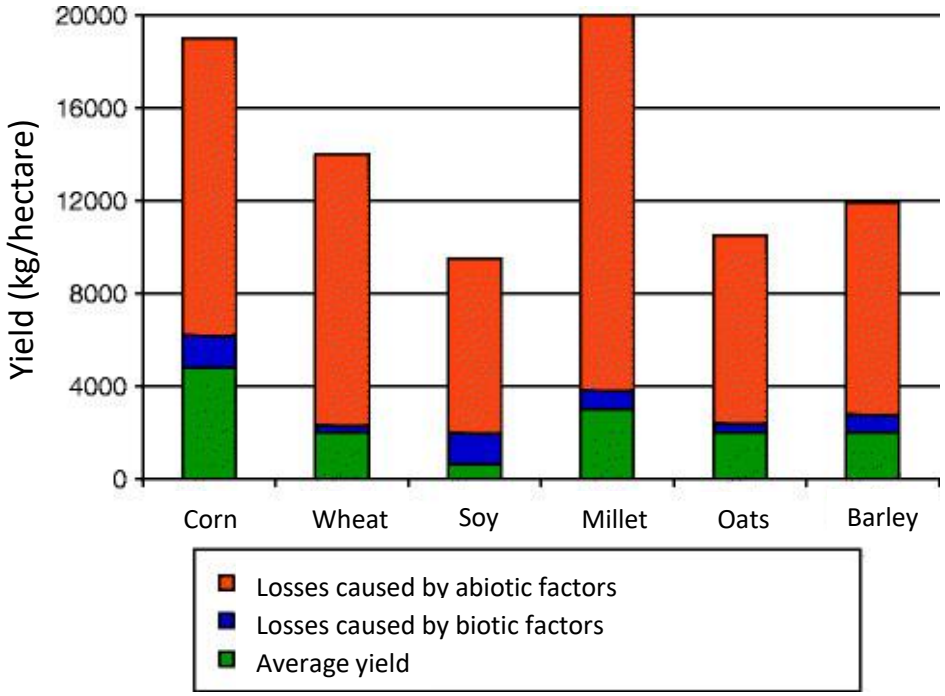
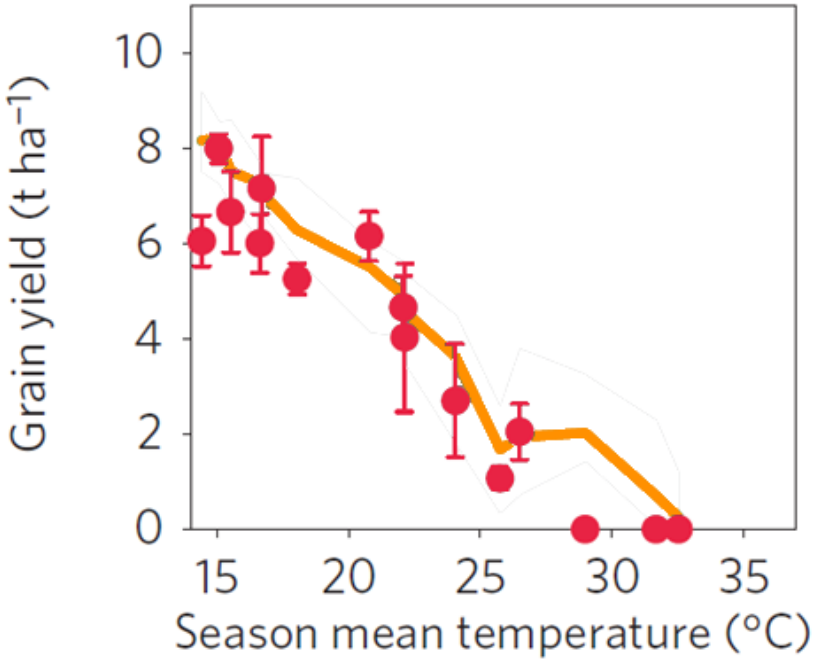
Comparative wheat phosphoproteome profiling pinpoints high temperature-associated breeding markers

Ive De Smet
VIB-UGent Center for Plant Systems Biology

IWGSC Webinar, 2024

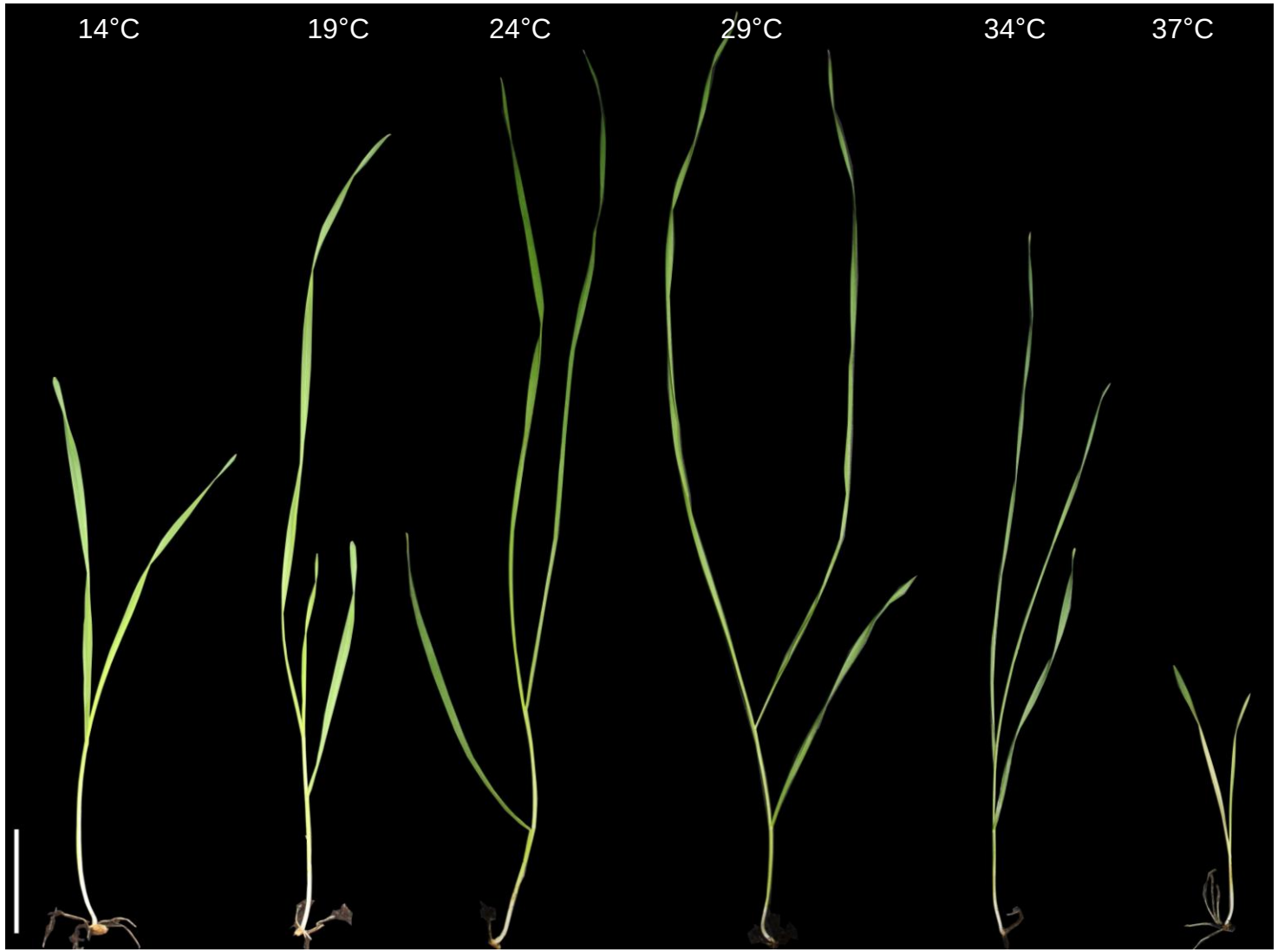
Abiotic stress impacts wheat yield





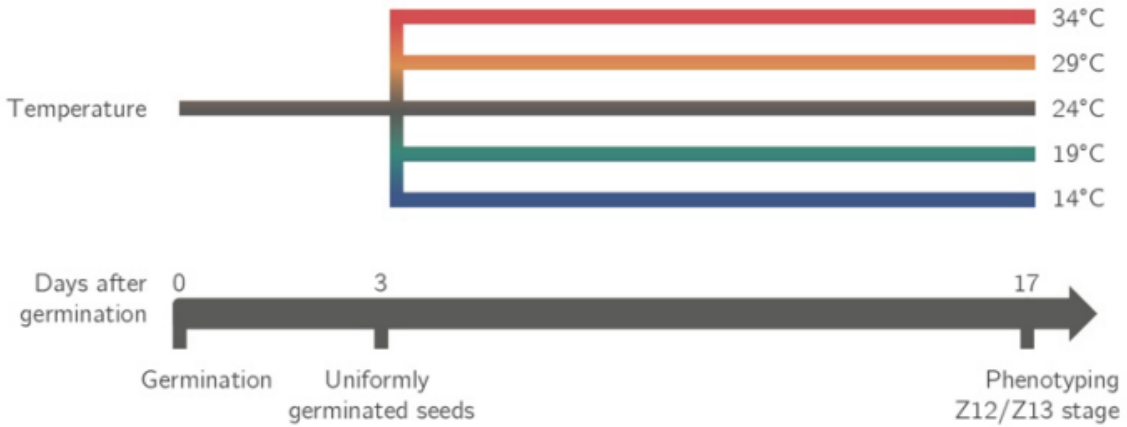
Ashraf *et al* (2012). *Crop Production for Agricultural Improvement* 1-15; www.seedquest.com/News/releases/2008/october/23973.htm; Adapted from Asseng *et al* (2014) *Nature Climate Change* 5:143-147

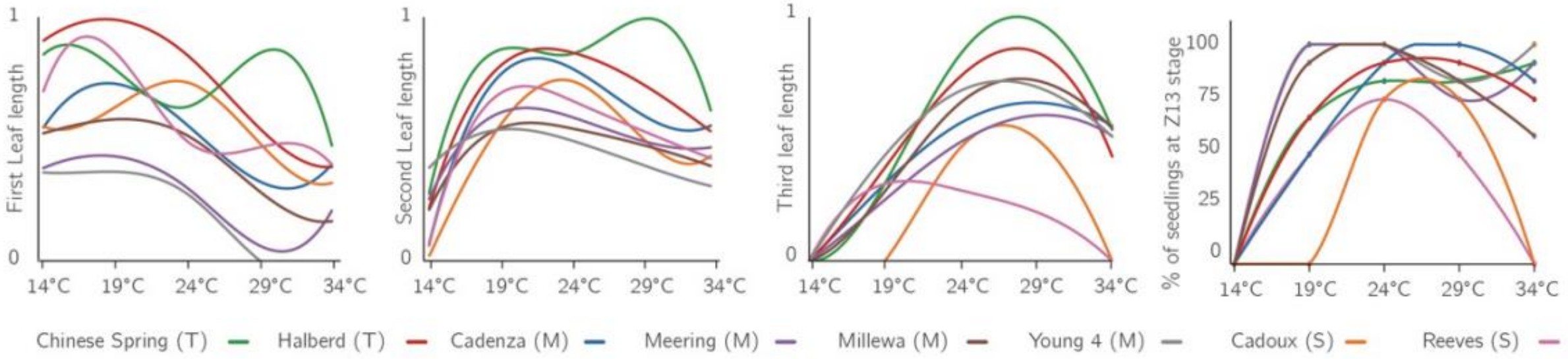
High temperature impacts wheat growth and development



Fonseca de Lima *et al* (www.biorxiv.org/content/10.1101/2024.08.20.608123v1); Zhu *et al* (unpublished)

High temperature impacts wheat growth and development





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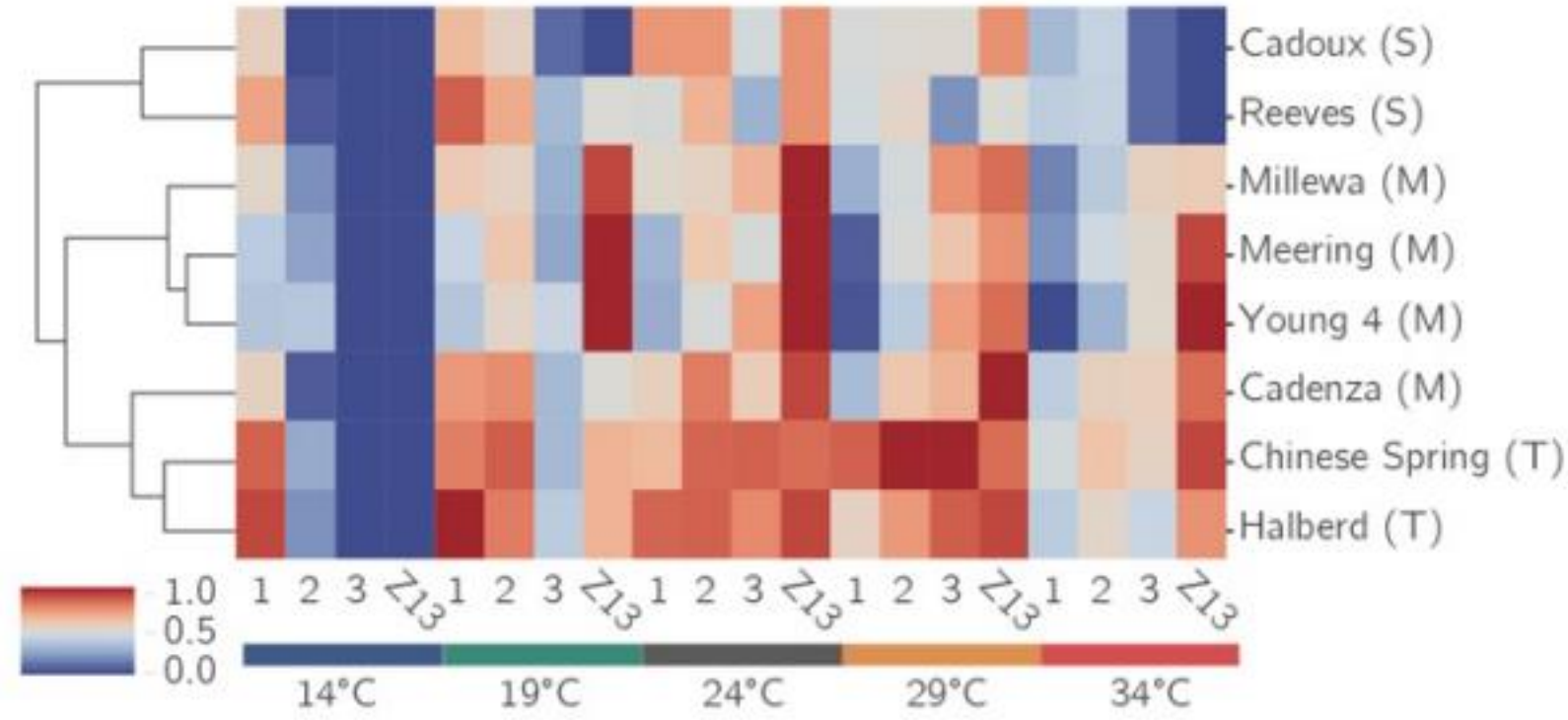
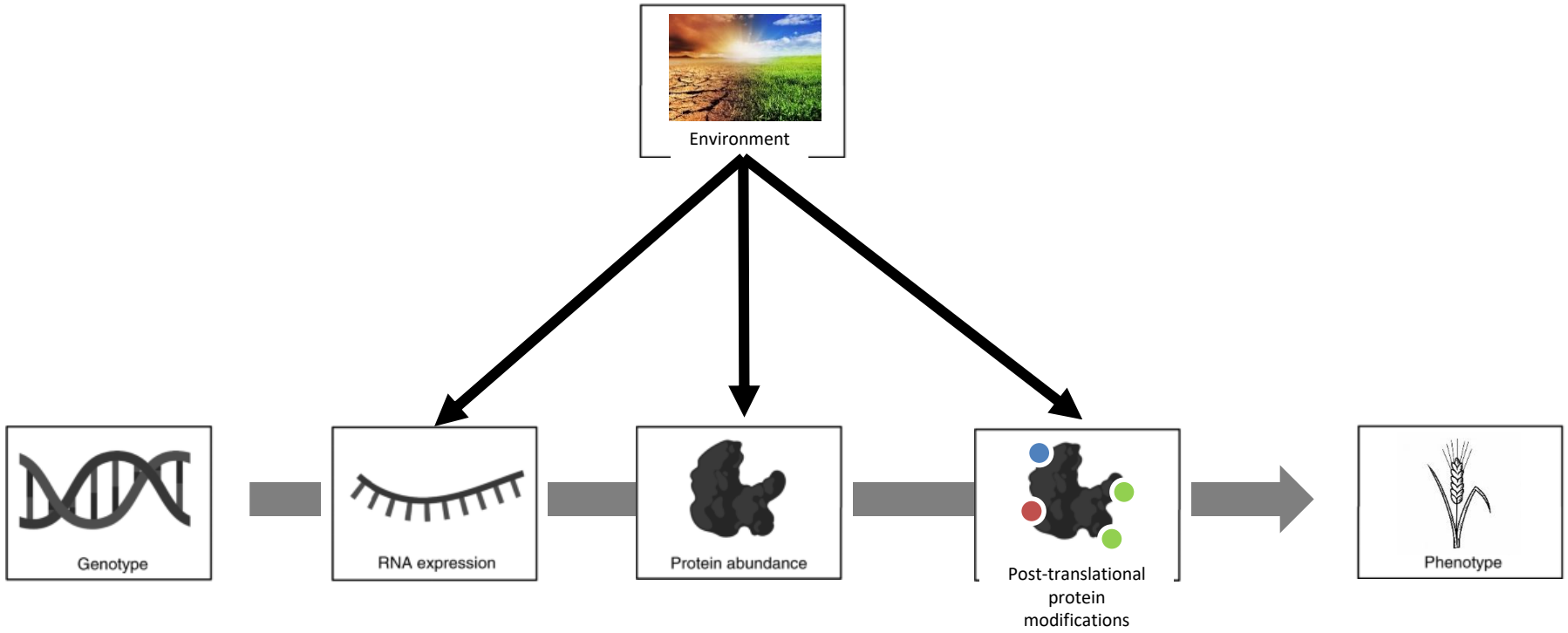
High temperature impacts wheat growth and development



Fonseca de Lima *et al* (www.biorxiv.org/content/10.1101/2024.08.20.608123v1)

Focus on signalling in plants

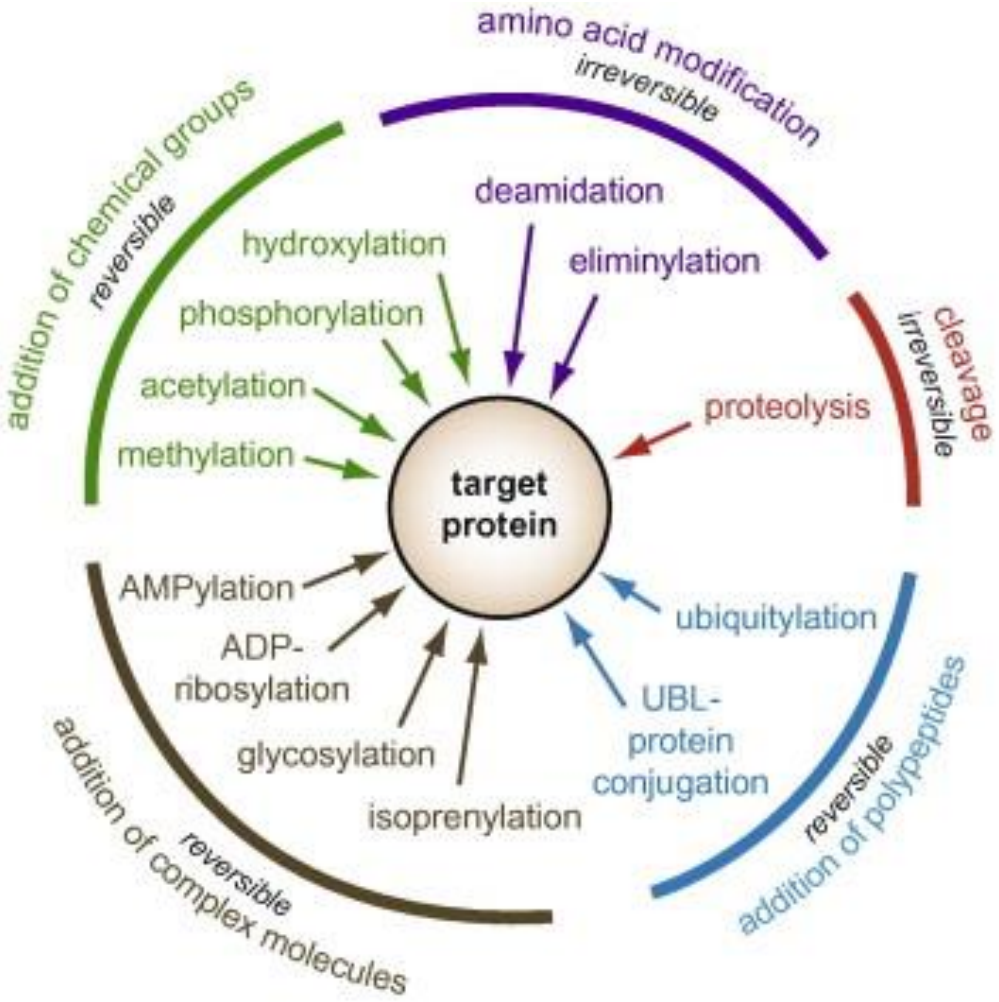


DNA | RNA | PROTEIN

GENOME | TRANSCRIPTOME | PROTEOME | PHENOME

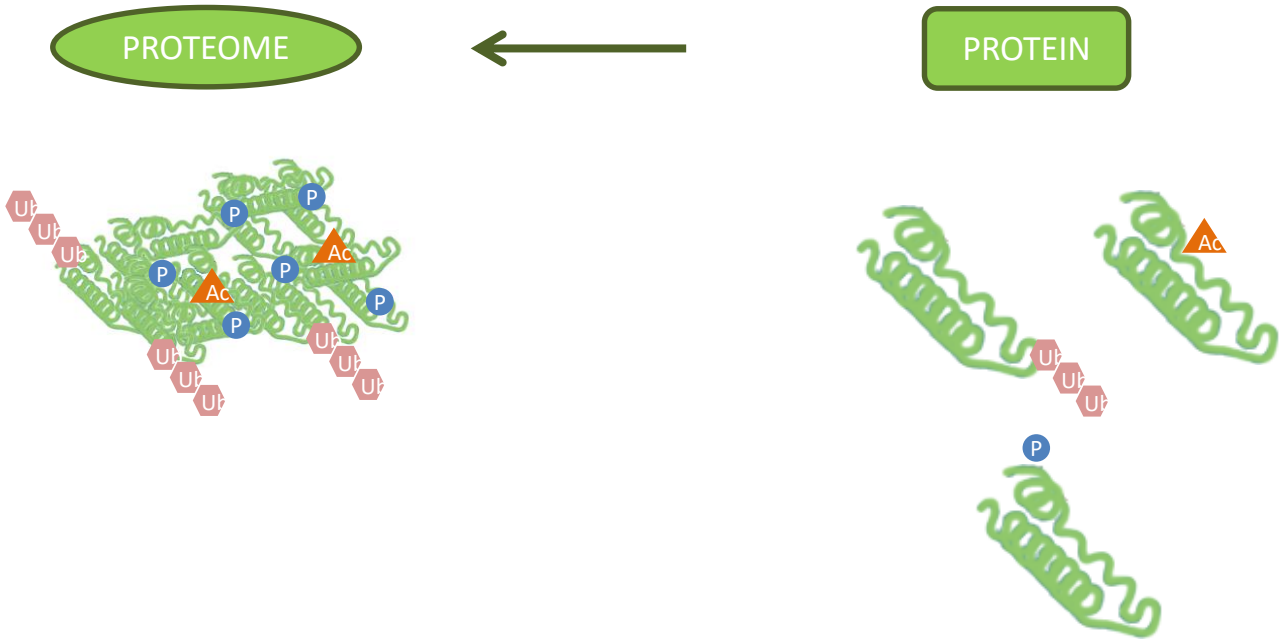
Protein pool expands through post-translational modifications

