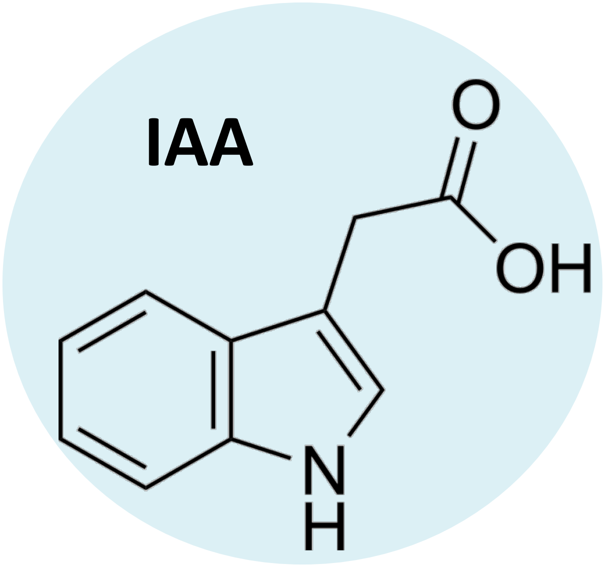
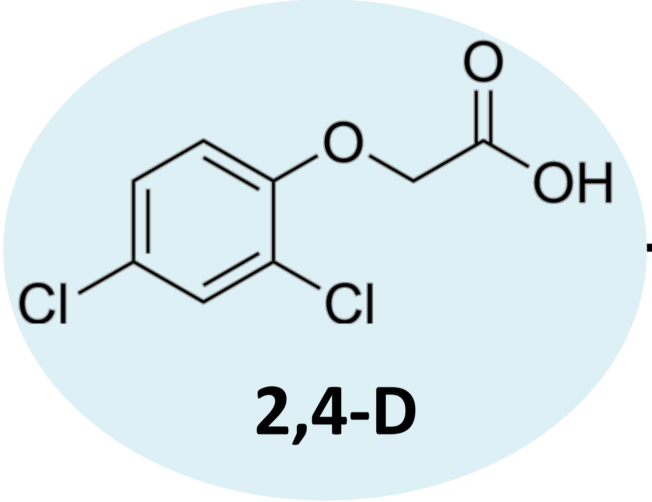
Auxin-mimic herbicides and resistance in Weeds

Dr. Franck Dayan, Professor
Colorado State University

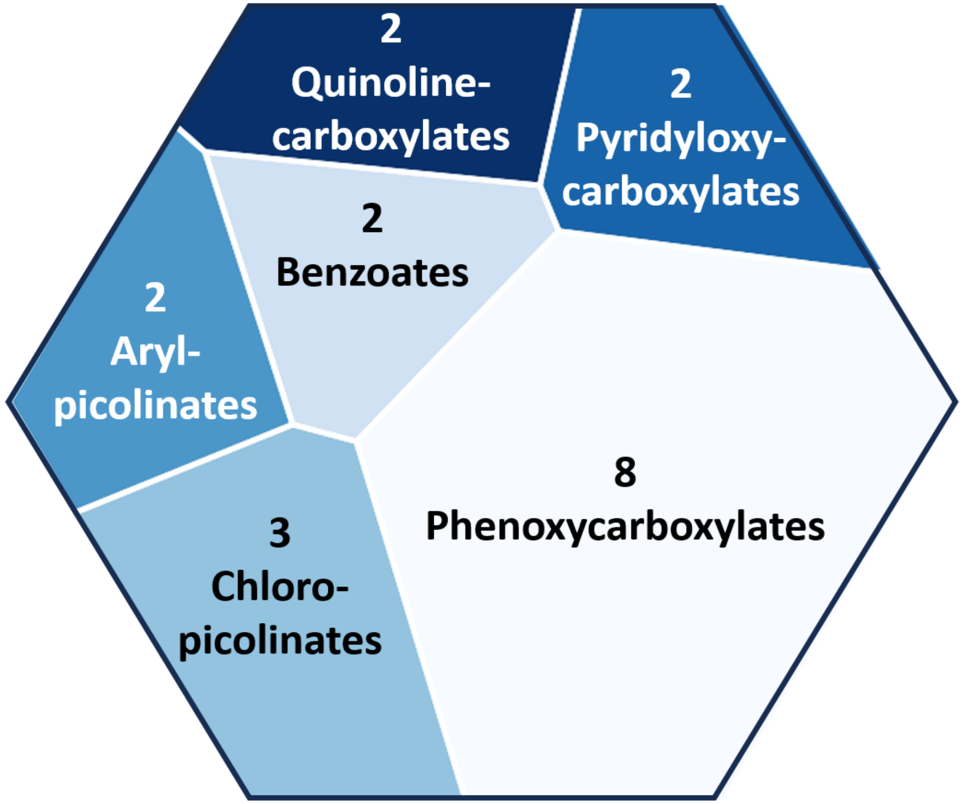
What are auxin-mimic herbicides?

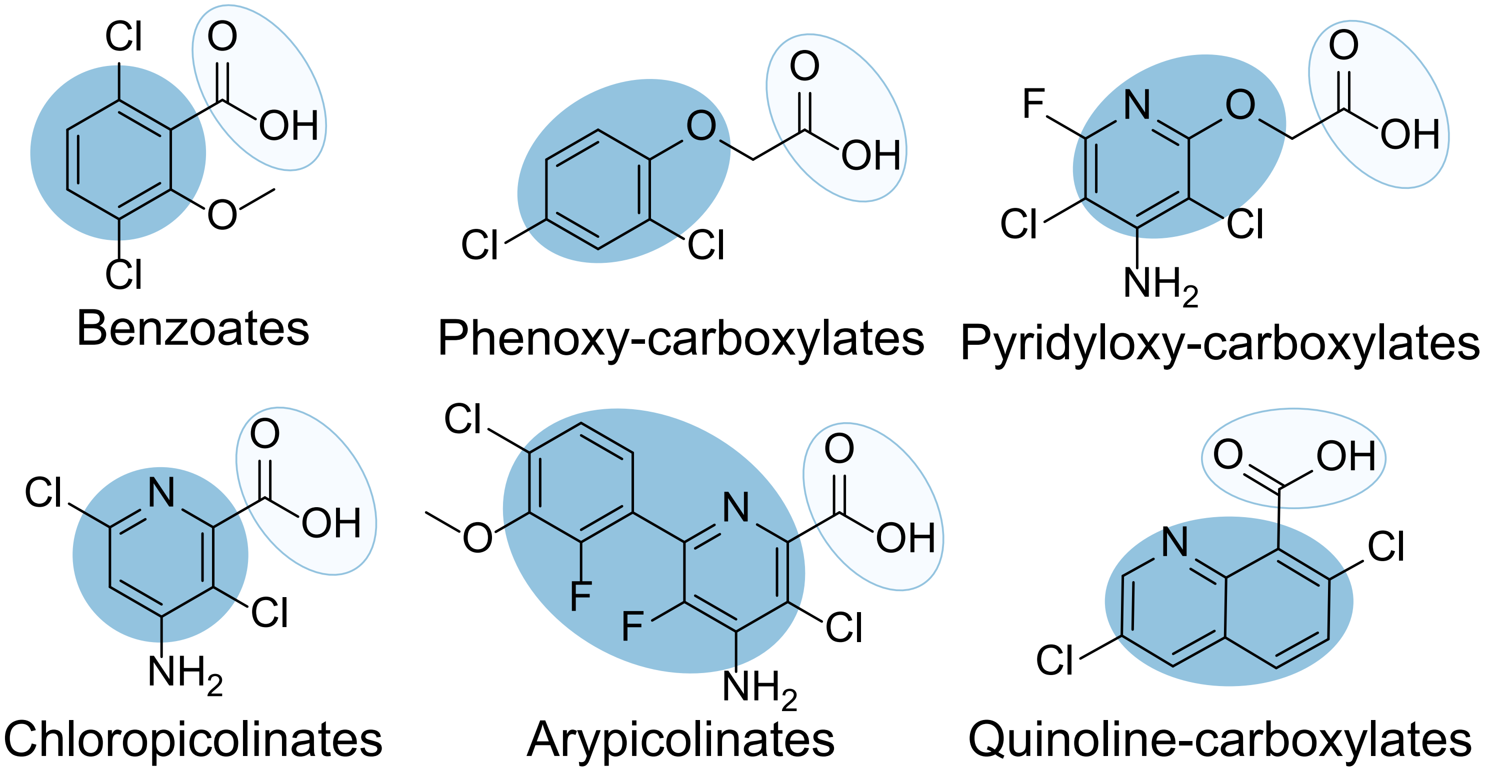
Auxin-mimic herbicides (AMHs) classified by HRAC as Group 4 encompass a group of molecules that mimic the action of the natural hormone (indole-3-acetic acid, IAA) in plants, affecting plant signaling, disrupting regulatory pathways, and ultimately inhibiting their growth and development





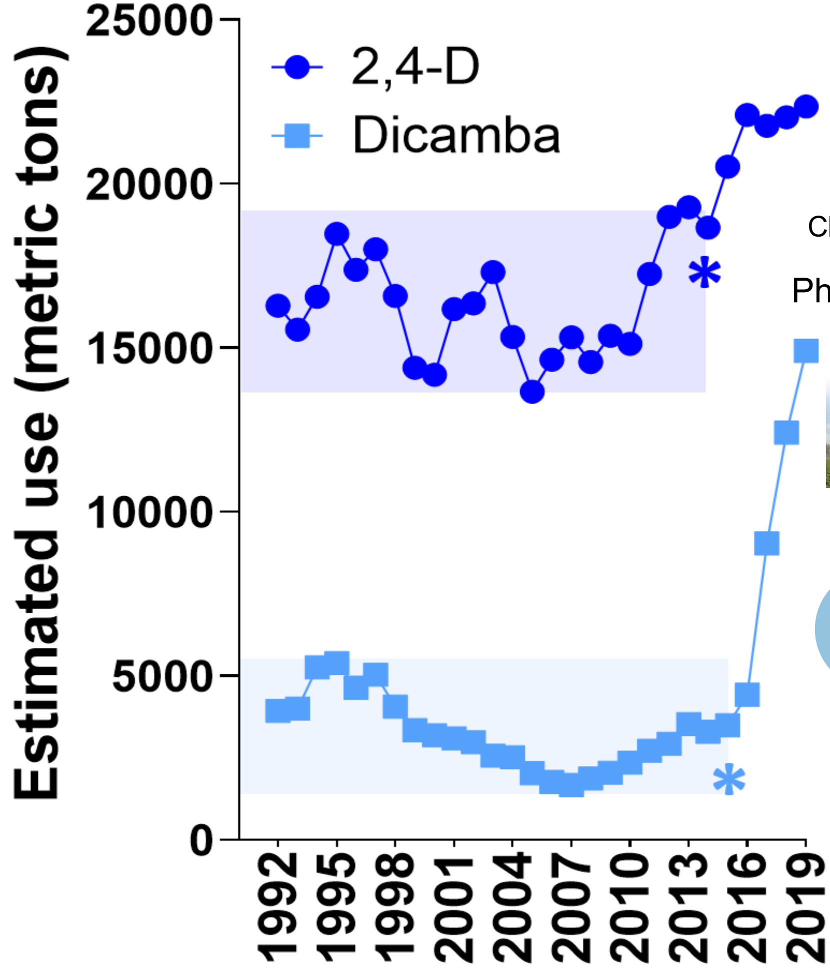
Classification of AMH by chemical structure



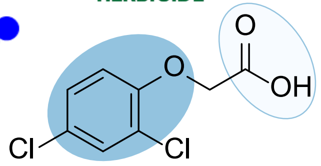


Moreno-Serrano, Gaines & Dayan 2024 Current status of auxin-mimic Herbicides. *Outlooks on Pest Management*, *35*(3), 105-112.

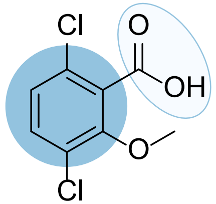
Top two AMHs chemical classes use in crop production



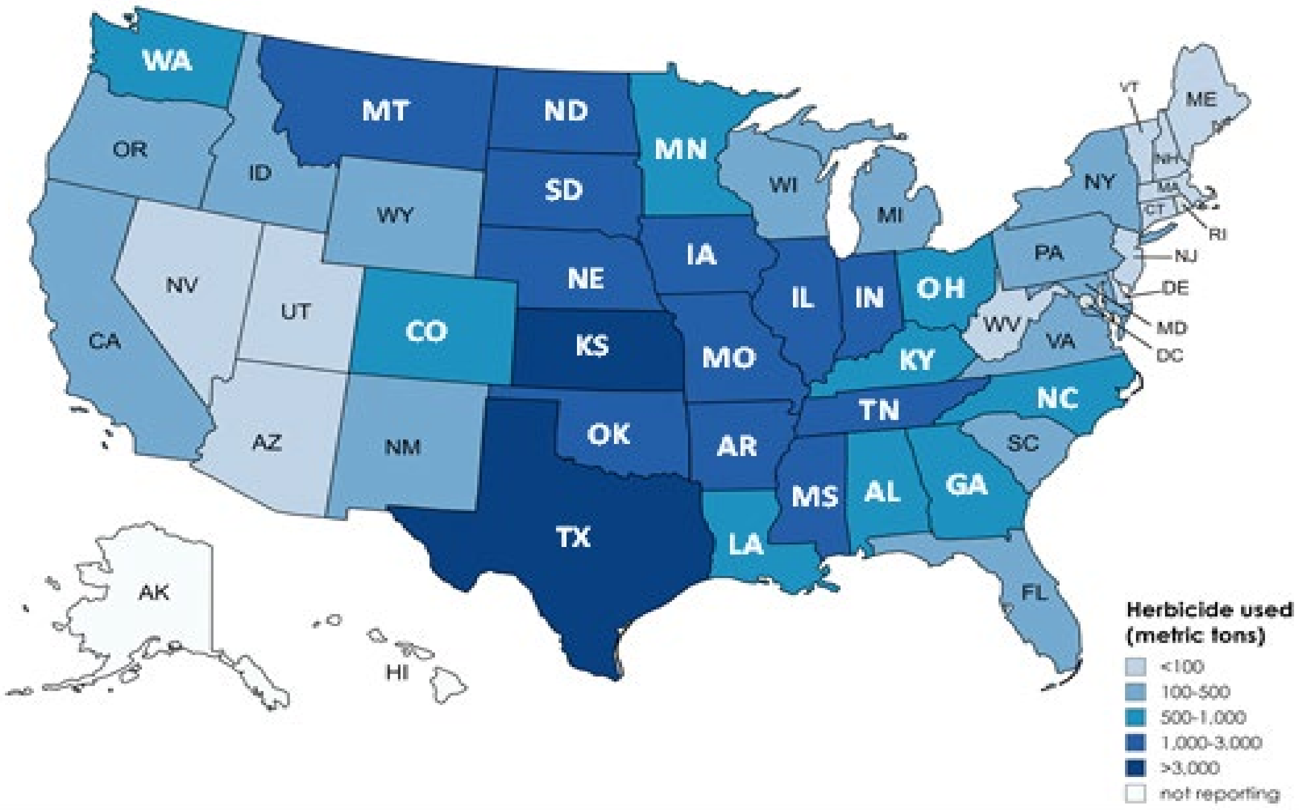
Enlist One®
COLEX•D® technology
HERBICIDE



Phenoxy-carboxylates

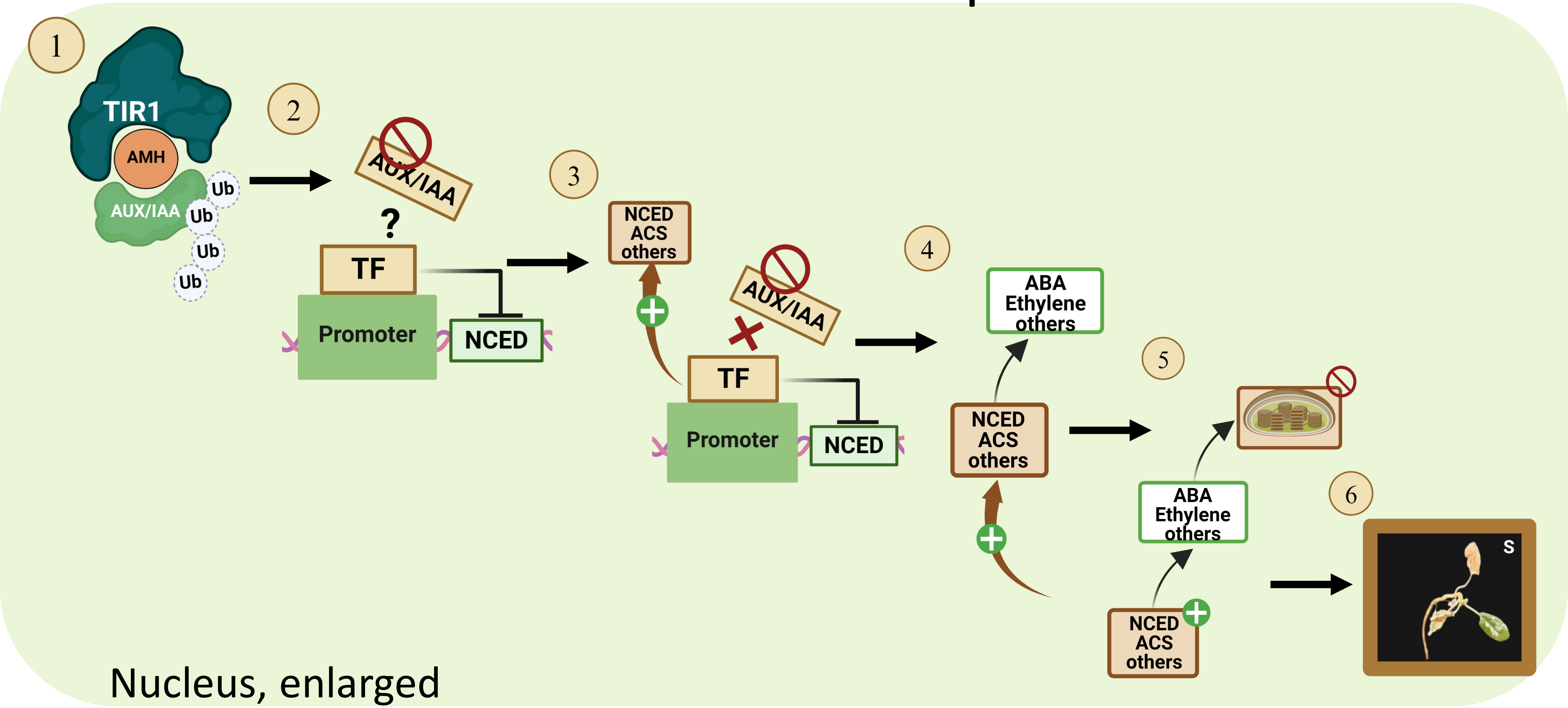


Benzoates



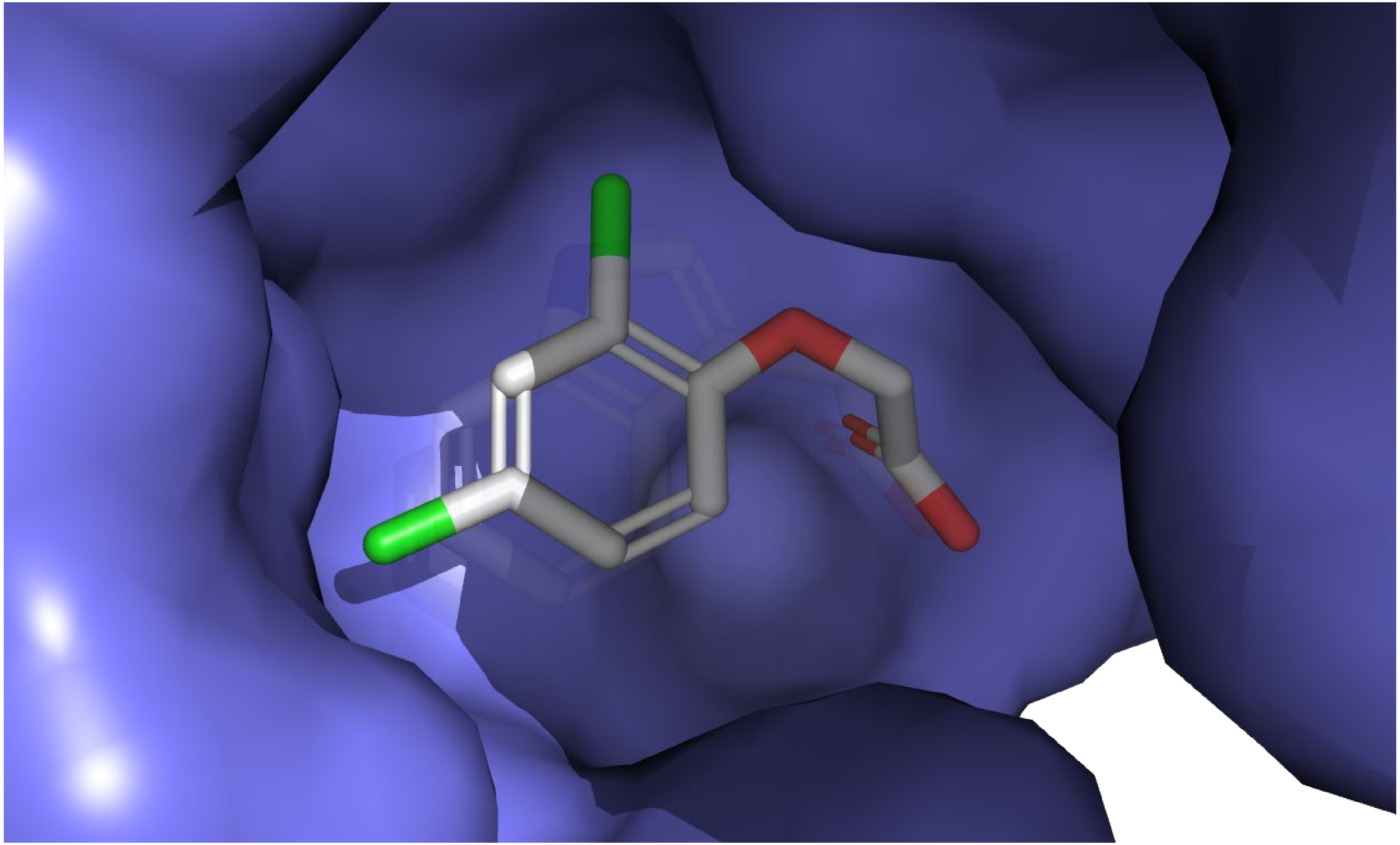
Moreno-Serrano, Gaines & Dayan 2024 Current status of auxin-mimic Herbicides. *Outlooks on Pest Management*, *35*(3), 105-112.

How do AMHs act in plants?



