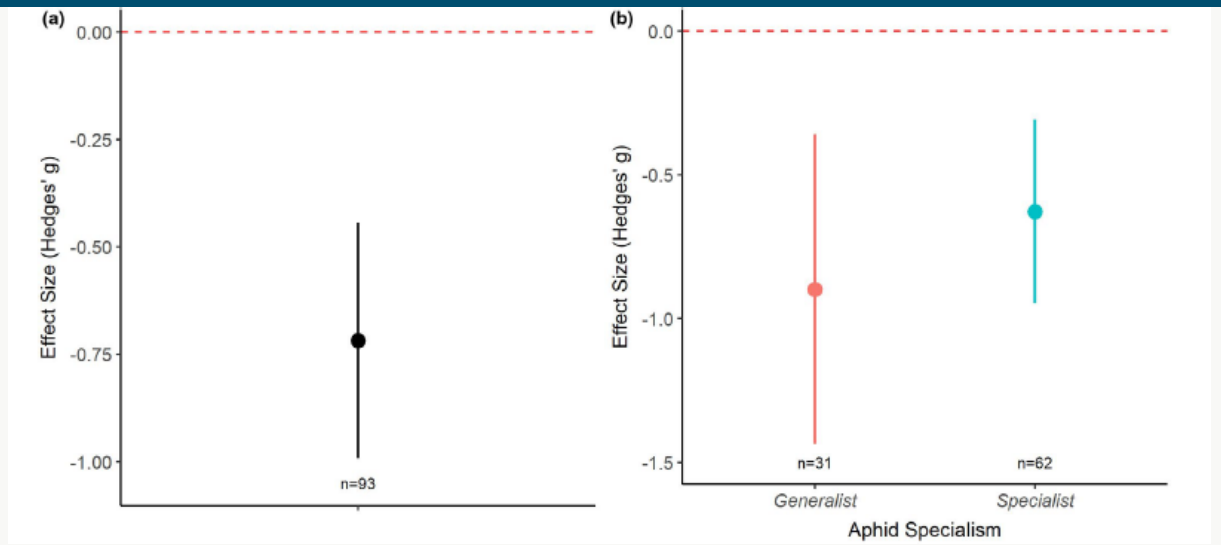


Does drought impact all aphids equally?

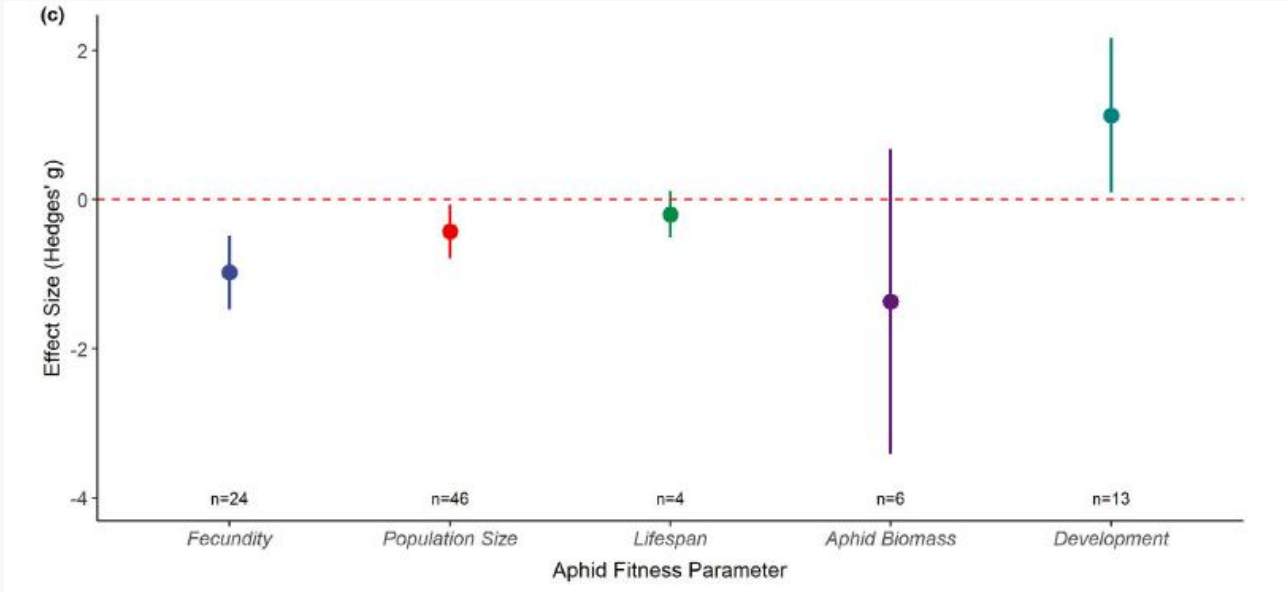
Leybourne et al., 2021, Ecology and Evolution

NEGATIVE EFFECTS OF DROUGHT ON APHIDS





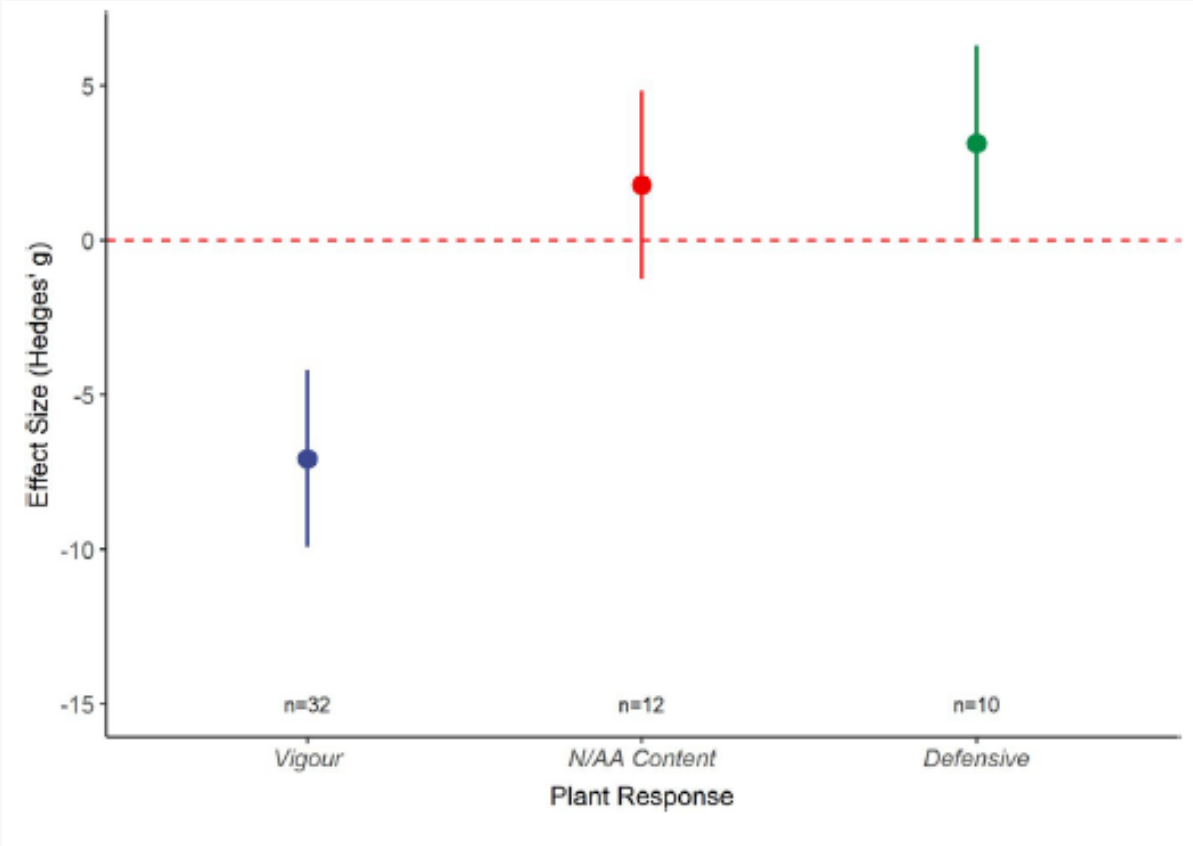
- General negative effect of drought in aphid fitness
- Negative effect consistent across fitness parameters