Protein pool expands through post-translational modifications

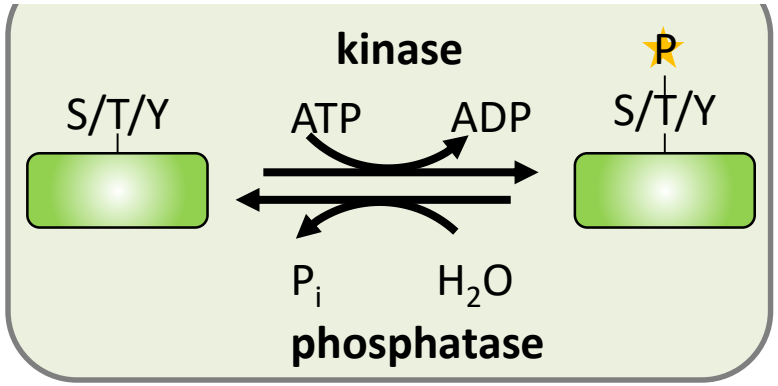


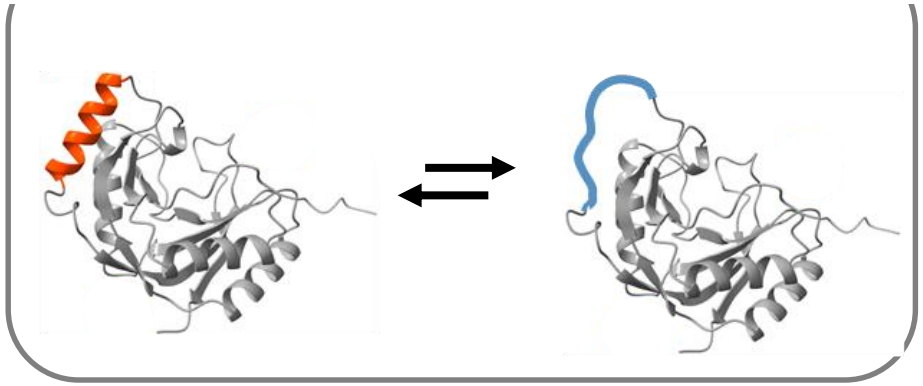
Ribet and Cossart (2010) *FEBS Letters* 584: 2748 - 2758

Protein pool expands through post-translational modifications



Focus on signalling in plants



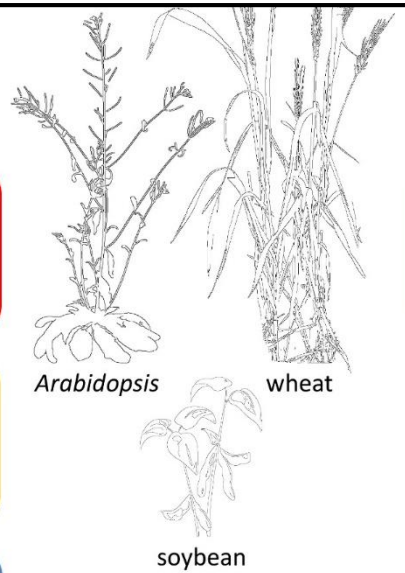


POST TRANSLATIONAL PROTEIN MODIFICATIONS
(MAINLY PHOSPHORYLATION)
PROTEIN STRUCTURE

HIGH TEMPERATURE STRESS

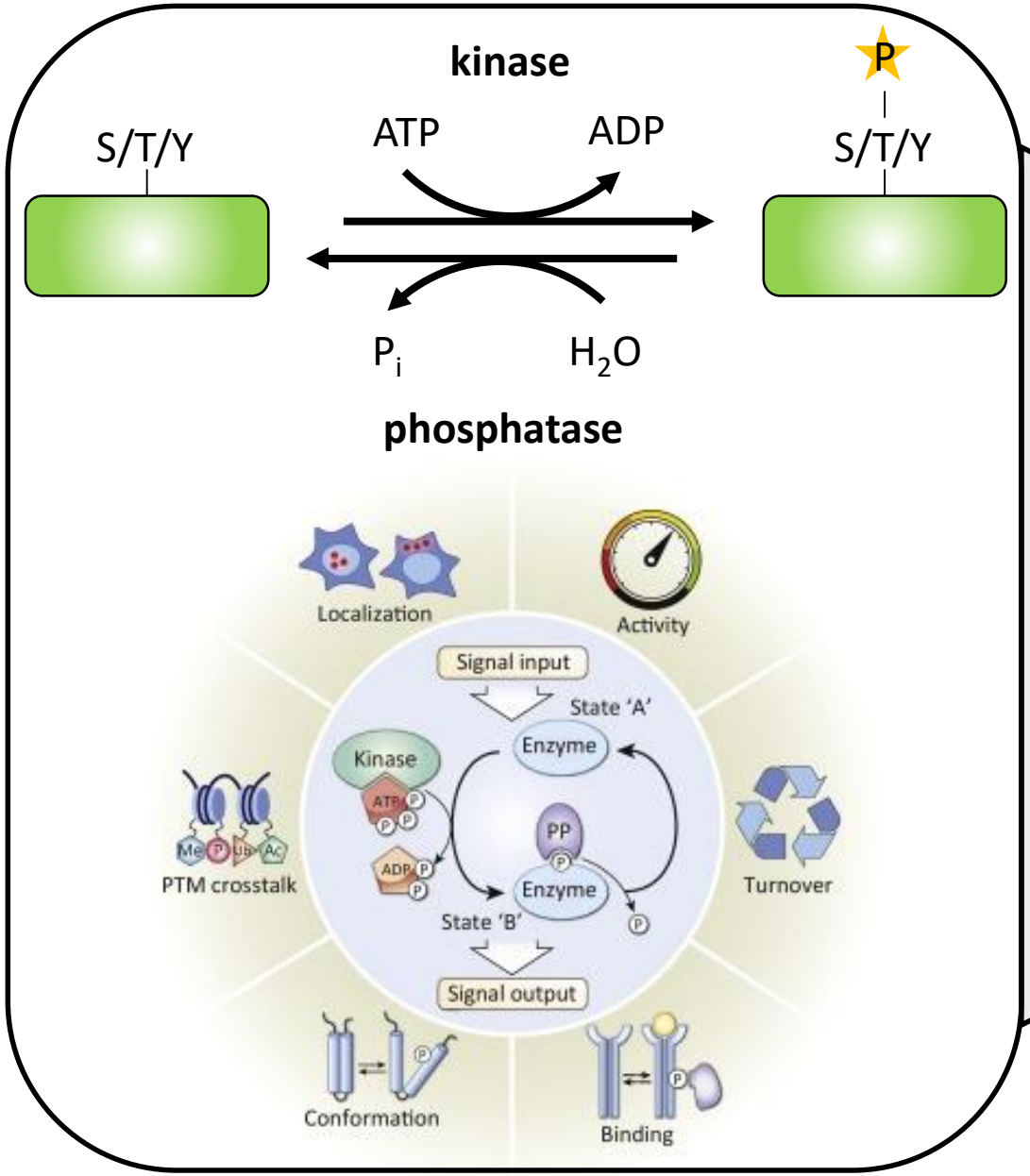
DROUGHT STRESS

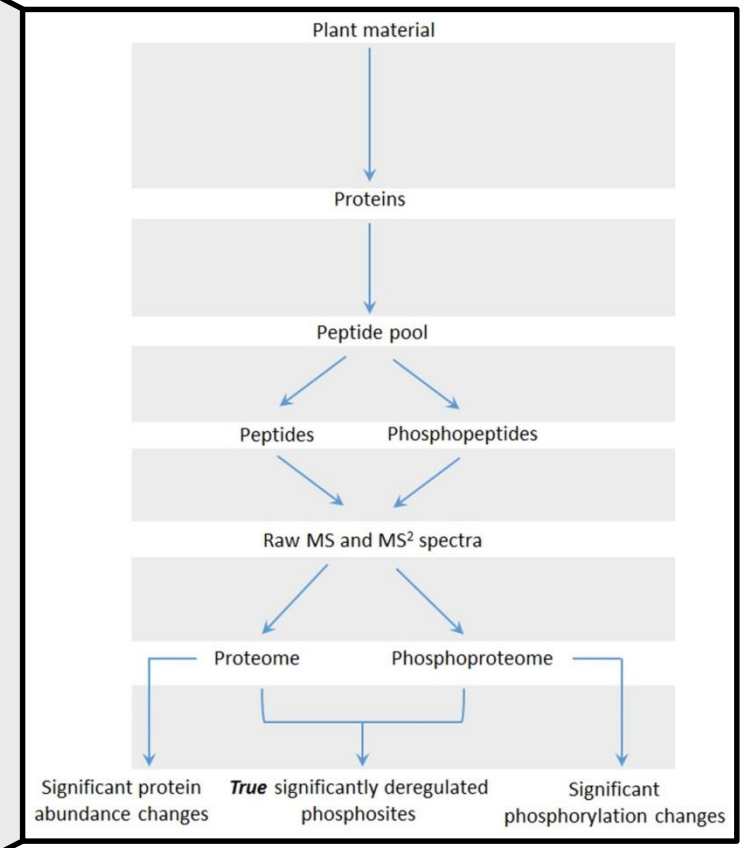
LOW TEMPERATURE STRESS



SHOOT GROWTH / FERTILITY

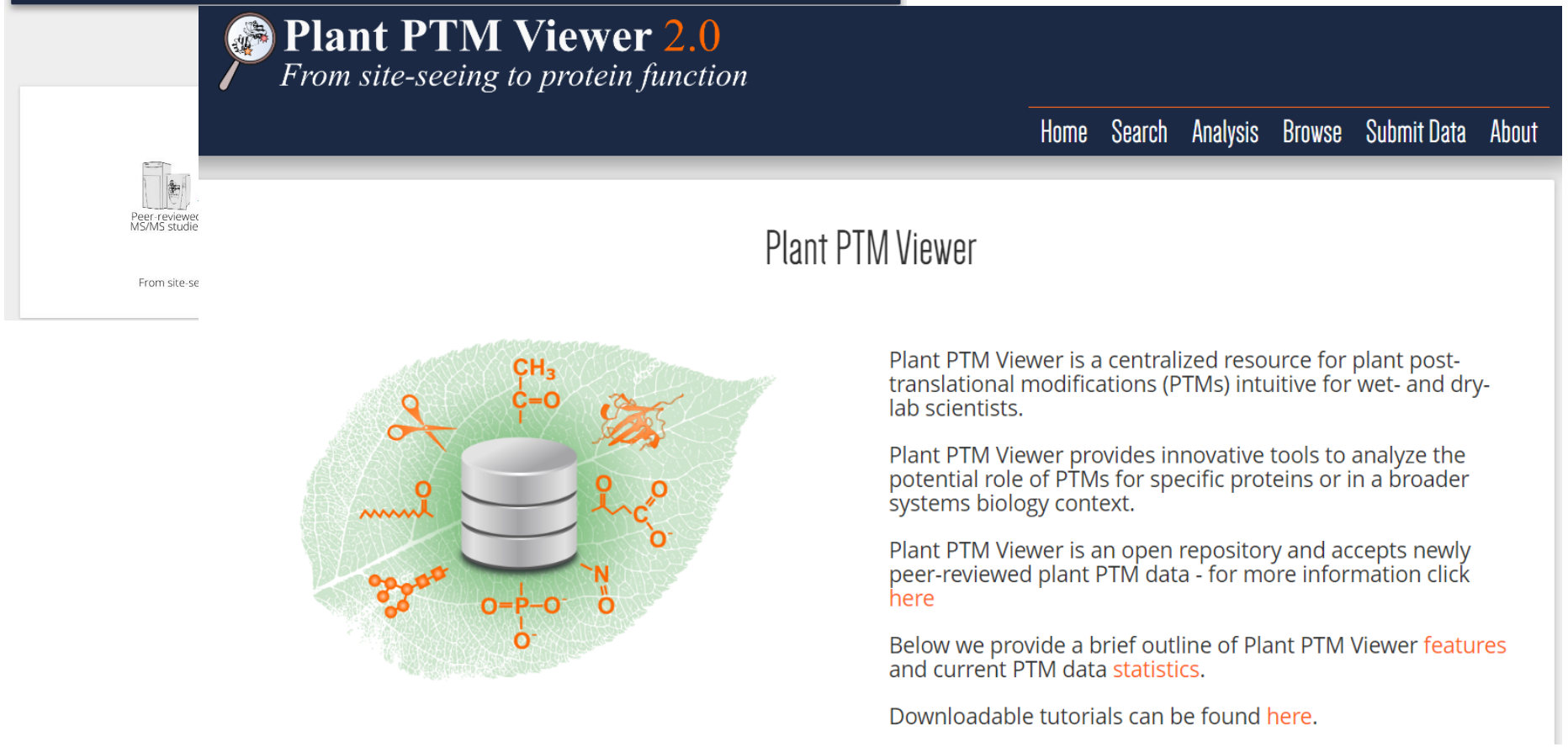
Phosphorylation is involved in everything





Humphrey *et al* (2015) *Trends Endocrinol Metab* 26(12):676-87; Vu, Stes *et al* (2016) *Journal of Proteome Research* 15(12):4304-4317

A resource for the community

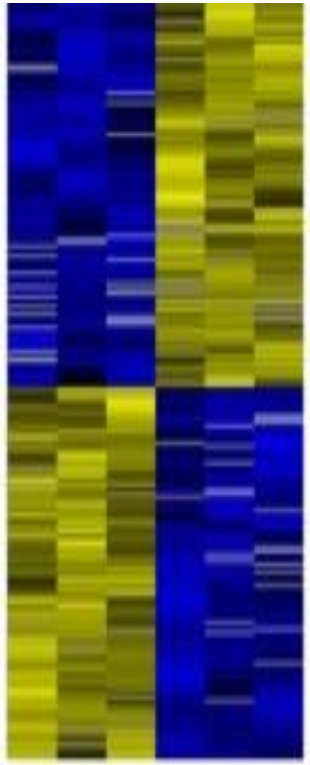


https://www.psb.ugent.be/webtools/ptm-viewer/

Willems *et al* (2024) *J Exp Bot*:75:4611-4624; Willems *et al* (2019) *Plant J* 99:752-762; Vu *et al* (2017) *Front Plant Sci* 8:332; Vu, Stes *et al* (2016) *Journal of Proteome Research* 15:4304-4317

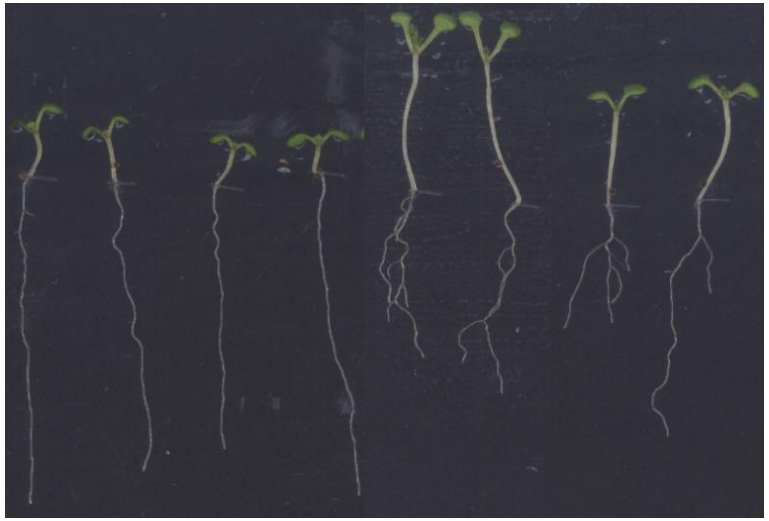
Discovery (and validation) in wheat / mode-of-action in *Arabidopsis*

Relevant candidates in wheat

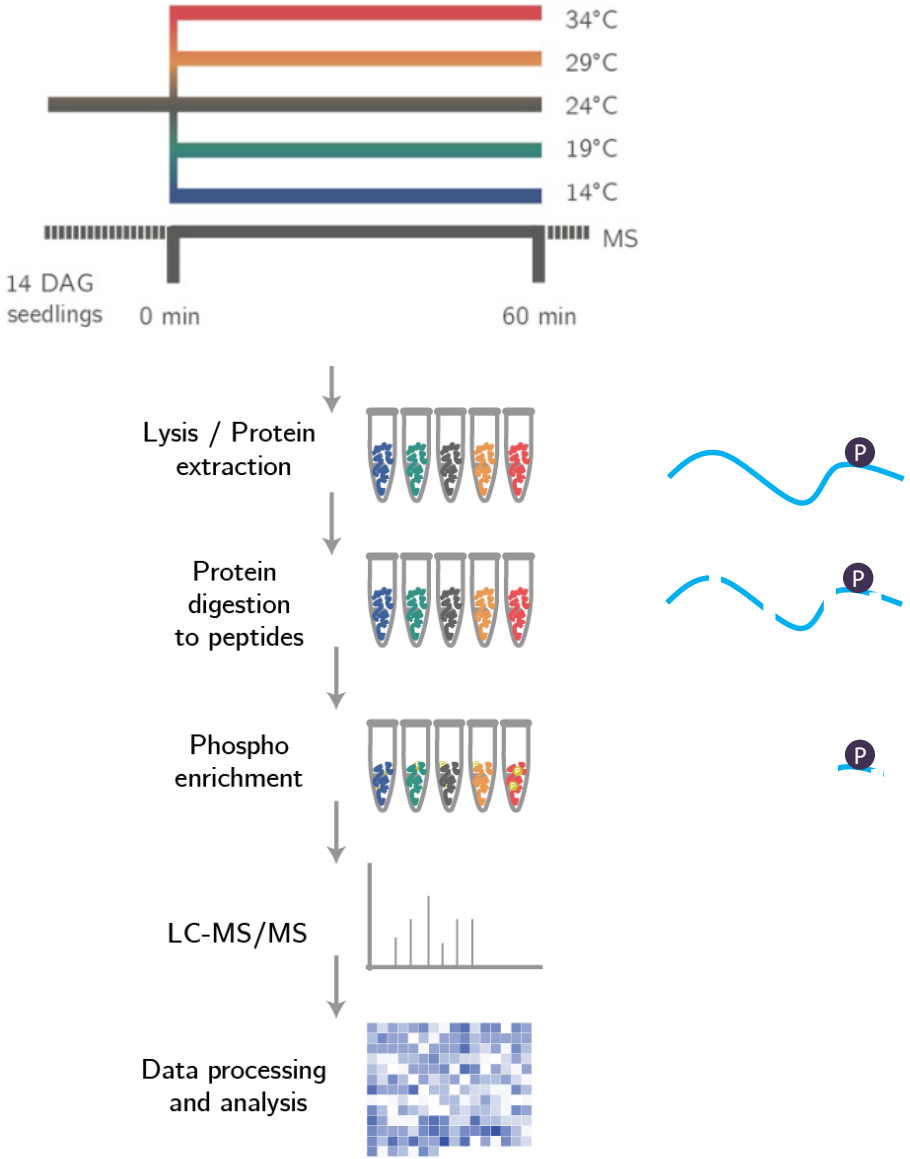


Validation in wheat

Mode-of-action in *Arabidopsis*



Temperature gradient phosphoprofiling in wheat



Fonseca de Lima *et al* (www.biorxiv.org/content/10.1101/2024.08.20.608123v1)

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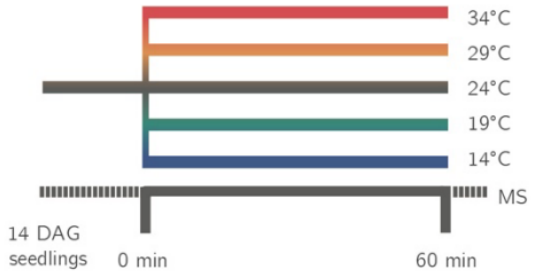