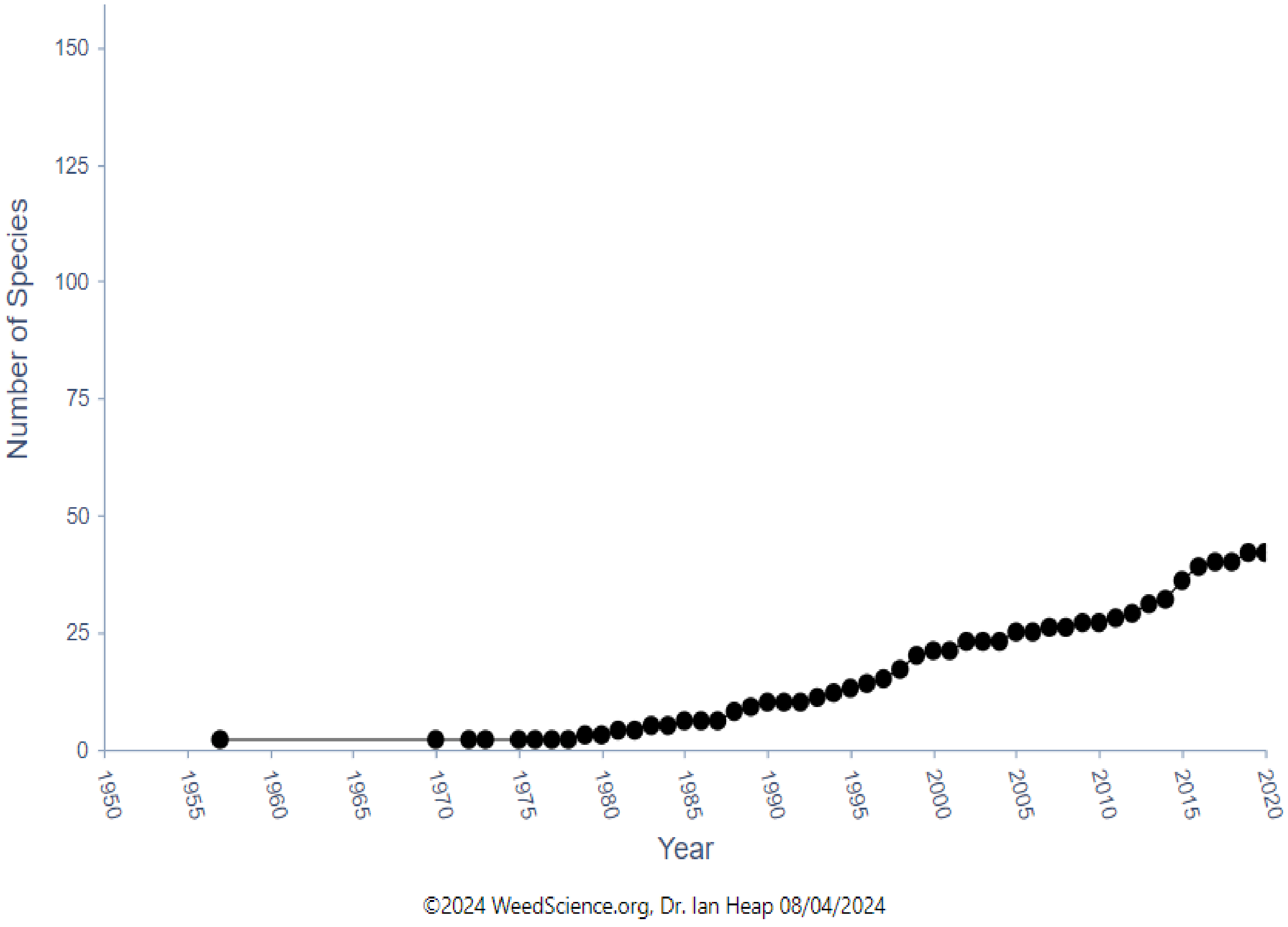
Adapted from: Gaines, 2006

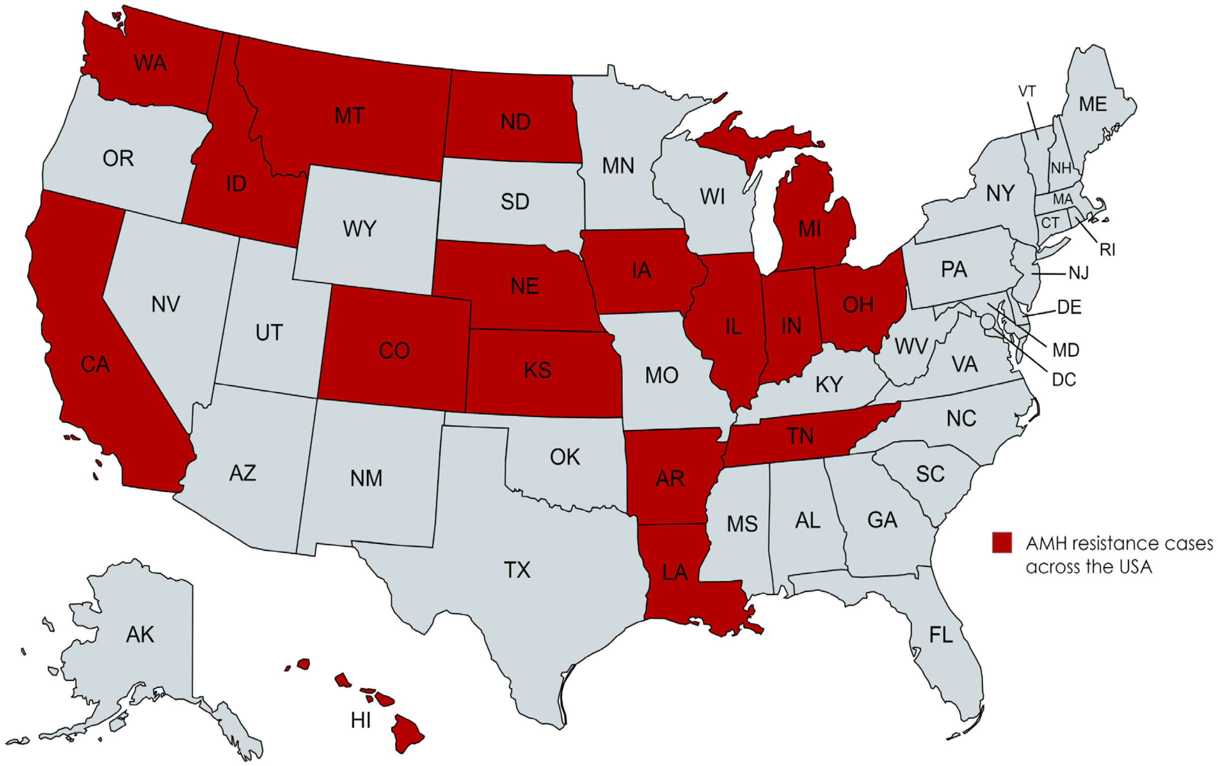
How do AMHs act in plants?



Adapted from Dayan, 2006

AMHs resistance cases reported in the globally and in the USA

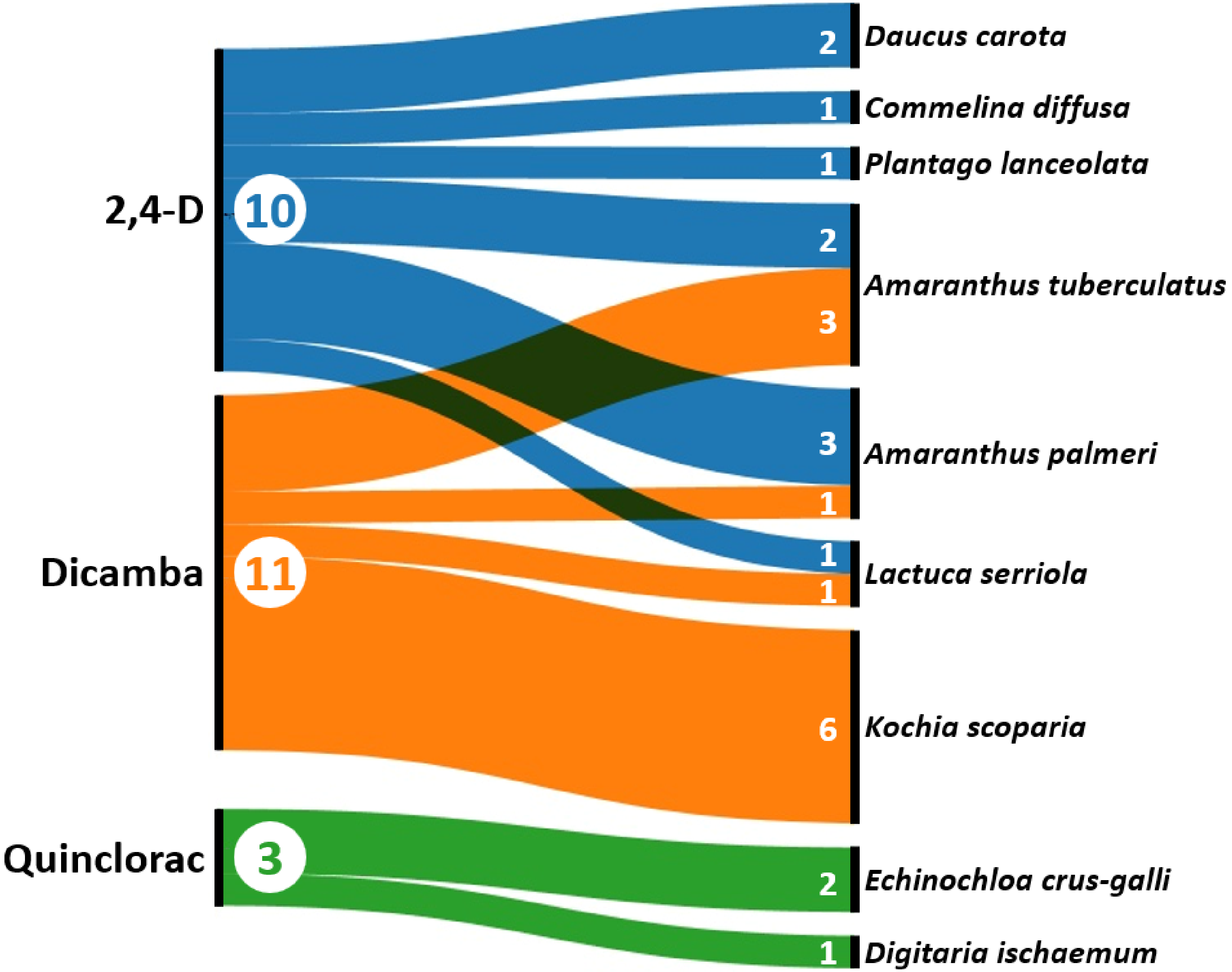


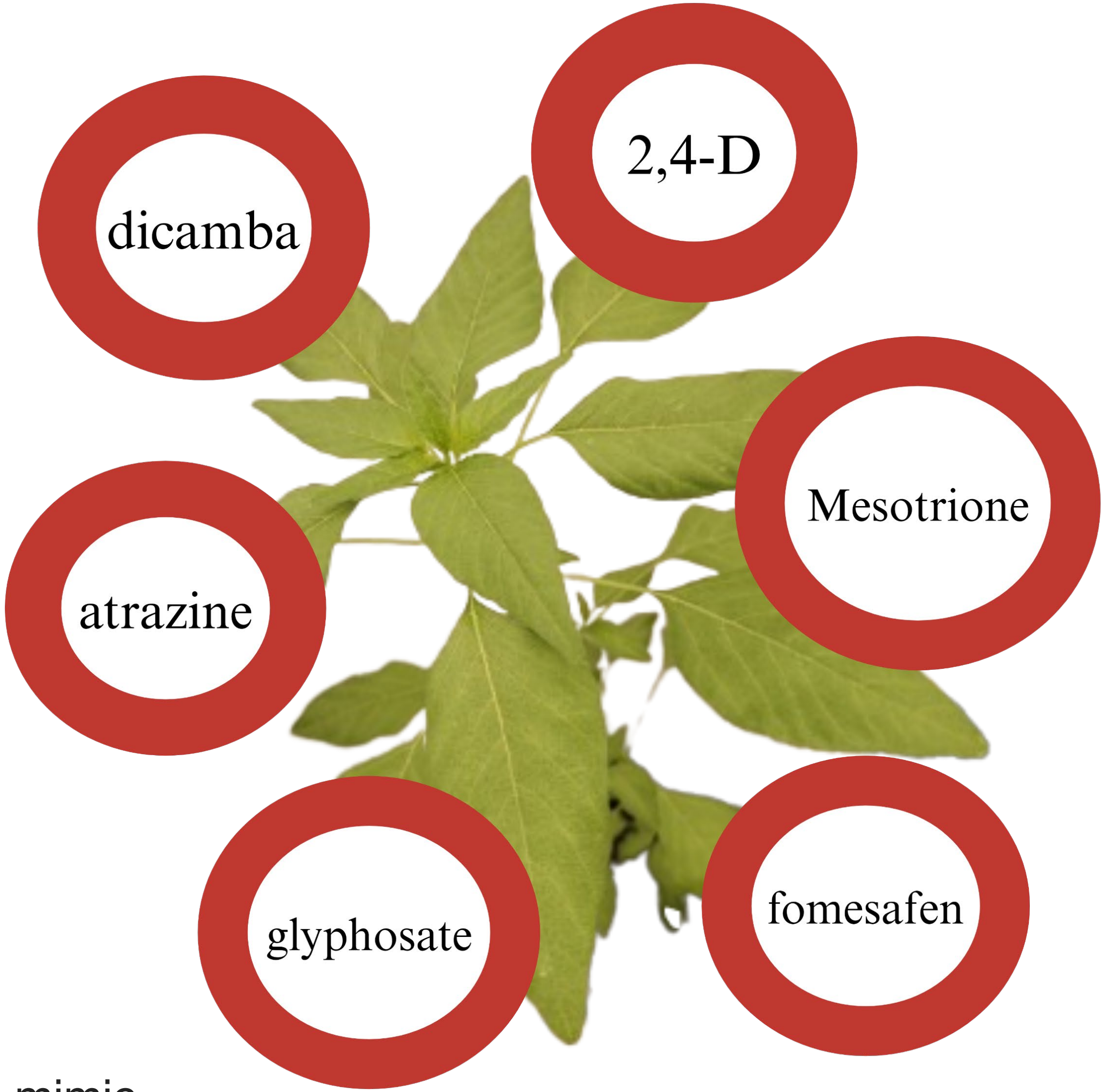


AMHs are among the top three herbicides used just behind of glyphosate (Group 9) and ALS (Group 2)

Moreno-Serrano, Gaines & Dayan 2024 Current status of auxin-mimic Herbicides. *Outlooks on Pest Management*, *35*(3), 105-112.

Resistance cases reported





Moreno-Serrano, Gaines & Dayan 2024 Current status of auxin-mimic Herbicides. *Outlooks on Pest Management*, *35*(3), 105-112.

Potential resistance mechanisms

Any trait which slows/prevents herbicide reaching the site of action, or reduces toxic effect at site of action

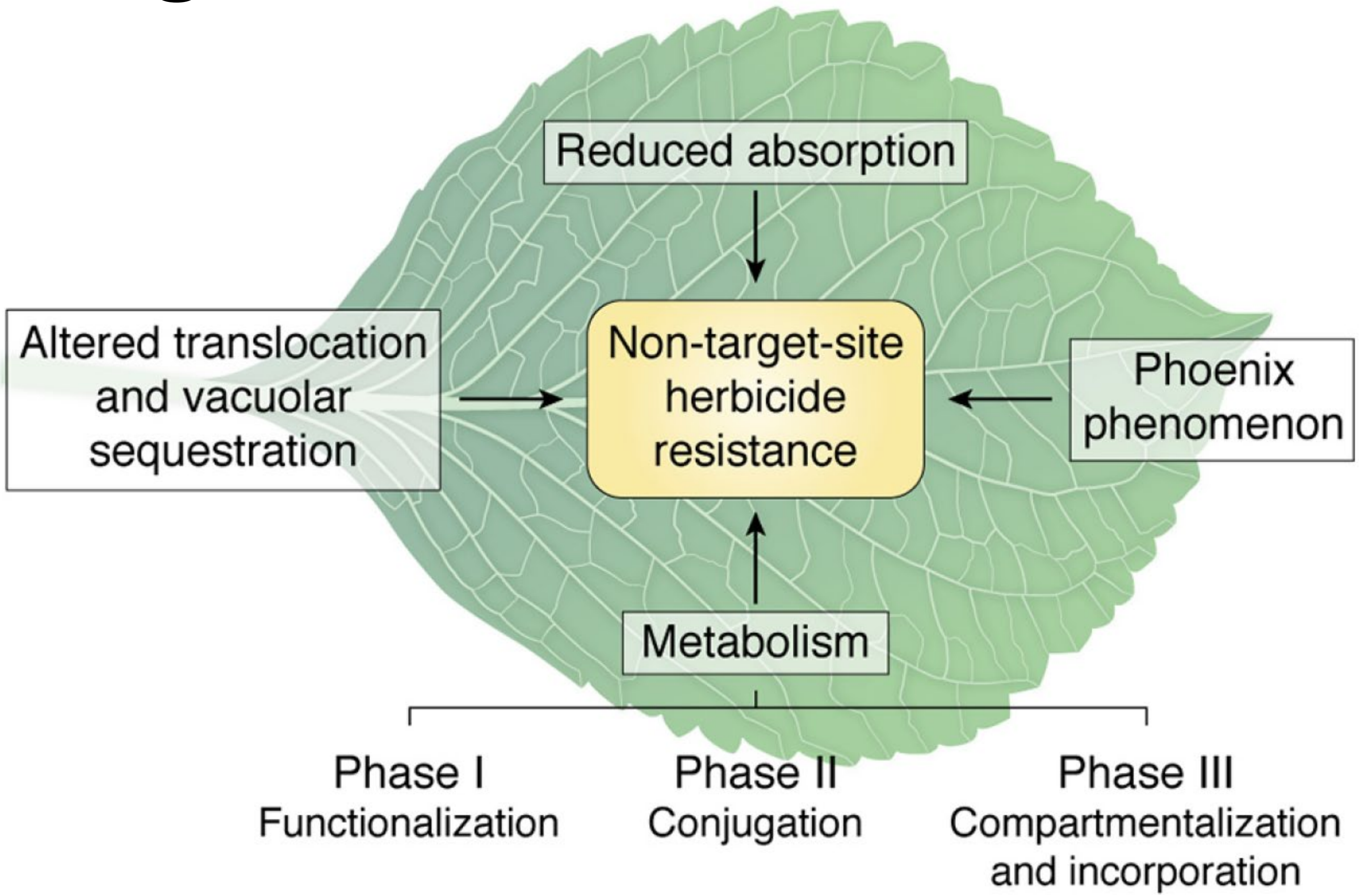
Non-Target Site

Metabolism	Altered translocation & sequestration	Reduced foliar uptake	General oxidative stress response

Target Site

Mutation/deletion	Increased expression/ Gene amplification

Non-target site resistance mechanisms



Gaines et al 2020 Mechanisms of evolved herbicide resistance JBC 295:10307

COLORADO STATE UNIVERSITY
THE COLLEGE OF AGRICULTURAL SCIENCES
Agricultural Biology Department

2,4-D metabolic resistance in waterhemp (*Amaranthus tuberculatus*)

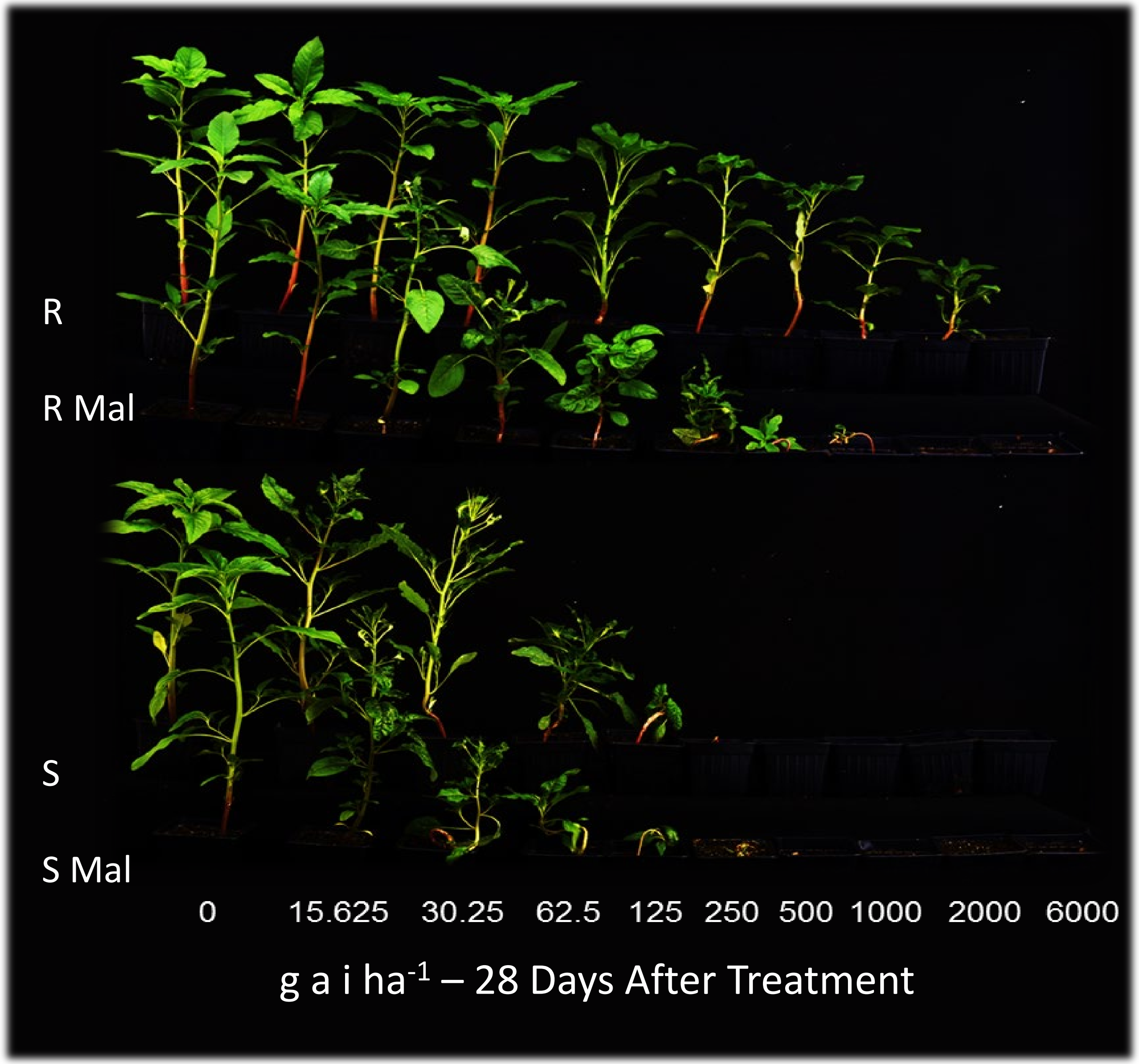
Figueiredo et al 2022 Identification of a novel 2, 4-D metabolic detoxification pathway in 2, 4-D-resistant waterhemp (Amaranthus tuberculatus). Journal of Agricultural and Food Chemistry, 70(49), 15380-15389.

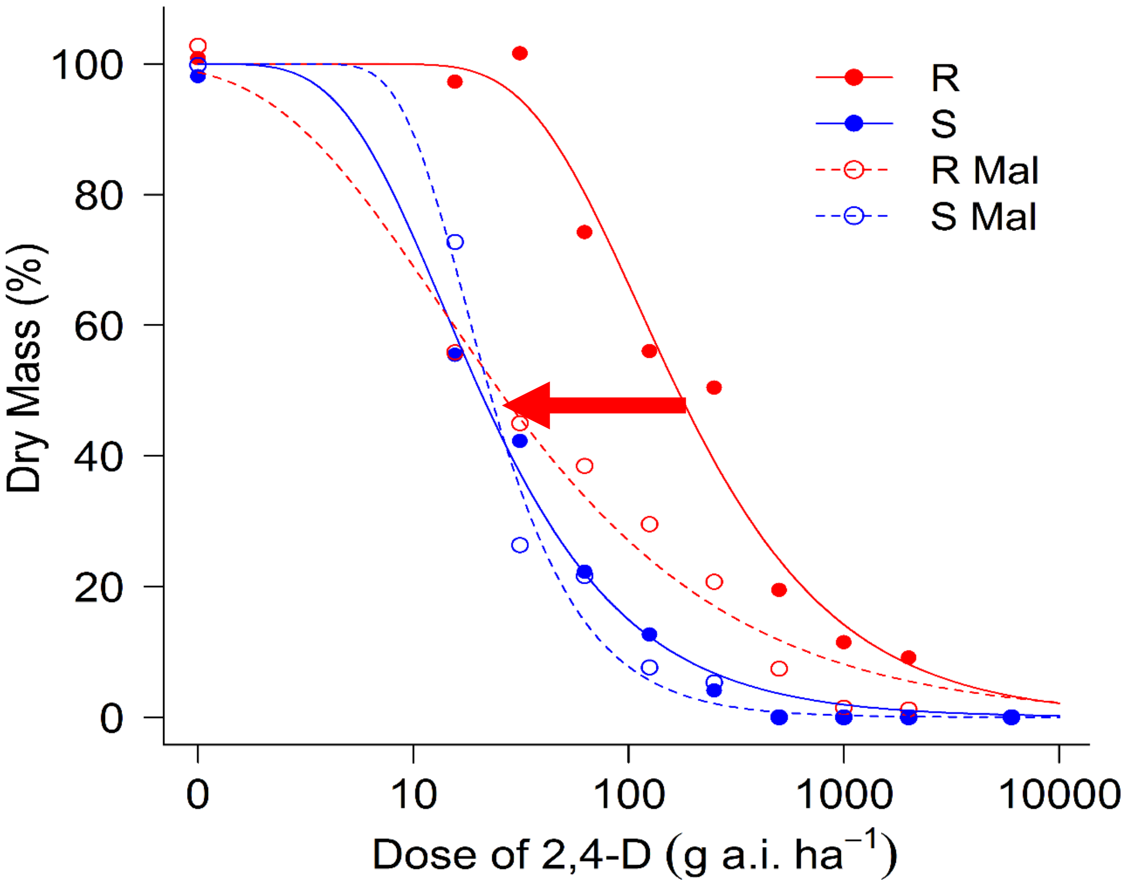
Figueiredo et al 2018 Metabolism of 2, 4-dichlorophenoxyacetic acid contributes to resistance in a common waterhemp population. Pest Management Science, 74(10), 2356-2362.