Leybourne et al., 2021,
Ecology and Evolution

NEGATIVE EFFECTS OF DROUGHT ON APHIDS



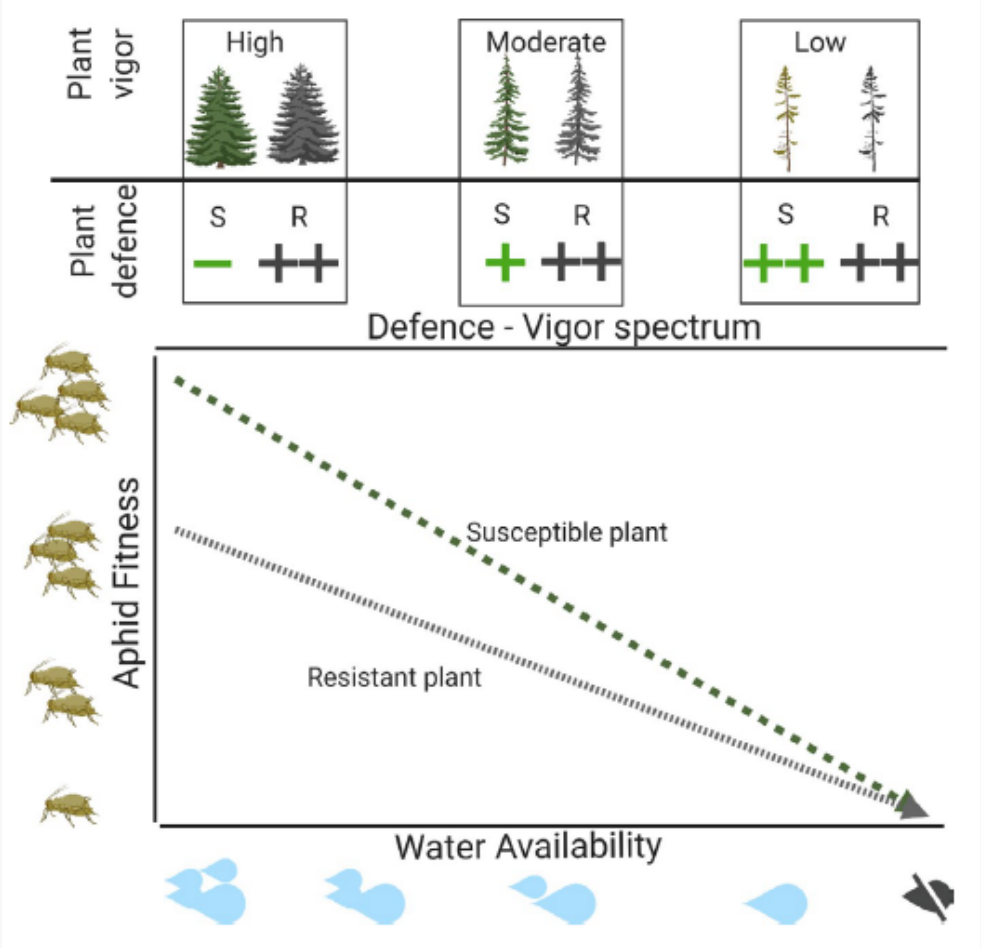


- Negative effect on plant physiology
- Increase in plant N and AA content
- Increase in plant defensive processes (e.g., secondary metabolites)

Leybourne et al., 2021,
Ecology and Evolution

THE PLANT RESISTANCE HYPOTHESIS





- Drought – Negative for aphids
- Impact on aphids potentially mediated by changes in plant physiology, defence, and biochemistry
- Possibly different impacts on aphid from resistant and susceptible plants

Leybourne et al., 2021, Ecology and Evolution

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TESTING THE PLANT RESISTANCE HYPOTHESIS

University of Dundee

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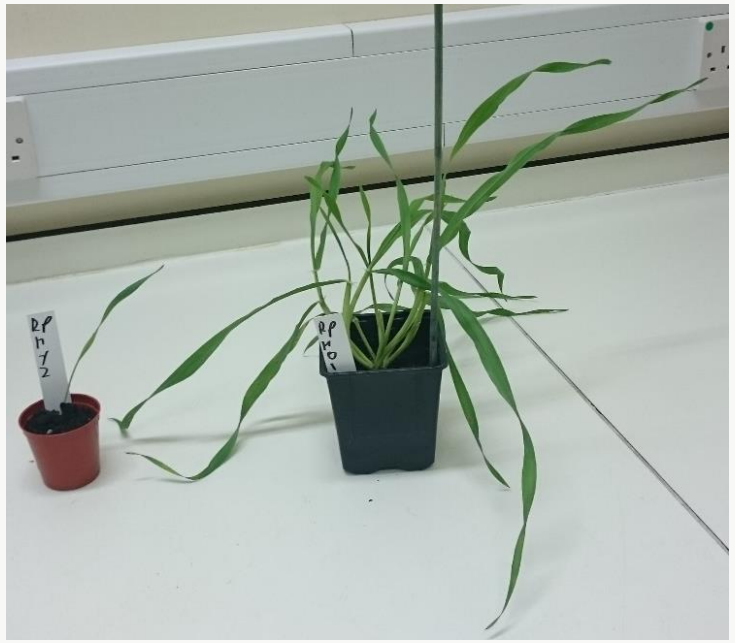






Modern Barley: *Hordeum vulgare* cv. Concerto

- Elite cultivar
- Commercially grown
- Susceptible



Wild Relative: *Hordeum spontaneum* 5 (Hsp5)

- Wild Israeli relative
- Arid conditions
- Partial-resistance against *R. padi* (Delp *et al.* 2009)
- Partial-resistance against *R. padi, S. avenae, U. humboldti*

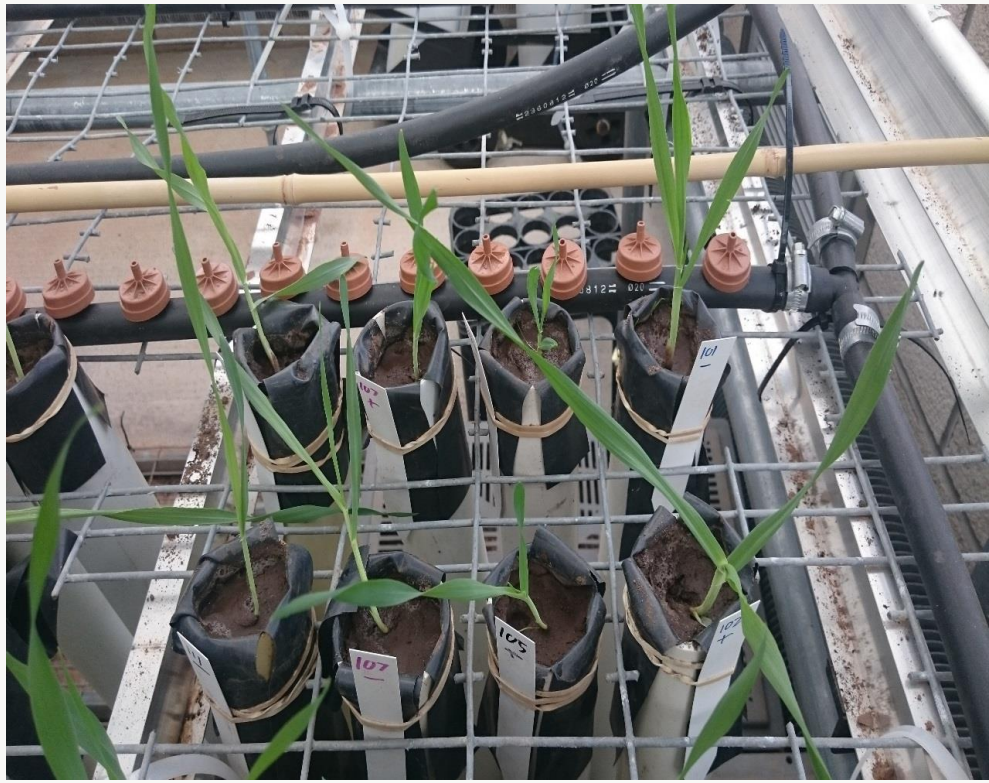
TESTING THE PLANT RESISTANCE HYPOTHESIS

Three treatments (based on soil properties):

- Control
- Water (reduced water availability)
- Compounding (water treatment + increased soil compaction)

Prolonged exposure of plants to treatment.
Two harvests:

- 24 h post-aphid infestation (molecular; *n* = *6*)
- 7 d post-aphid infestation (physiological; *n* = *14*)