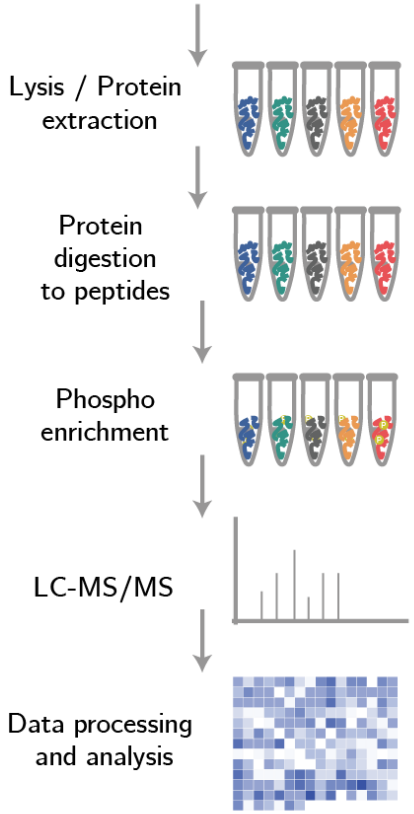

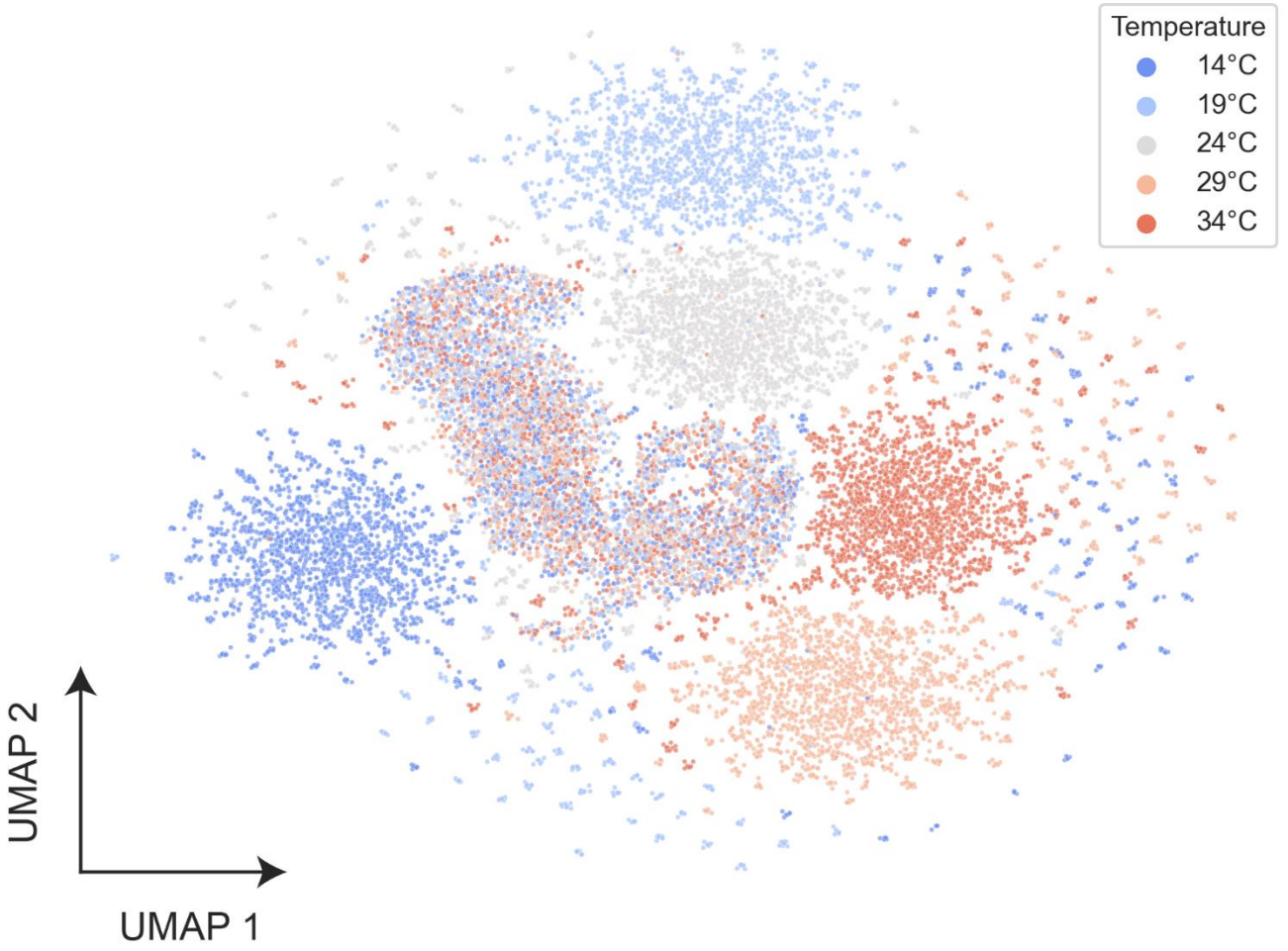

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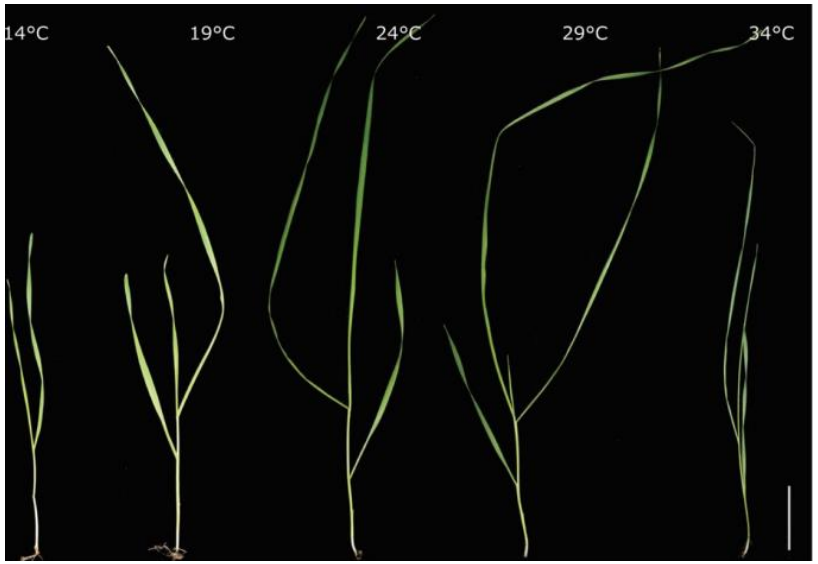

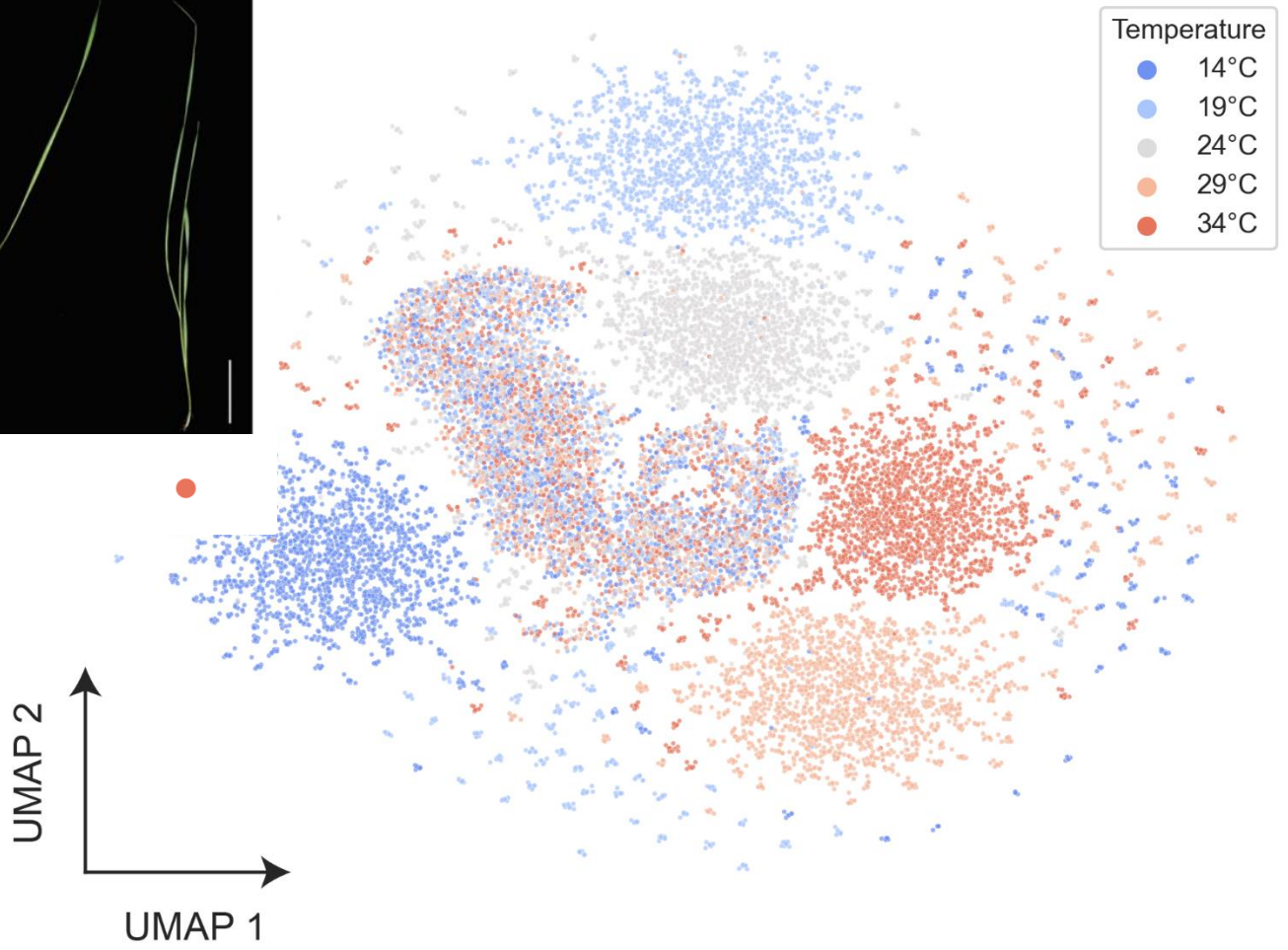

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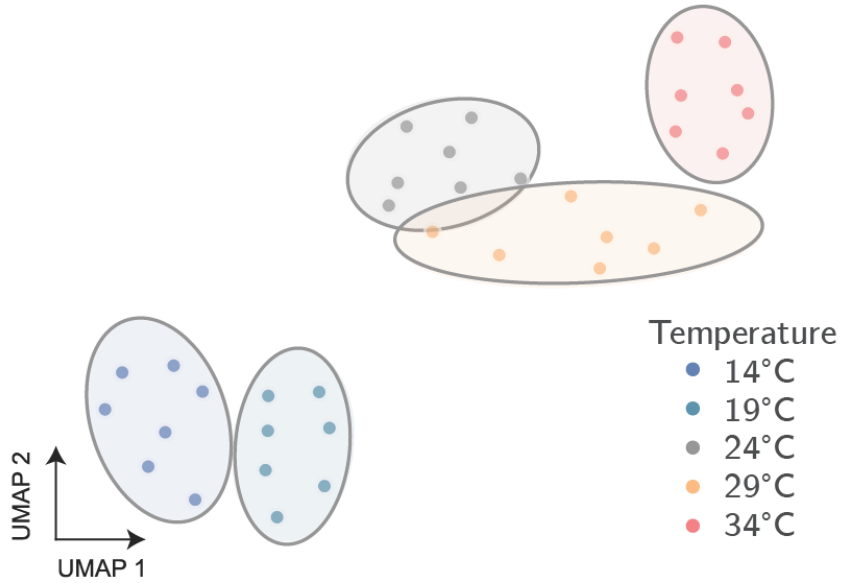

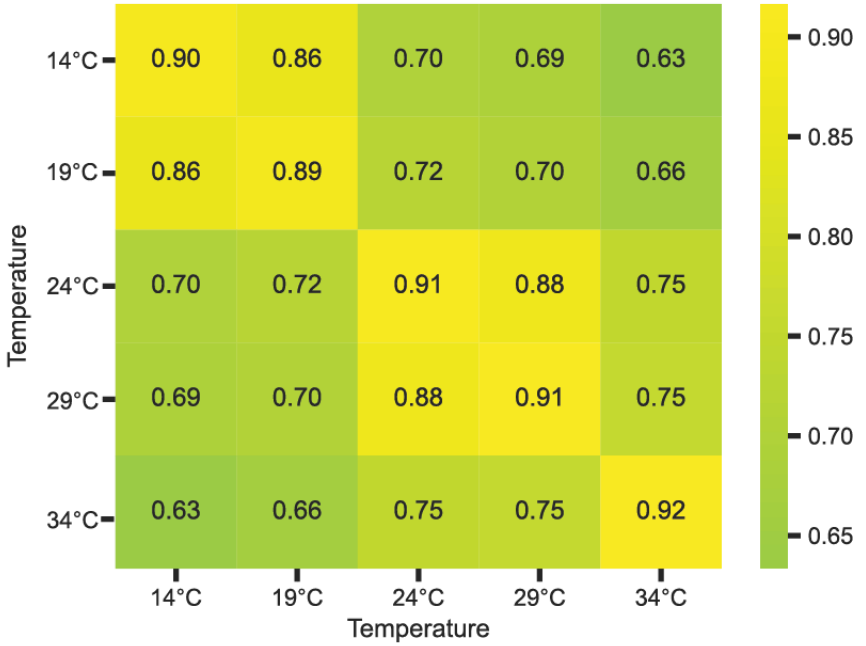

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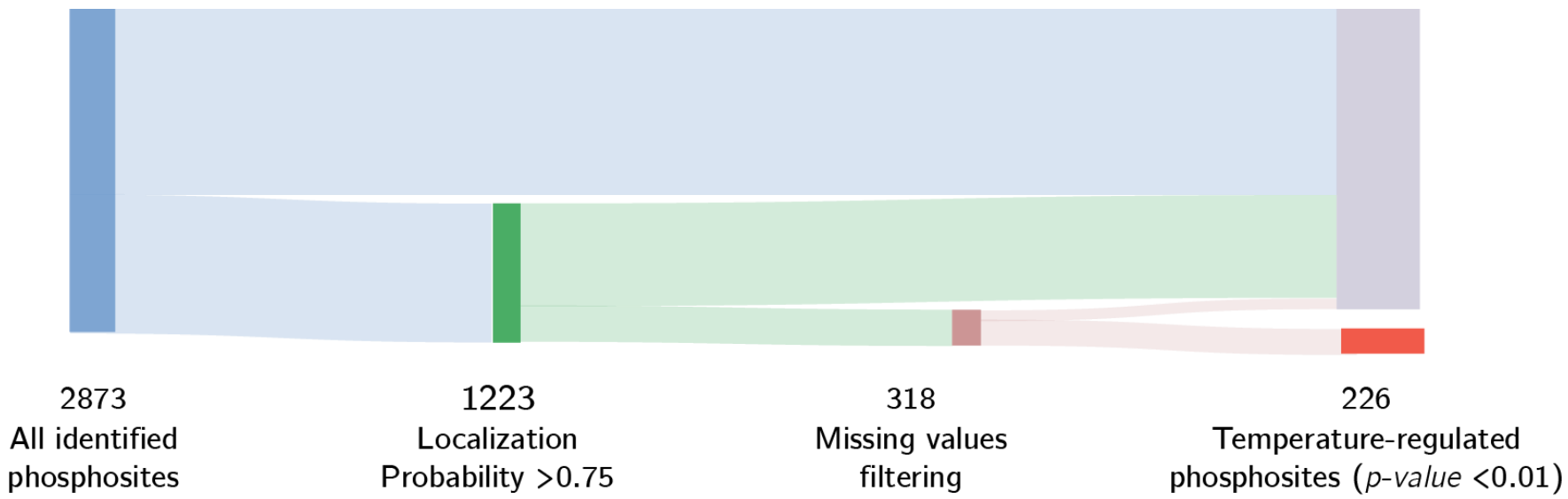

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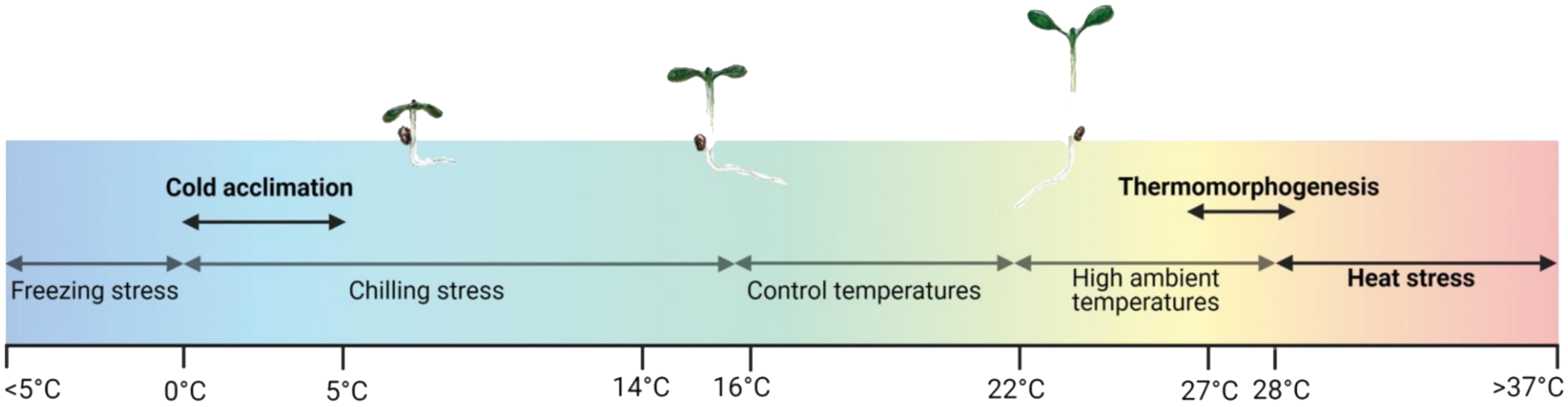

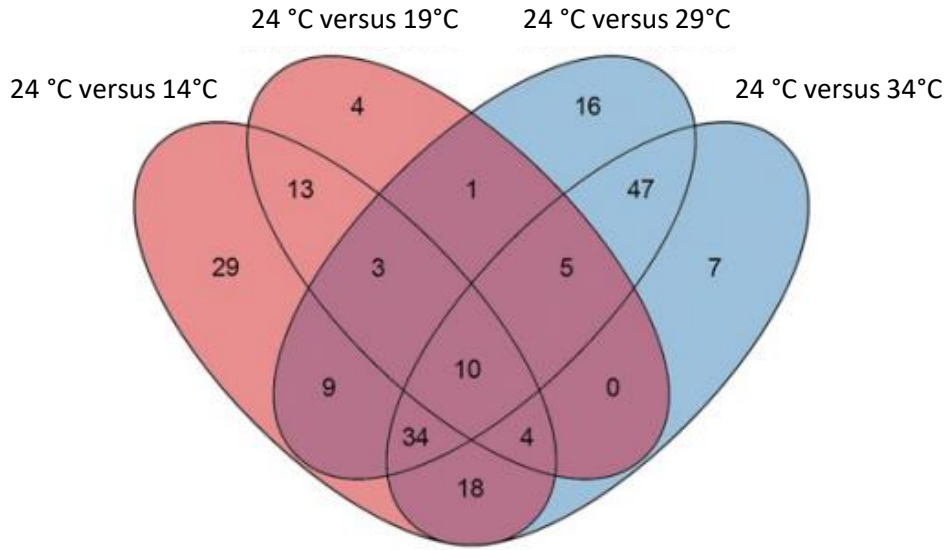

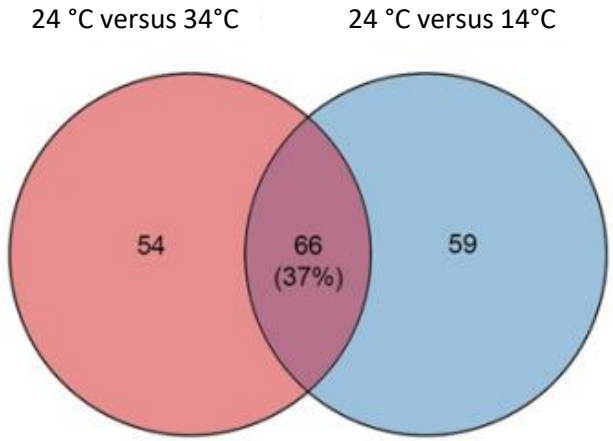

Praat *et al* (2021) *J Exp Bot* 21: 7459–7473; Fonseca de Lima *et al* (www.biorxiv.org/content/10.1101/2024.08.20.608123v1)

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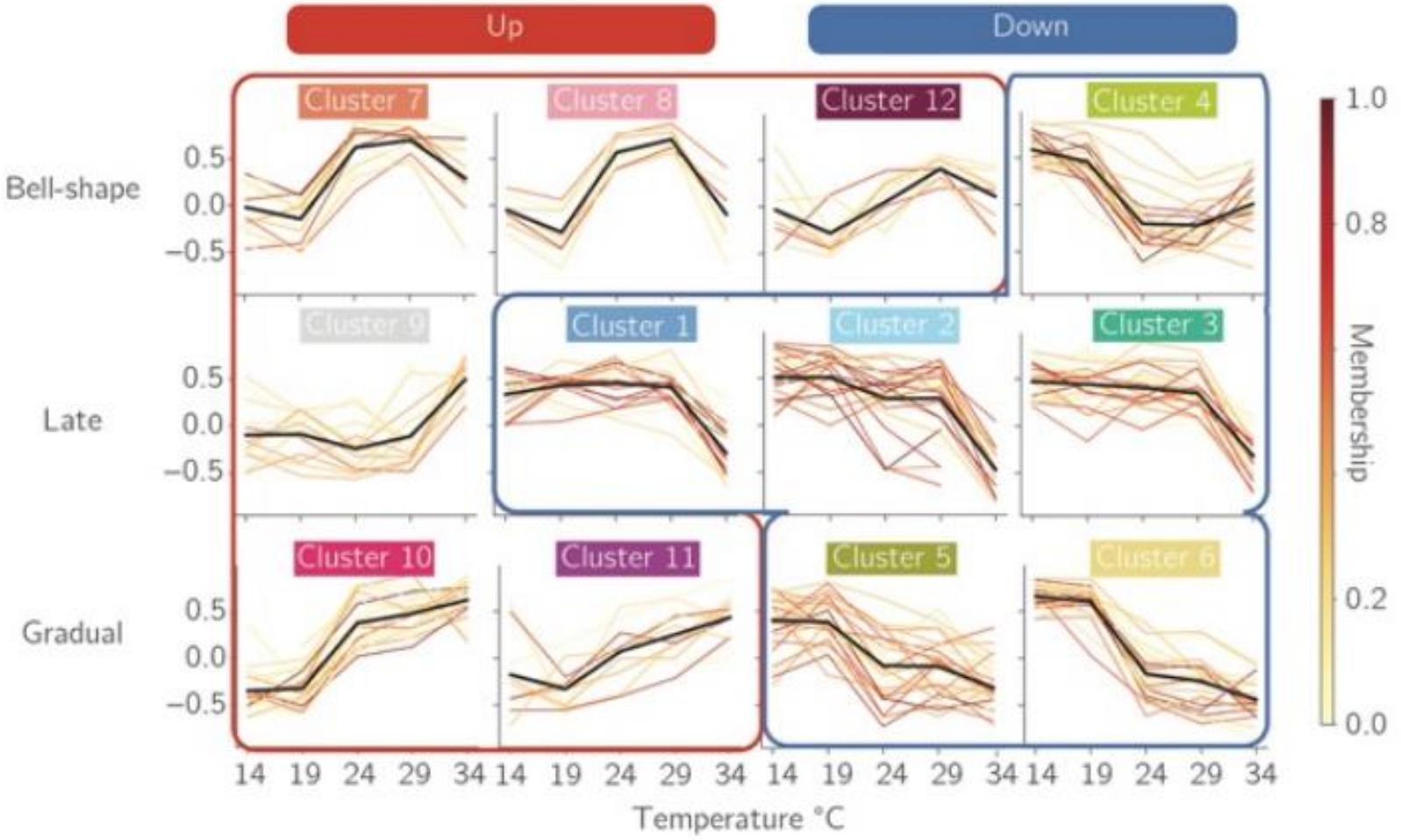
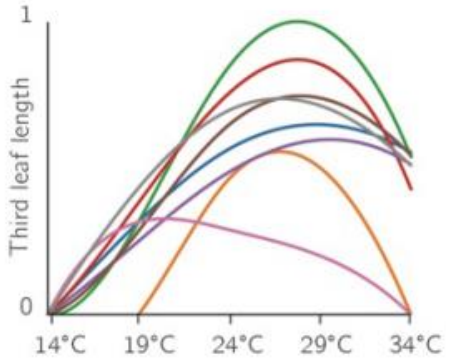
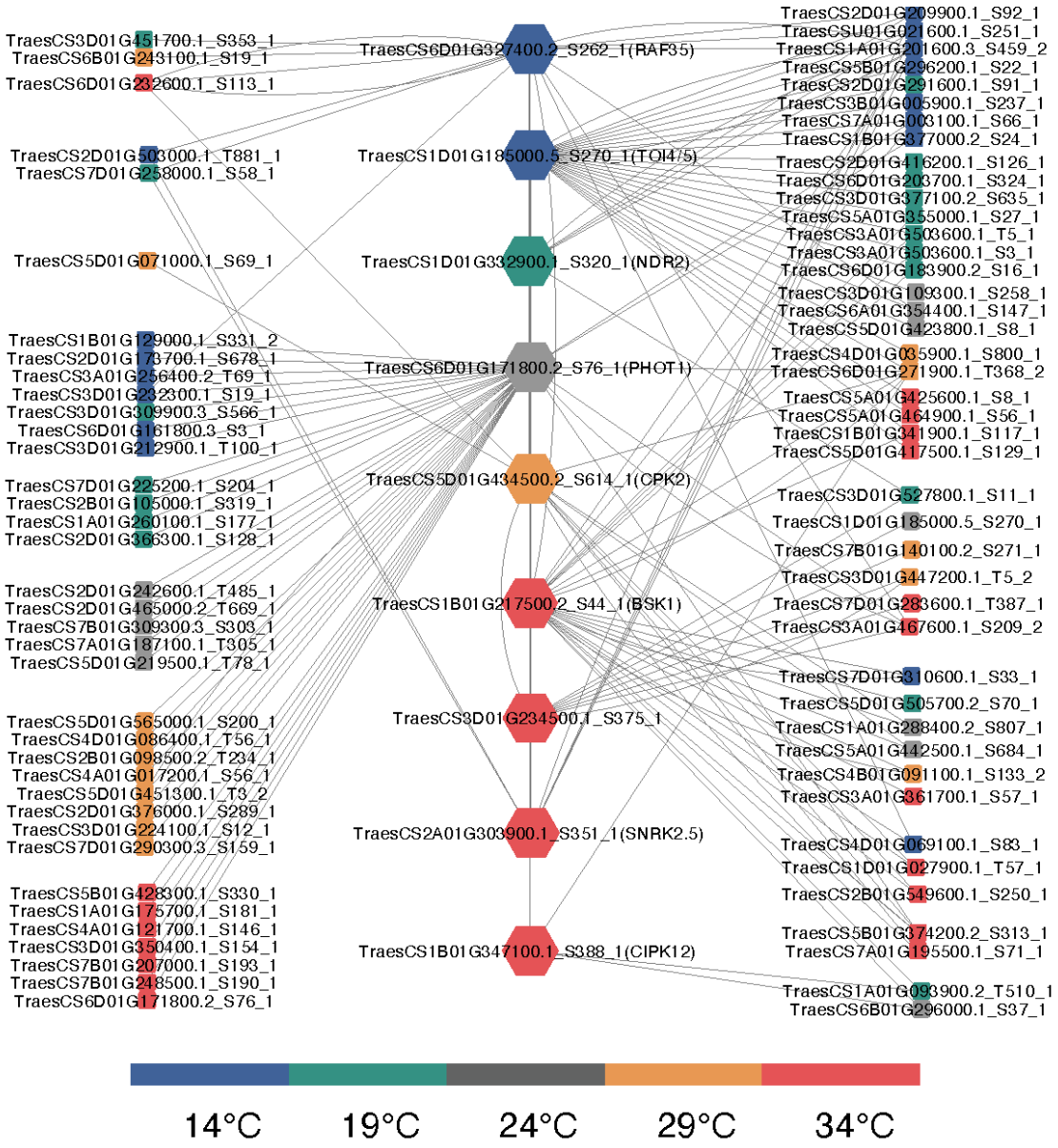