11


Days After 2,4-D Treatment
500 g ae ha-1
S
R
0
1
2
3
4
5
6
7

Malathion synergizes 2,4-D



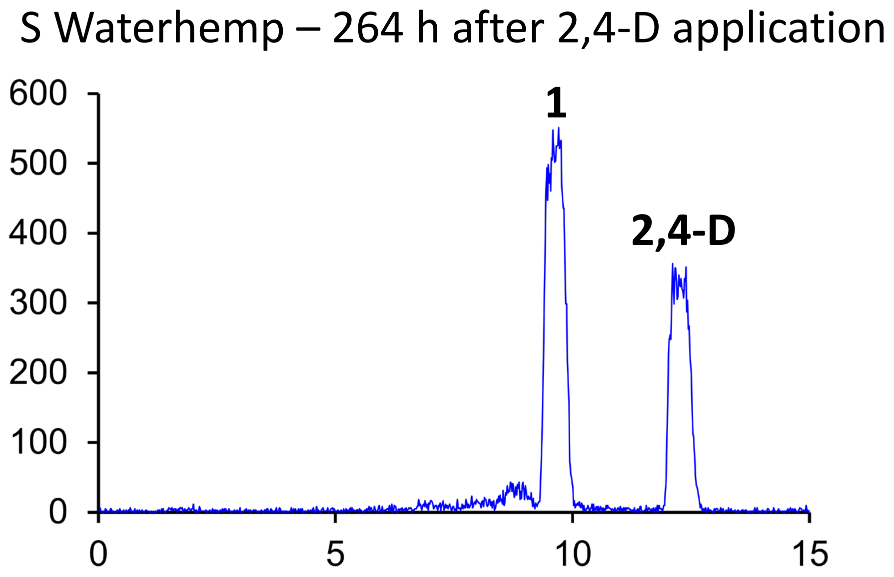


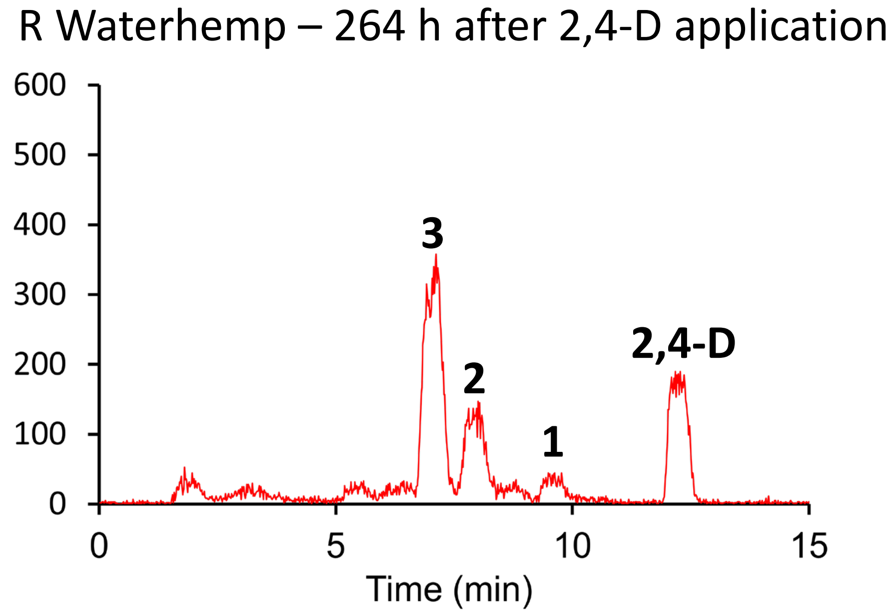
Estimated effective dose: 50%

	Estimate (g ai ha^{-1})	Std. Error
R	192	44
R Mal	24	8
S	21	5
S Mal	23	3

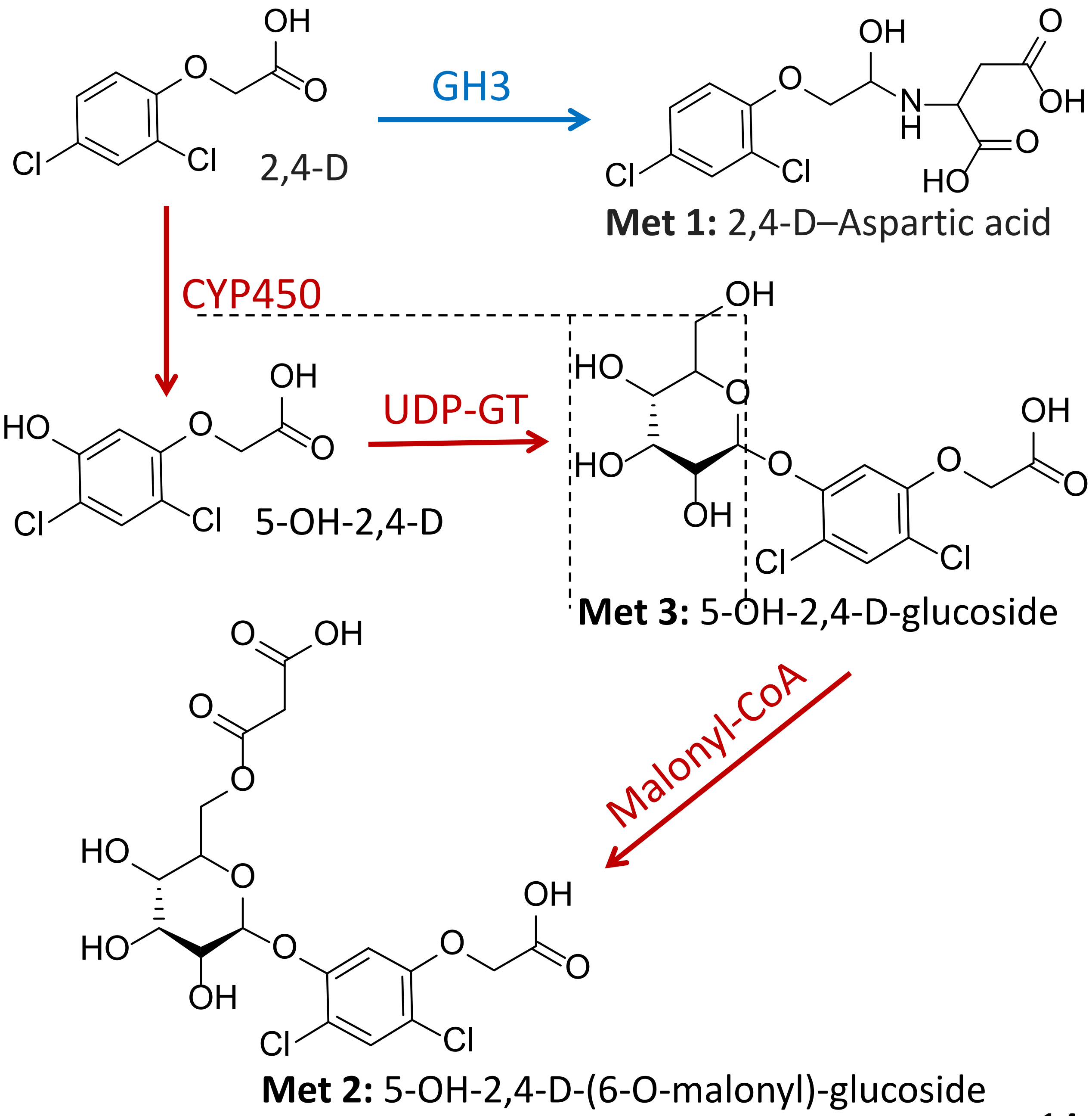
Figueiredo, et al. (2018) *Pest management science*

2,4-D Metabolism – Quantification

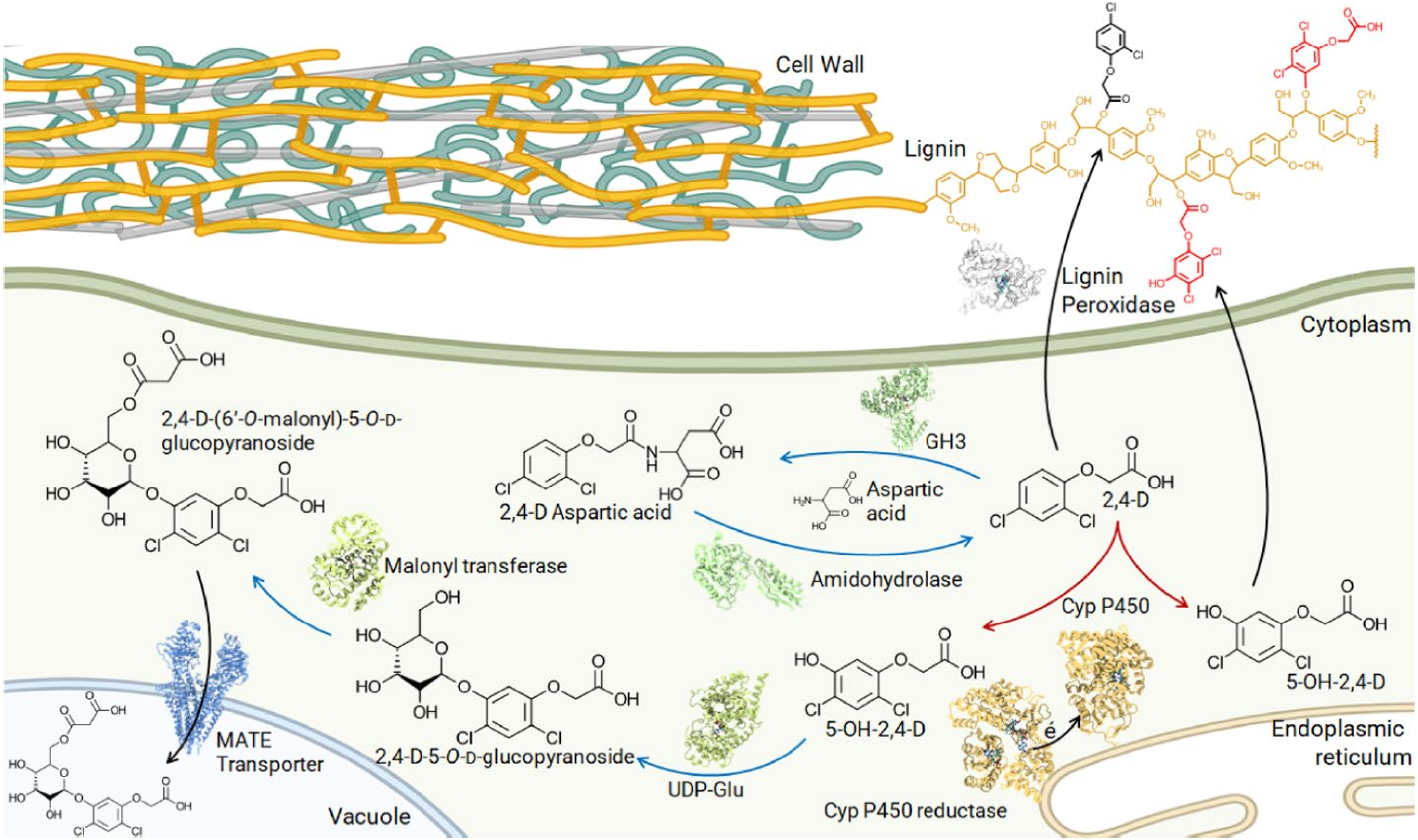




2,4-D metabolism in Waterhemp

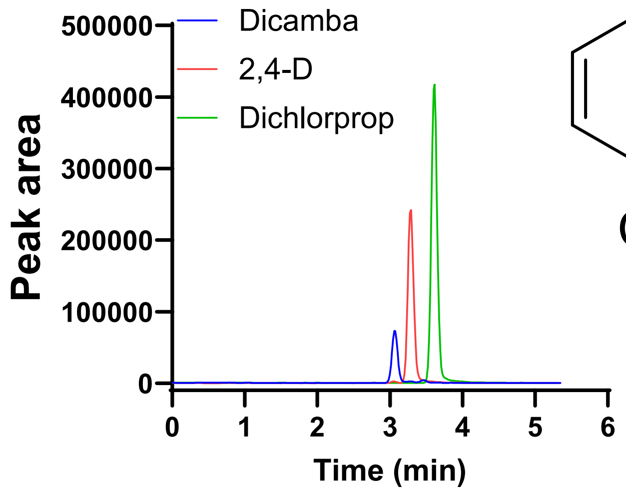


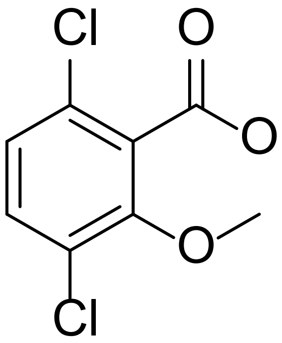
Figueiredo, et al. (2018) *Pest management science*



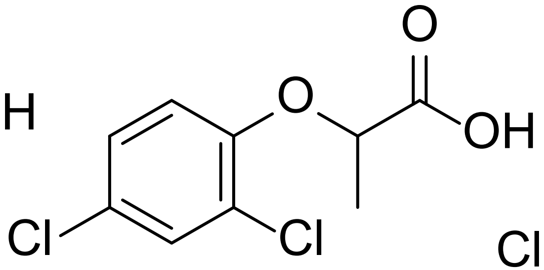
de Figueiredo et al 2022 Identification of a novel 2, 4-D metabolic detoxification pathway in 2, 4-D-resistant waterhemp JAFC 70:15380

Resistance to Scorch EX in kochia

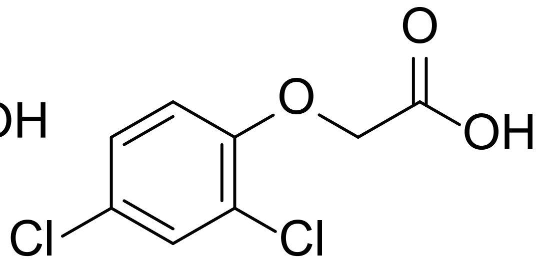




Dicamba

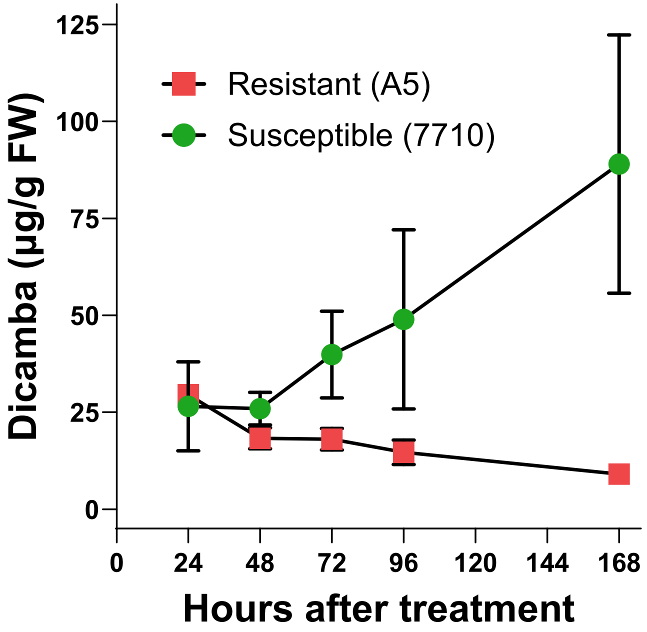


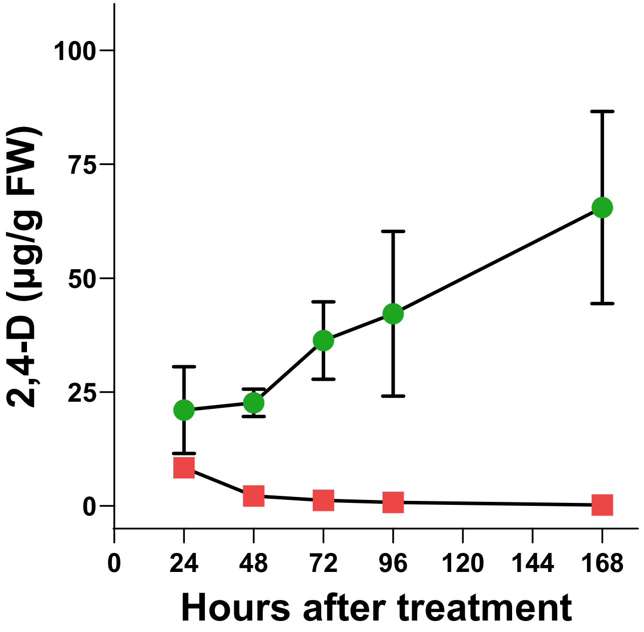
Dichlorprop

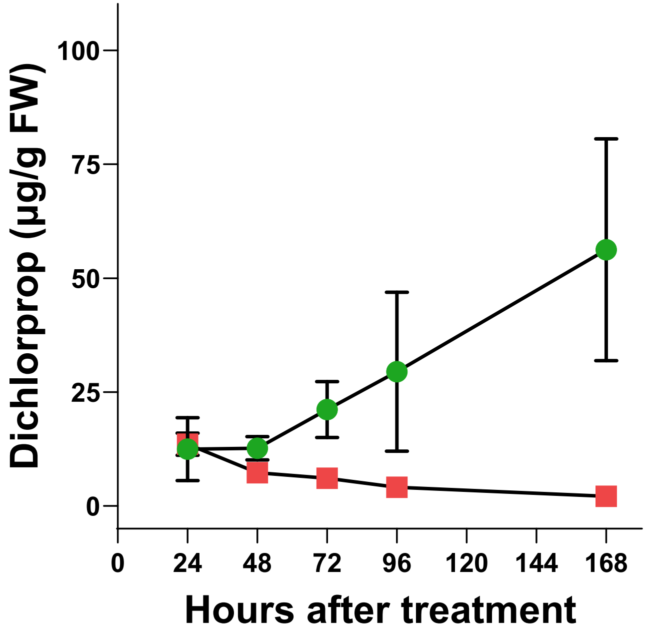


2,4-D

Scorch EX is a UPL product with dicamba, 2,4-D and dichlorprop







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Non-Target Site

Metabolism	Altered translocation & sequestration	Reduced foliar uptake	General oxidative stress response

Target Site

Mutation/deletion	Increased expression/ Gene amplification

PNAS RESEARCH ARTICLE | AGRICULTURAL SCIENCES OPEN ACCESS

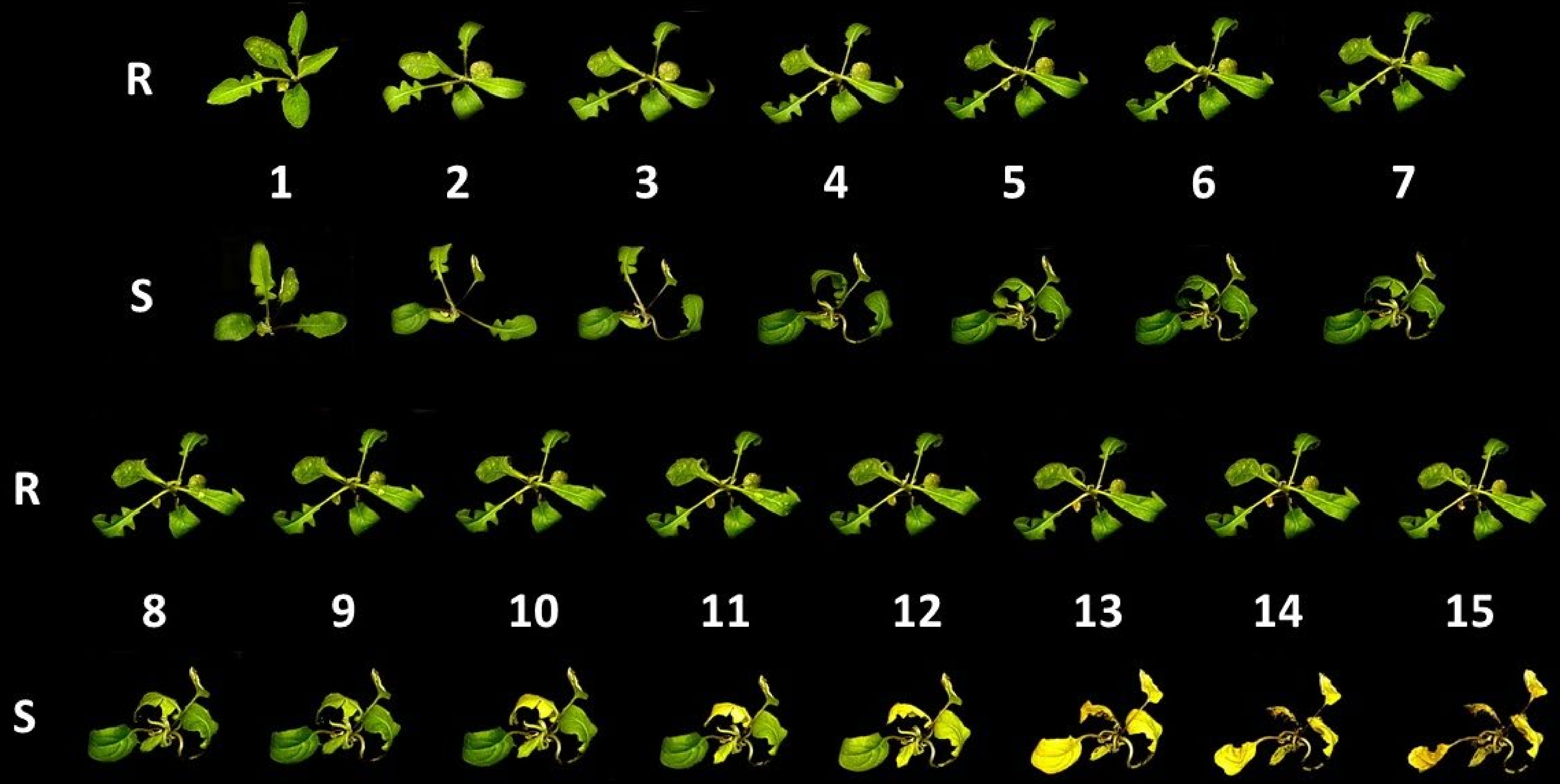
An in-frame deletion mutation in the degron tail of auxin coreceptor *IAA2* confers resistance to the herbicide 2,4-D in *Sisymbrium orientale*

Marcelo R. A. de Figueiredo[a], Anita Küpper[a,b], Jenna M. Malone[c], Tijana Petrovic[c], Ana Beatriz T. B. de Figueiredo[a], Grace Campagnola[d], Olve B. Peersen[d], Kasavajhala V. S. K. Prasad[e,f], Eric L. Patterson[a,g], Anireddy S. N. Reddy[e,f], Martin F. Kubeš[h], Richard Napier[h], Franck E. Dayan[a,f], Christopher Preston[c], and Todd A. Gaines[a,f,1]