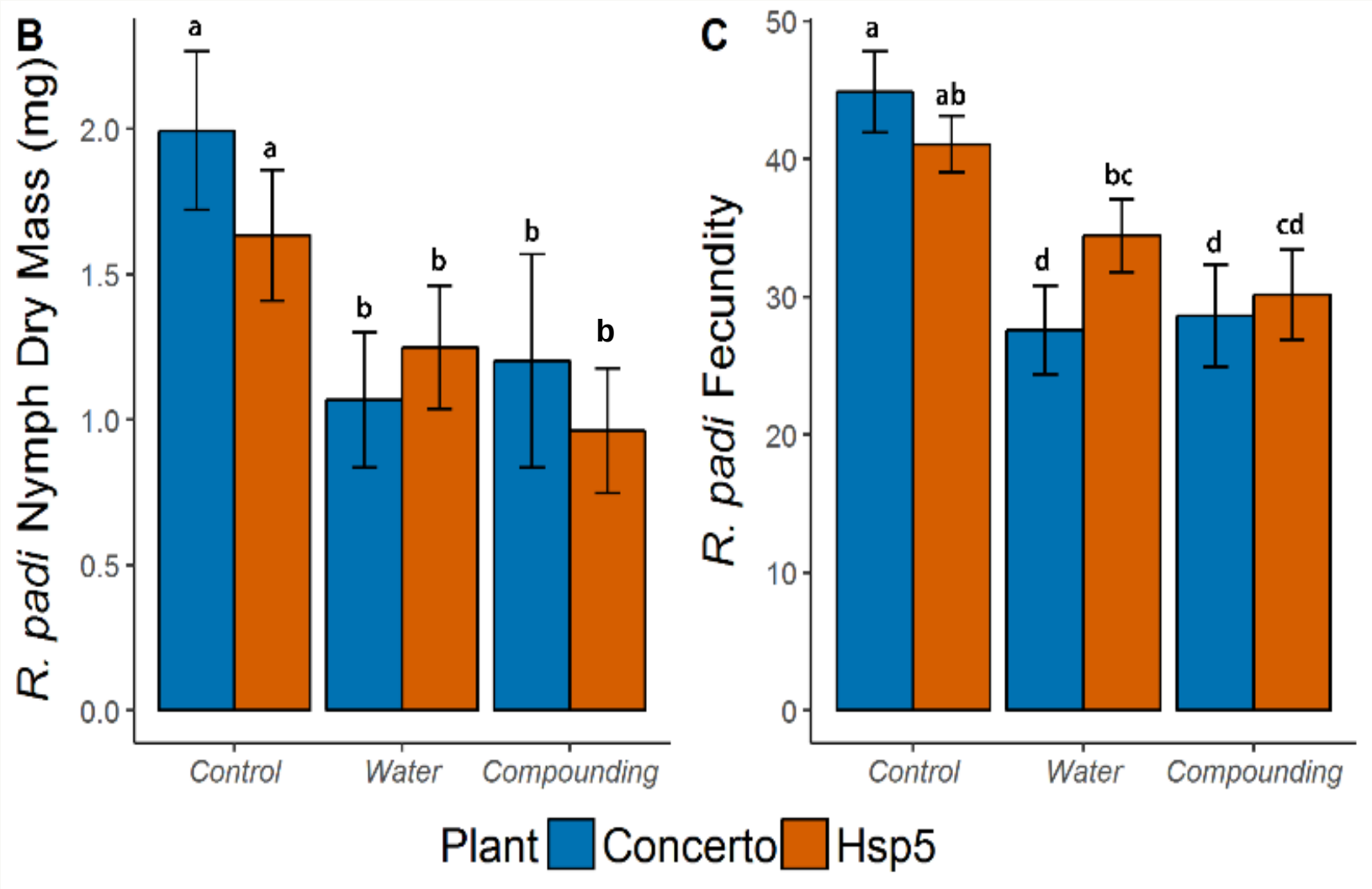
TESTING THE PLANT RESISTANCE HYPOTHESIS



A range of plant physiological parameters assessed

- Development time
- Shoot mass
- Root mass
- Root:shoot
- Root length

Leybourne et al., 2022, *Journal Experimental Botany*

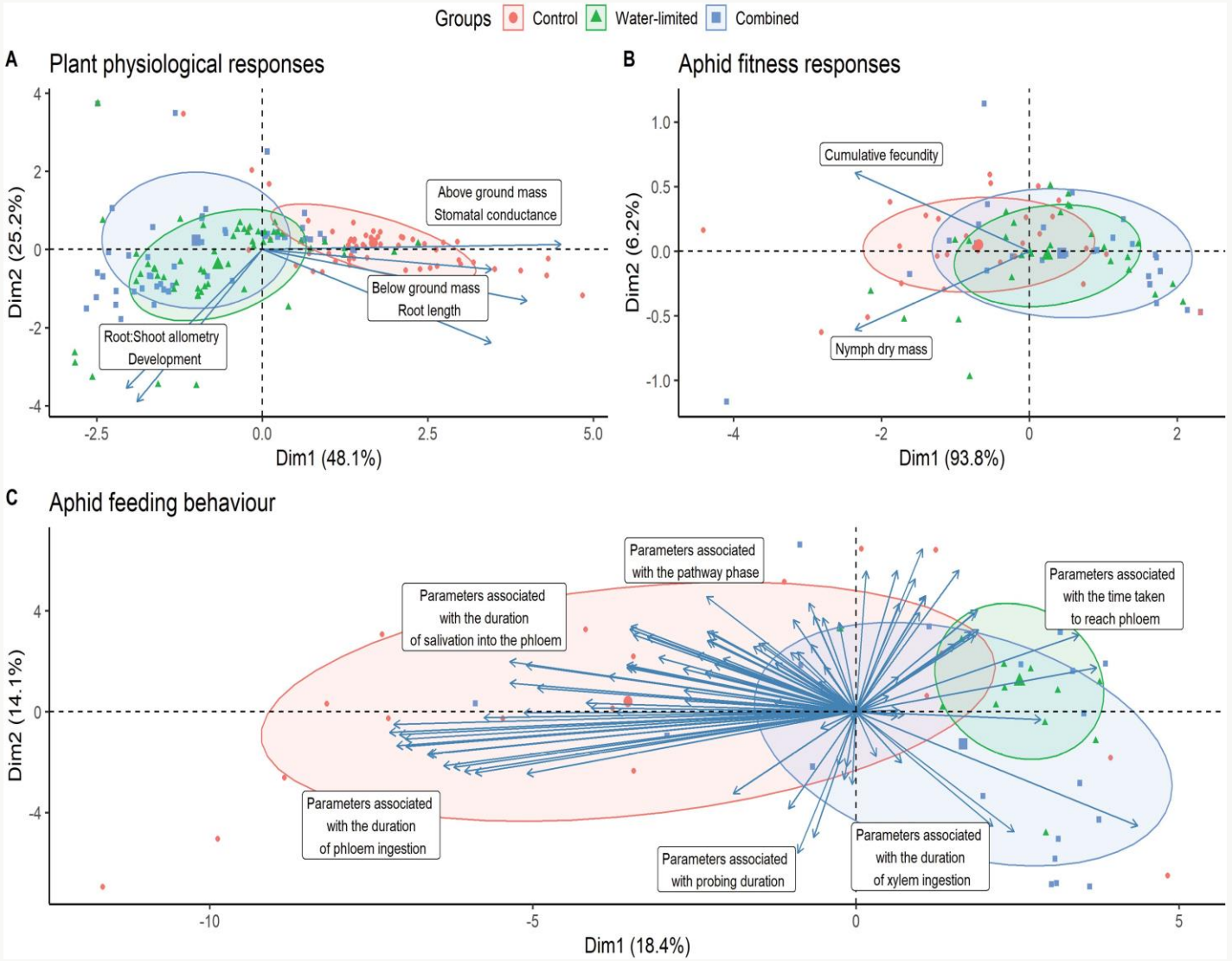


TESTING THE PLANT RESISTANCE HYPOTHESIS





Leybourne et al., 2022, *Journal Experimental Botany*



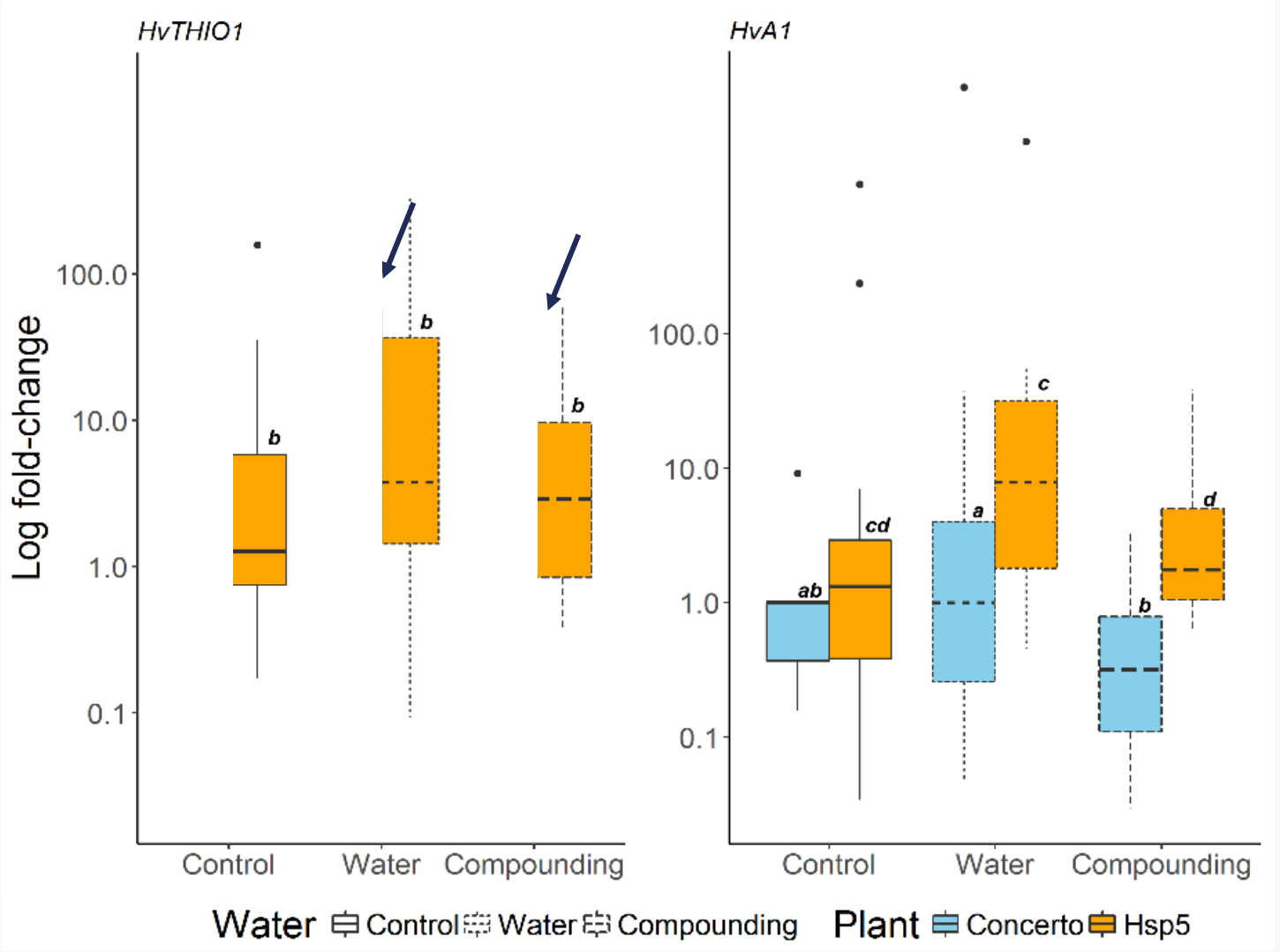
TESTING THE PLANT RESISTANCE HYPOTHESIS

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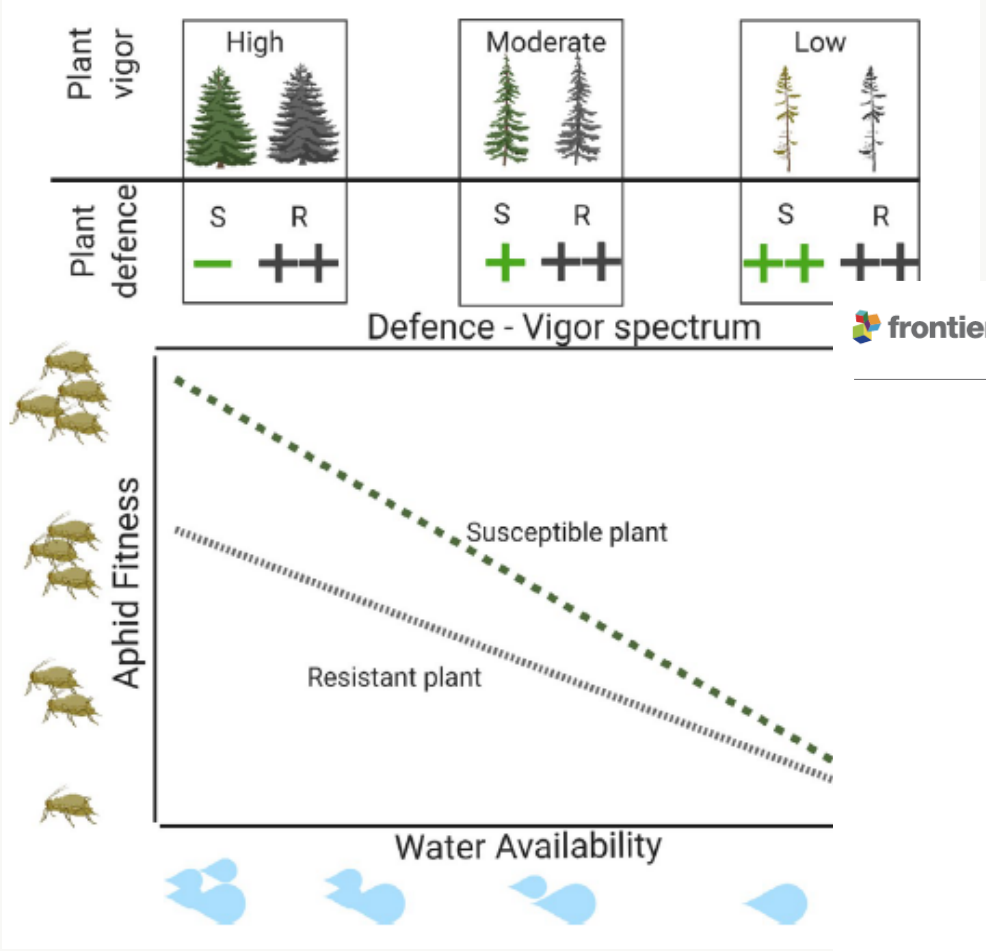
Also examined aphid responses:

- Detoxification genes (some effect)