Fonseca de Lima *et al* (www.biorxiv.org/content/10.1101/2024.08.20.608123v1)

Signalling network from temperature gradient phosphoprofiling in wheat



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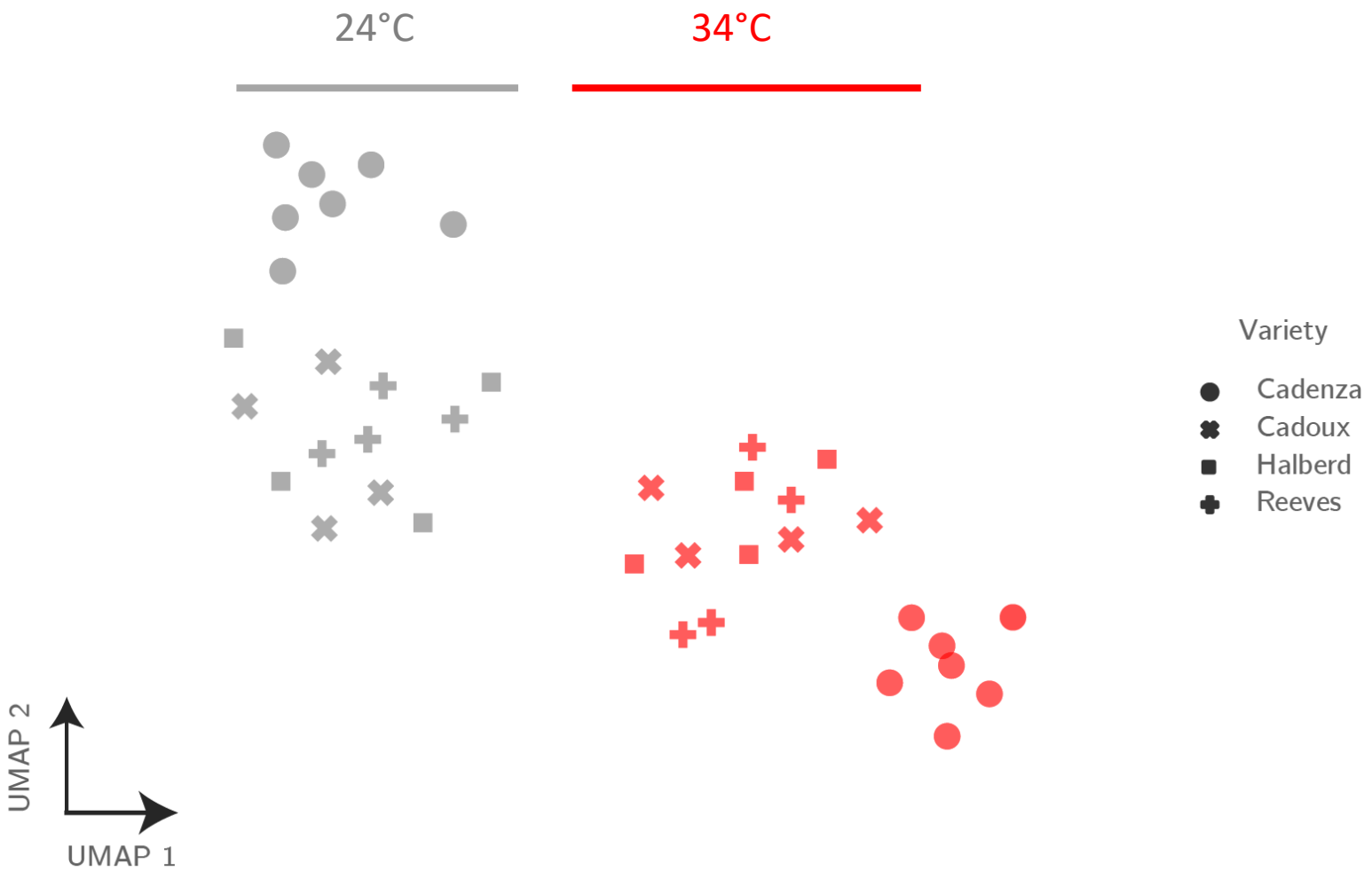
Temperature-regulated phosphoproteome: variety-dependent molecular responses



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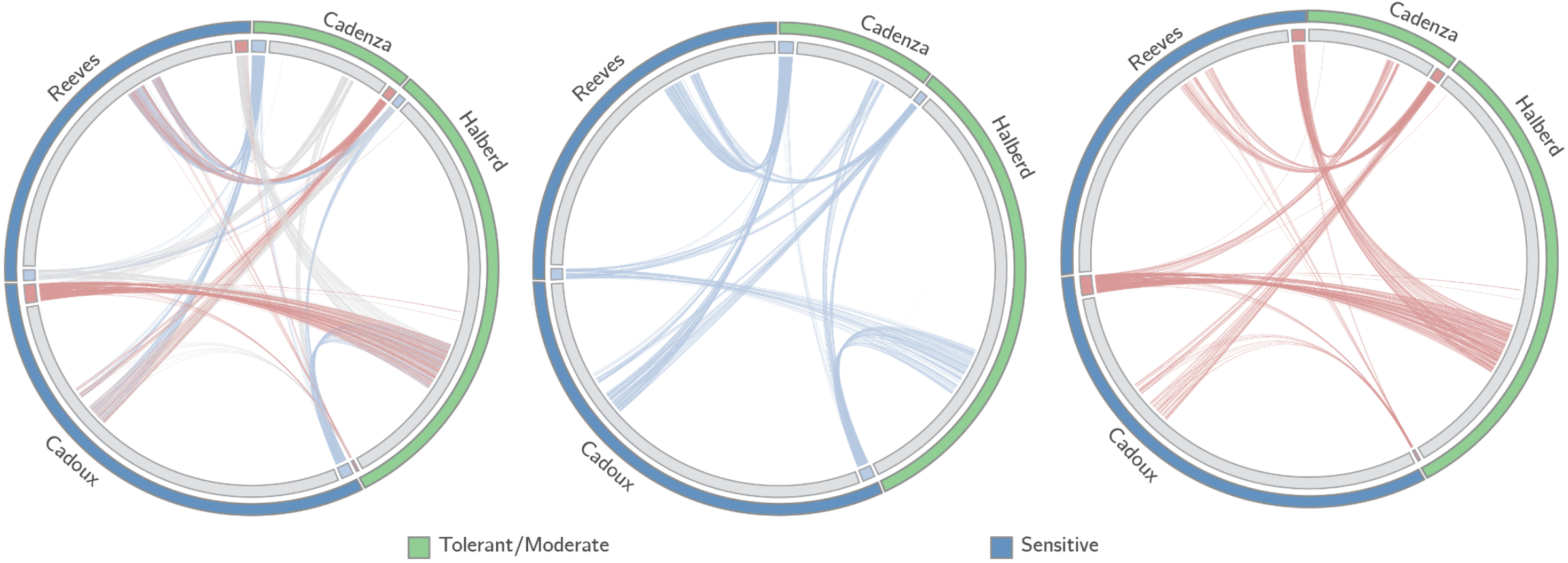

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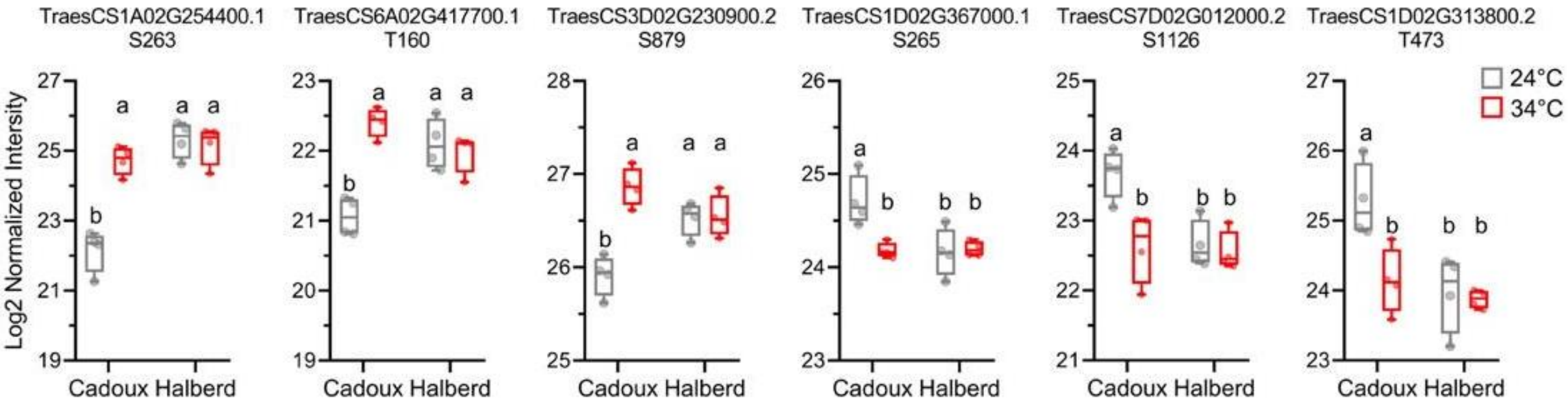
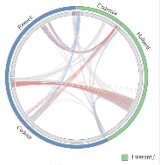


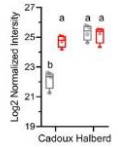
Fonseca de Lima *et al* (www.biorxiv.org/content/10.1101/2024.08.20.608123v1)

Predictive for breeding?

Capture environment-regulated phosphoproteome
in
sensitive and tolerant varieties
in
a growth chamber



Comparative analysis of phosphoproteome data



Identification
of
putative phosphoprotein-based biomarkers

Predictive for breeding?

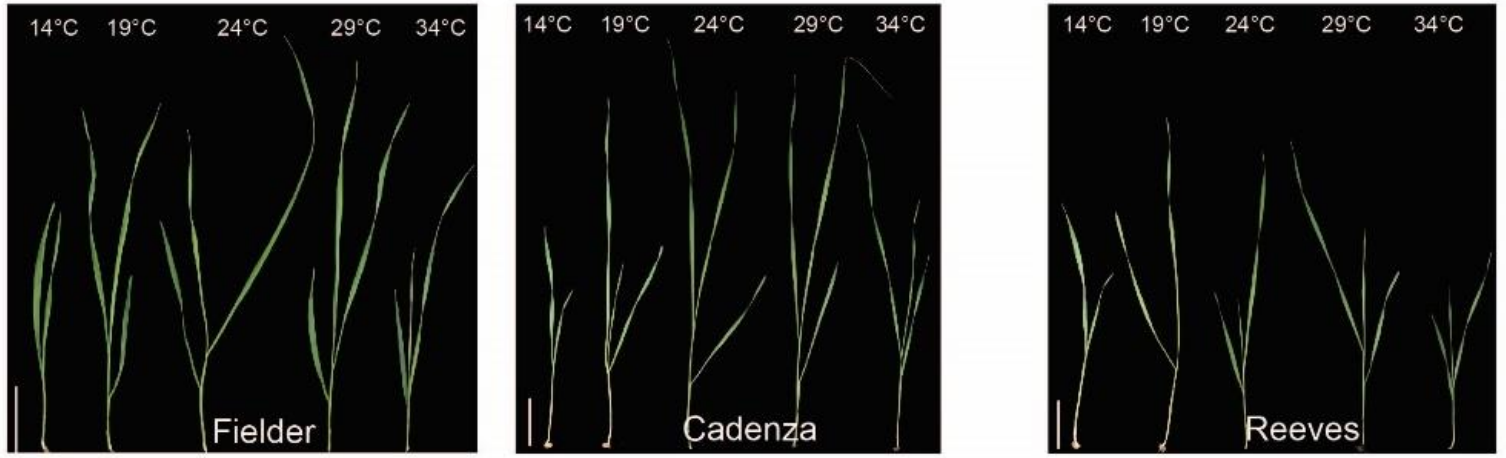
Breeding population

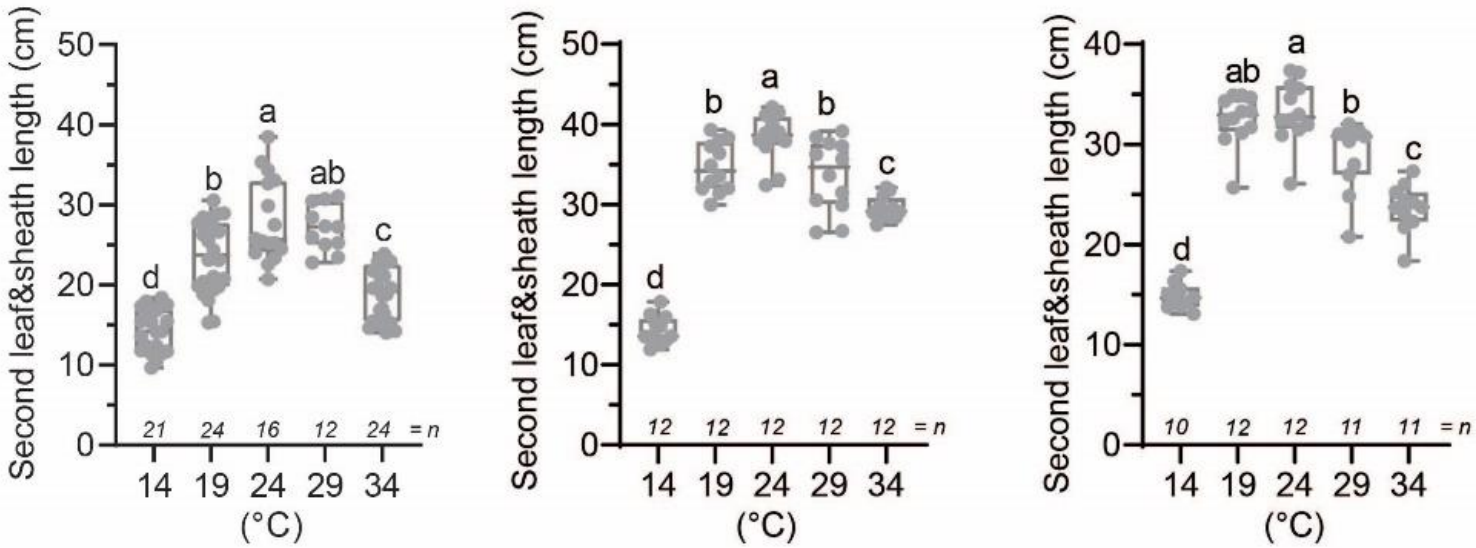
Physiological and genomic data
(sensitive versus tolerant variety)

(Samples of) selected lines

Phosphoproteomics
(or phosphoantibody-based approach)

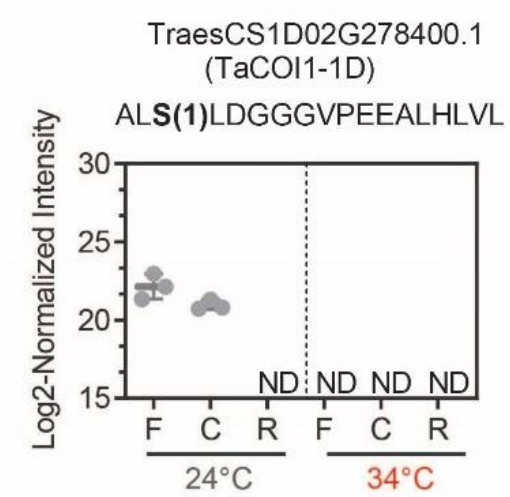
High temperature impacts wheat growth

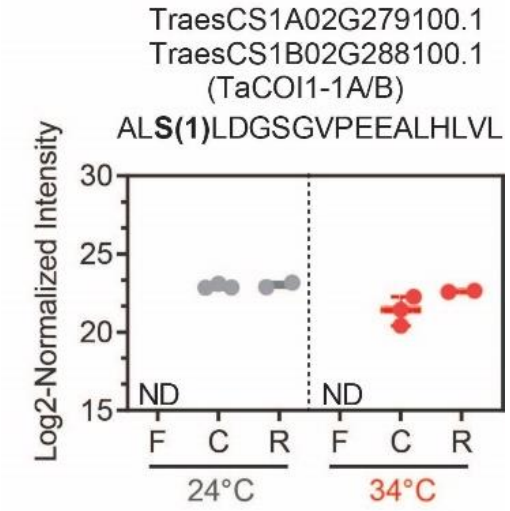


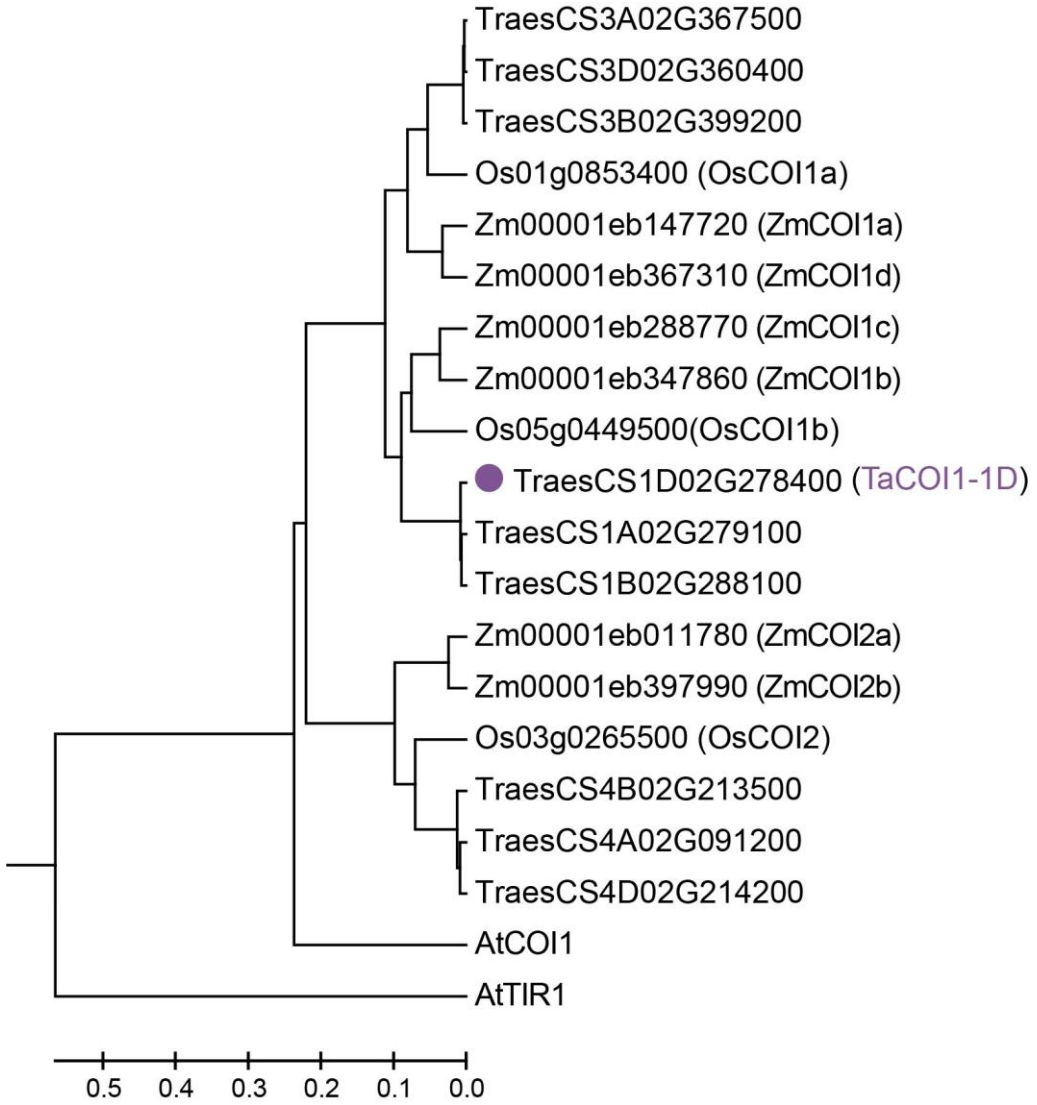


Zhu *et al* (unpublished)