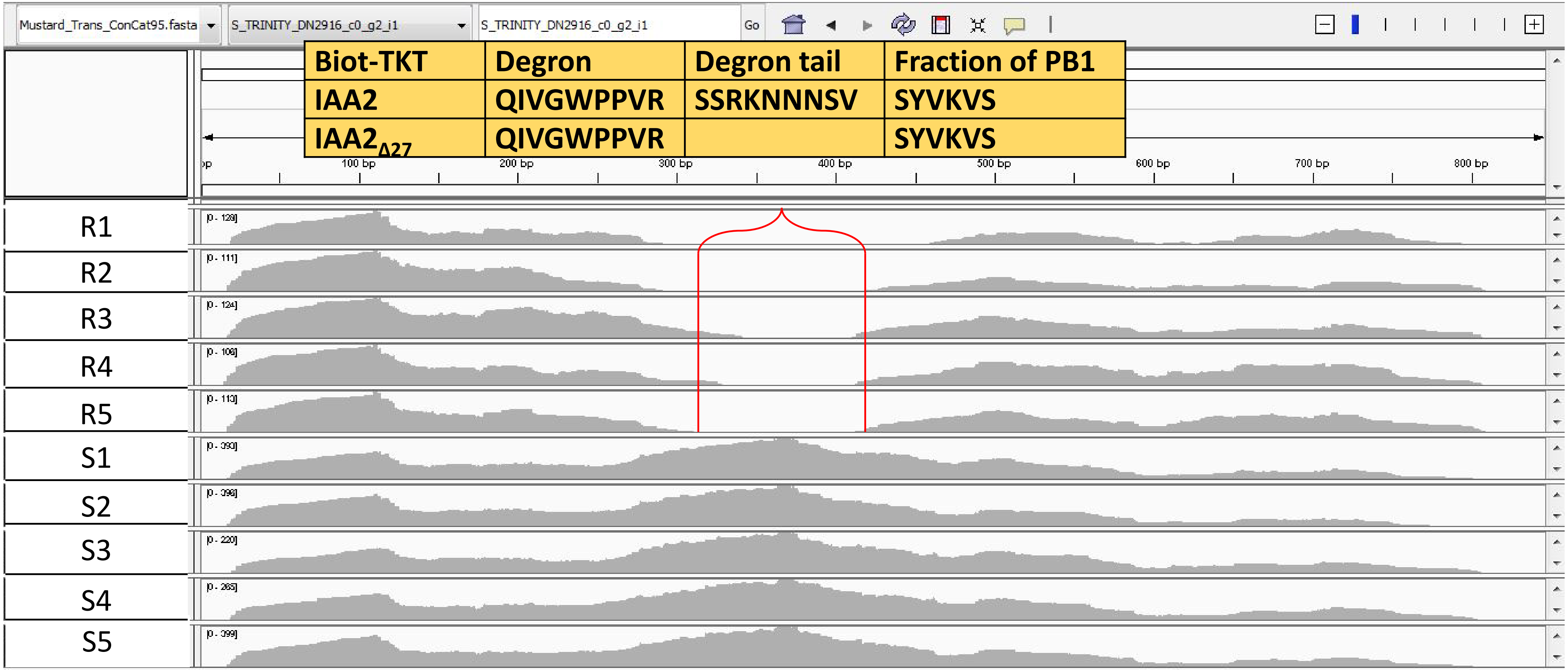
Edited by Sean Cutler, University of California, Riverside, CA; received March 25, 2021; accepted December 9, 2021

February 25, 2022 | 119 (9) e2105819119 | https://doi.org/10.1073/pnas.2105819119

Days after treatment
2,4-D at 250 g a.i./ha

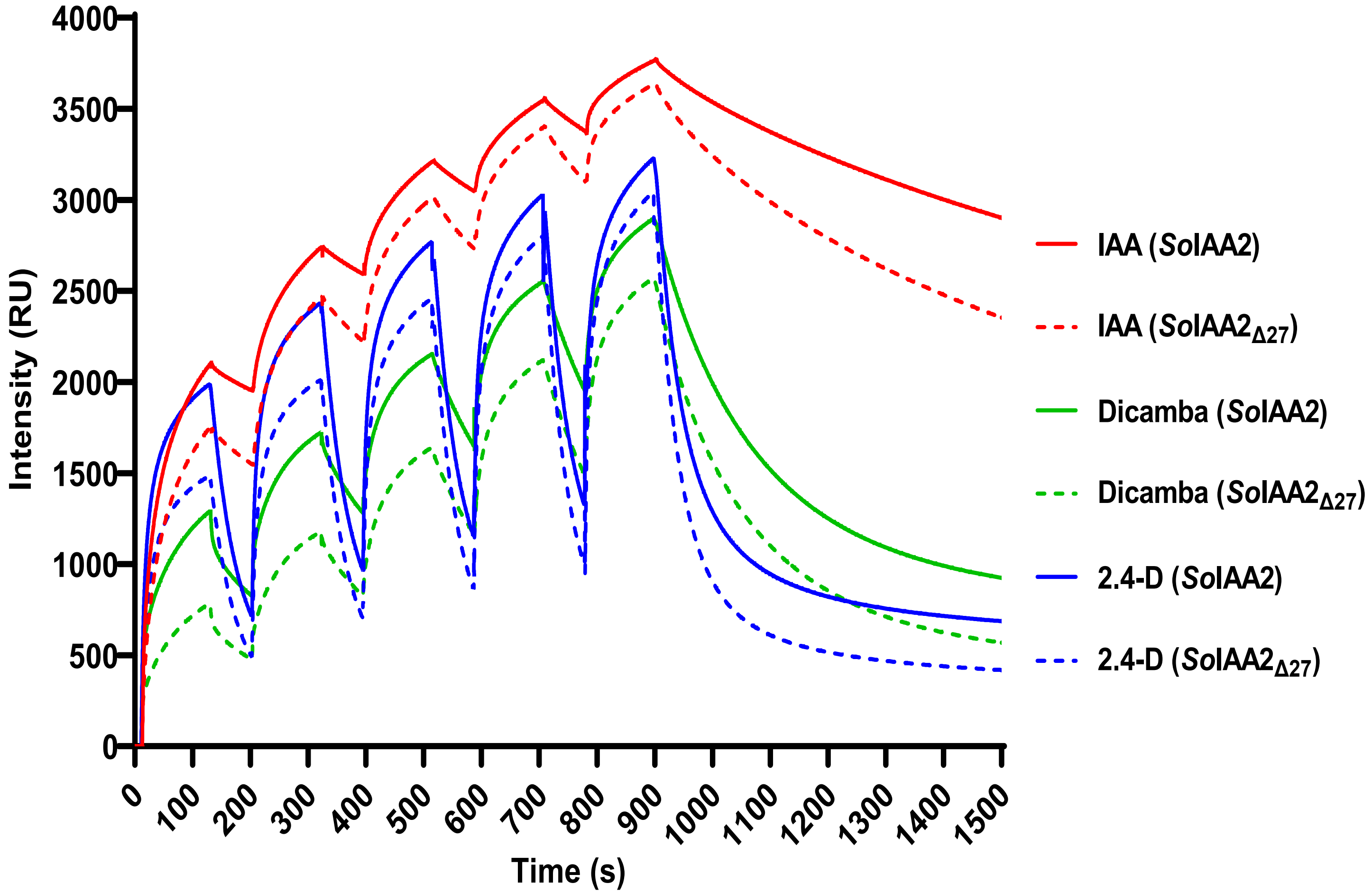


RNA-Seq Alignment: lower expression in R RILs in IAA2, gap in coverage



Biot-TKT	Degron	Degron tail	Fraction of PB1
IAA2	QIVGWPPVR	SSRKNNNSV	SYVKVS
$IAA2_{\Delta 27}$	QIVGWPPVR		SYVKVS

SPR – Affinity binding assays (TIR1 protein)

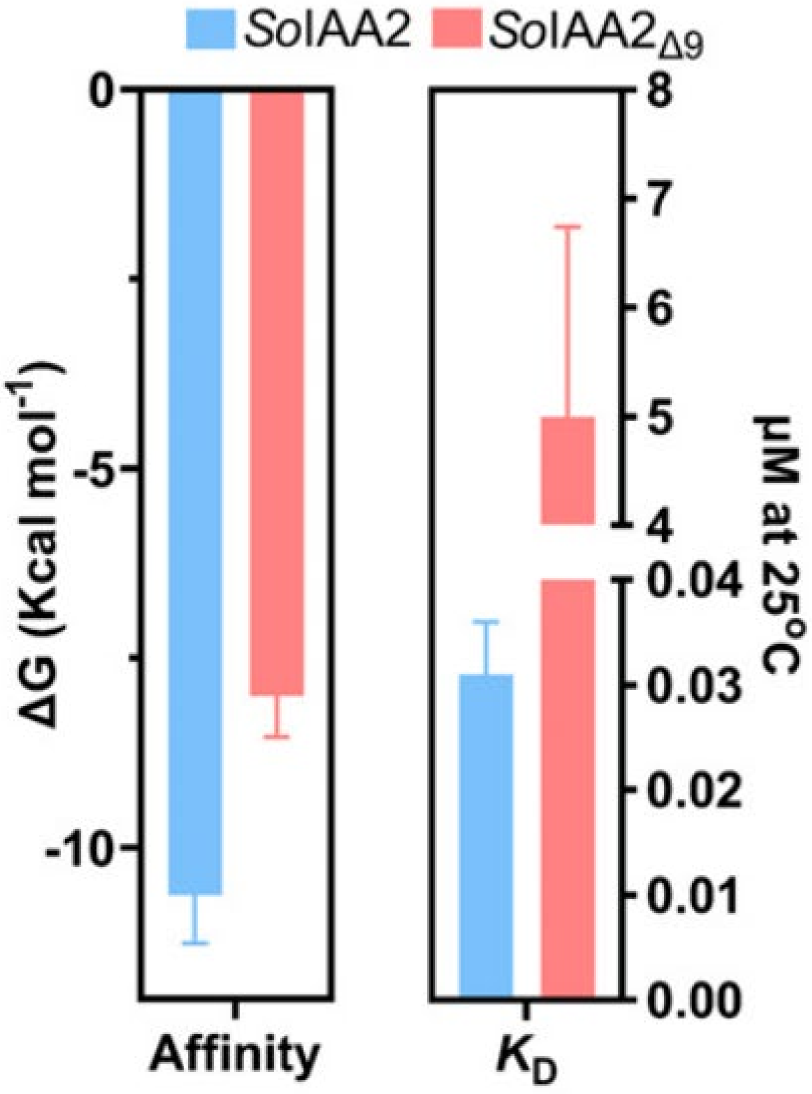


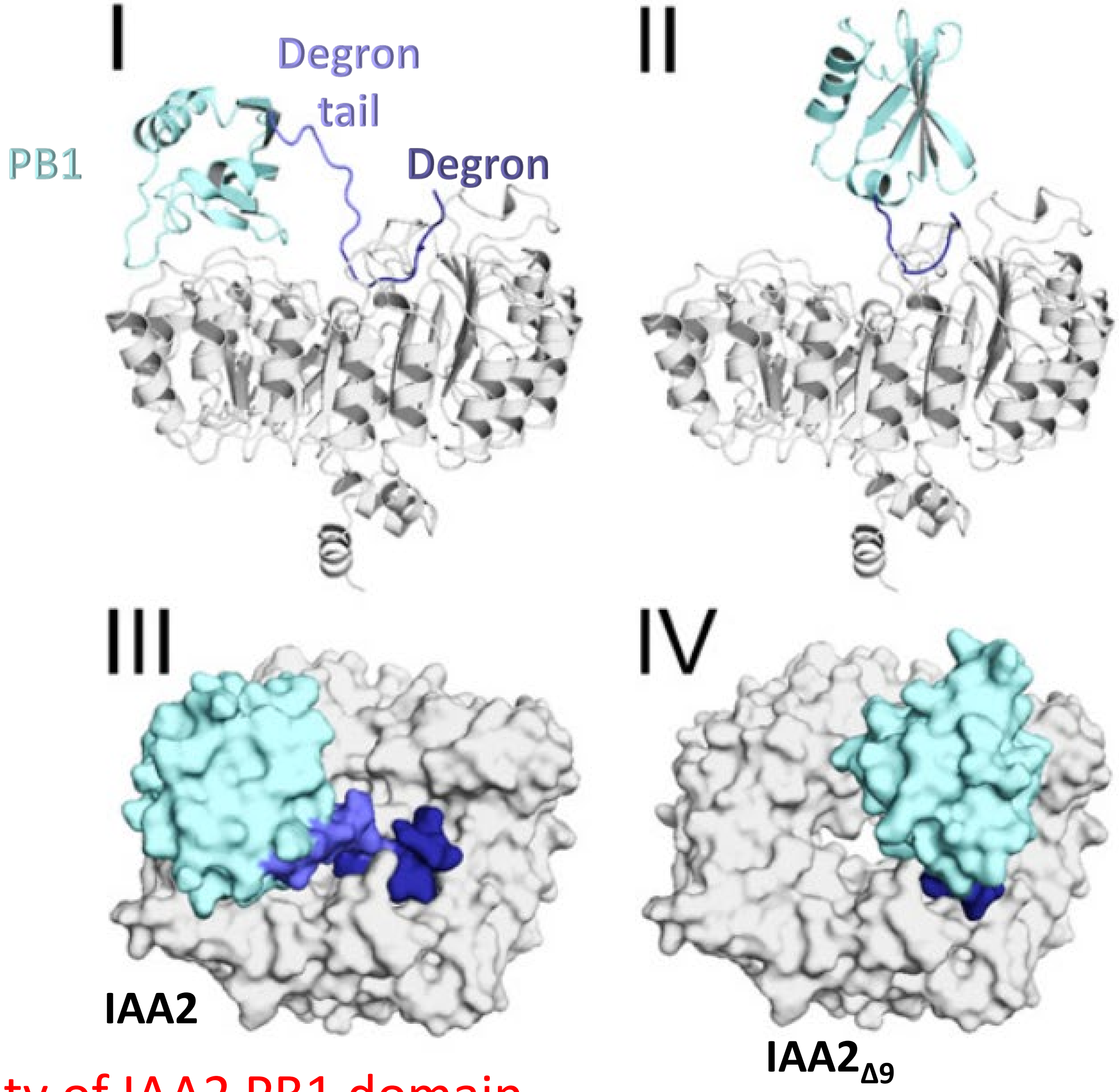
Auxin-binding activity	Auxin	KD (nM)
TIR1-*So*IAA2$_{\Delta27}$	IAA	40.7
TIR1-*So*IAA2	IAA	11.4
TIR1-*So*IAA2$_{\Delta27}$	2,4-D	296
TIR1-*So*IAA2	2,4-D	135
TIR1-*So*IAA2$_{\Delta27}$	Dicamba	694
TIR1-*So*IAA2	Dicamba	250

Binding association (Ka) is lower for *So*IAA2$_{\Delta27}$ – Lower recognition and binding interactions

Dissociation (Kd) is higher for *So*IAA2$_{\Delta27}$ – Higher instability of complex formation

TIR1 and IAA2 binding prediction





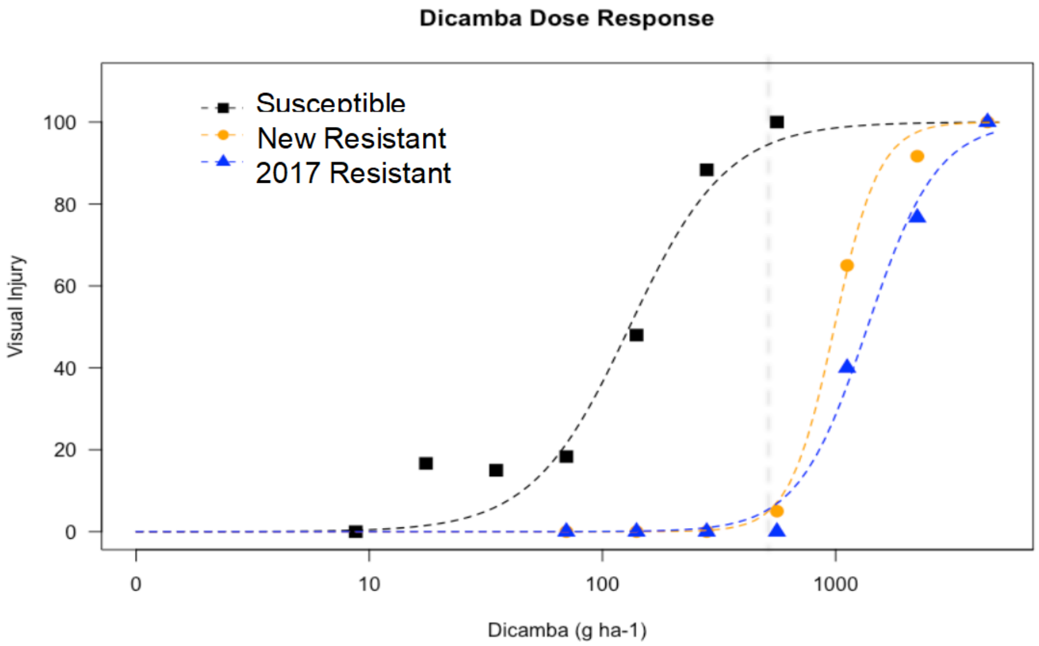
The lost of 9 AA may reduce the capacity of IAA2 PB1 domain

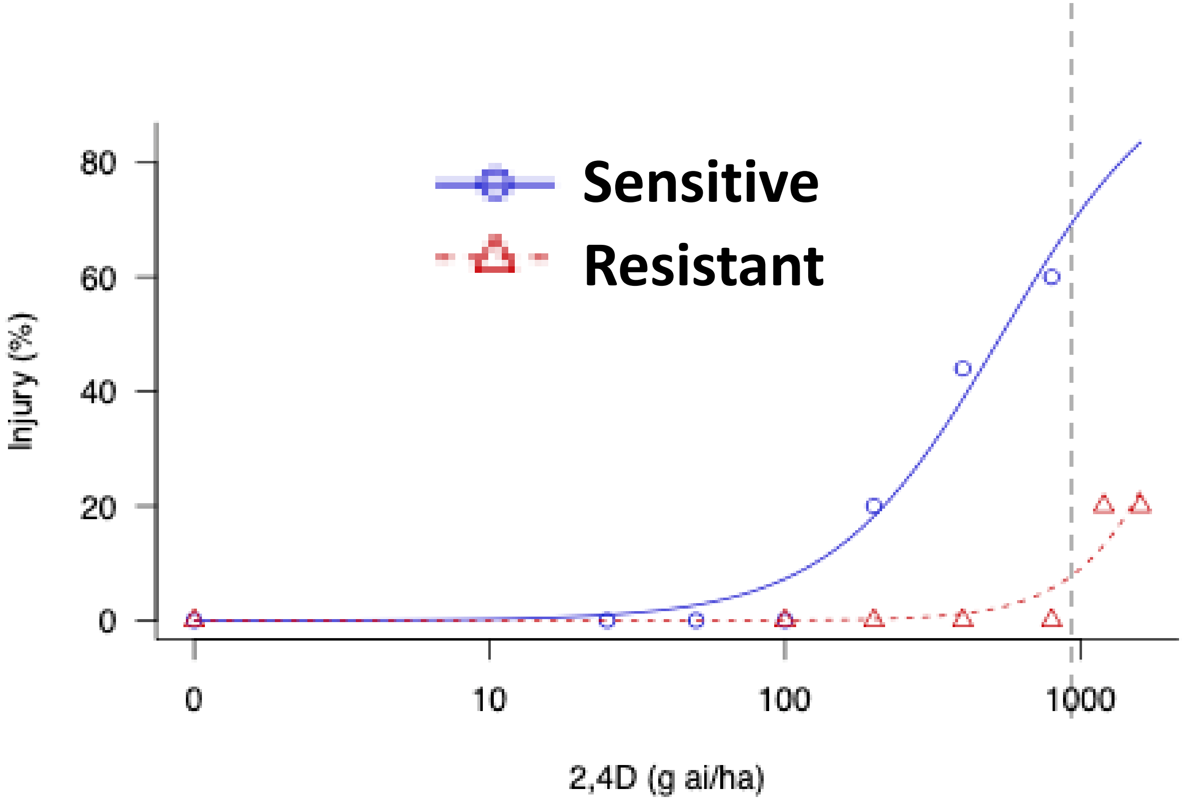
A transposable element insertion in *IAA16* disrupts splicing and causes dicamba resistance in *Bassia scoparia*

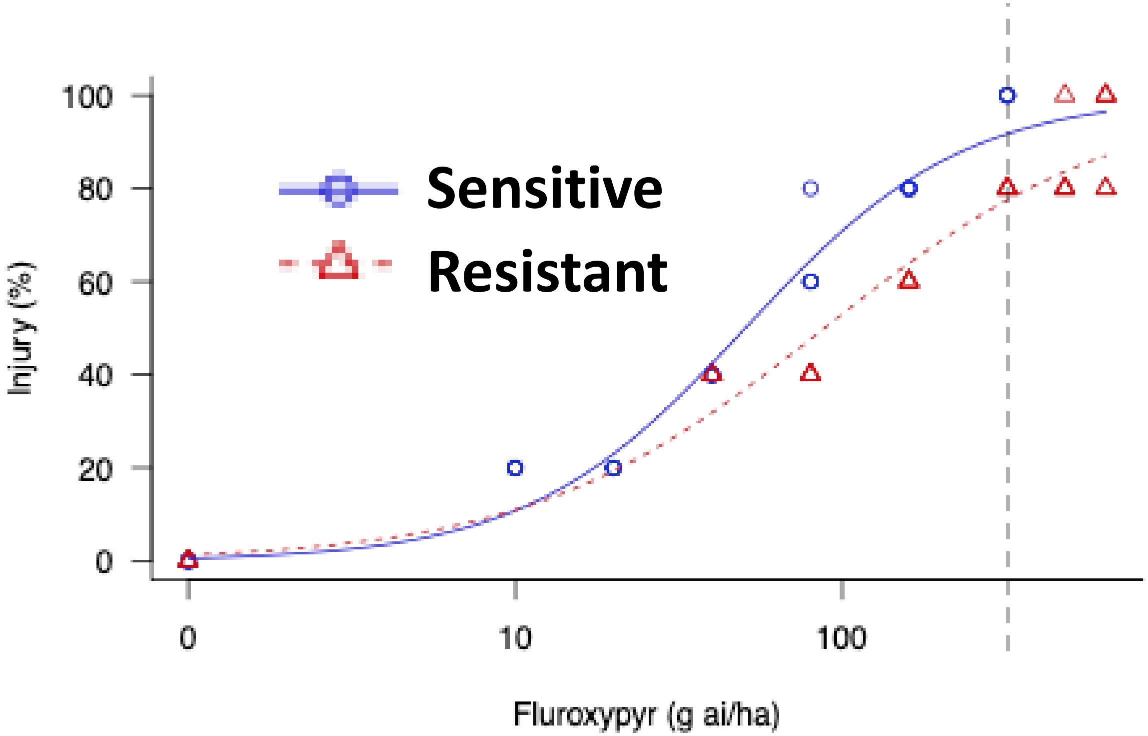
Jacob S. Montgomery, Neeta Soni, Sofia Marques Hill, Sarah Morran, Eric L. Patterson, Seth A. Edwards, Sandaruwan Ratnayake, Yu-Hung Hung, Pratheek H. Pandesha, R. Keith Slotkin, Richard Napier, Franck Dayan, Todd A. Gaines

Montgomery et al 2024 A transposable element insertion in IAA16 interrupts normal splicing and generates a novel dicamba resistance allele in Bassia scoparia. *Plant Journal, online*

Montgomery et al 2024 A transposable element insertion in IAA16 interrupts normal splicing and generates a novel dicamba resistance allele in Bassia scoparia. *Plant Journal, online*