- Effectors (no response)



Leybourne et al., 2022, *Journal Experimental Botany*

TESTING THE PLANT RESISTANCE HYPOTHESIS



- Exposure to drought stress reduces plant vigour
- Drought stress broadly reduces aphid fitness

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frontiers | Frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 18 April 2022
doi: 10.3389/fevo.2022.846908

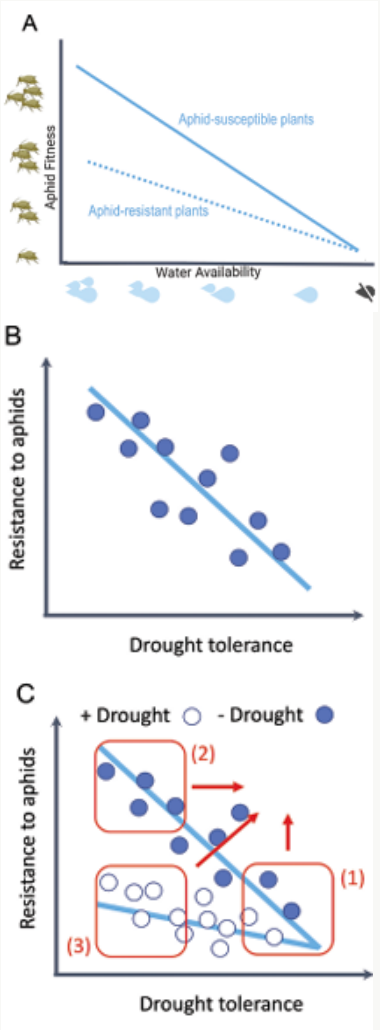
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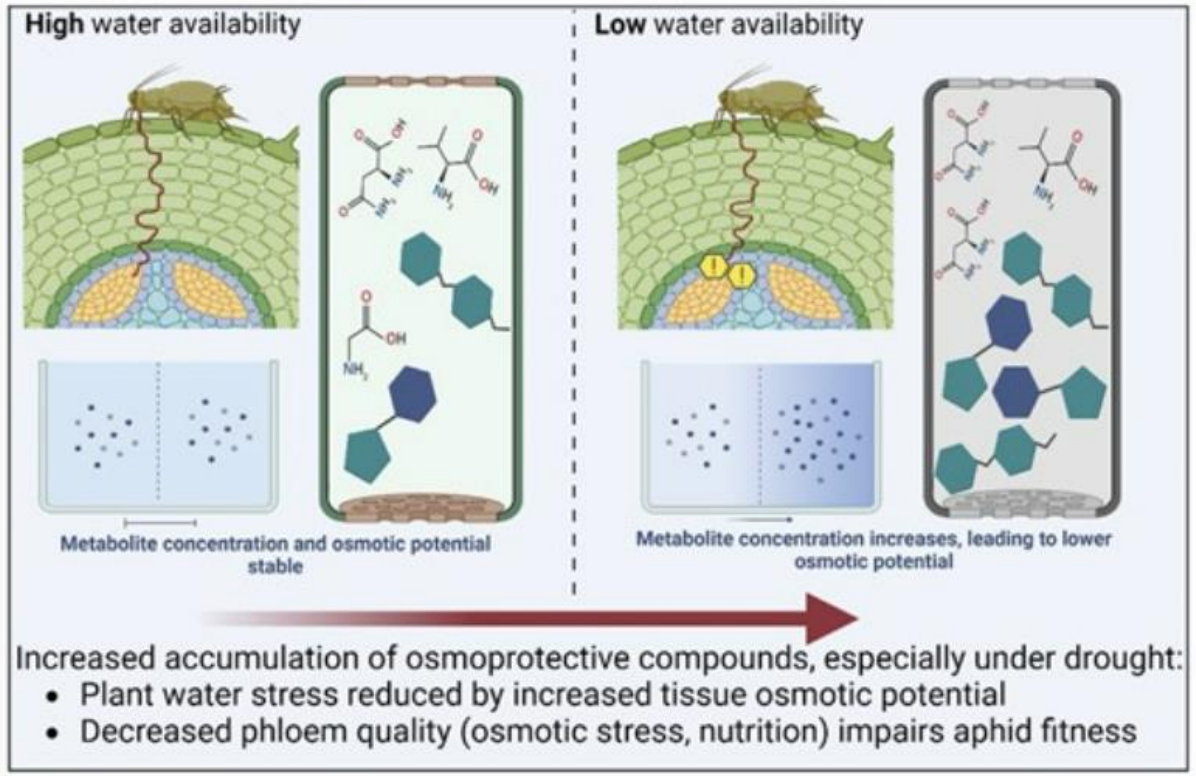
Plant Water Stress Reduces Aphid Performance: Exploring Mechanisms Driven by Water Stress Intensity