TaCOI11-D – A high temperature-regulated wheat (phospho)protein

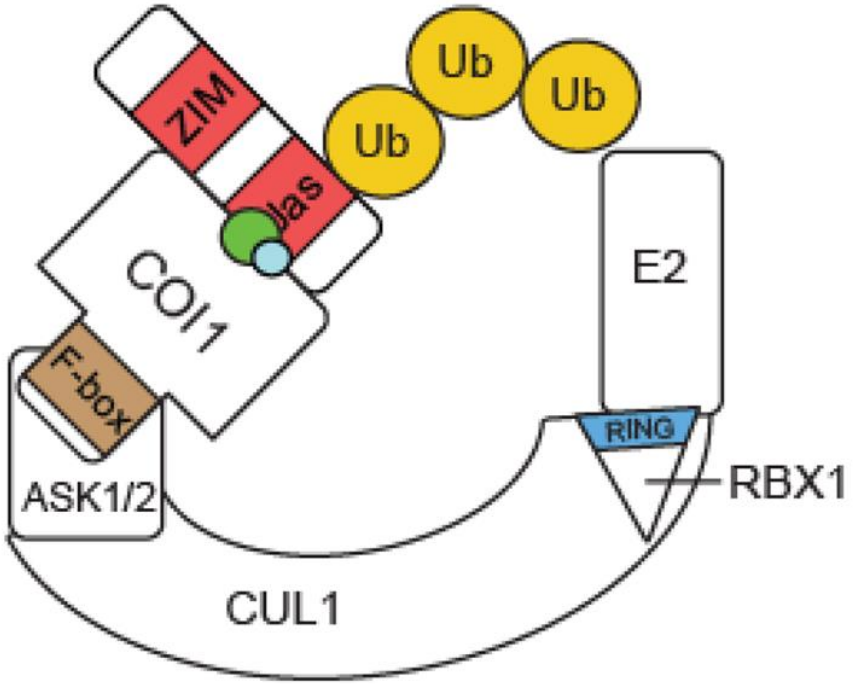






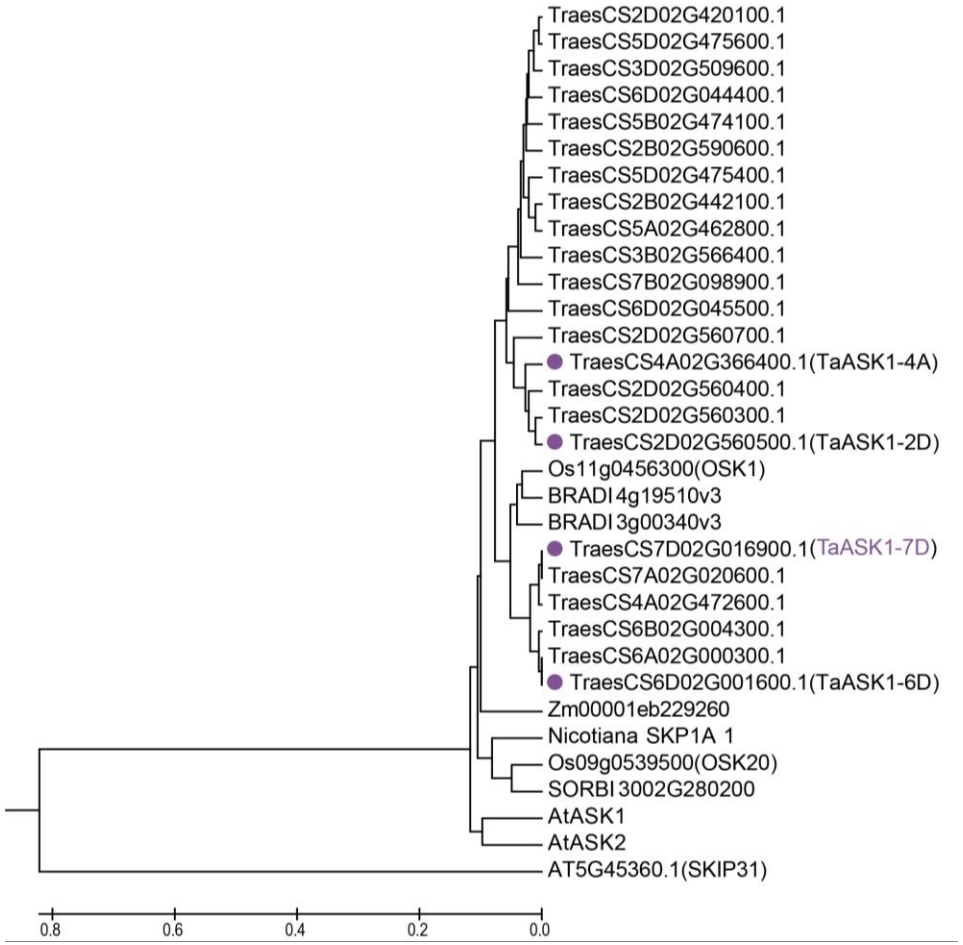
Vu and Zhu *et al*., 2018, *J Exp Bot*; Fonseca de Lima *et al*, 2024 (www.biorxiv.org/content/10.1101/2024.08.20.608123v1); Zhu *et al* (unpublished)

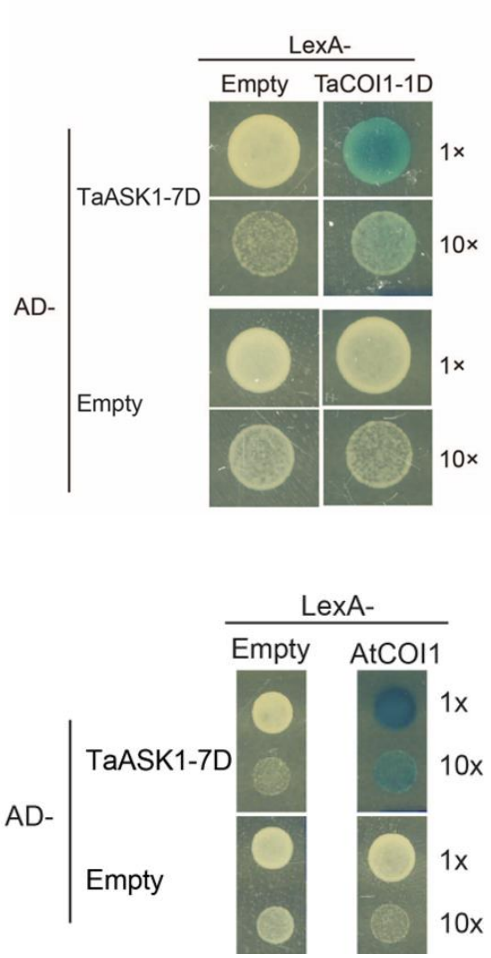
TaCOI11-D – A high temperature-regulated wheat JA receptor?

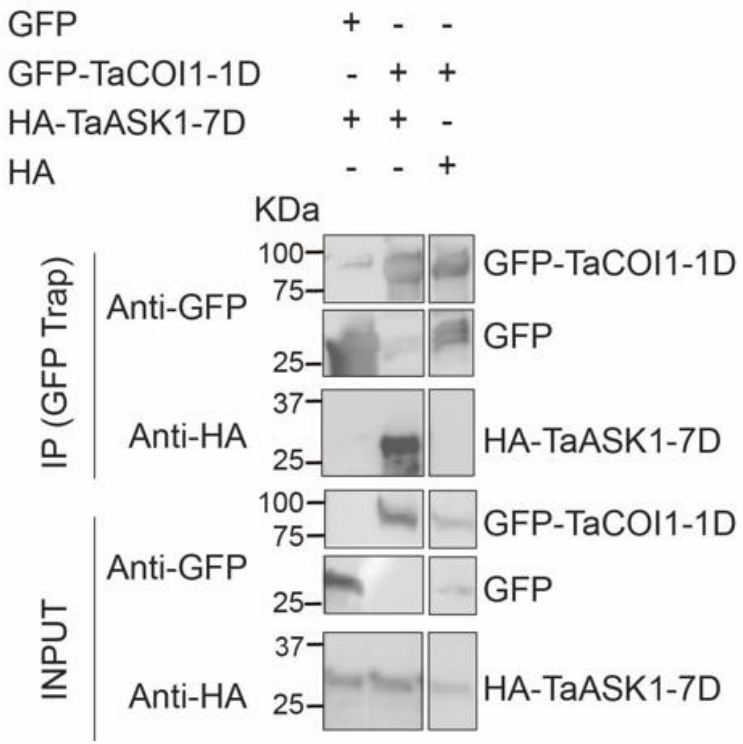


Durand *et al.*, 2016, *Plants*

Wheat TaCOI1-1D interacts with TaASK orthologues

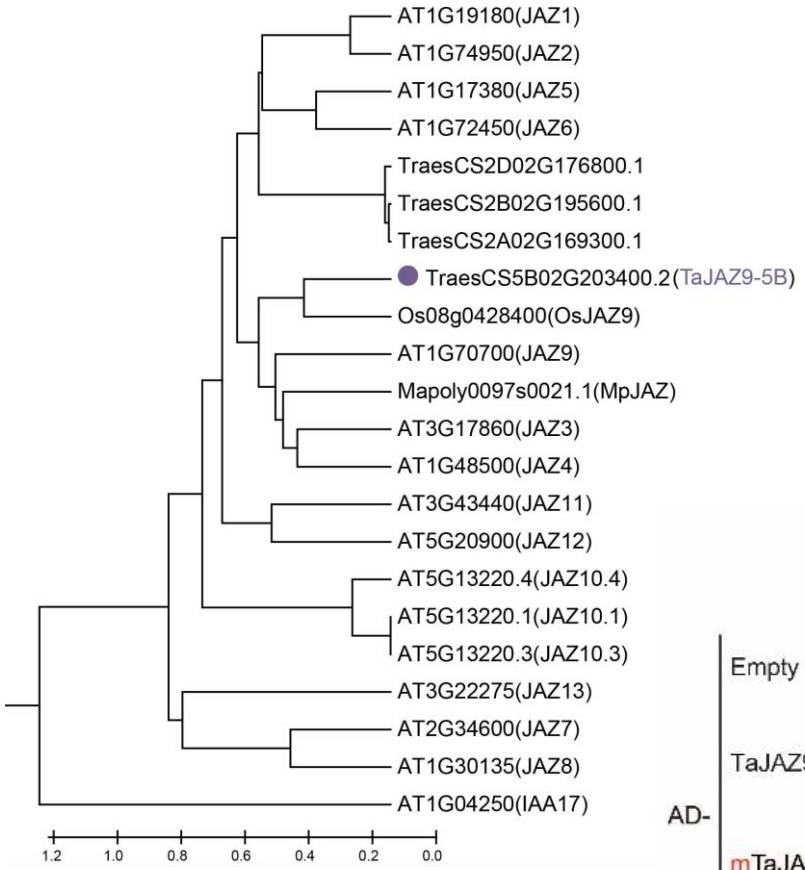


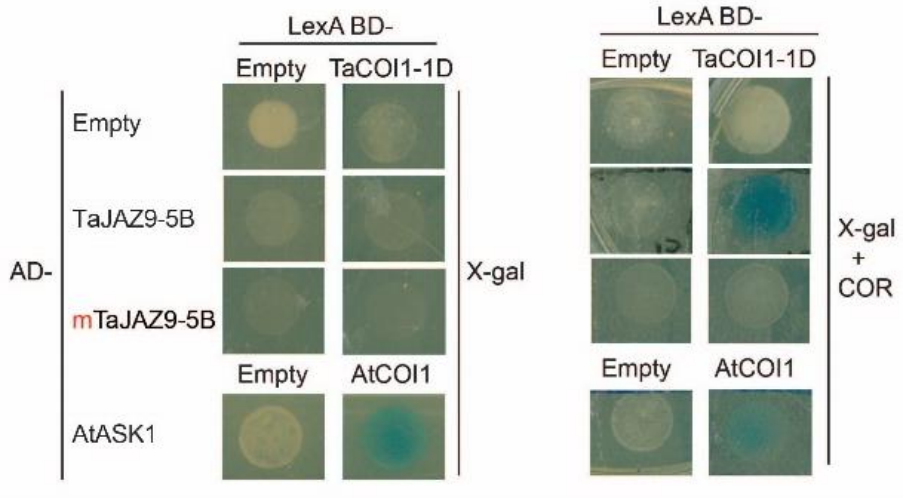


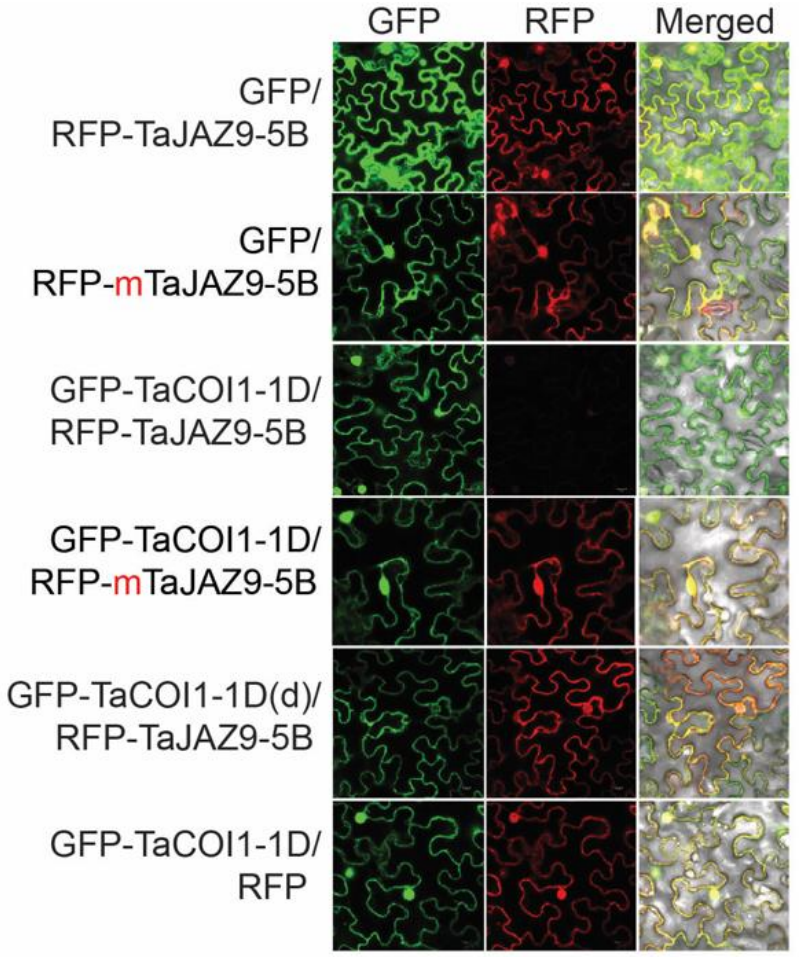


Zhu *et al* (unpublished)

TaCOI1-1D interacts with TaJAZ9-5B in CORONATINE-dependent way

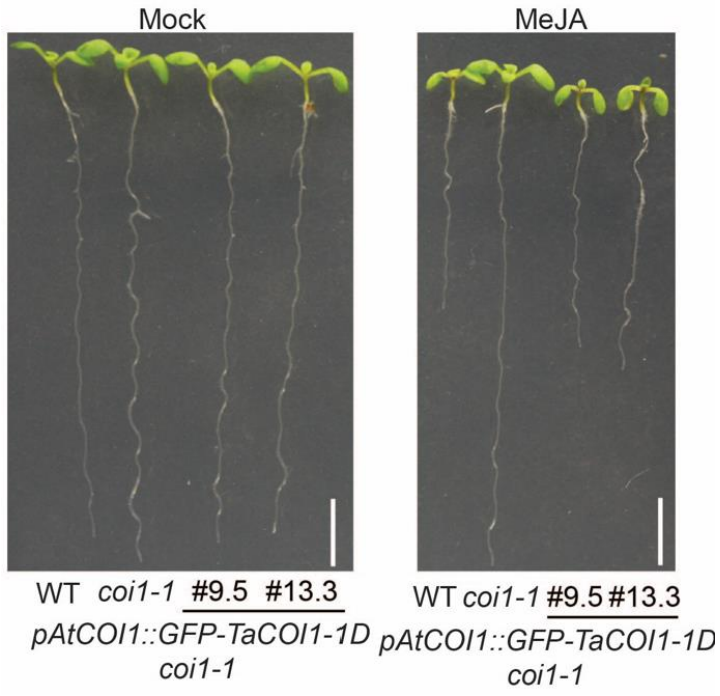


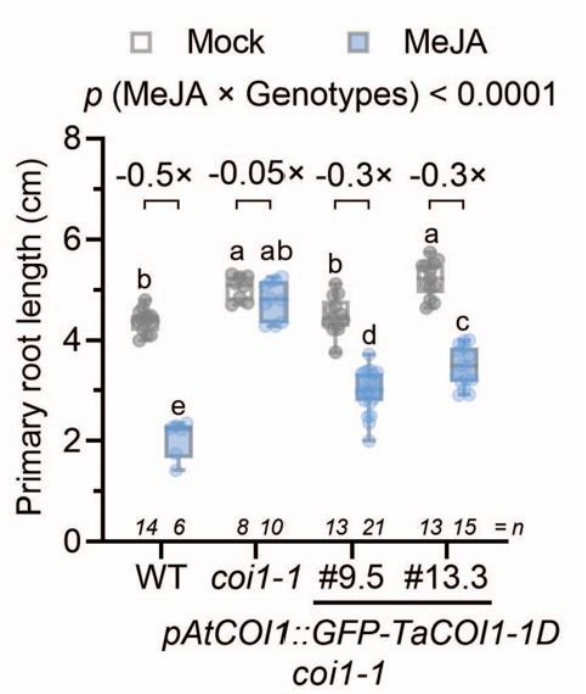


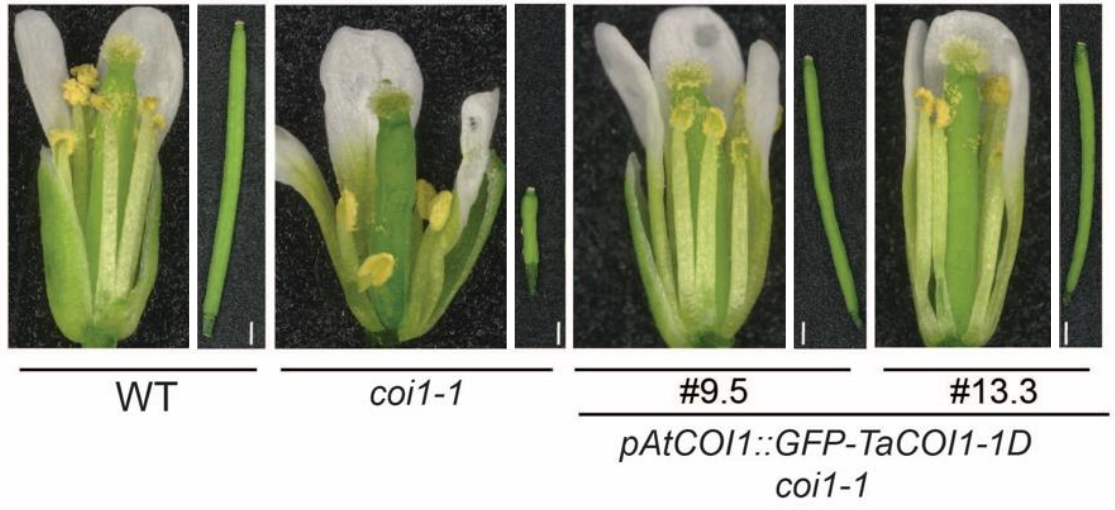


Zhu *et al* (unpublished)

Wheat TaCOI1-1D can rescue Arabidopsis *coi1-1* mutant

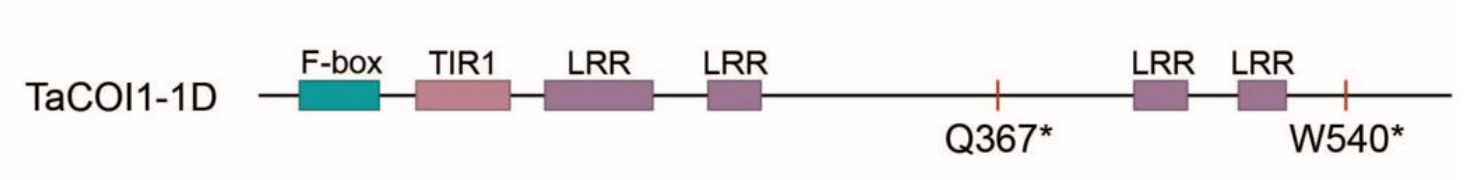


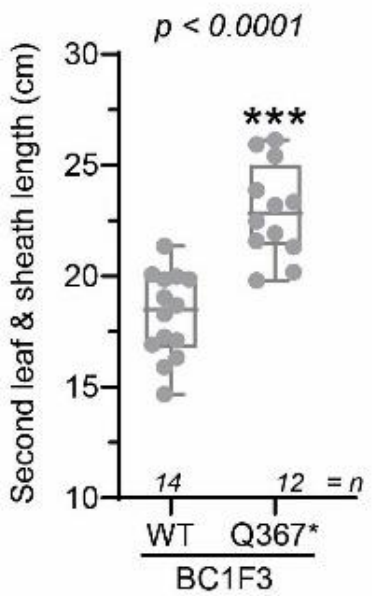


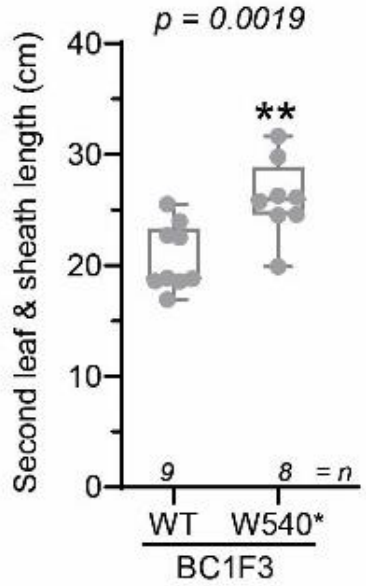


Zhu *et al* (unpublished)