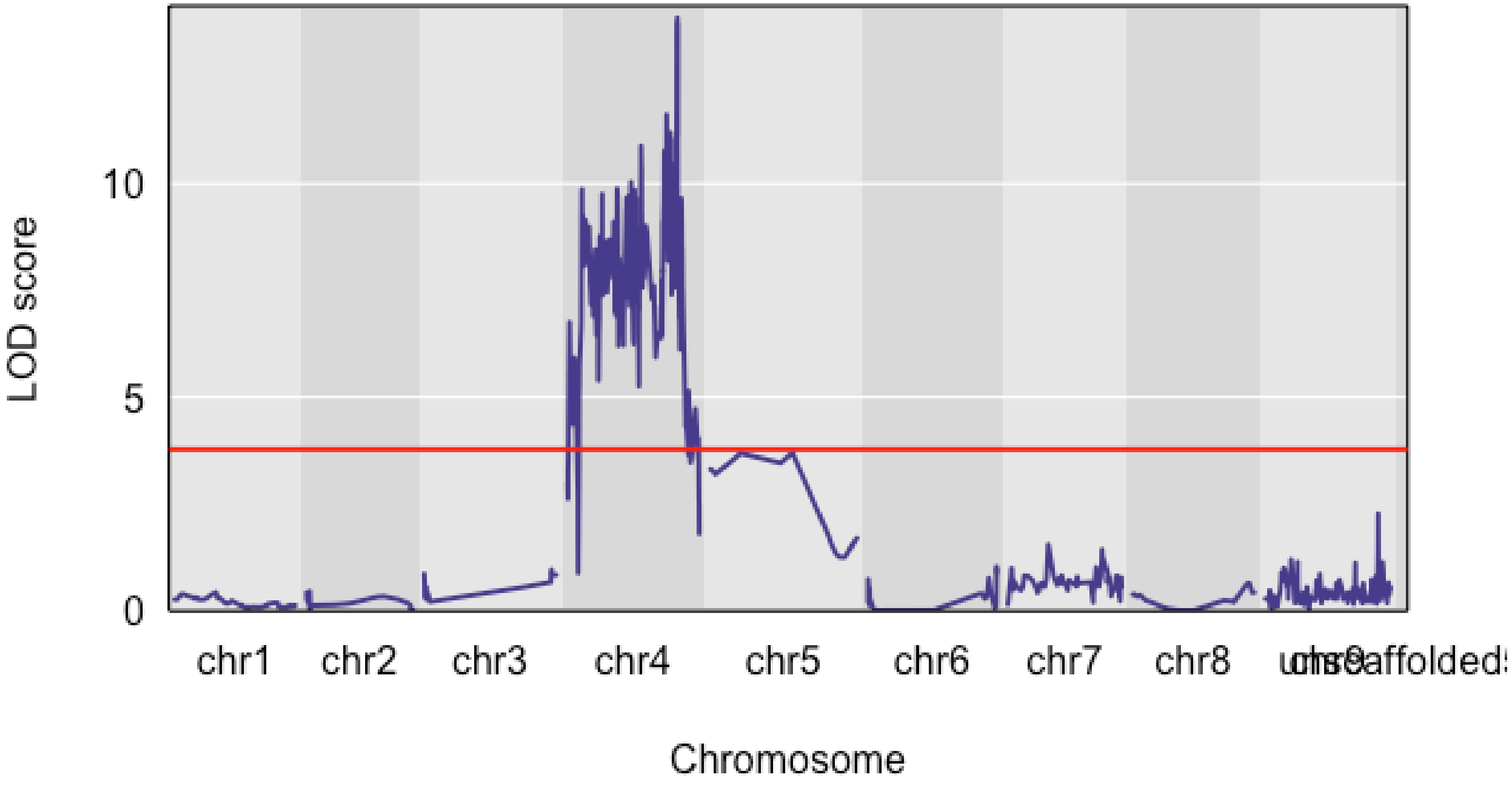


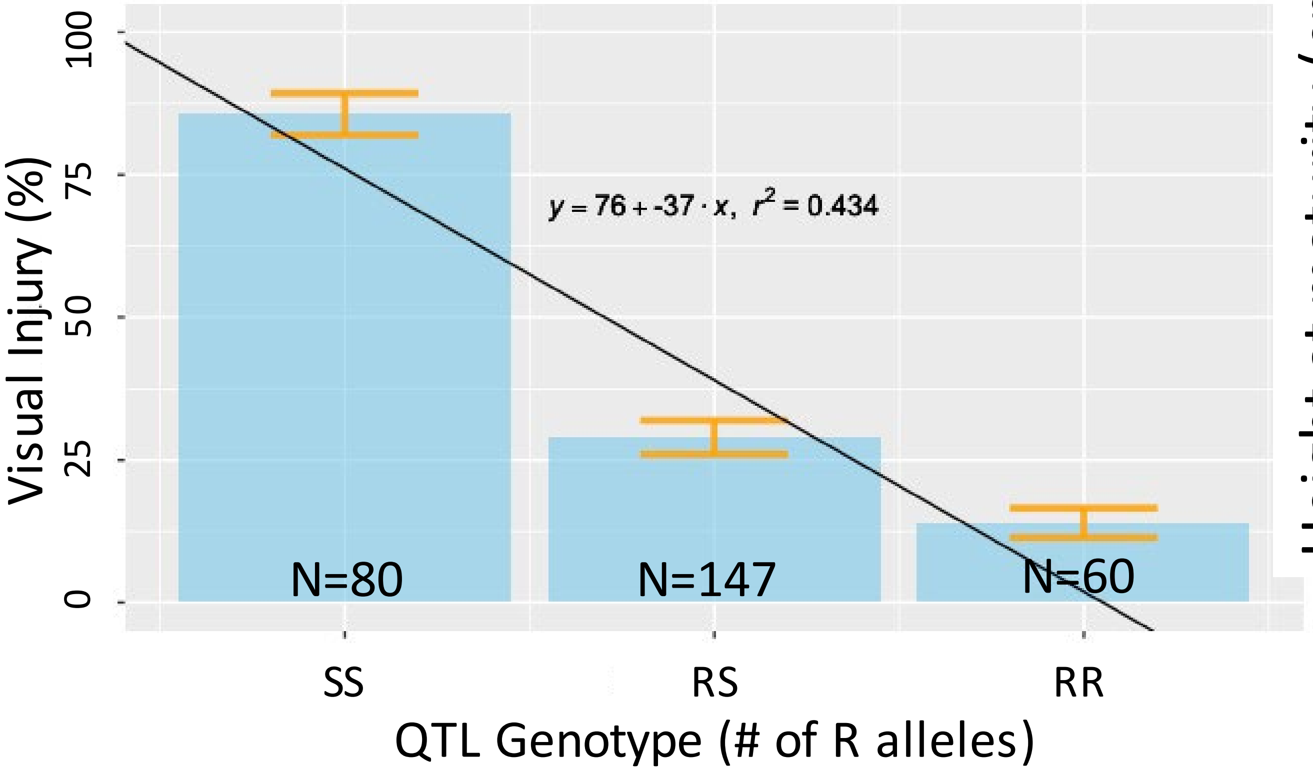


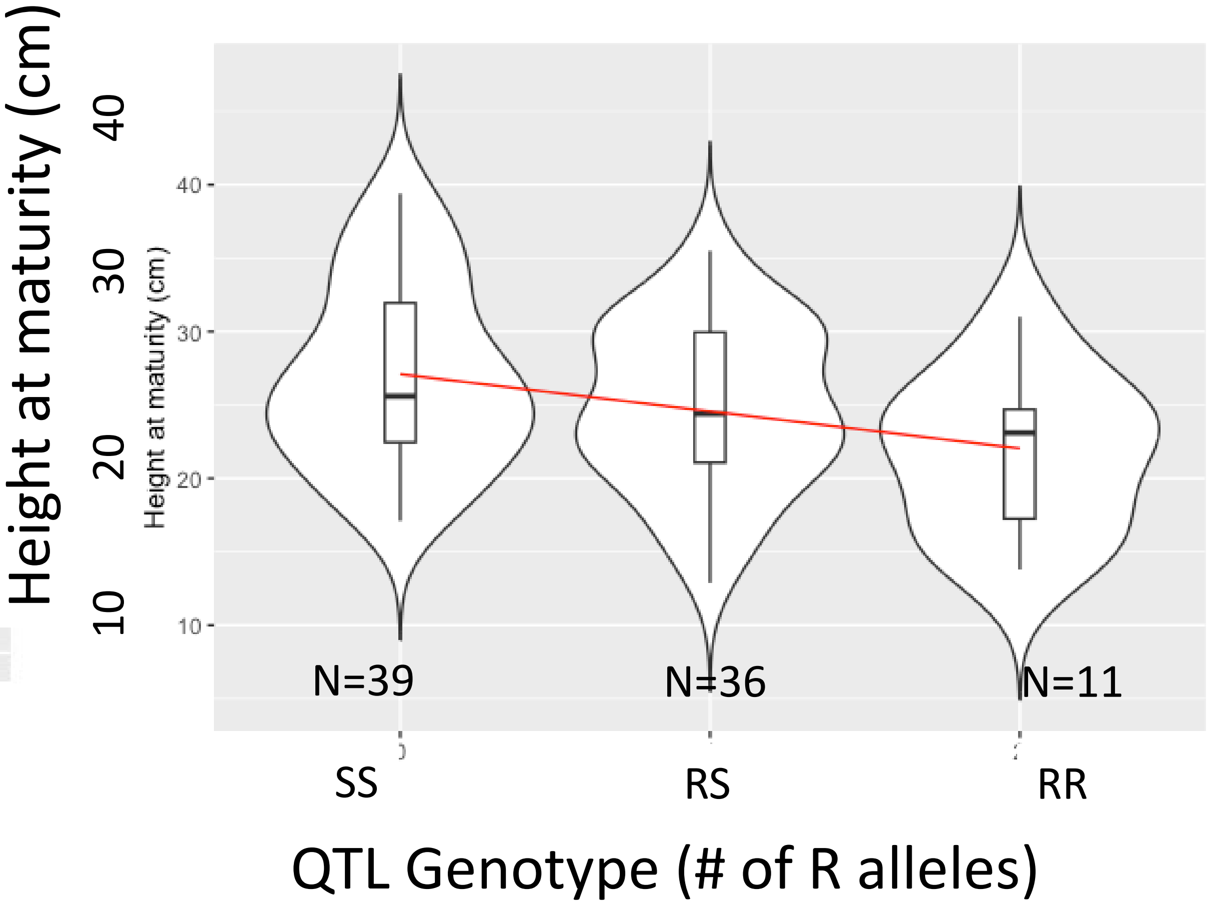


One high-effect QTL exists on chr4

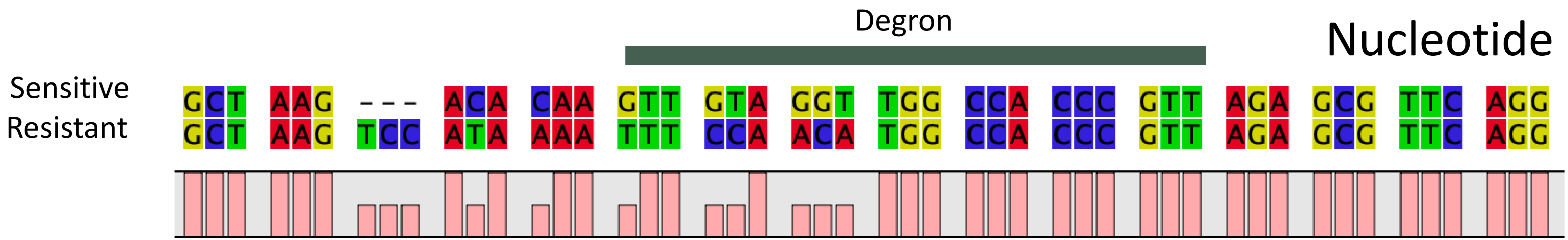
348,844 variants detected
2,473 variants passed filtering
Significance plotted in red
Peak centered at 88 Mbp
IAA16 located at 87.4 Mbp on chr 4

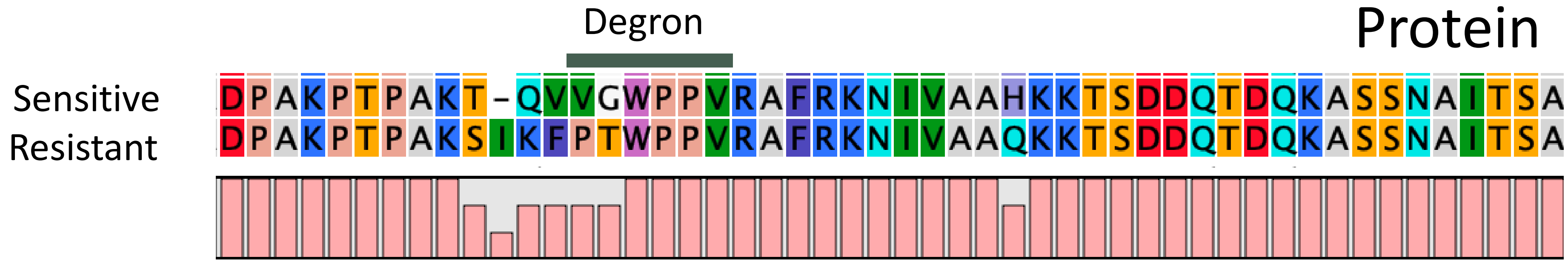



Visual Injury (%)
100
75
50
25
0
$y = 76 + -37 \cdot x,\ r^2 = 0.434$
N=80
N=147
N=60
SS
RS
RR
QTL Genotype (# of R alleles)

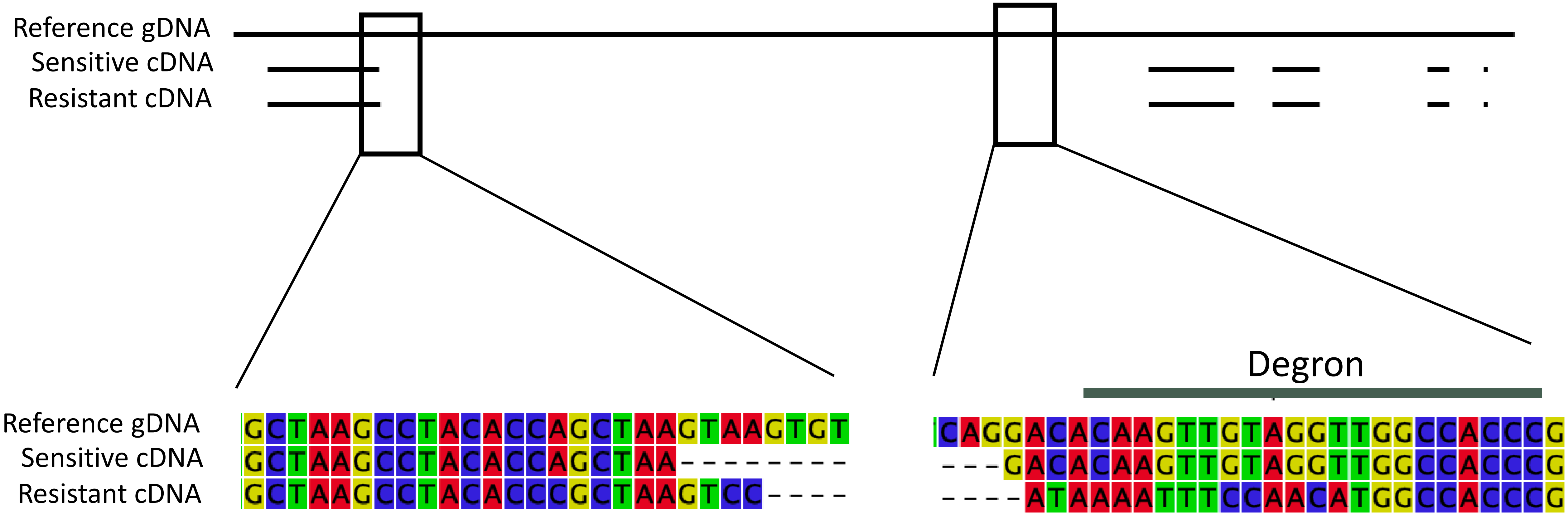

Height at maturity (cm)
40
30
20
10
Height at maturity (cm)
N=39
N=36
N=11
SS
RS
RR
QTL Genotype (# of R alleles)

$IAA16_{Mutant}$ is hyper variable around the degron



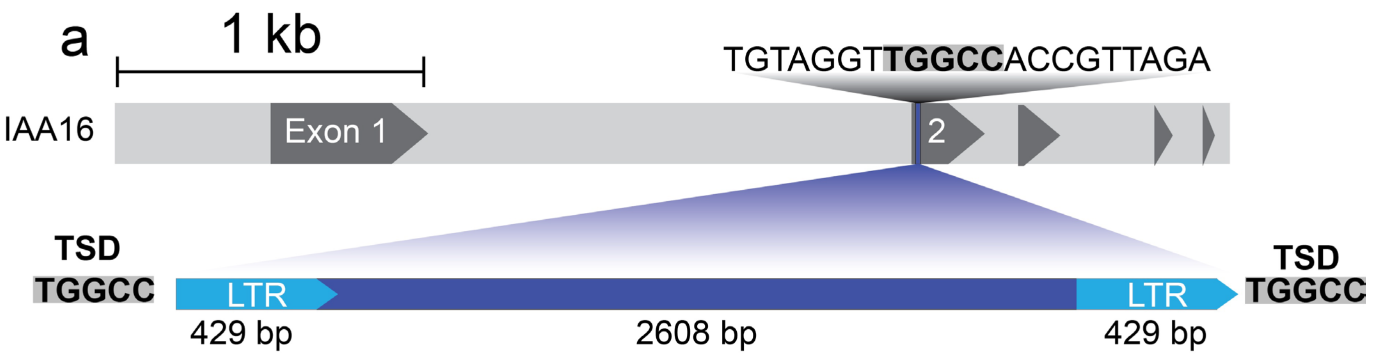


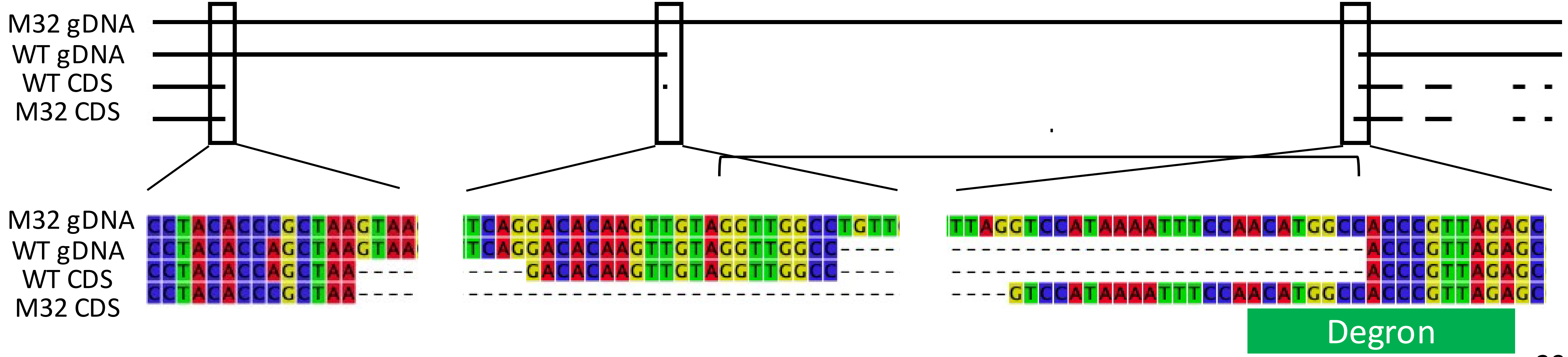
Variable region of *IAA16* flanks splice junction



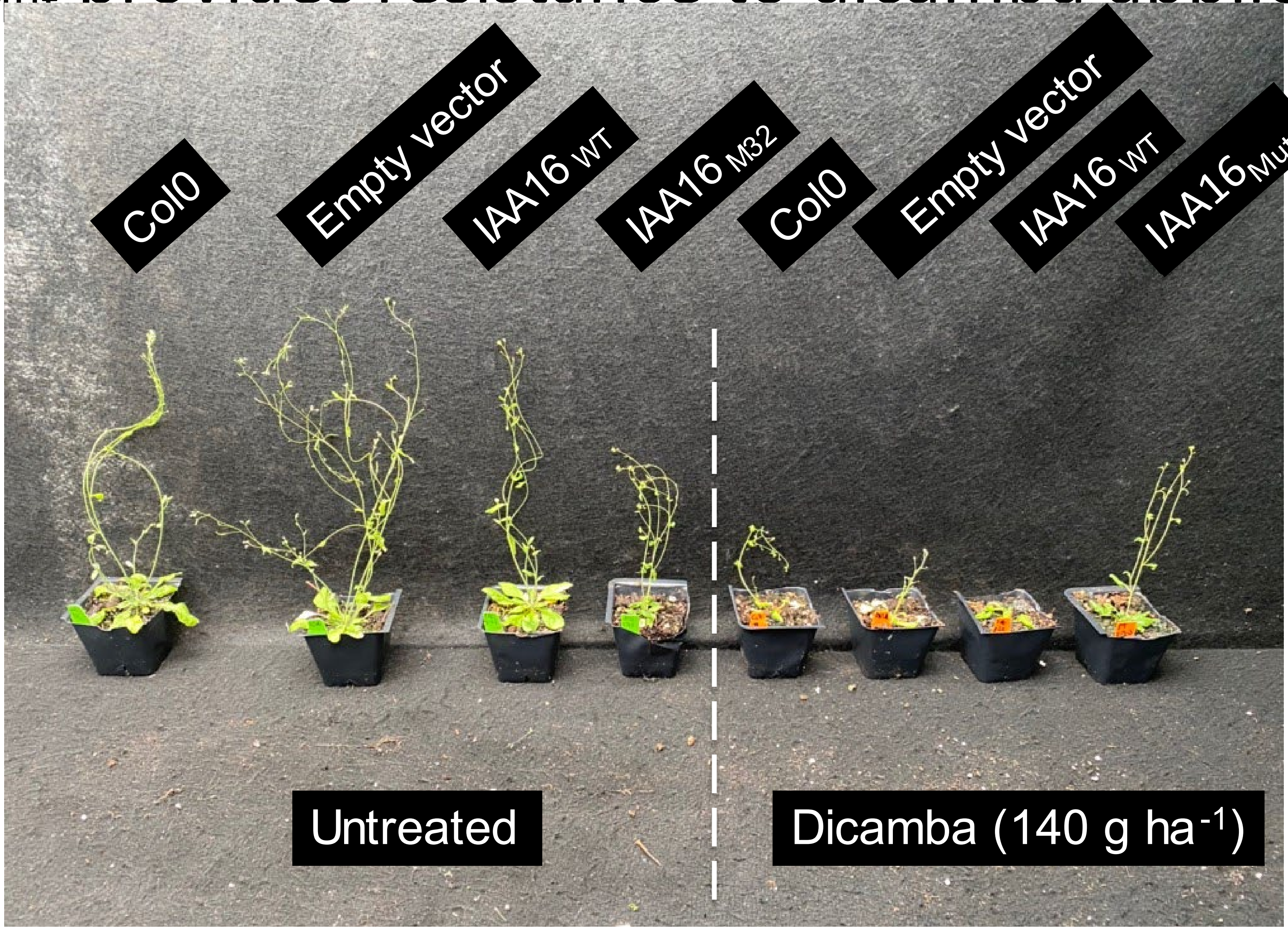
Transposable element insertion at the beginning of exon 2 disrupts normal splicing

Tissue of homozygous resistant F
plant used for HiFi resequencing
Reads assembled into contigs *de novo*