Jessica T. Kansman[1], Saumik Basu[2], Clare L. Casteel[3], David W. Crowder[2], Benjamin W. Lee[2], Chad T. Nihranz[3] and Deborah L. Finke[1]*

[1] Division of Plant Science and Technology, Columbia, MO, United States, [2] Department of Entomology, Washington State University, Pullman, WA, United States, [3] Plant Pathology and Plant-Microbe Biology, Cornell University, Ithaca, NY, United States

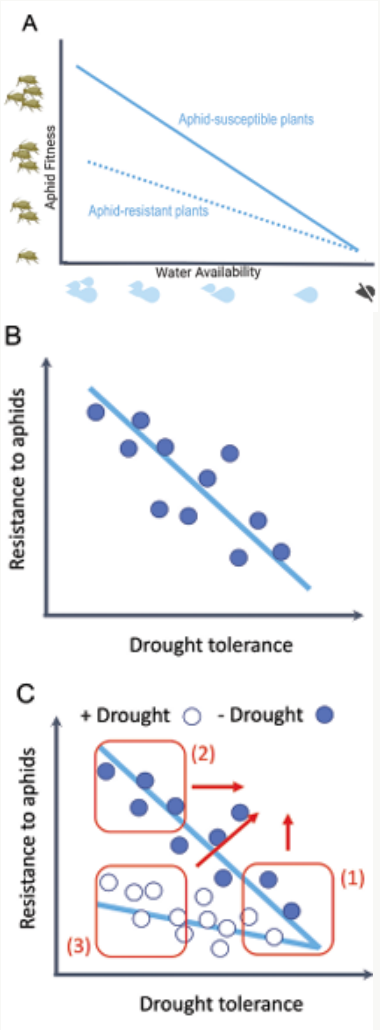
EXPANDING THE PLANT RESISTANCE HYPOTHESIS

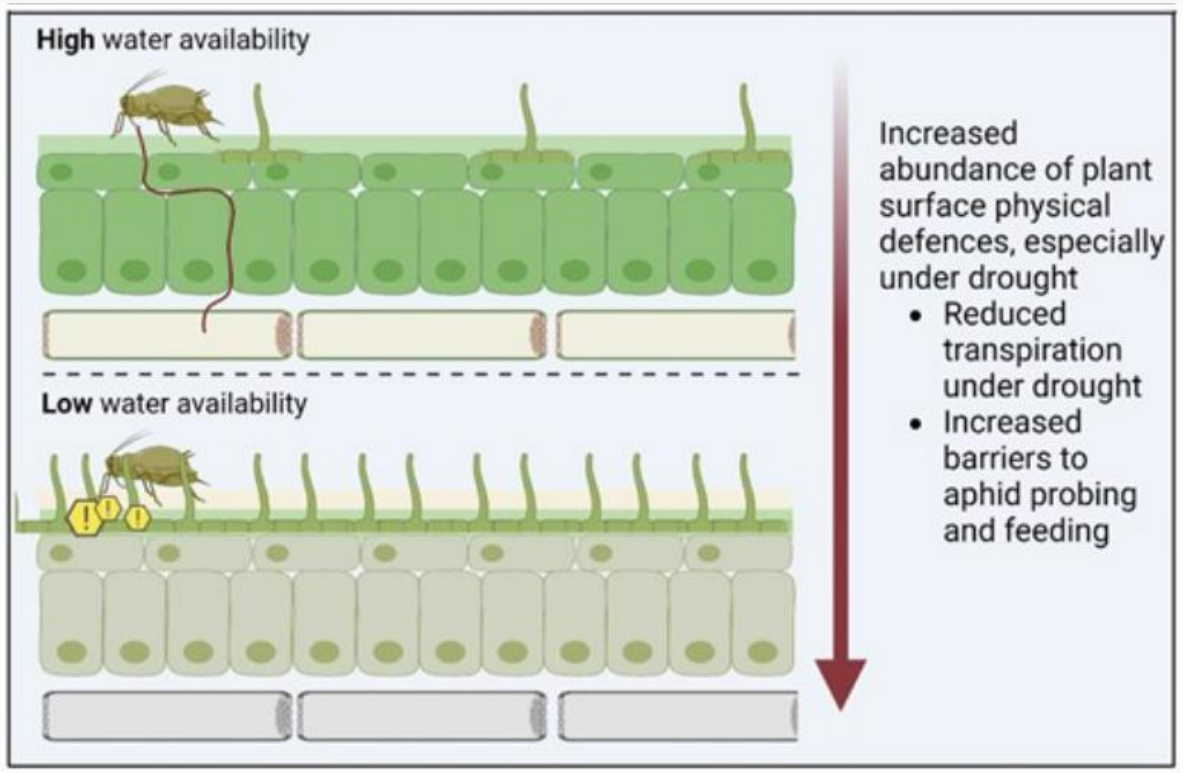




Ramirez et al., 2023, *Journal of Experimental Botany*

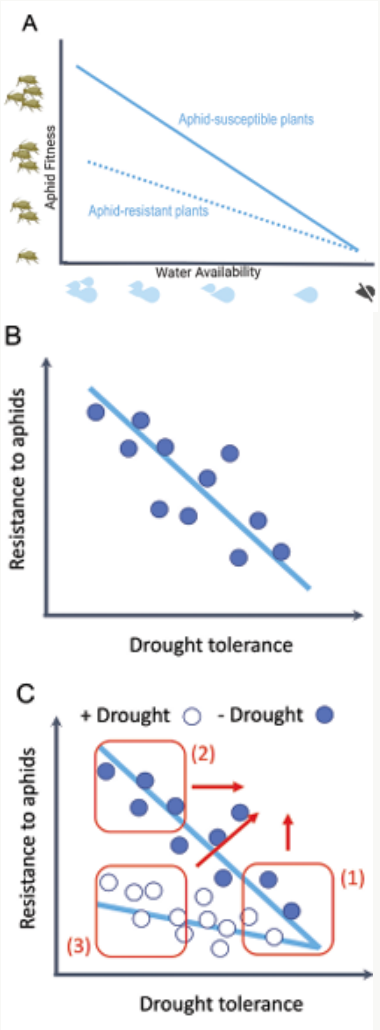
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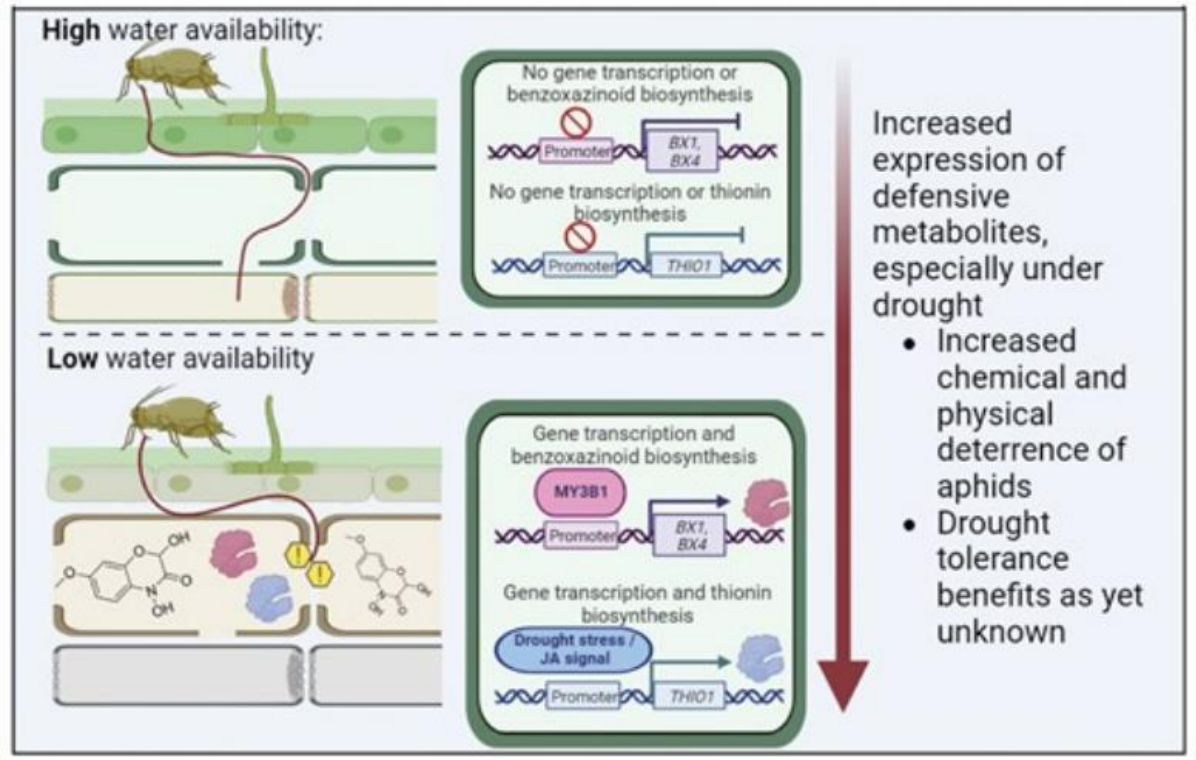