TaCOI1-1D mediates TaJAZ9-5B degradation

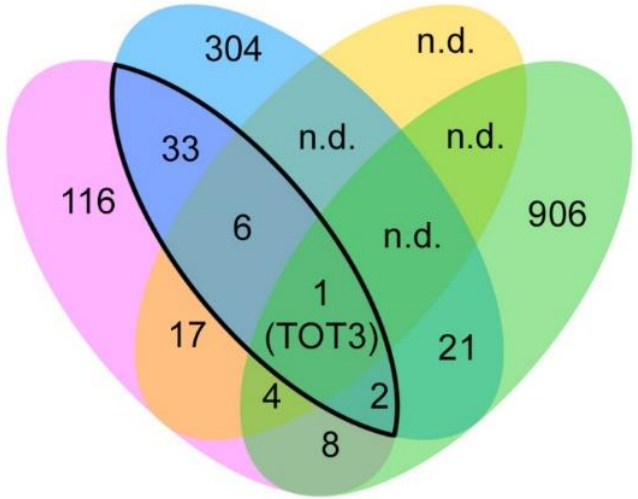






Zhu *et al* (unpublished)

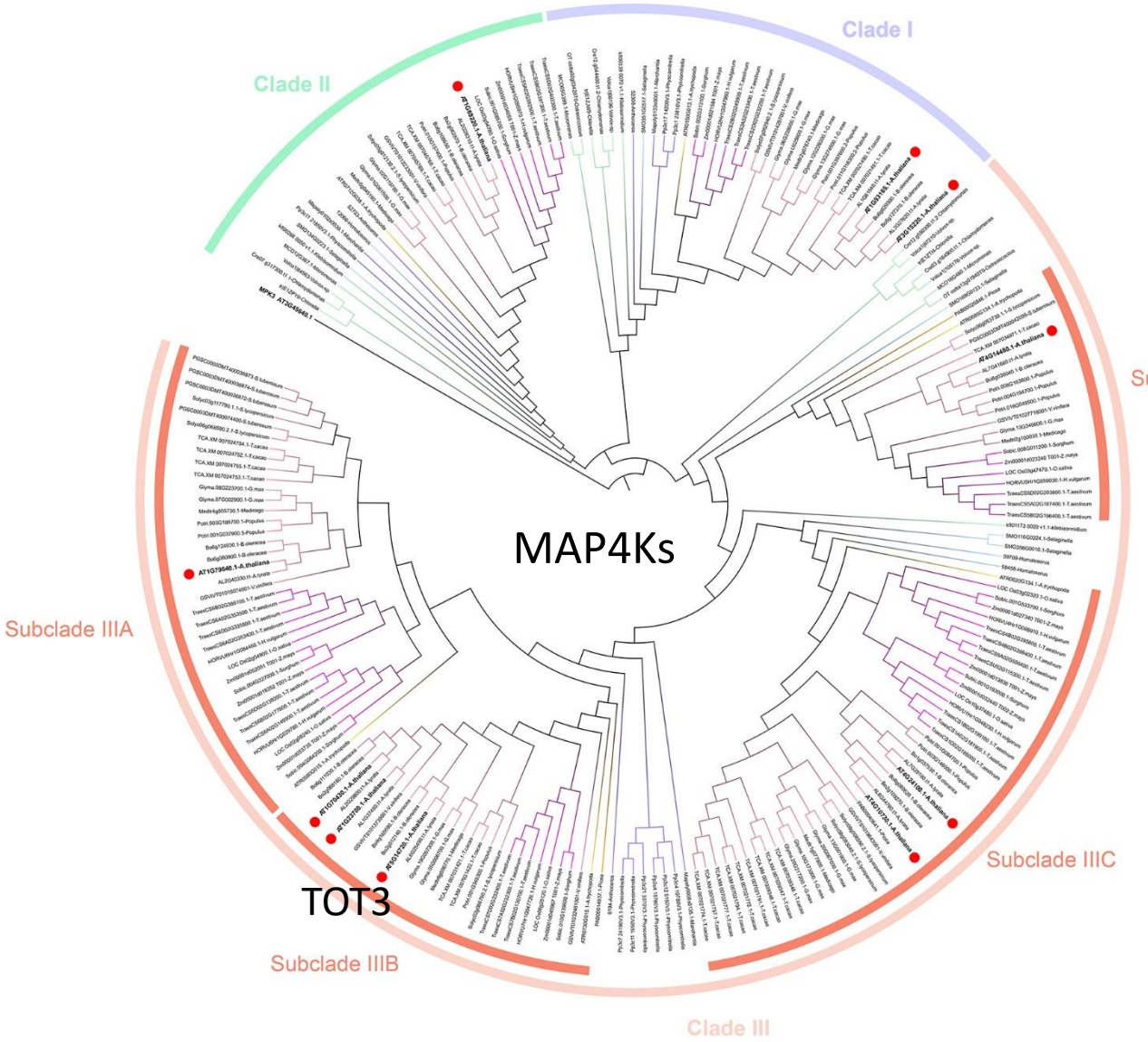
Are there conserved temperature-regulated proteins?



- TARGETs OF TEMPERATURE (TOTs)
- Warm temperature *A. thaliana* phosphoproteome (21 °C vs 27 °C)
- Warm temperature wheat / soybean phosphoproteome
- Predicted membrane localization of *A. thaliana* proteins
- *A. thaliana* kinases

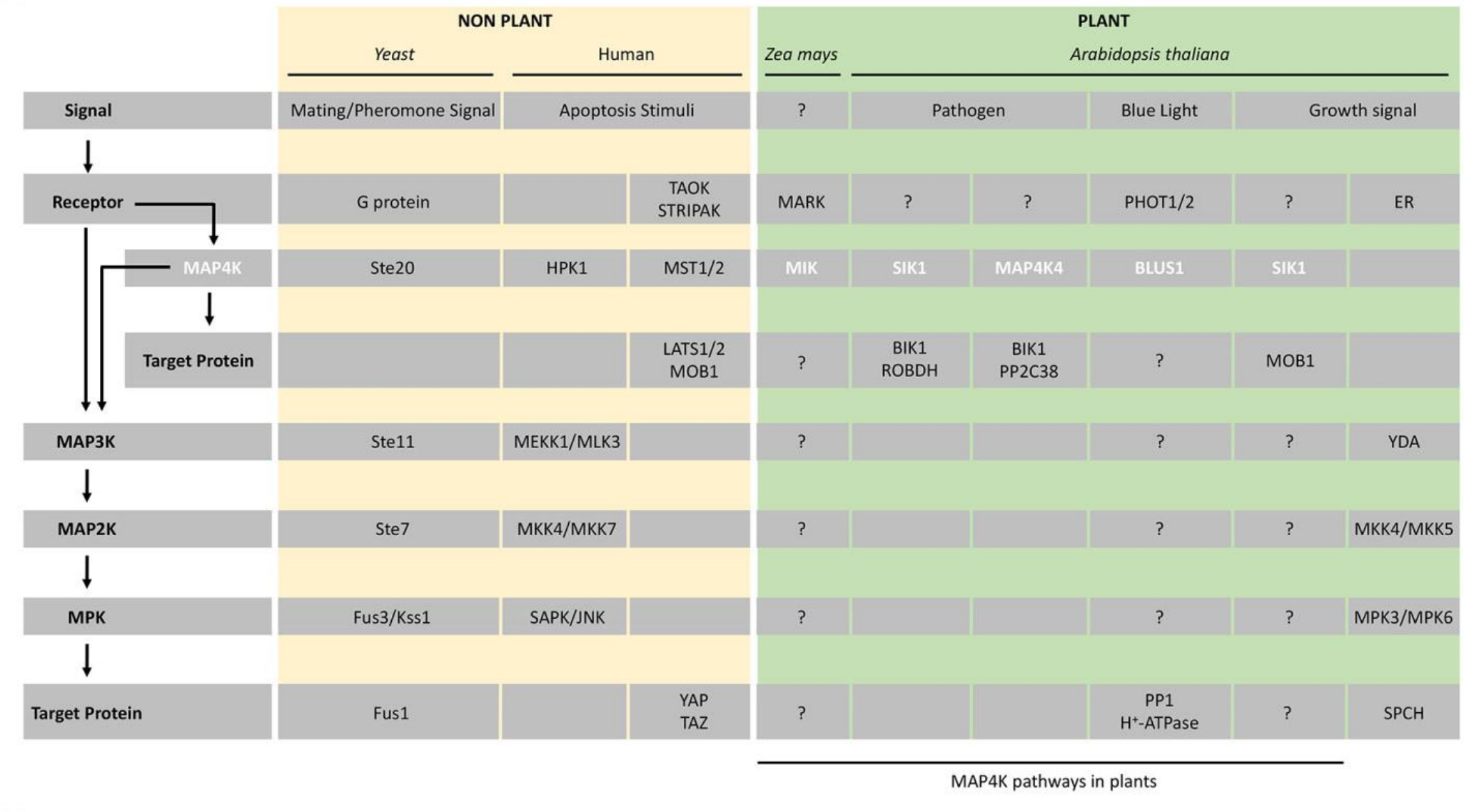
Vu *et al* (2021) *Nature Communications* 12(1):2842

TOT3 is a MAP4K



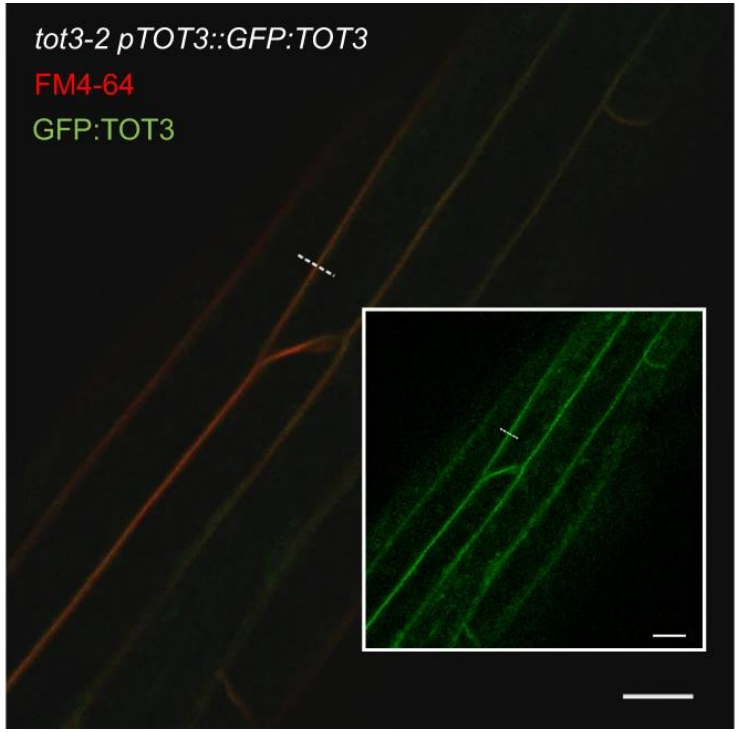
Pan *et al* (2021) *Front Plant Sci* 12:650171

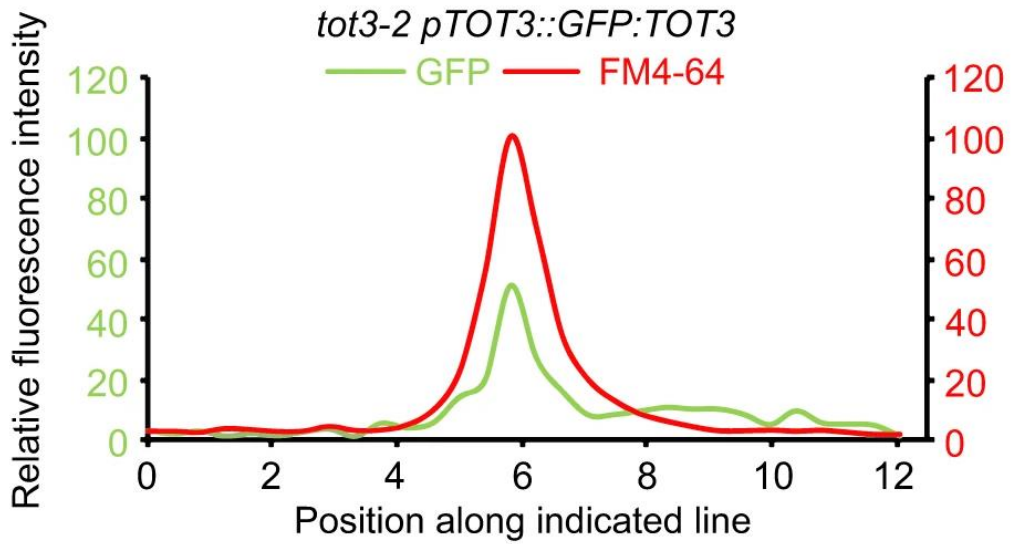
MAP4Ks are hardly explored in plants



Pan and De Smet (2020) *Front Plant Sci* 11:1220

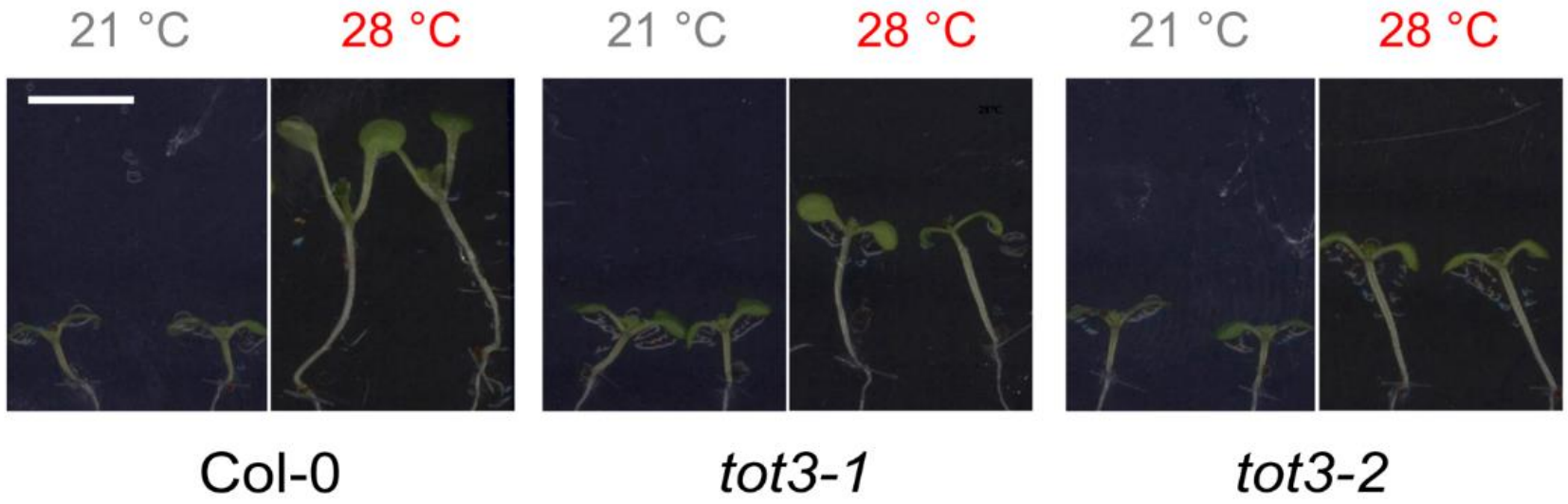
TOT3 localizes to the plasma membrane

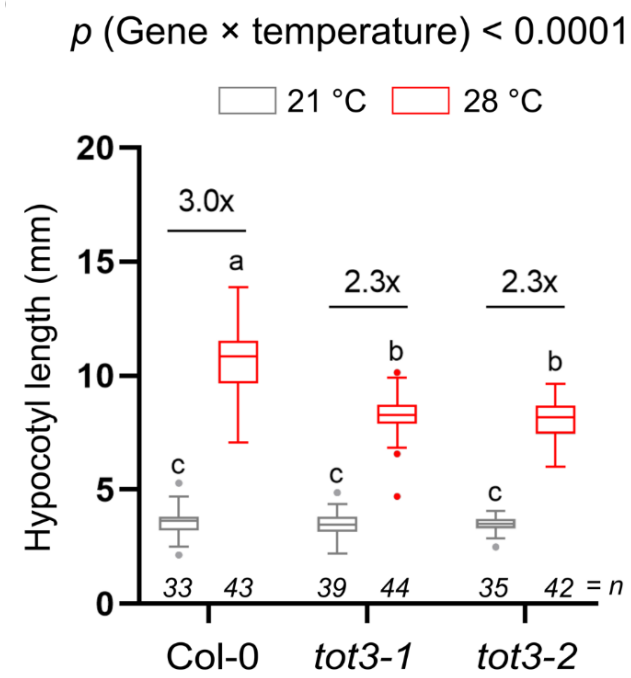




Vu *et al* (2021) *Nature Communications* 12(1):2842

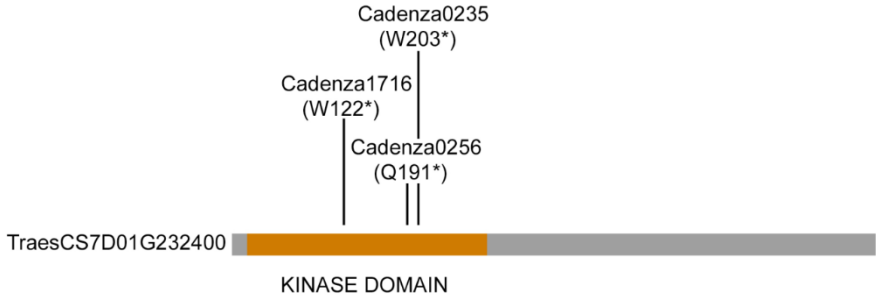
TOT3 is required for warm temperature-mediated growth in *Arabidopsis*

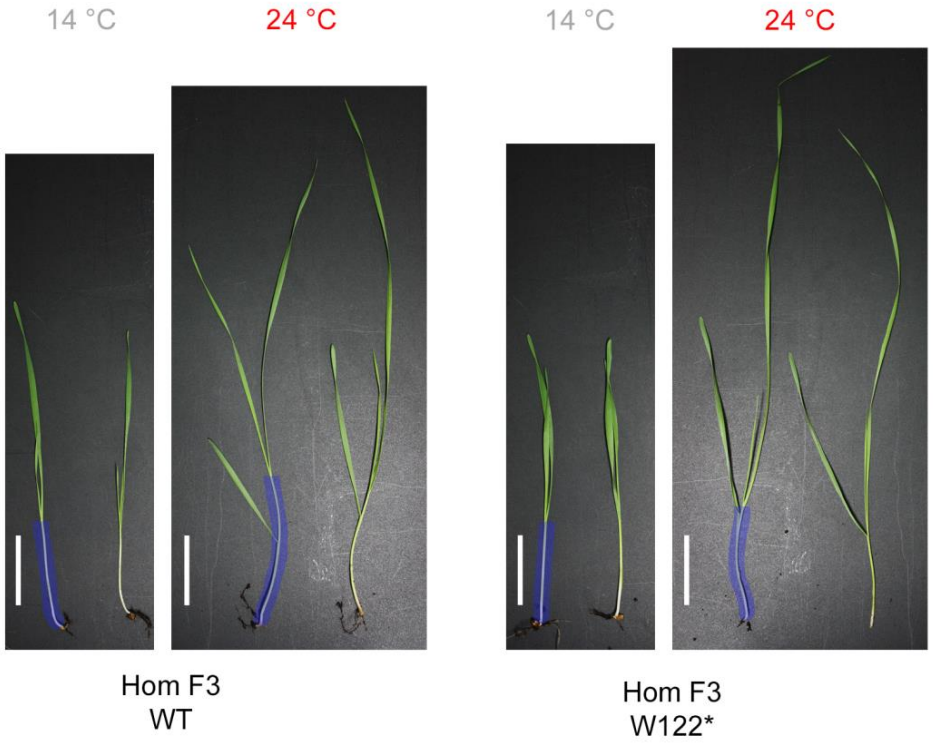


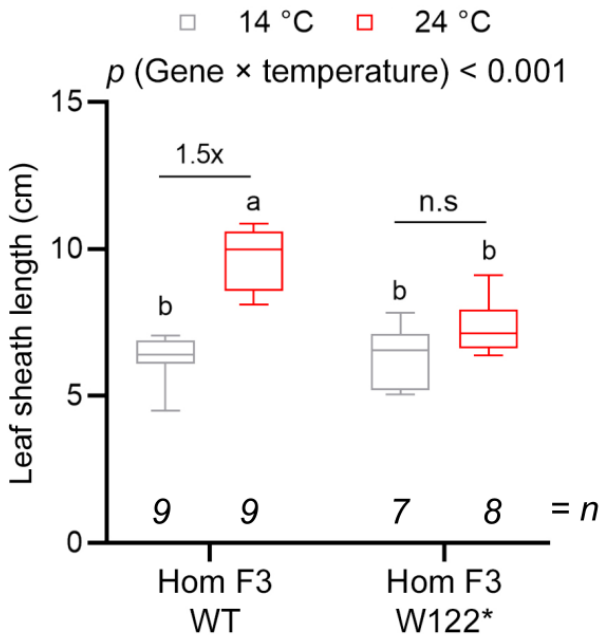


Vu *et al* (2021) *Nature Communications* 12(1):2842

TOT3 is required for warm temperature-mediated growth in *wheat*





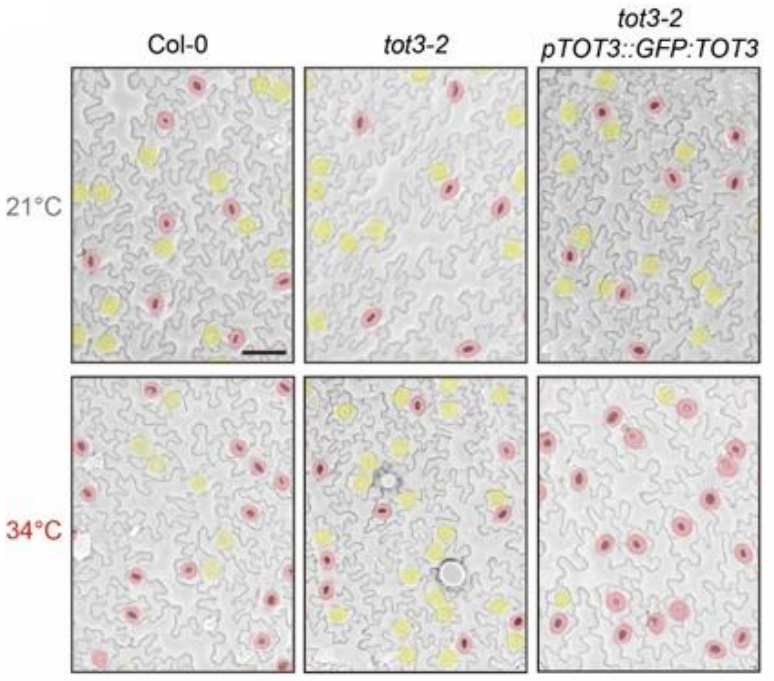


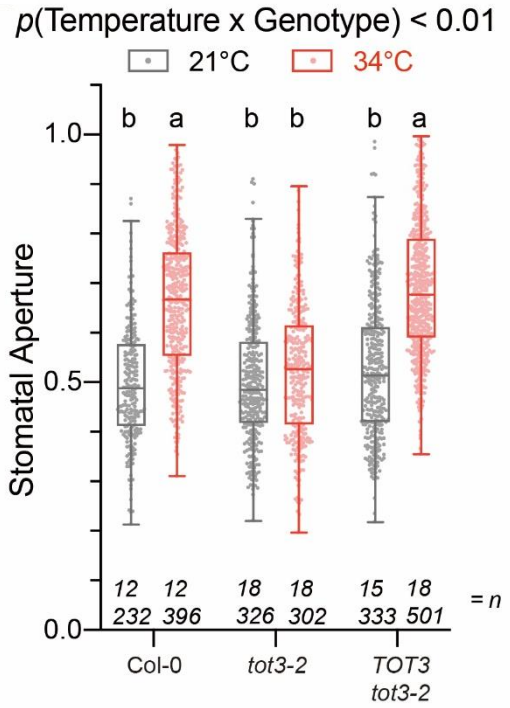
Vu *et al* (2021) *Nature Communications* 12(1):2842