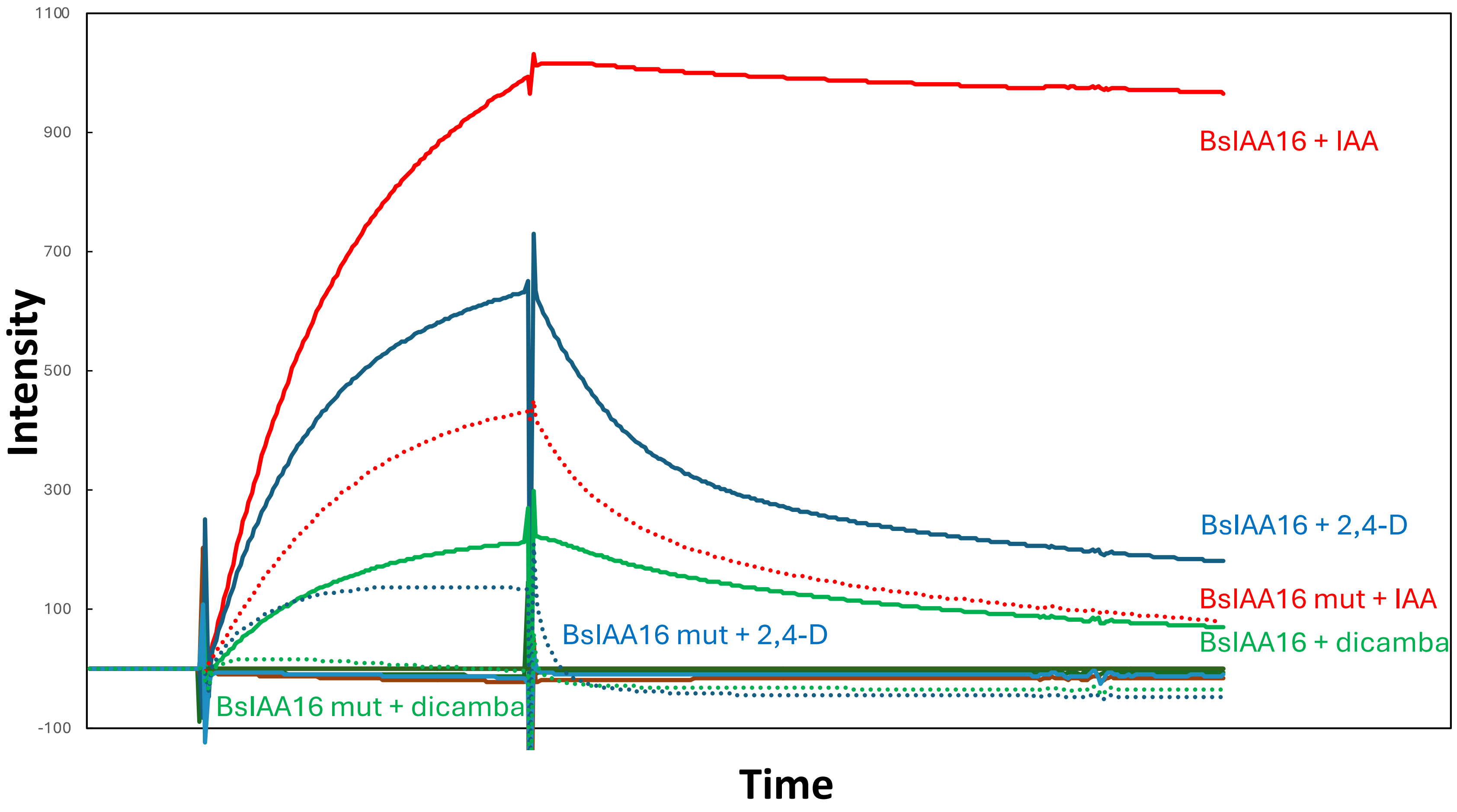


IAA16$_{Mut}$ provides resistance to dicamba applied POST

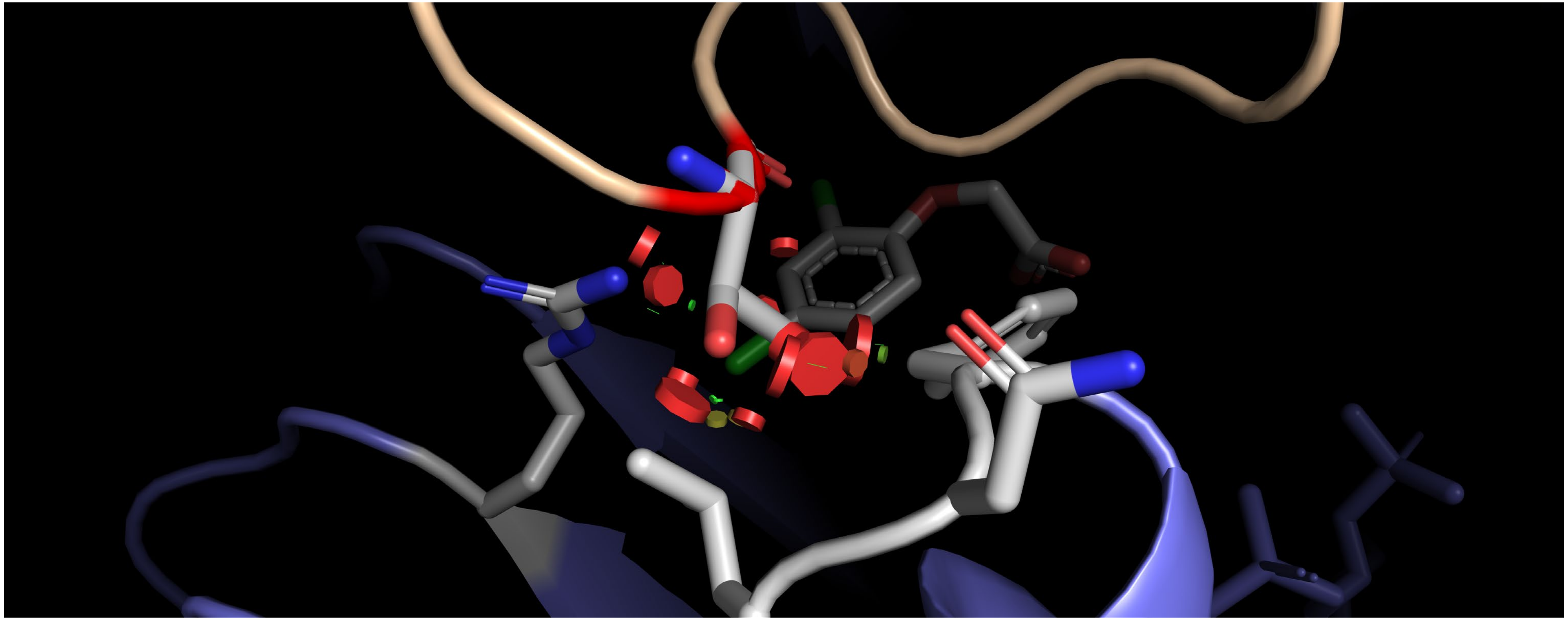


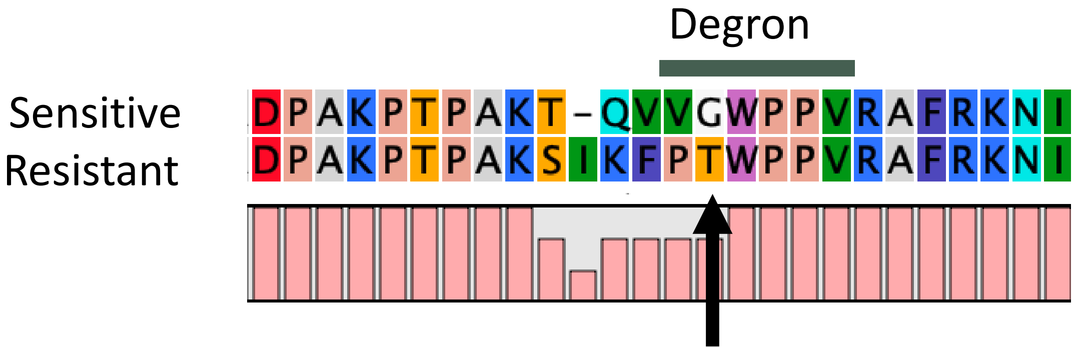
IAA16mut has lower binding affinity to TIR1

SPR assay tested binding affinity and dissociation for IAA16 alleles with TIR1 in the presence of natural and synthetic auxins
Dotted lines are the mutant IAA16 allele, solid are WT
Shifts downward indicate lower binding affinity
Quicker reduction after binding indicate quicker dissociation



Mutation affects protein-protein interaction

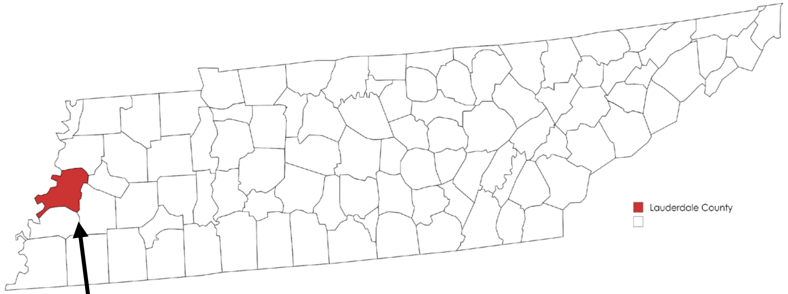


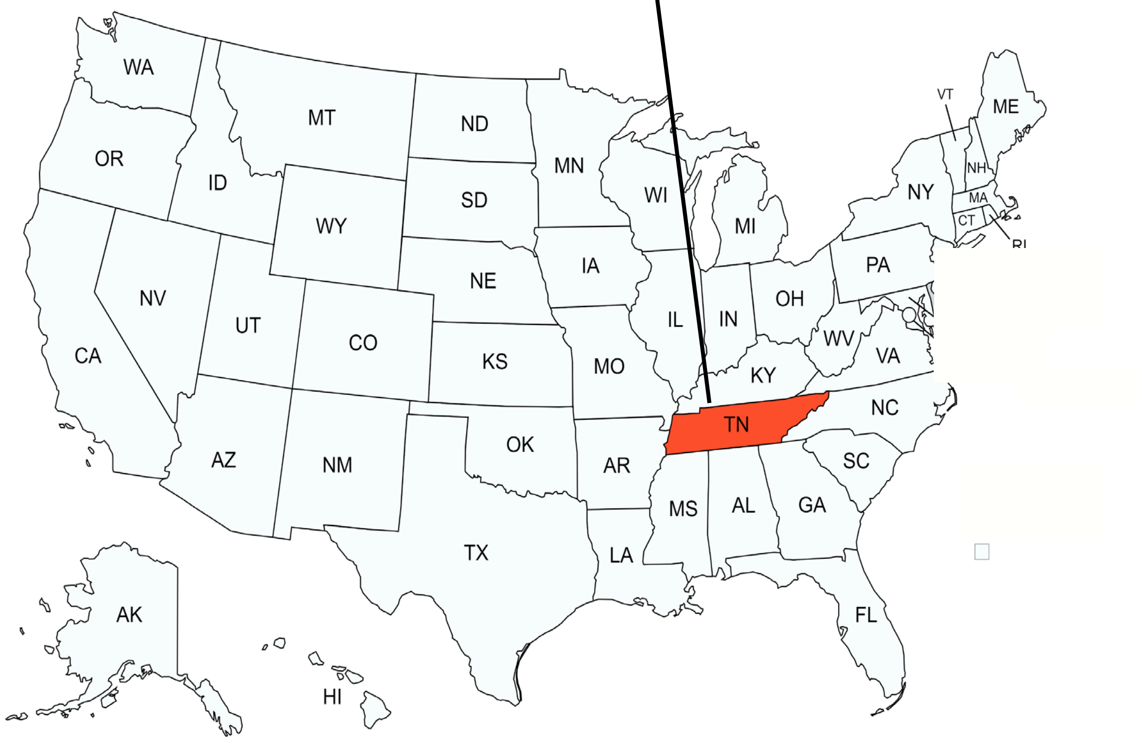


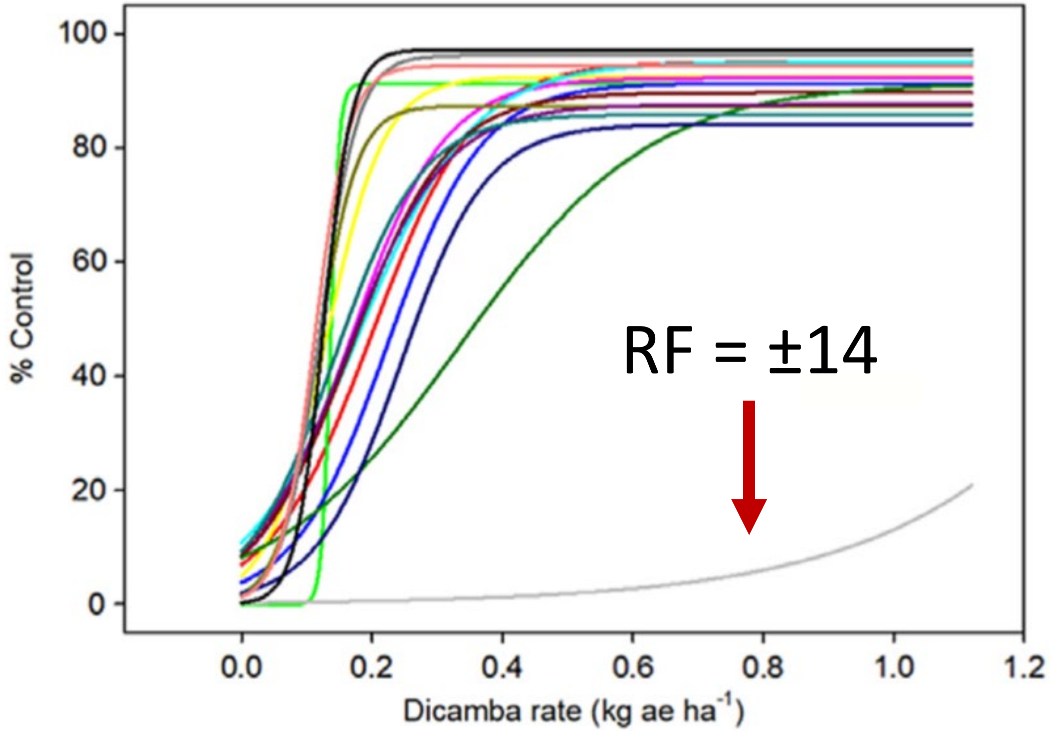
Unraveling the resistance mechanism to dicamba in Palmer amaranth (*Amaranthus palmeri*)

A survey identified dicamba-resistance Palmer amaranth

Dr. Larry Steckel

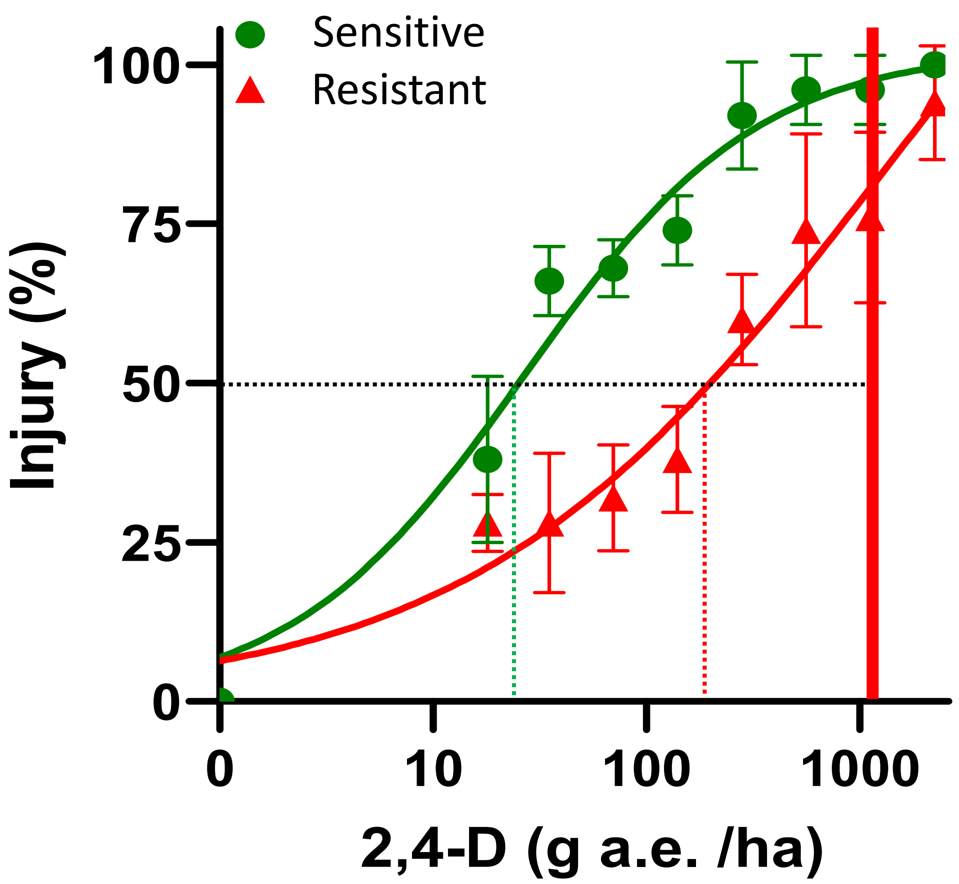


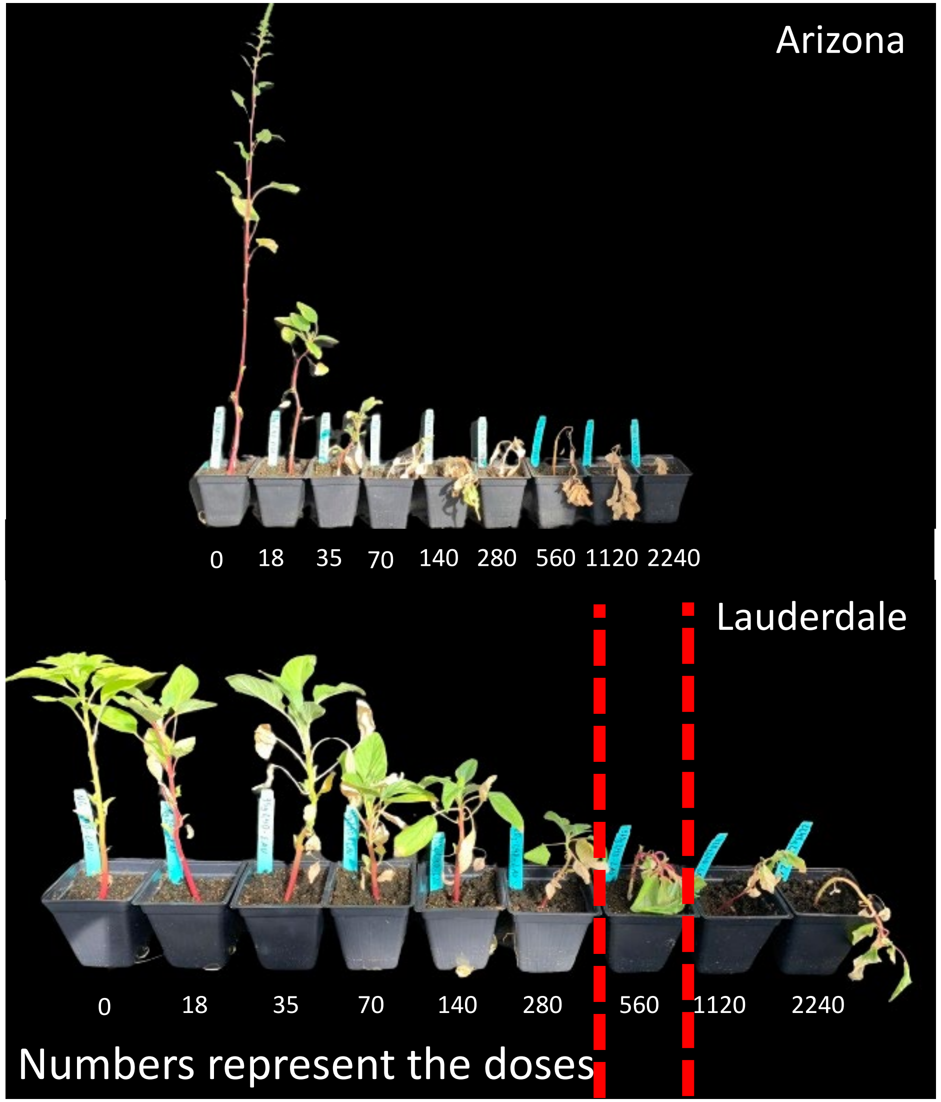




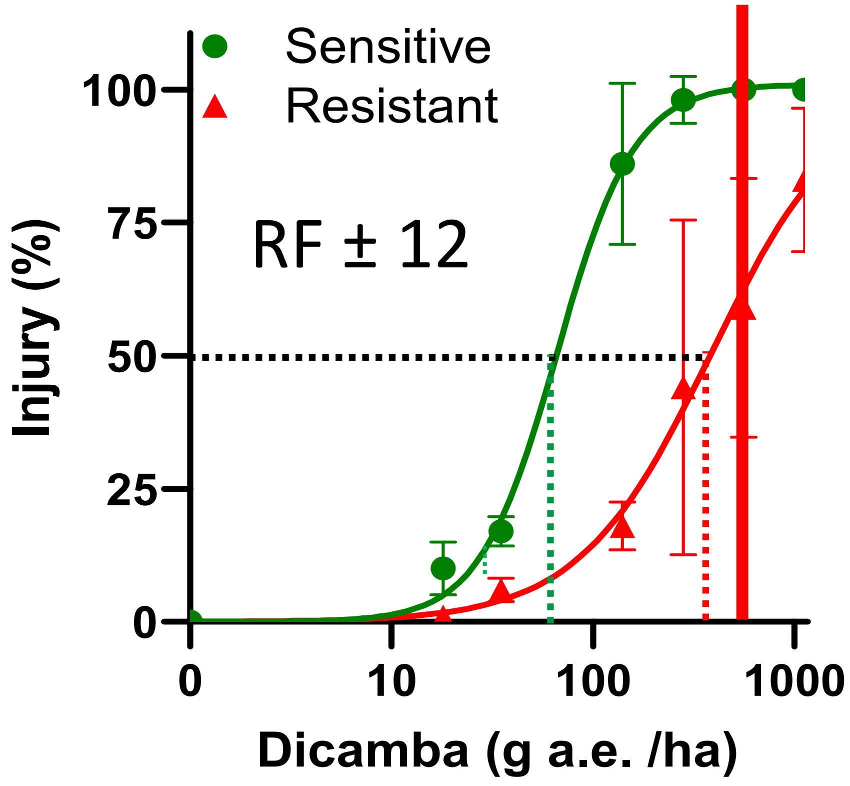
Foster, D., & Steckel, L. *Weed Technol,* (2022)