Ramirez et al., 2023, *Journal of Experimental Botany*

EXPANDING THE PLANT RESISTANCE HYPOTHESIS





Ramirez et al., 2023, *Journal of Experimental Botany*

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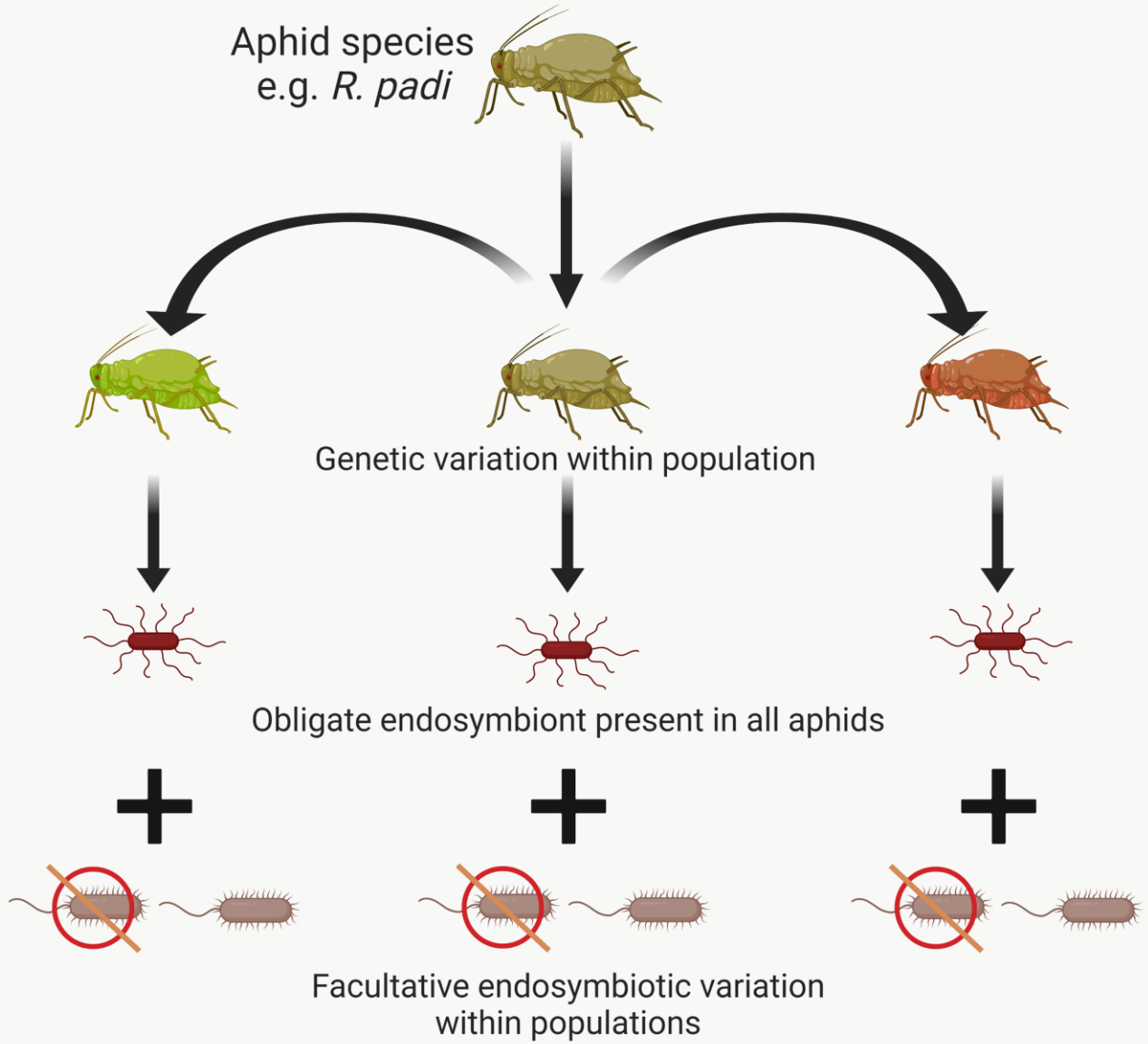




TOWARDS HOLISTIC SYSTEMS: INTRA-SPECIES DIVERSITY

UNIVERSITY OF LIVERPOOL

- Influence fitness
- Confer resistance
  - Natural enemies (parasitoid wasps)
  - Insecticides
- Influence interactions with environment
- Determine host range

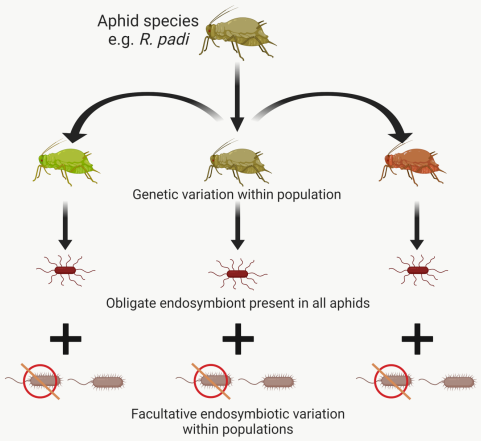


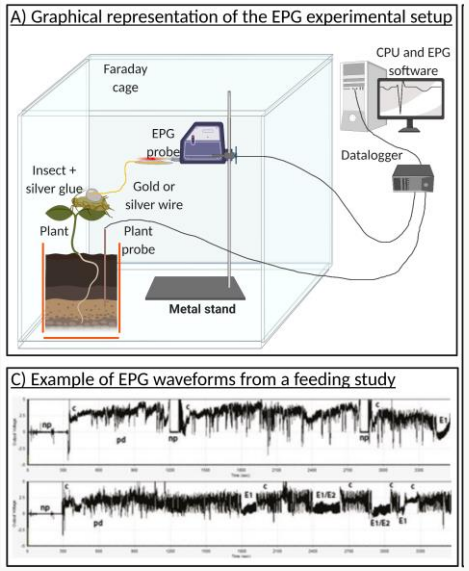


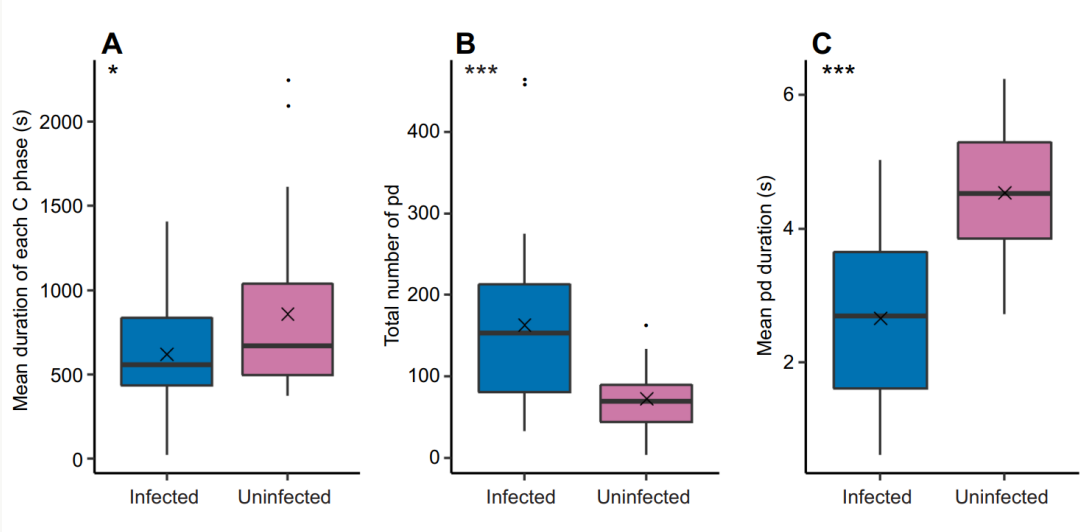
Main facultative endosymbionts:

- *Hamiltonella defensa*
- *Regiella insecticola*
- *Serratia symbiotica*
- *Fukatsia symbiotica*
- *Aresnophonus spp.*
- *Rickettsia spp.*
- *Ricketsiella spp.*
- *Spiroplasma spp.*

TOWARDS HOLISTIC SYSTEMS: INTRA-SPECIES DIVERSITY





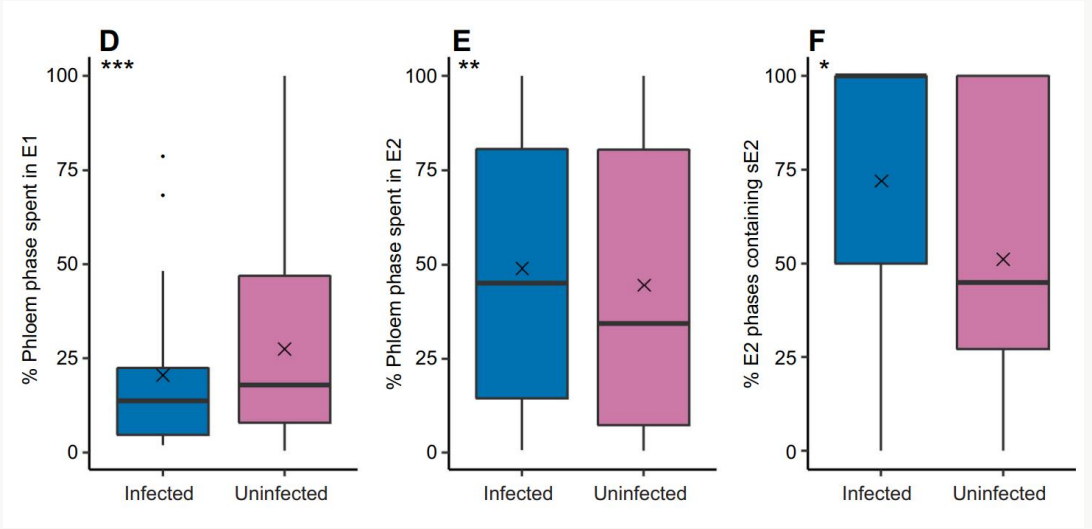


Impacts interactions with mesophyll:

1. Decreased duration of mesophyll contact
2. Increase number of cell punctures
3. Decreased duration of each cell puncture

Impacts interactions with phloem:

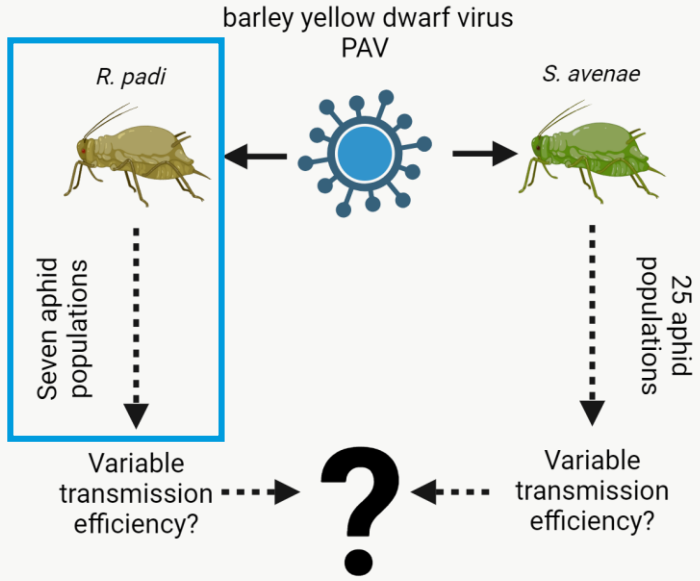
1. Decrease in % time salivating into phloem
2. Increase in % time ingesting phloem
3. Increase in % of sustained ingestion of phloem



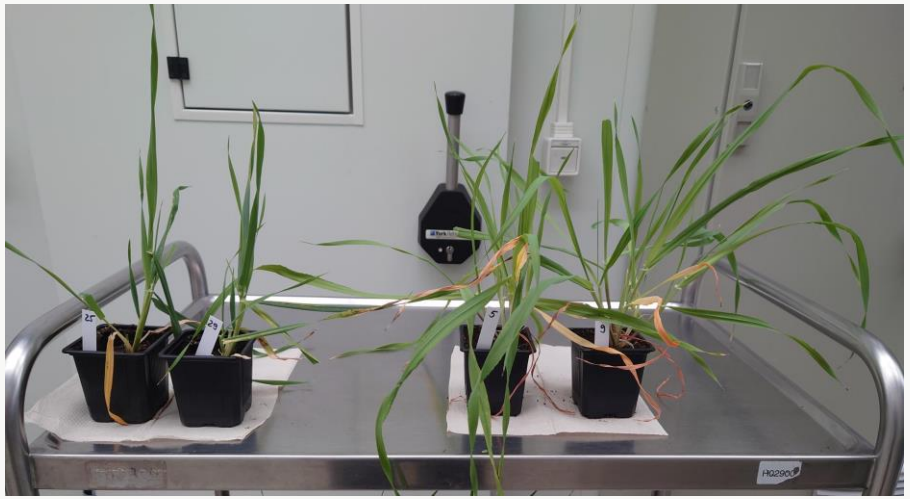
Leybourne et al., 2020, Journal Experimental Biology