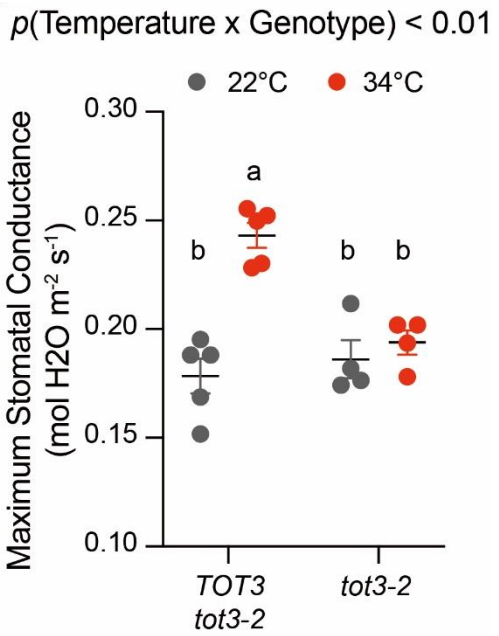
TOT3 is expressed in stomata in Arabidopsis

Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

TOT3 is required for stomatal opening at high temperature in *Arabidopsis*

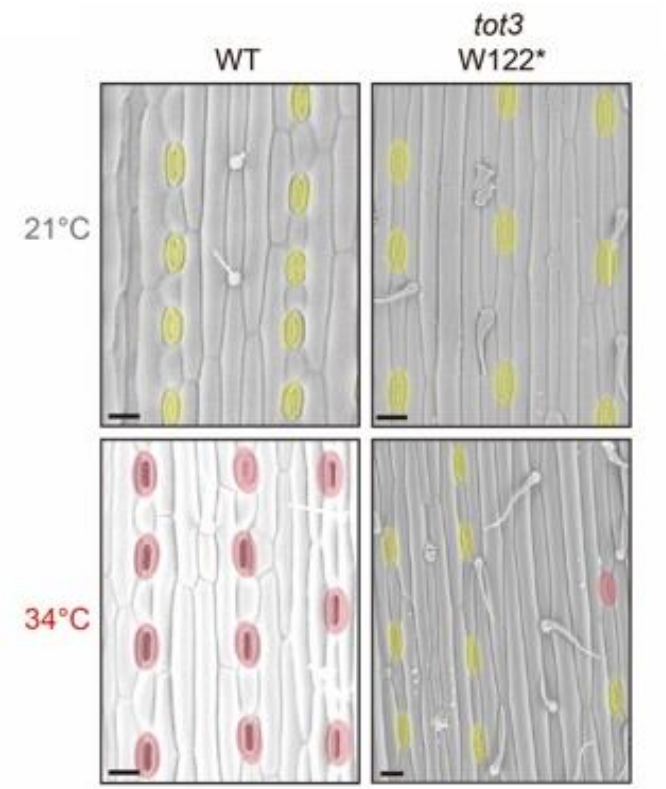


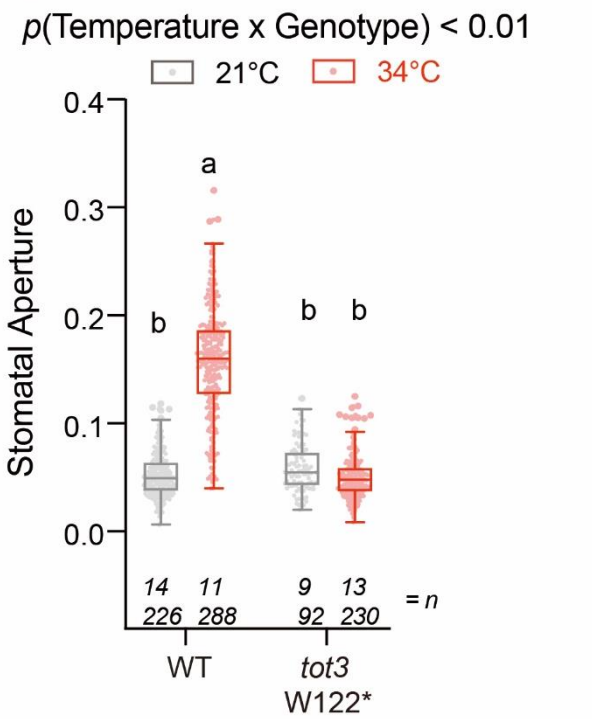


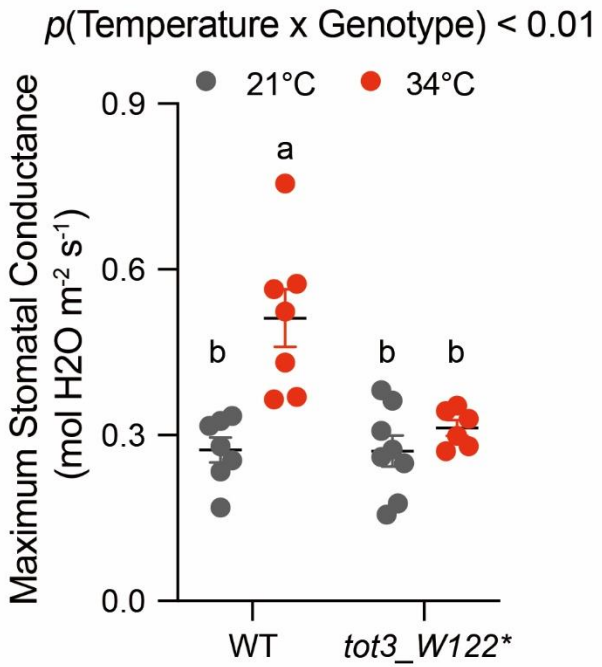


Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

TOT3 is required for stomatal opening at high temperature in *wheat*

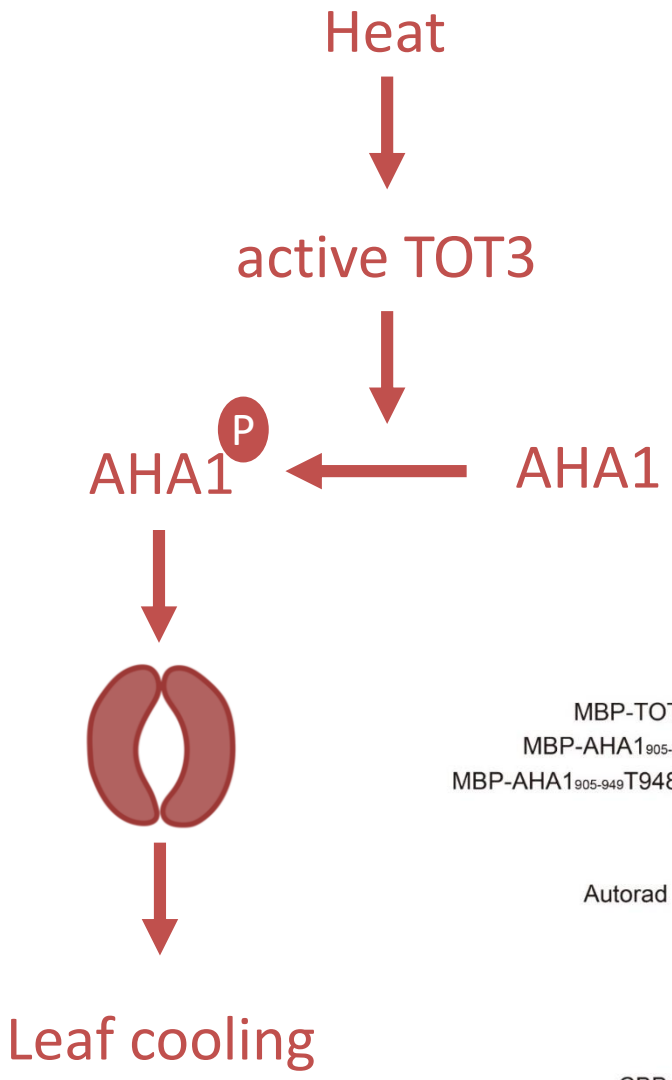


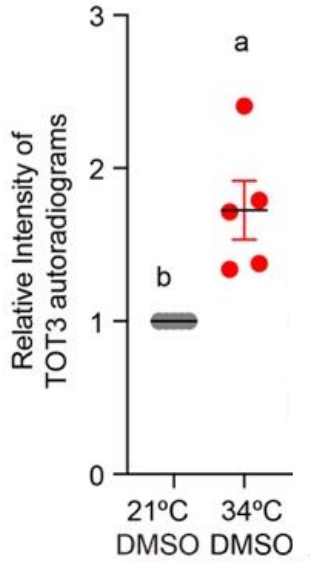


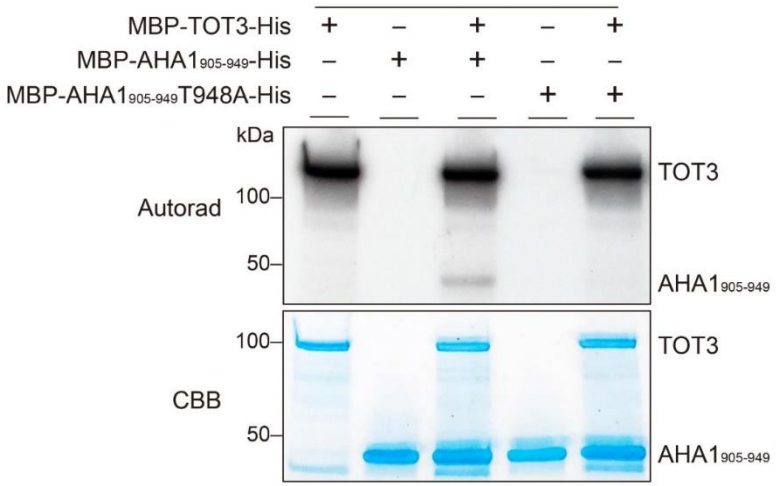


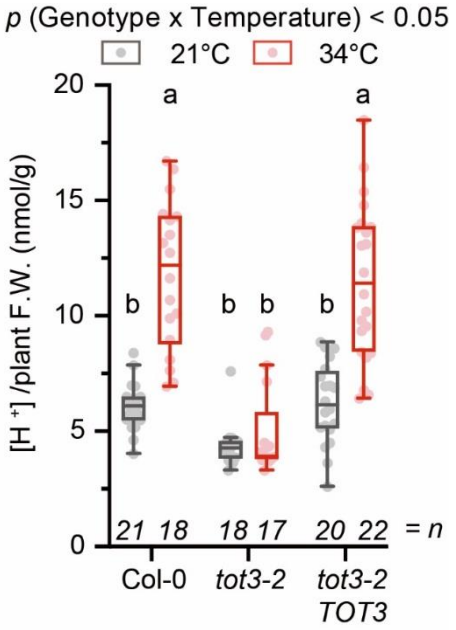
Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

TOT3 controls AHA1 activity to open stomata by phosphorylating T948 upon heat









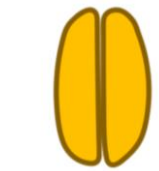
Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

What happens under drought?

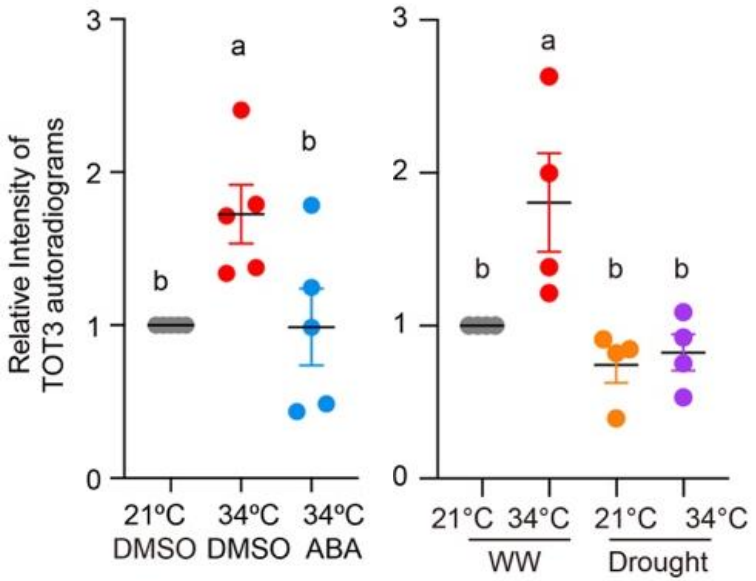
Drought

ABA → less active TOT3

active OST1

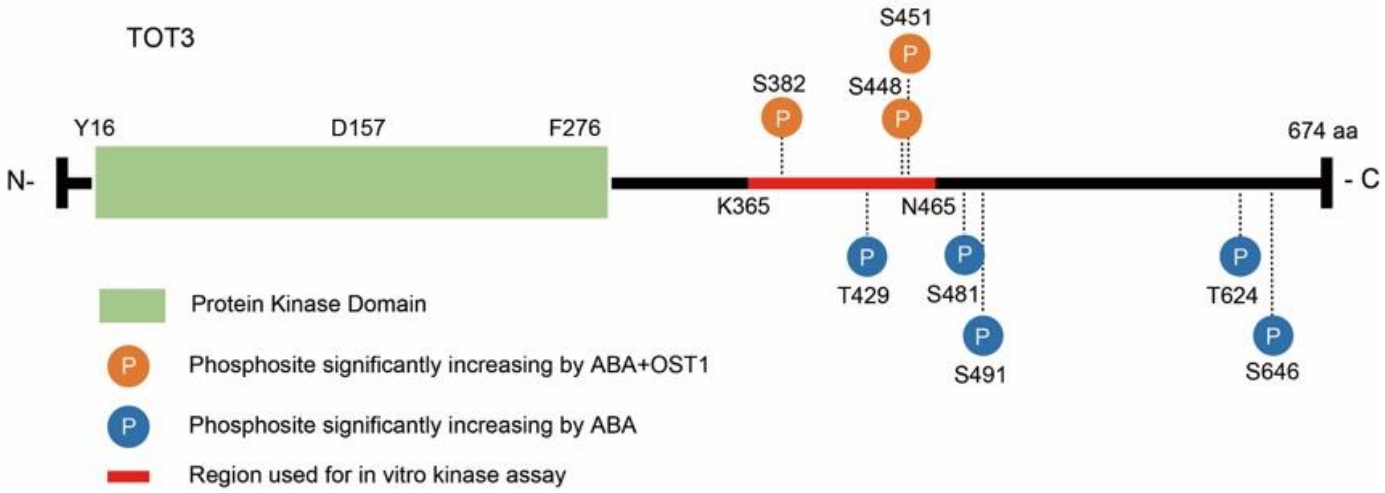


Water retainment

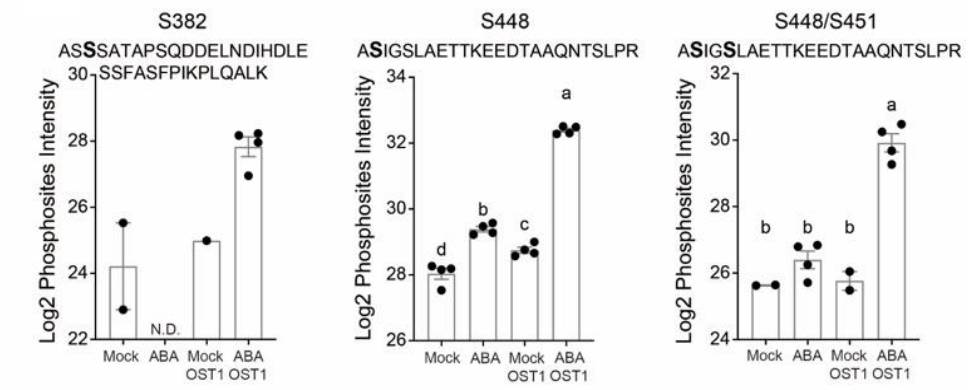


Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

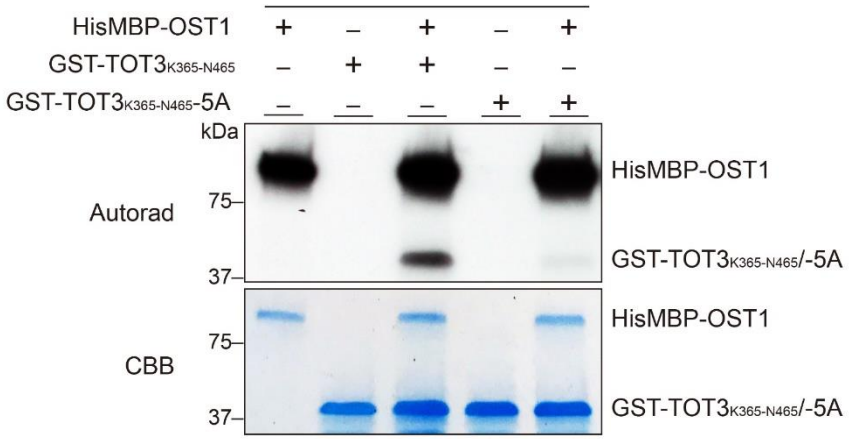
OST1 directly phosphorylates TOT3



Transient tobacco assay

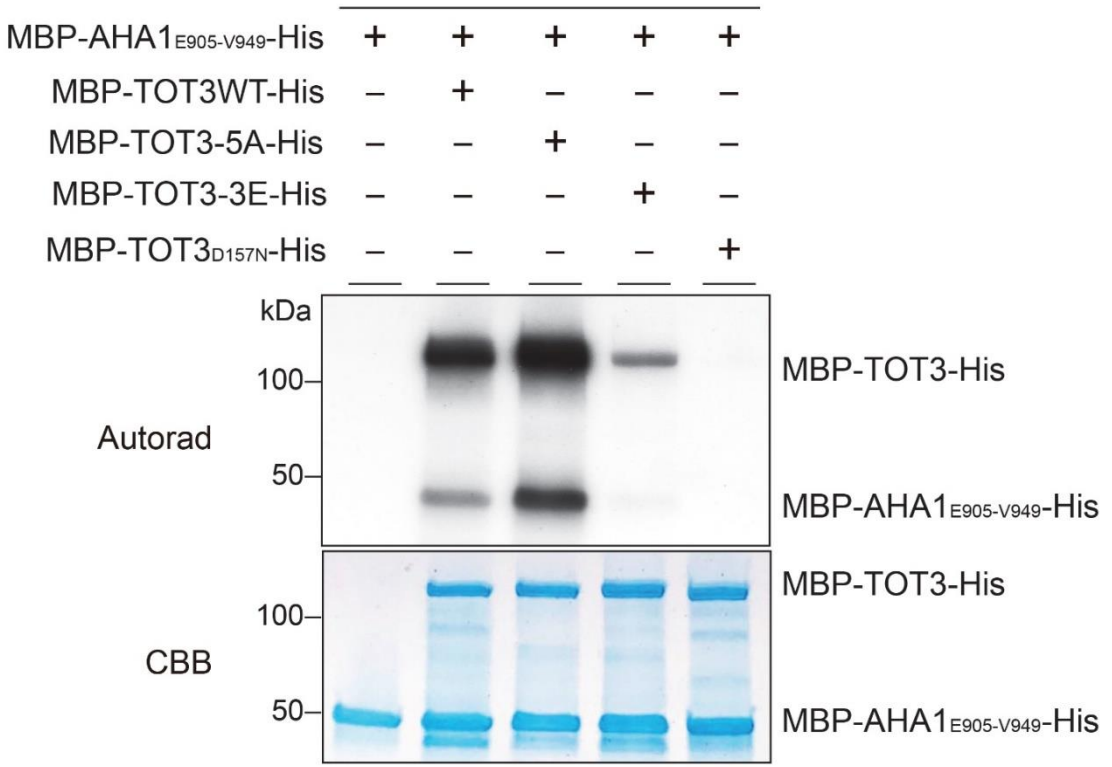


In vitro kinase assay



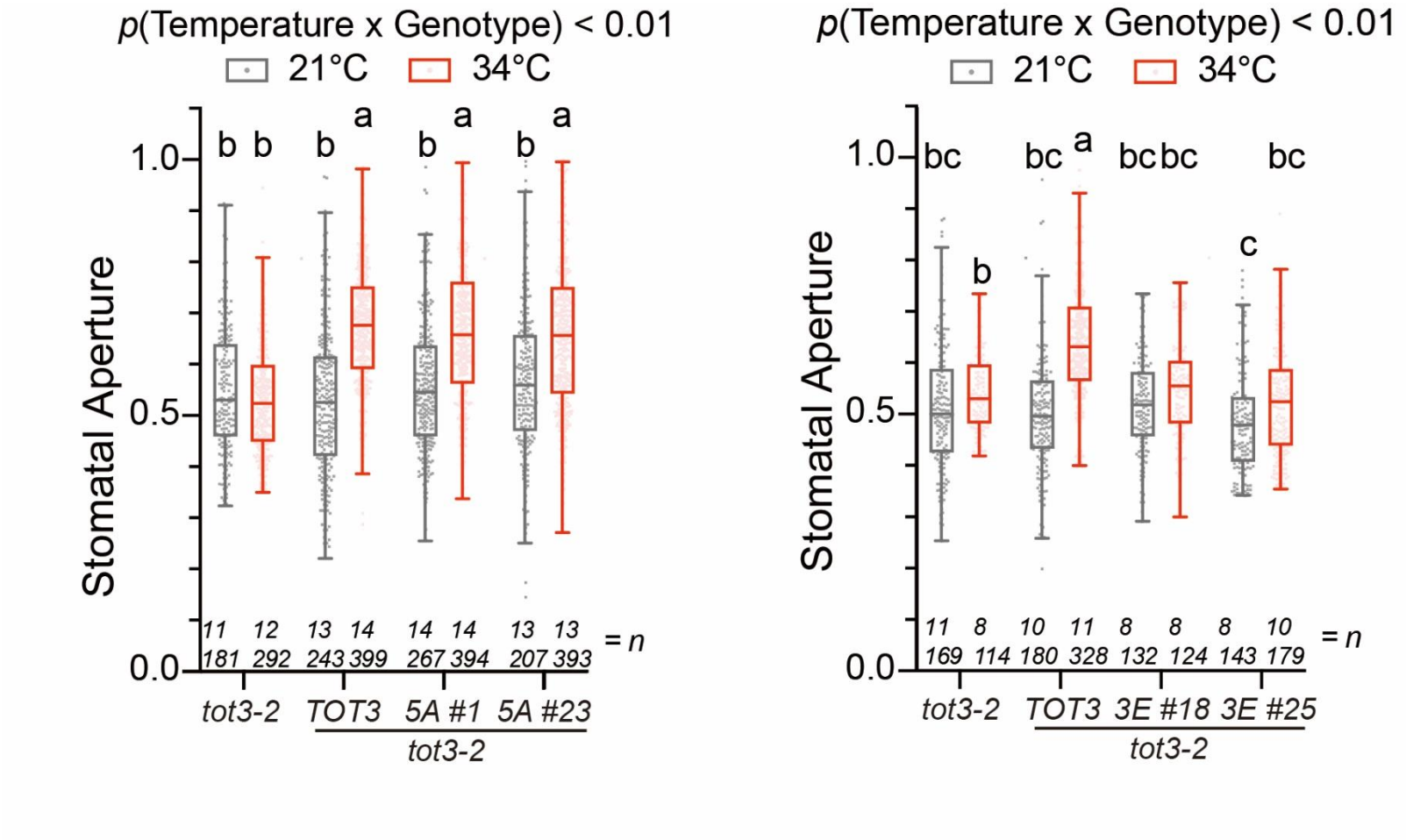
Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