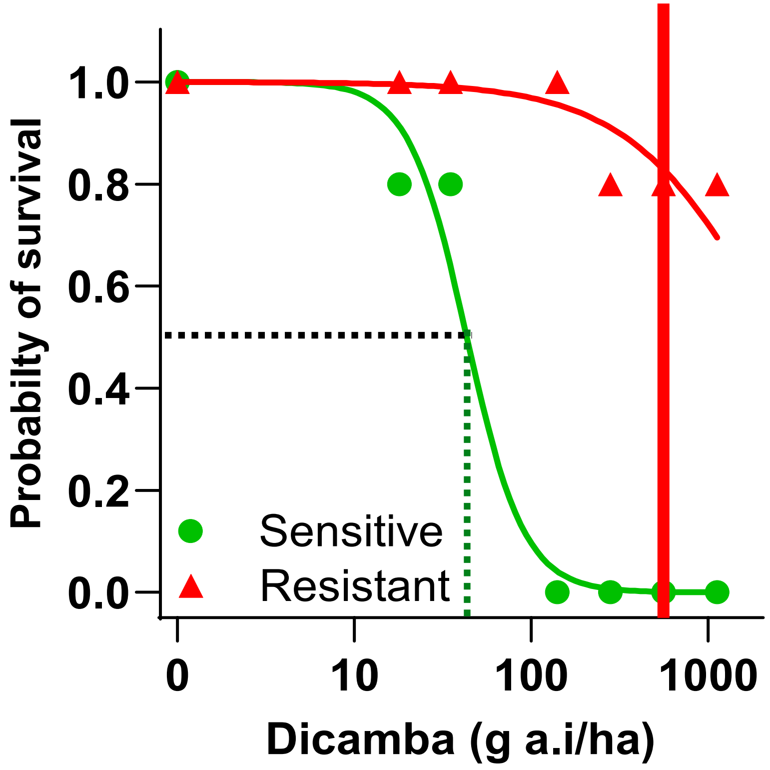
DRC of the auxin mimic herbicides

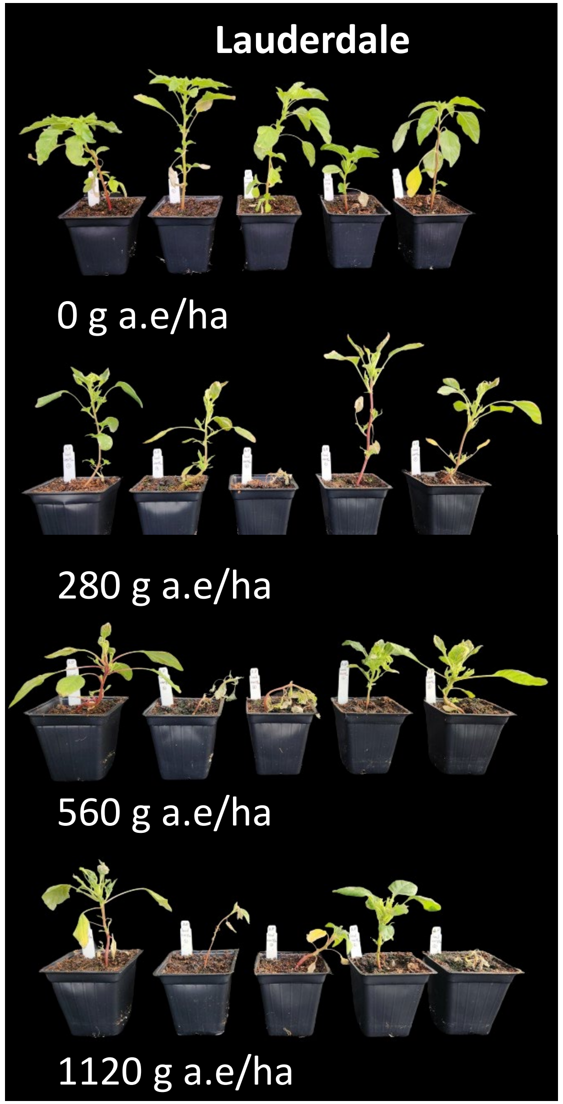




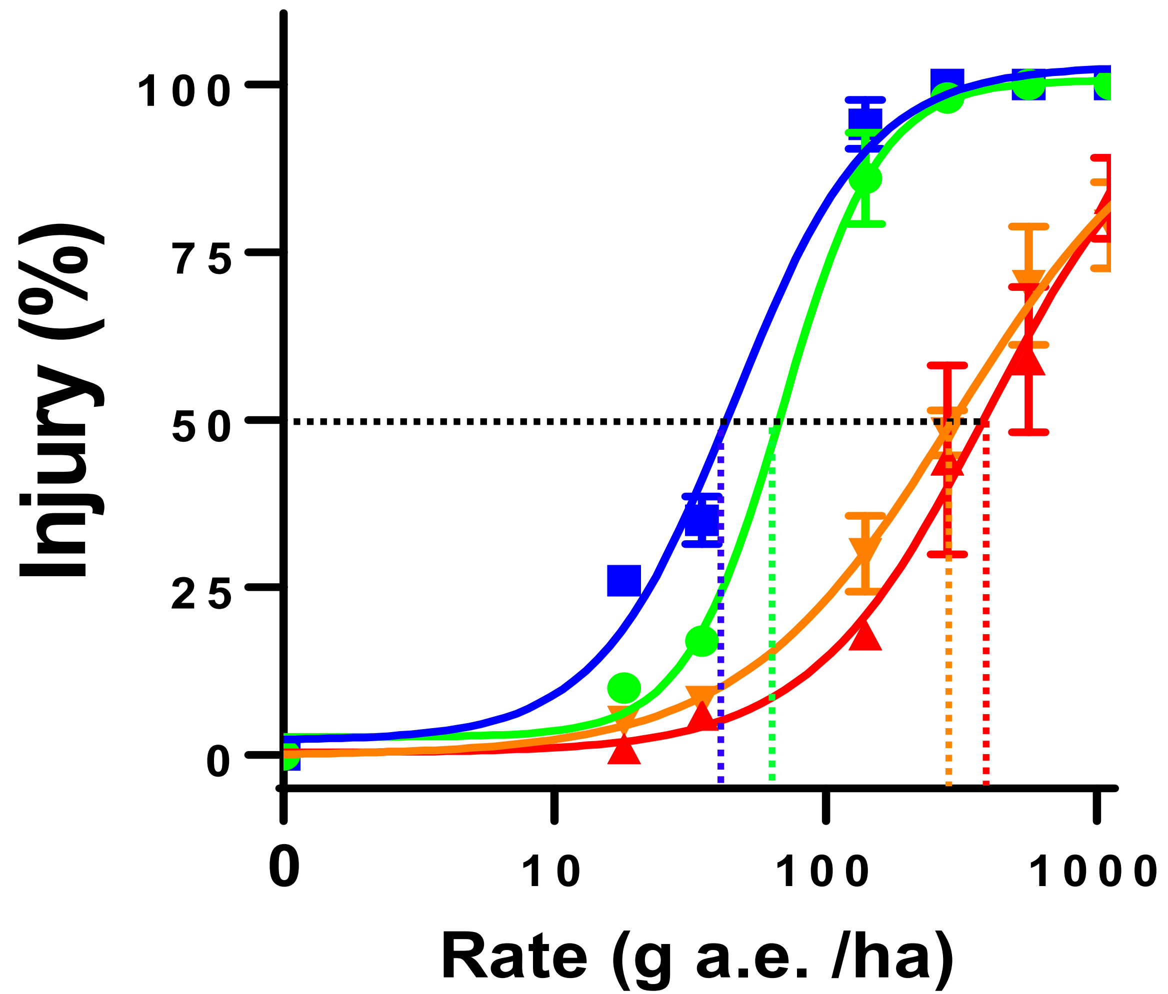
Visual injury in response to dicamba



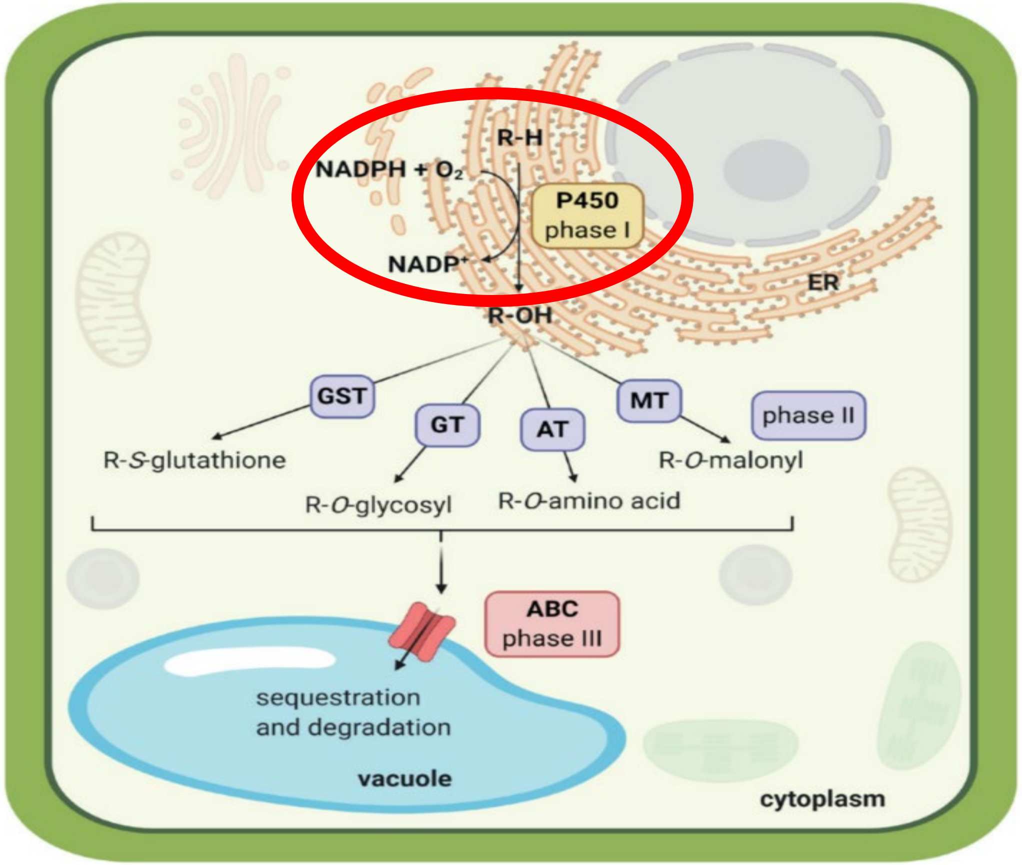




Enhanced metabolism not mediated by P450

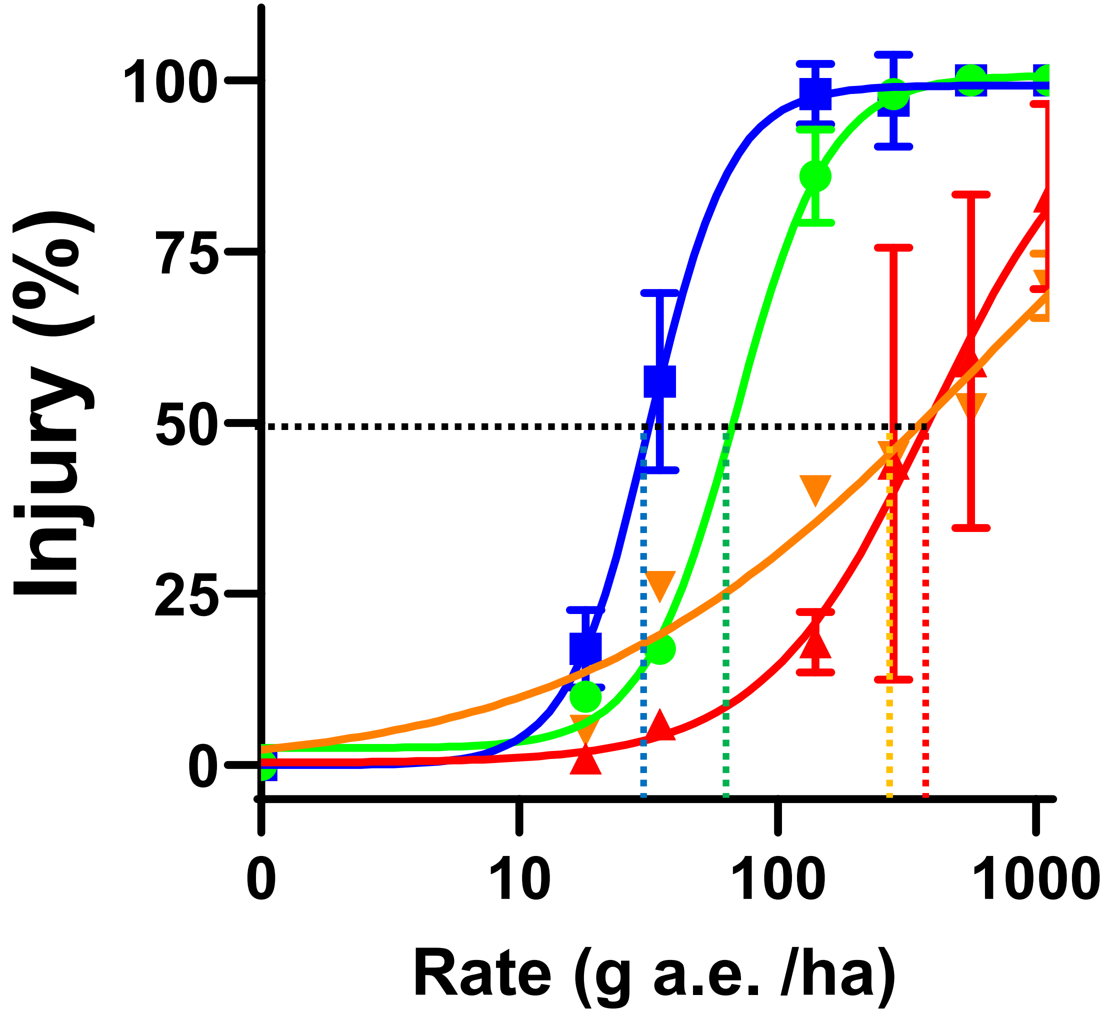


= Sensitive
= Sensitive + malathion
= Resistant
= Resistant + malathion

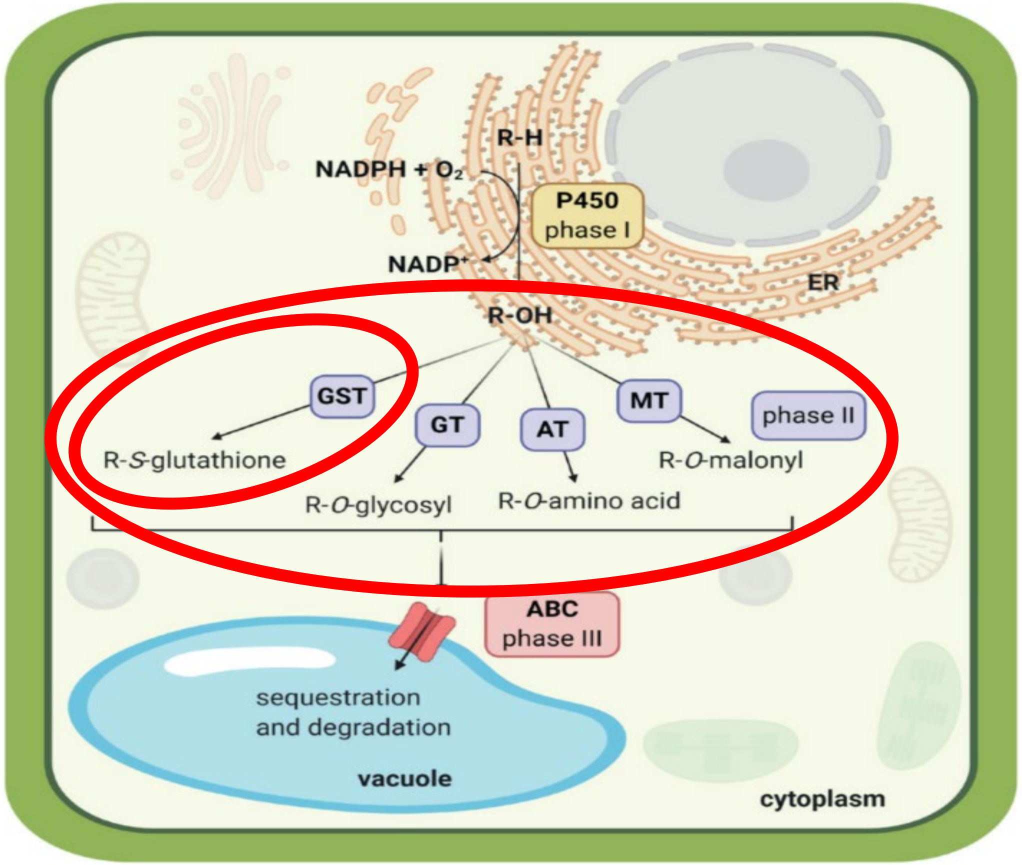


Rigon et al., 2020

Enhanced metabolism not mediated by GST

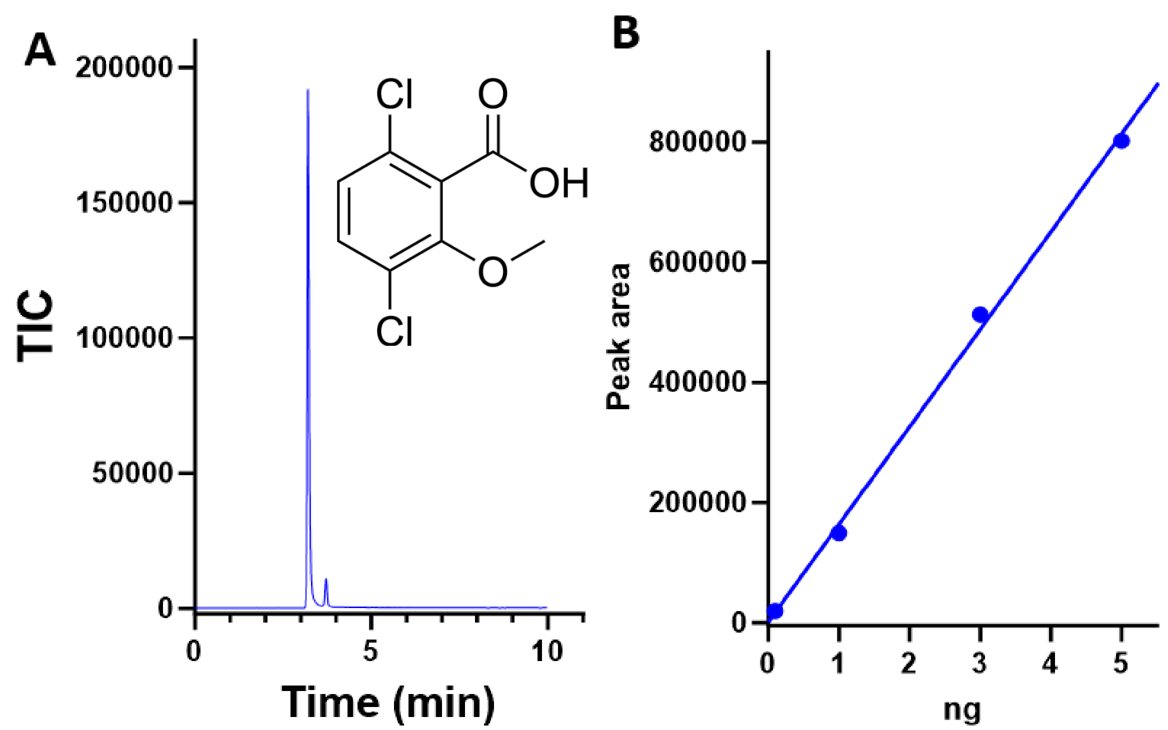


= Sensitive
= Sensitive + NBD
= Resistant
= Resistant + NBD



Rigon et al., 2020

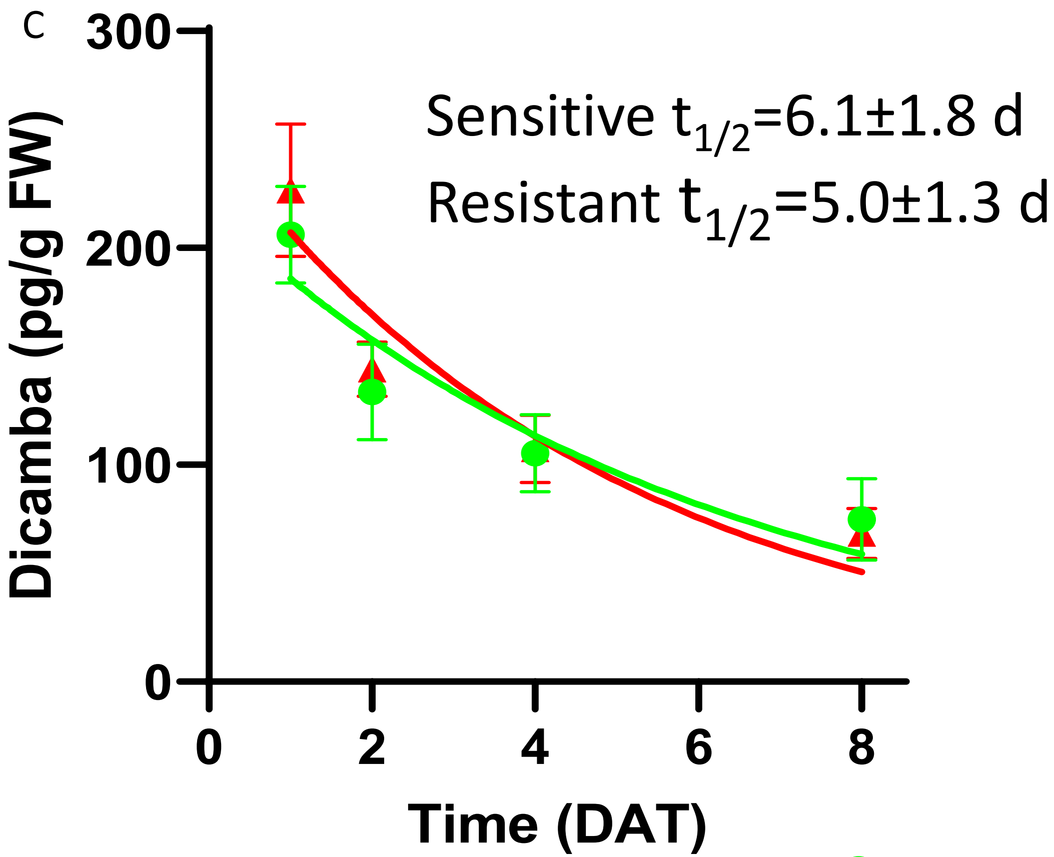
NTSR mechanism is not mainly involved in the resistance



LC-MS/MS analysis of dicamba

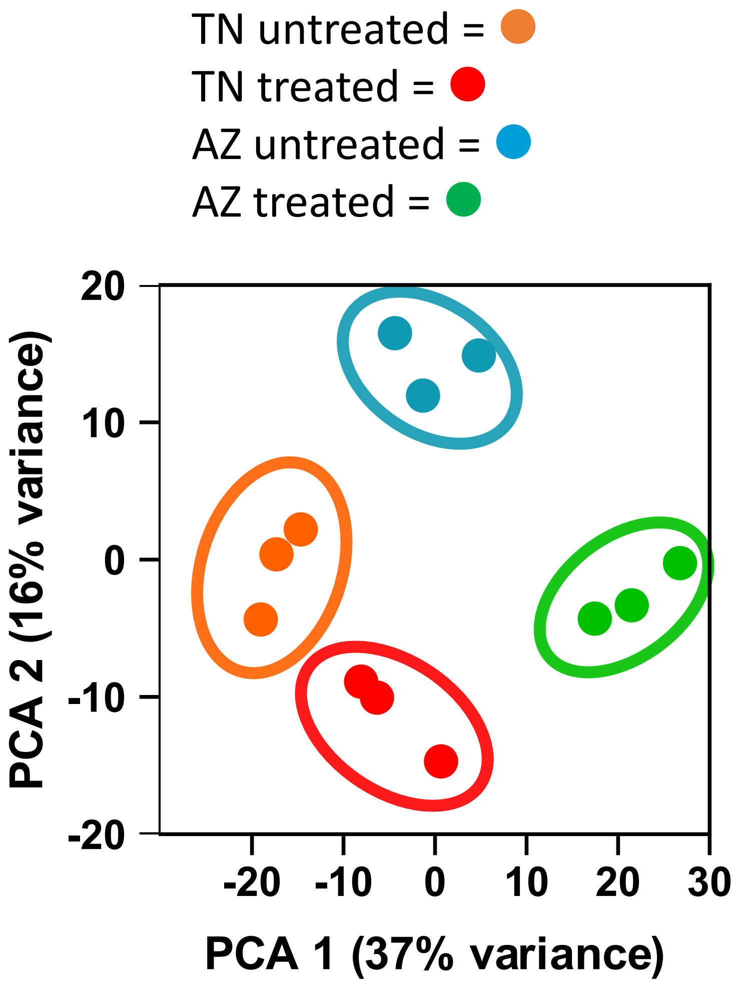
A) Chromatographic separation of the dicamba