TOWARDS HOLISTIC SYSTEMS: INTRA-SPECIES DIVERSITY

UNIVERSITY OF LIVERPOOL







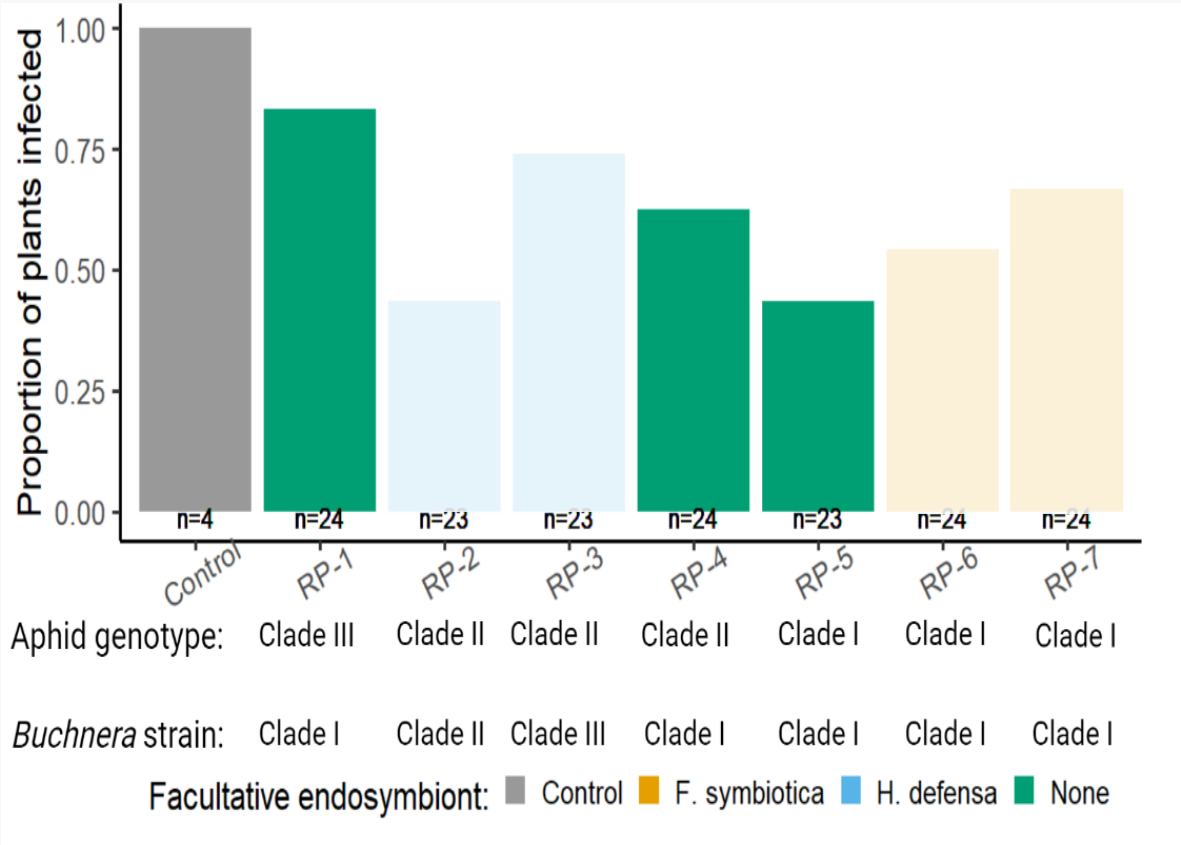


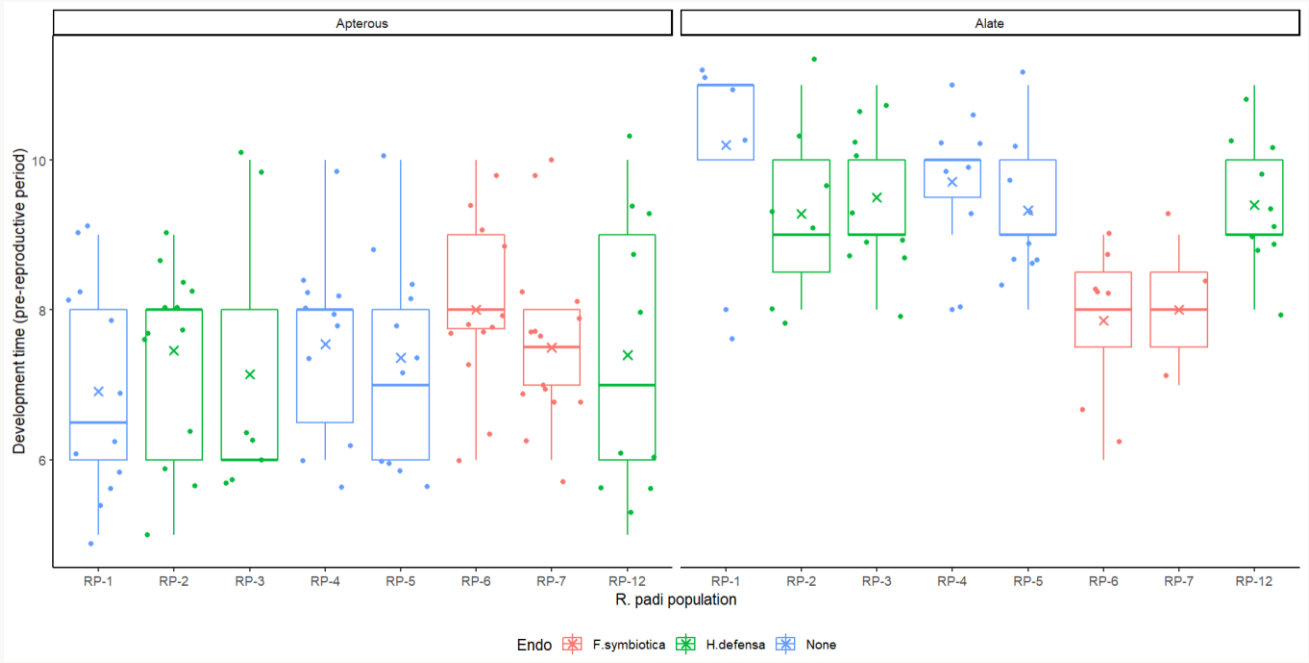


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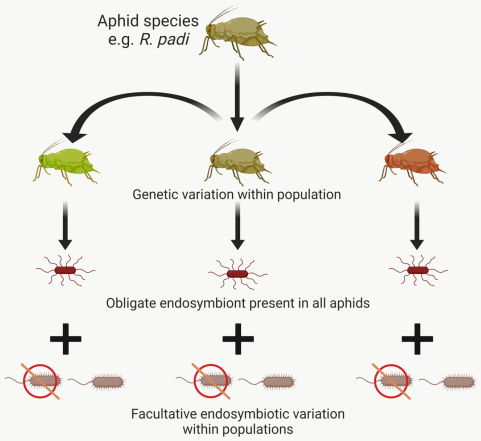
542 SNPs that potentially contribute towards variable transmission efficiency in *R. padi*

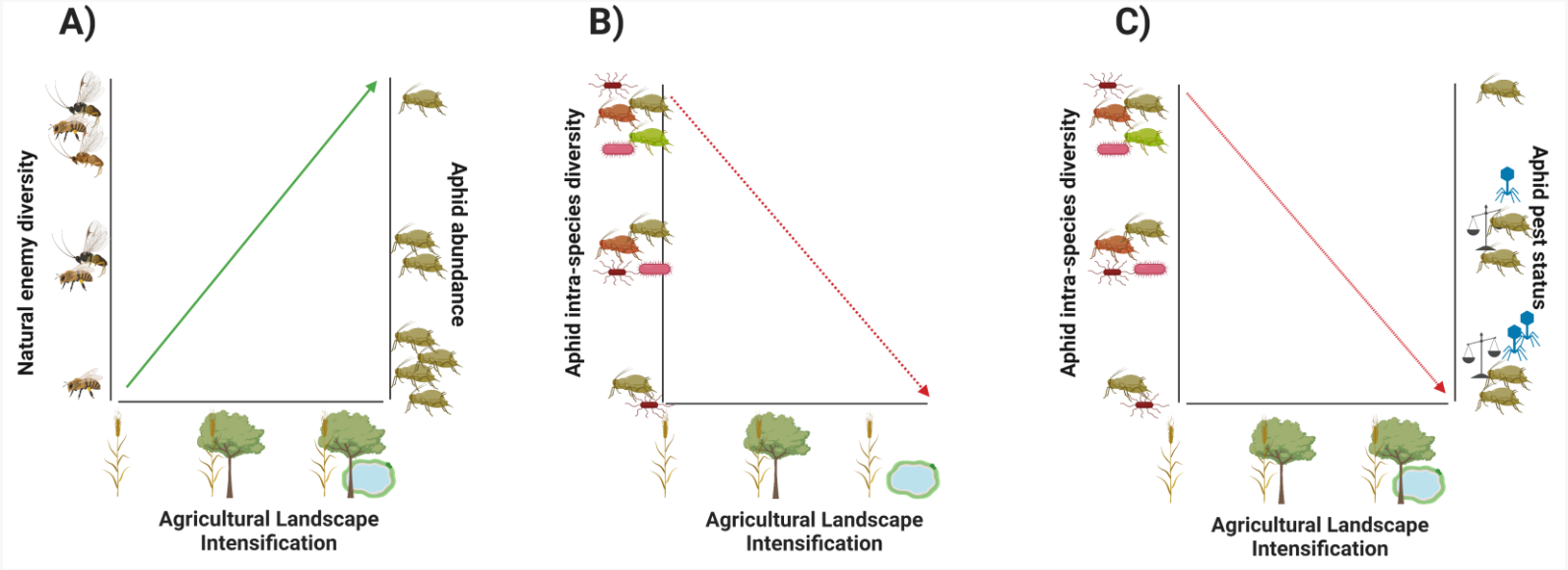


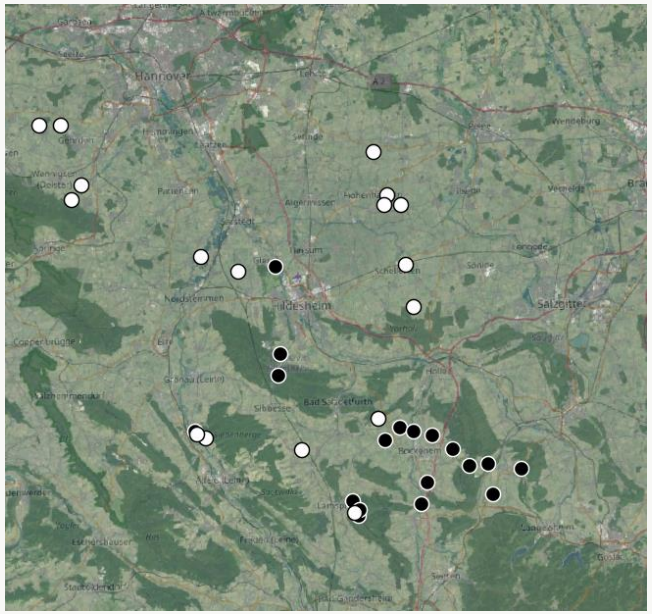


Leybourne et al., 2024, *BioRxiv*

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Leybourne, Martin. *In Prep*

1: Identifying plant traits that provide resistance against aphids

2: Drought impacts on aphids, plants, and aphid-plant interactions

3: The plant resistance hypothesis

4: How diversity within the impacts aphid-plant-environment interactions





THE PEOPLE BEHIND THE SCIENCE

The James Hutton Institute

University of Dundee

- Dr Alison Karley (JHI)
- Dr Jorunn Bos (UoD)
- Dr Tracy Valentine (JHI)



Leibniz Universität Hannover

Alexander von Humboldt Stiftung/Foundation

- Prof Emily Martin (LUH)
- Petra Melloh (LUH)

UNIVERSITY OF LIVERPOOL

ROYAL COMMISSION EXHIBITION OF 1851

UK Research and Innovation

- Dr Sharon Zytynska
- Elinor Baird
- Dr Torsten Will (JKI)