OST1-mediated TOT3 phosphorylation leads to loss of kinase activity



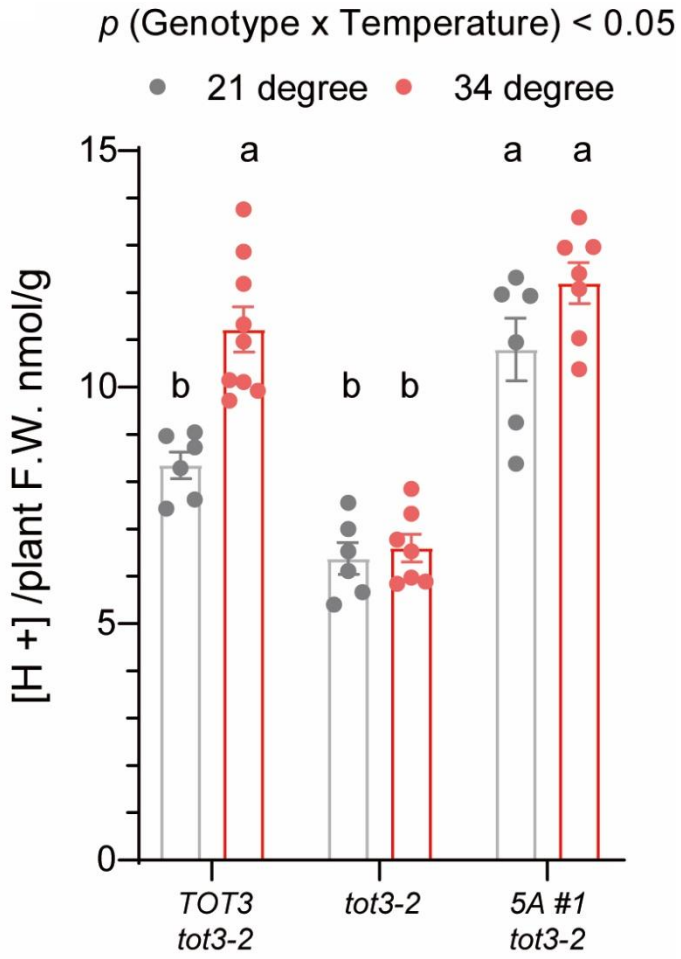
Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

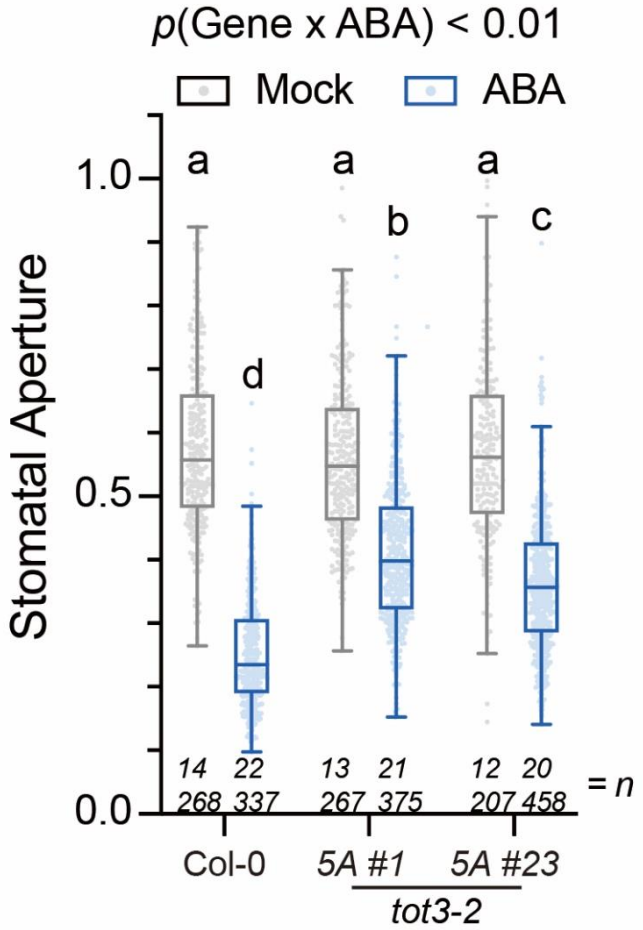
TOT3-5A = active / TOT3-3E = inactive



Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

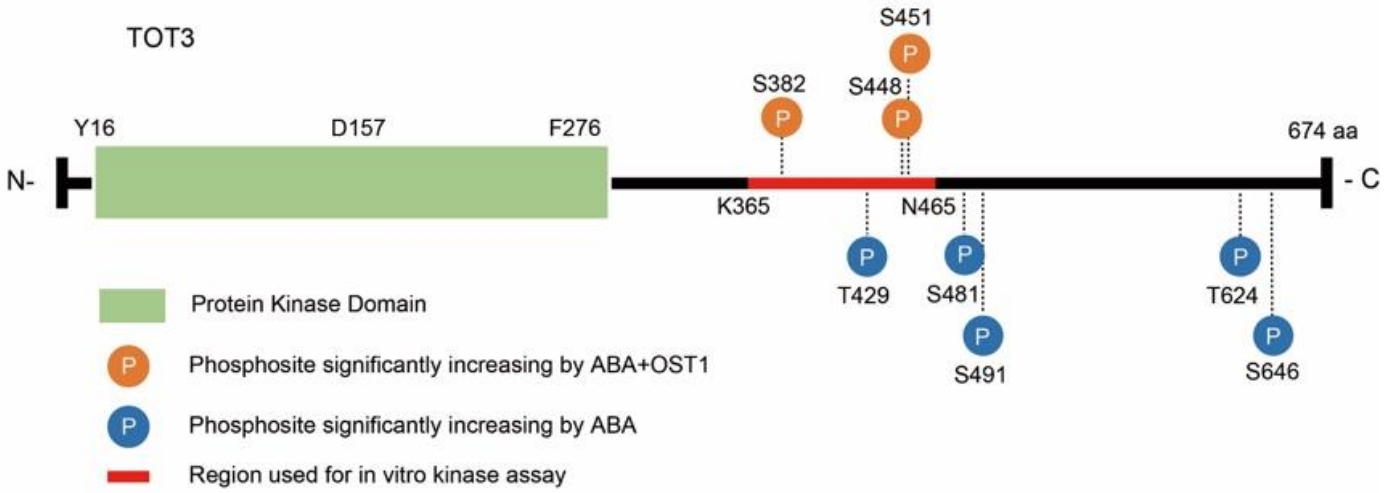
Impaired OST1-mediated TOT3 phosphorylation leads to more proton pump activity and reduced ABA-activated stomatal closure



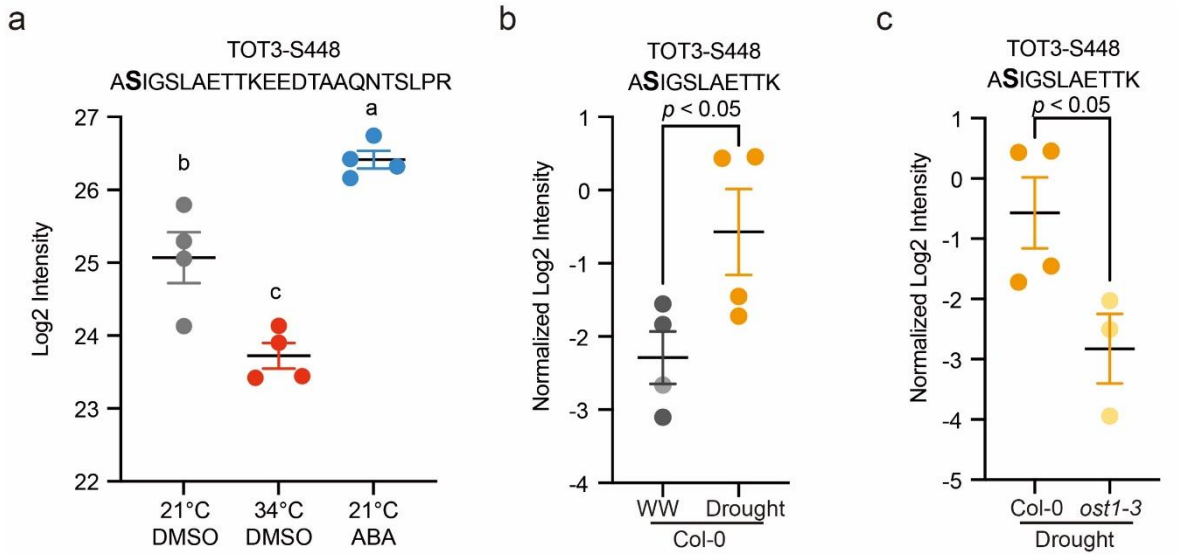


Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

OST1 phosphorylates TOT3 upon ABA or drought

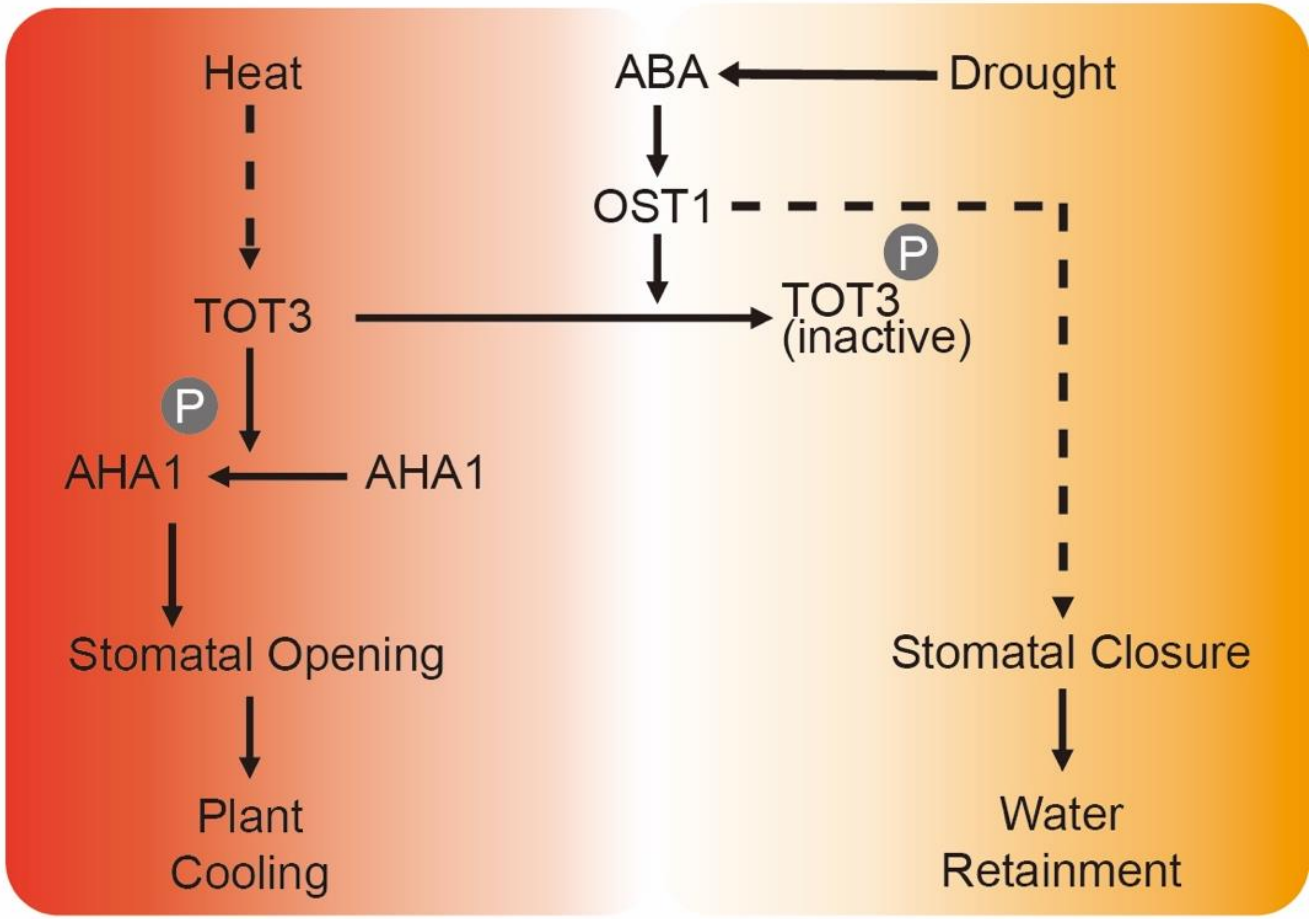


Arabidopsis



Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

OST1 and TOT3 interplay balances water loss / cooling under under drought / heat



Xu *et al* (https://www.researchsquare.com/article/rs-3228667/v1)

Take Home Messages

- Capturing protein phosphorylation allows the identification of novel signaling pathways, including components that control temperature signaling and plasticity
- Phosphorylated proteins can be valuable breeding markers
- TOT3 function is conserved in wheat and Arabidopsis
- The TOT3-AHA1-OST1 signaling module integrates environmental signaling
- TaCOI1-1D encodes a JA receptor that is involved in regulating wheat growth

WHO DID THE WORK?

Group alumni

L.D. Vu, E. Stes, L. Joos, I. Verstraeten, S. Zhu, N. Nikonorova, P. Neyt, X. Xu

Collaborators

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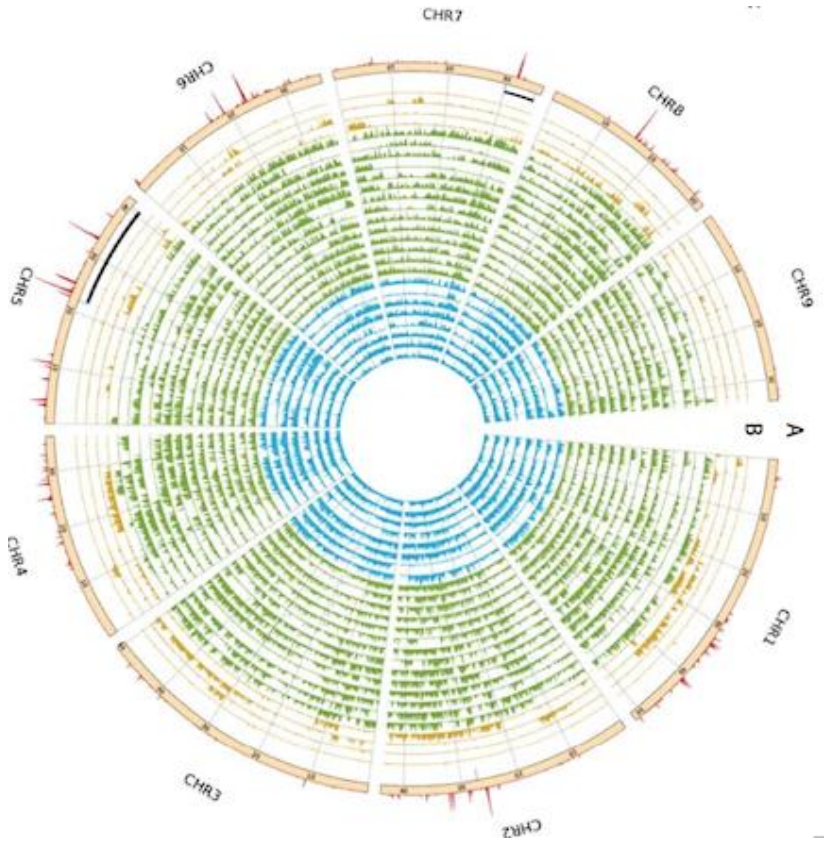

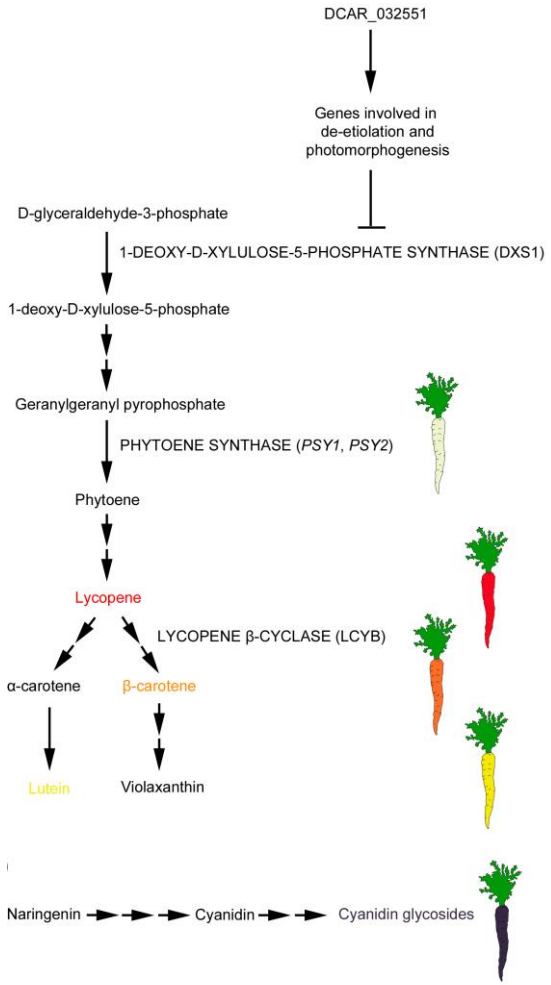

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ArtGenetics

Persoonlijk blog

#artgenetics - Belgian researchers @david.vergauwen (art historian) and @desmetive (VIB-UGent) reveal plant diversity over time 🍓🍍🍆🥕 ... meer

Trends in Plant Science

CellPress

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Down the Rabbit Hole–Carrots, Genetics and Art

David Vergauwen[1] and Ive De Smet[2,3,*,@]

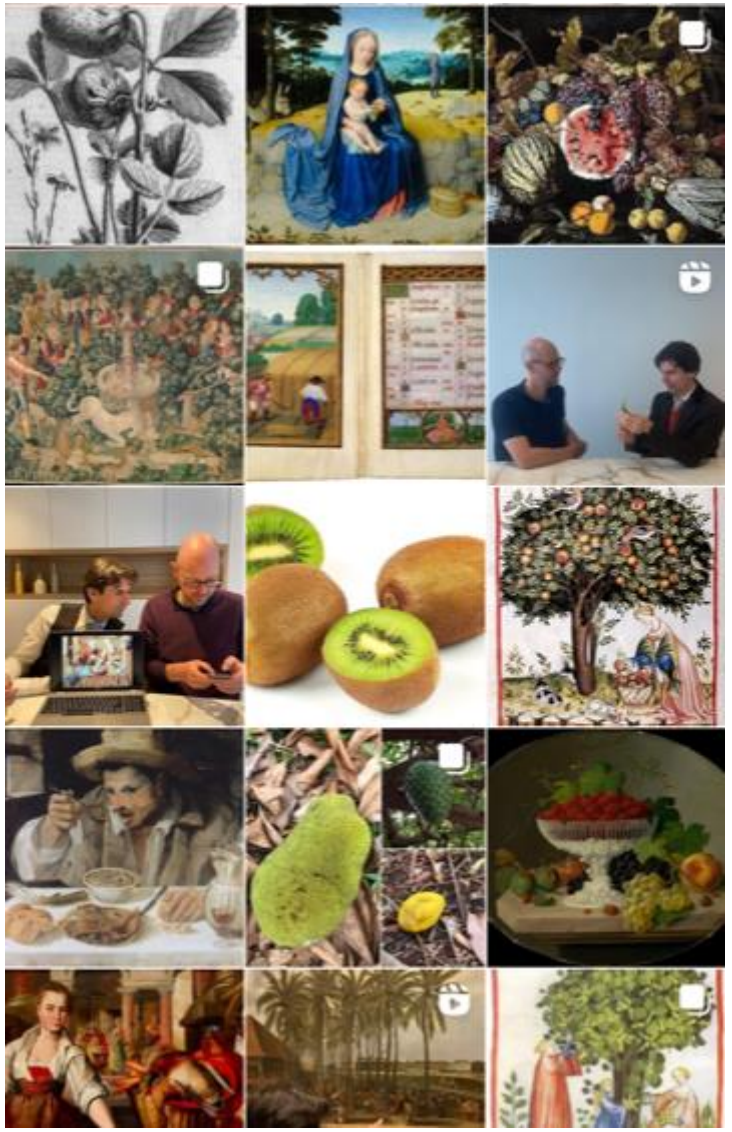
The recent carrot genome assembly provides insight into carotenoid accumulation in carrots, and allows–together with other genetic information–to provide a molecular explanation for color differences observed in carrots painted throughout the centuries.

Carrots and Art

The large, unbranched cultivated carrot some of the molecular mechanisms and underlying genetic network responsible for the observed colour differences.

On the Origin of the Carrot

The origin of carrot is complex, but recent studies shed some light on the geographical distribution and domestication origin of wild and cultivated carrot [3]. Eastern and Western type carrots can be recognized, with the origin of the former in western to central Asia (purple, red or orange-yellow roots) and the latter derived from the Eastern type (yellow, orange, or–sometimes–white roots) [3,4]. The carrot was probably first domesticated somewhere in the area between the north east of Kabul (Afghanistan) and north Kashmir (India) around AD 900 [5]. Later, in the 10th century, a Bagdad-based cook, Ibn Sayyar al-Warraq, mentioned in his '*Kitāb al-Tabi*', a book with about 600 artist to truthfully represent the plants and their color. Assumptions on the exactness of the image can be made according to when and where it was made. A fine painting by a seventeenth century Dutch painter can on historical and stylistic grounds be said to be more 'realistic' than an Egyptian mural and will therefore be a more accurate historical source. In addition, color tones or intensity can be affected over time depending on the preservation of the art. A fresco in a Roman bar ('*Caseggiato del Termopolio*') dated between 98 and 138 depicts a vegetable that is conic shaped and vaguely yellow, which might be one of the first representations of a cultivated carrot, although it is more likely to be a parsnip. In 512, we see–next to a pale yellow wild one–an orange, branched carrot depicted in the *Juliana Anicia Codex*. From the 11th century drawings of (yellow) carrots started to



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