B) Calibration curve of dicamba



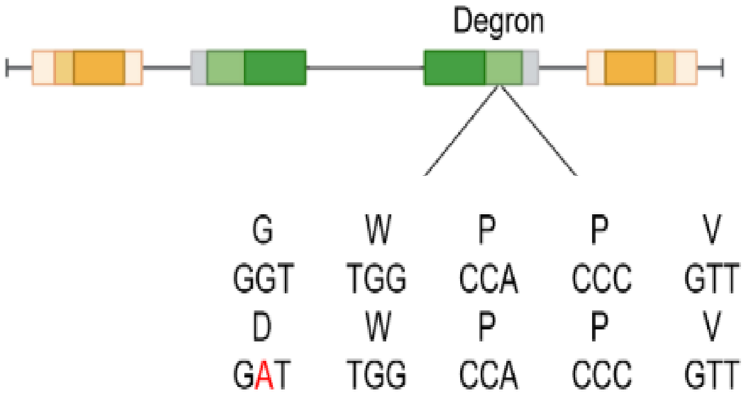
C) Metabolism of dicamba in sensitive (●=Sensitive) and resistant (▲=Resistant) Palmer amaranth biotypes. **(P = 0.65)**

RNA-seq experiment and bioinformatic



IAA16

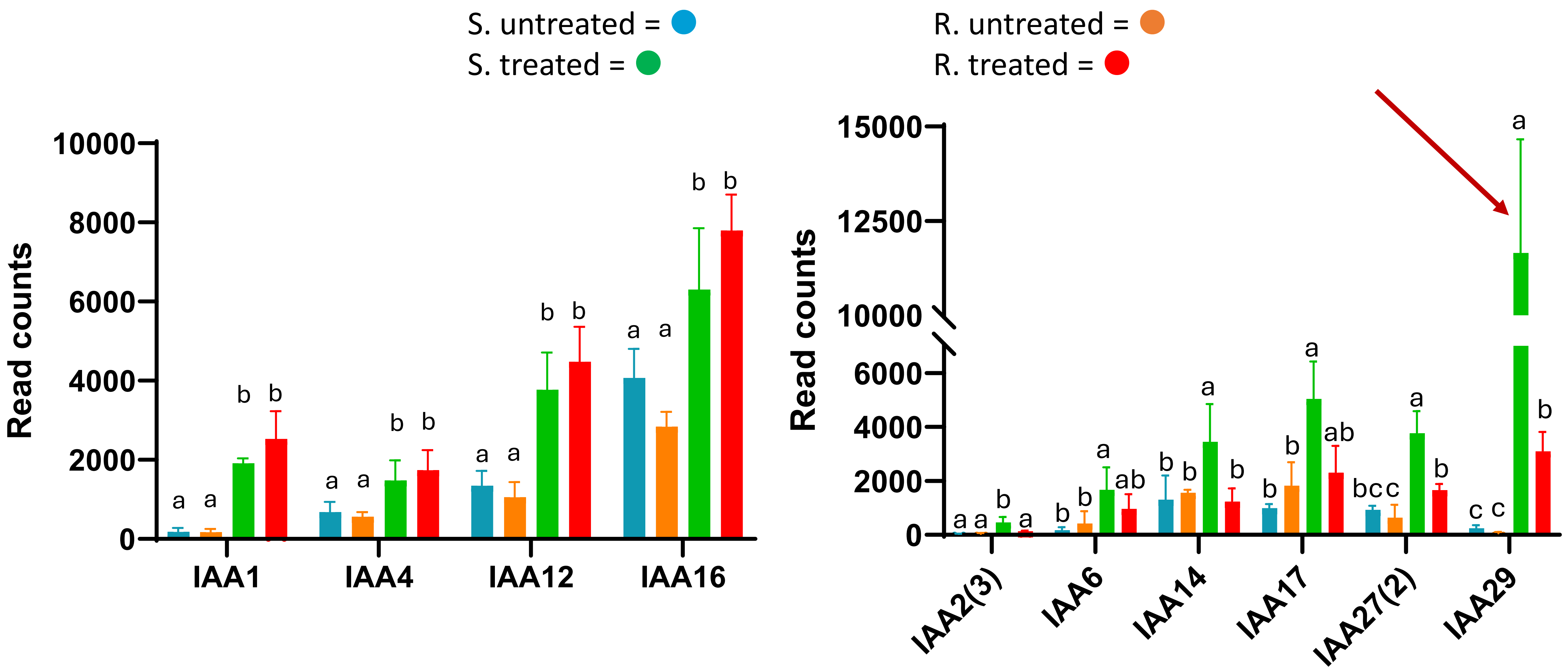
Visual inspection of AUX/IAA 16 in Palmer amaranth



We also inspected TIR1

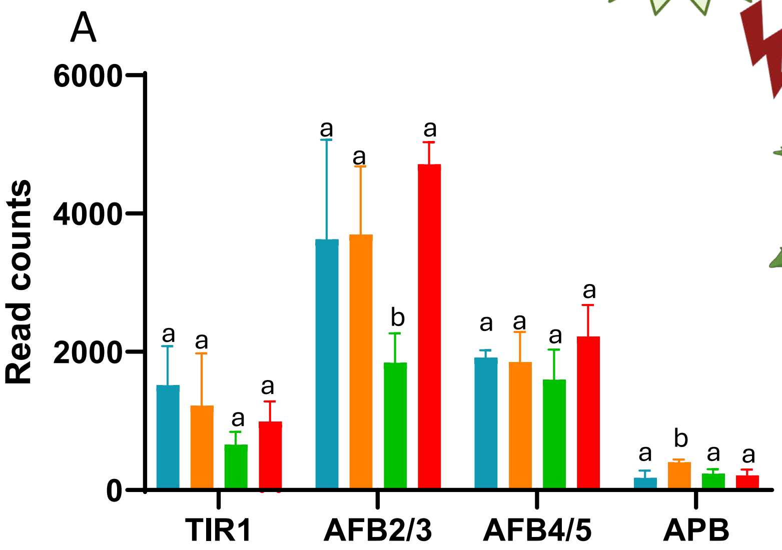
Ghanizadeh et al., 2024

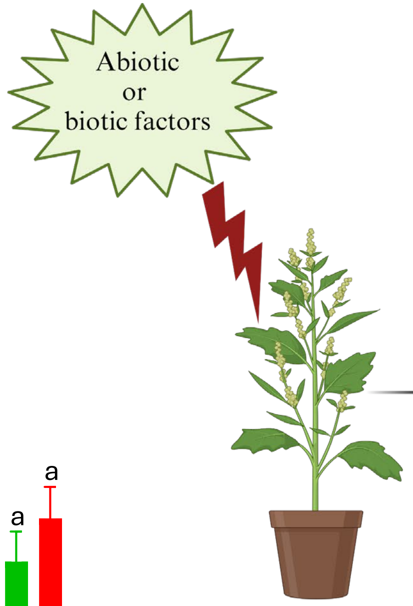
Gene expression of AUX/IAA in Palmer

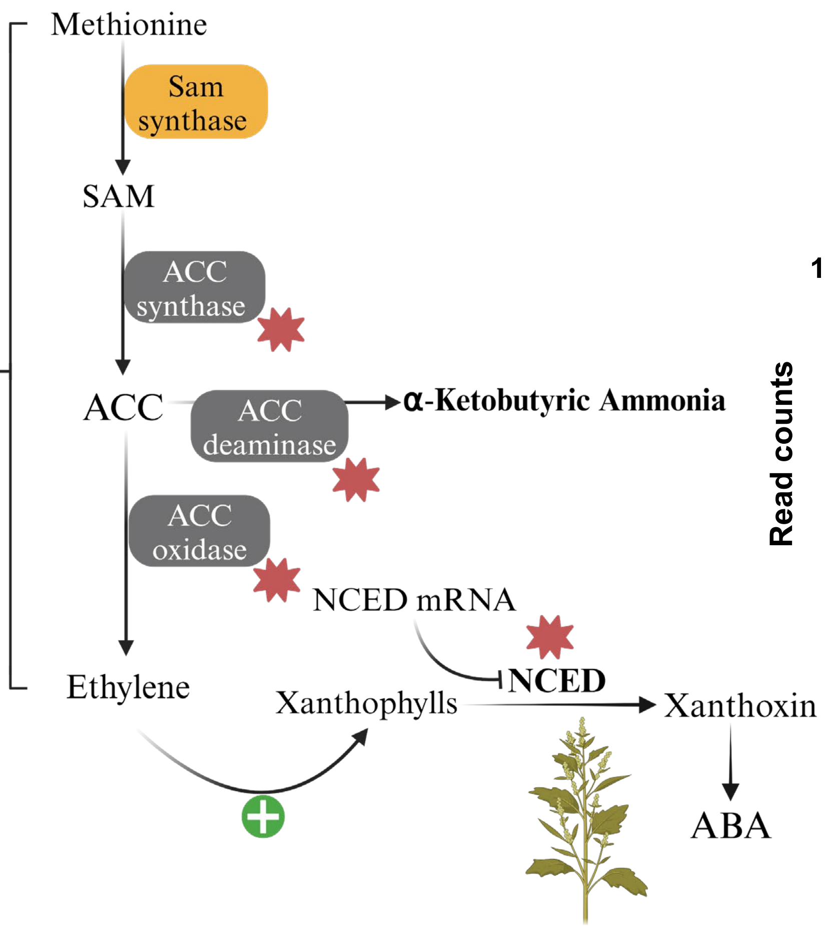


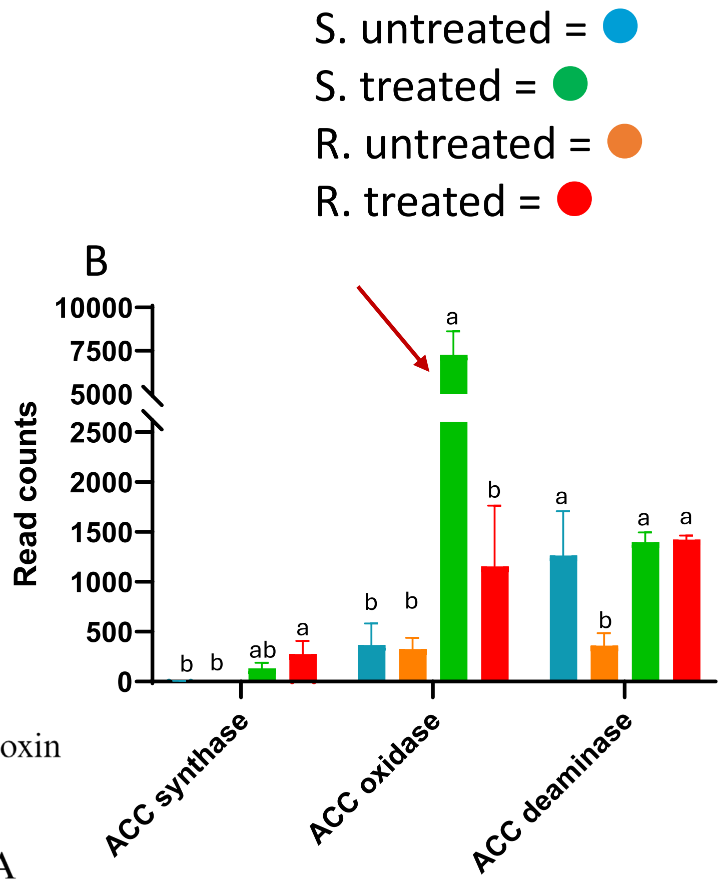
AUX/IAA that responded **differently**

AMHs interaction and auxin-response genes





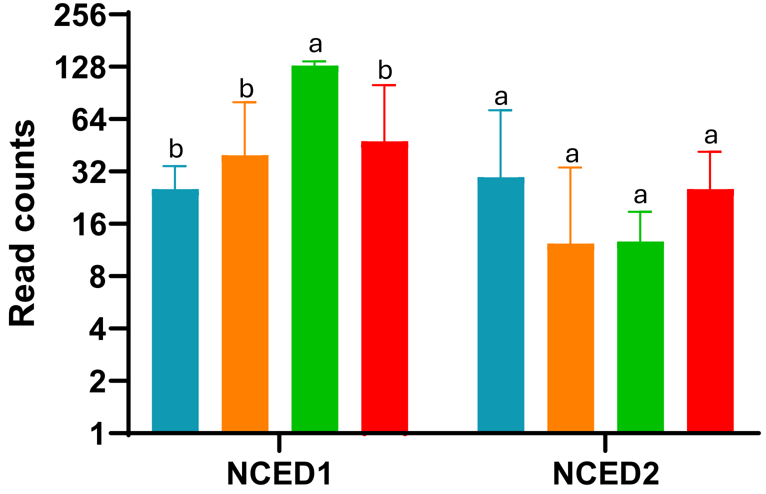


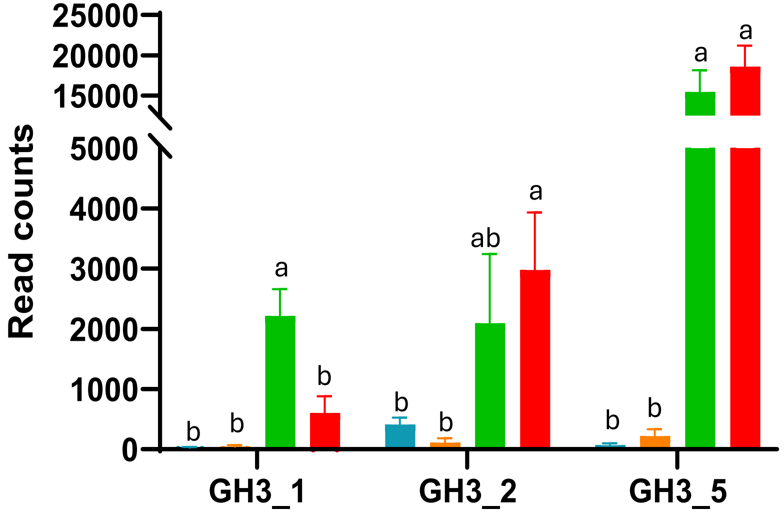


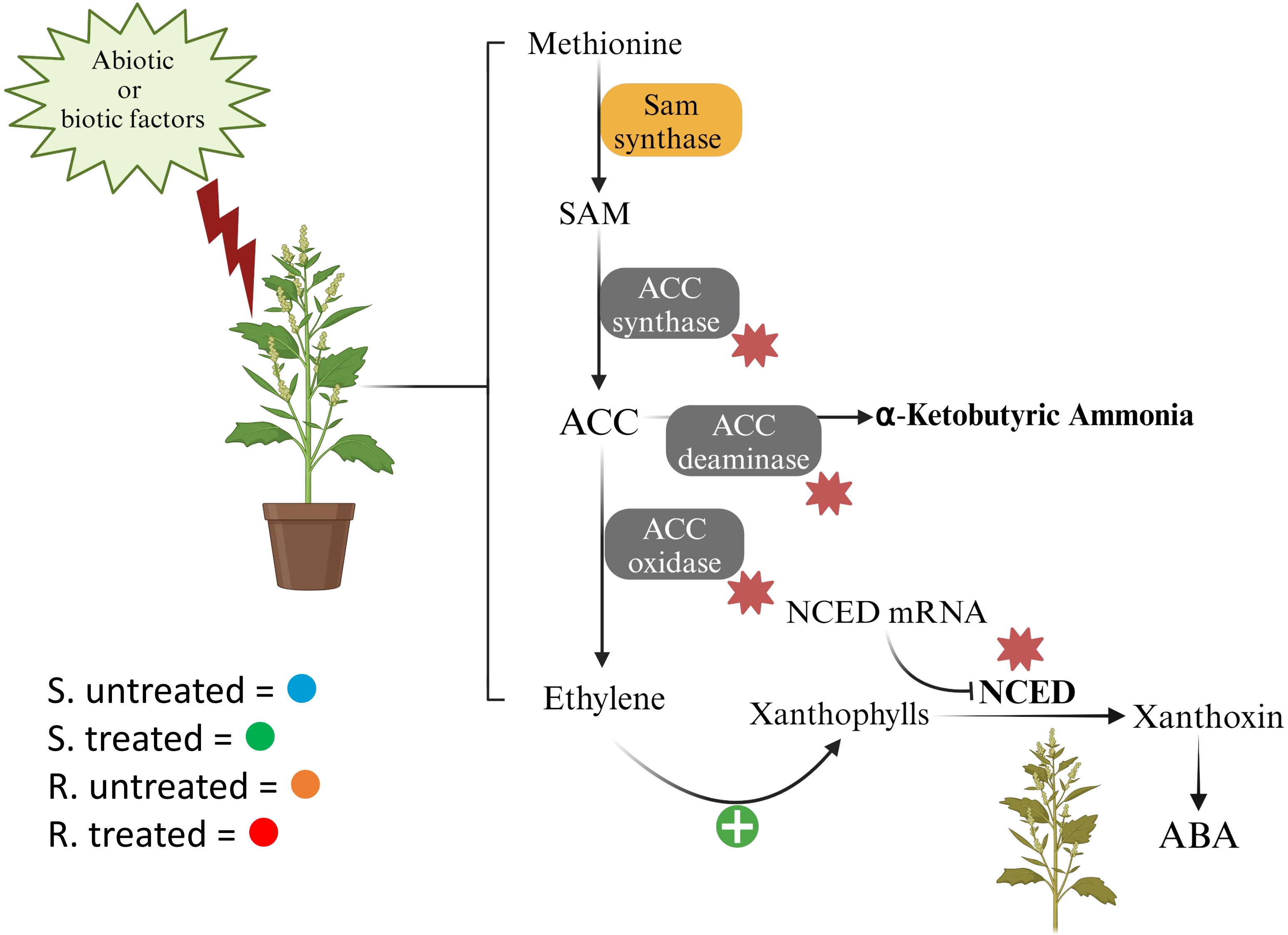
A. Response of TIR1, AFB, and APB in Palmer amaranth biotypes.

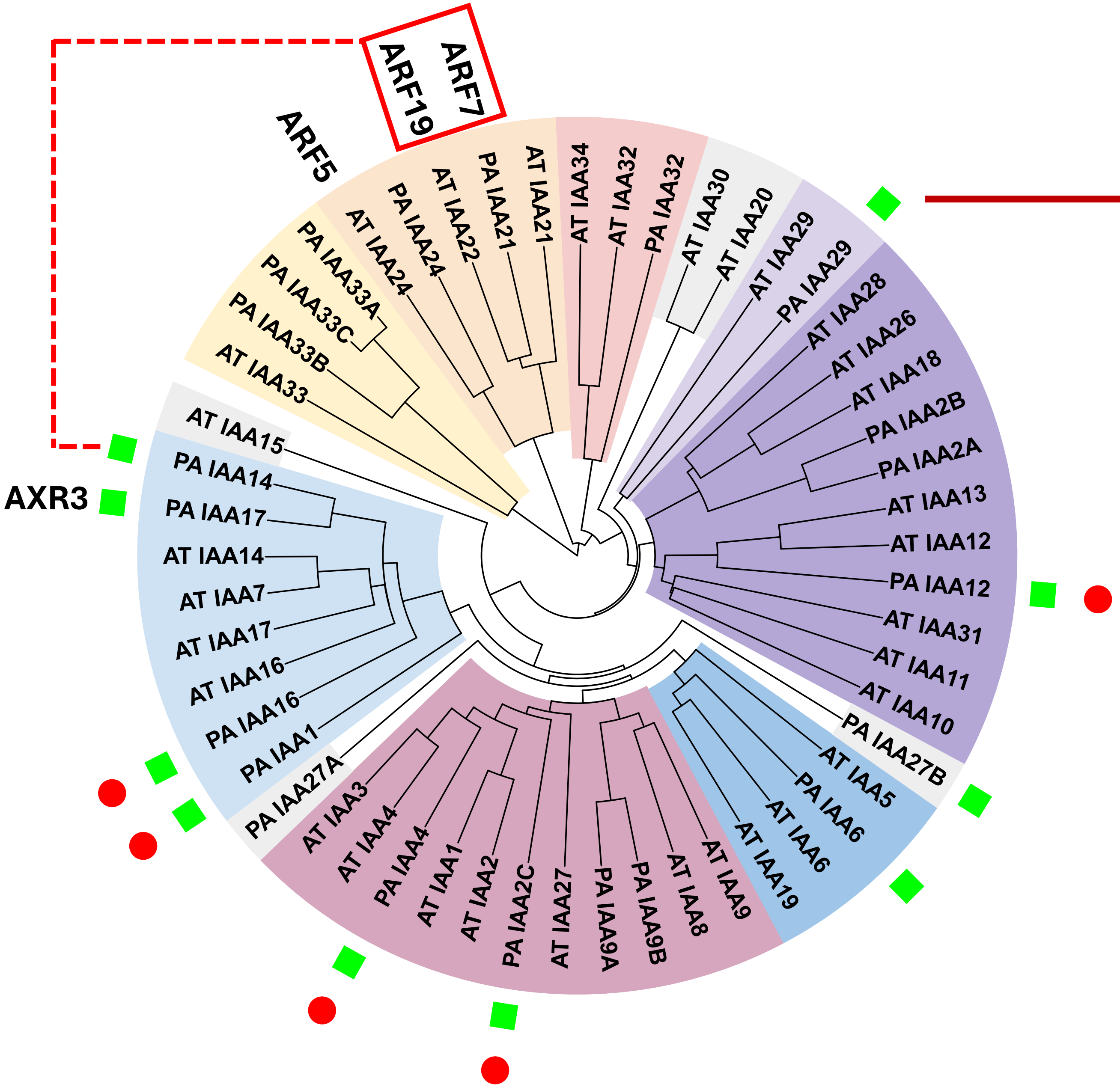
B. Analysis of the three main enzymes involved in ethylene biosynthesis.

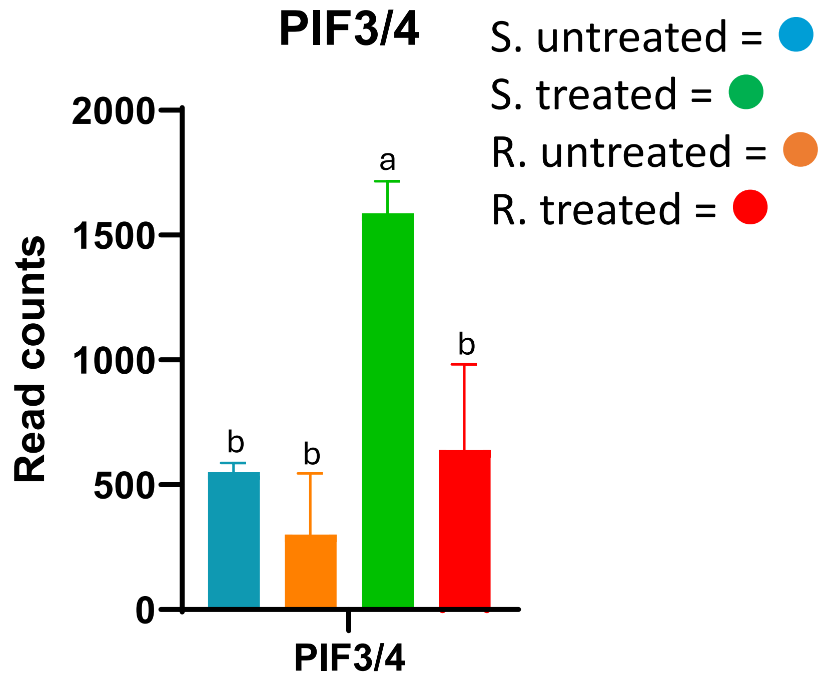
Analysis of auxin response-genes











Mutants deficient in PIF4 do not display elongation responses or leaf hyponasty

Auxin-responsive gene IAA29 is no longer responsive

Questions

Fall 2025

AB 509 Herbicide Selectivity and Action

Online asynchronous course intended for graduate students and working professionals in industry, government, and consulting positions with interest in herbicide use.

Topics covered include the physicochemical properties of herbicides, their selectivity (placement and metabolic tolerance), their mechanism of action, uses in weed management, visual symptoms of herbicide treatment, how plants can evolve resistance to these compounds, why herbicide applications fail, and controversial topics related to the use of herbicides.

Online registration will open April 2025. Contact: Franck Dayan at franck.dayan@colostate.edu or Todd Gaines at todd.gaines@colostate.edu