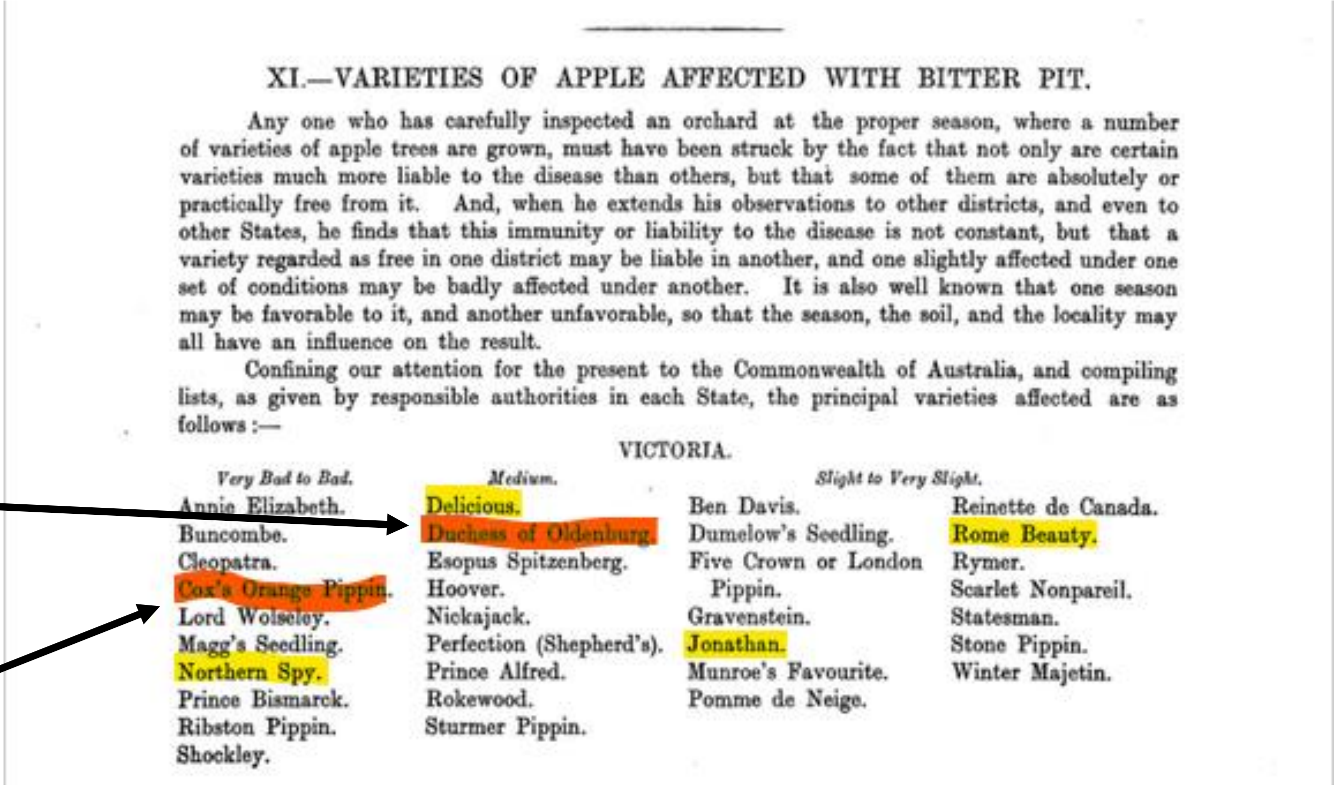
RAPID FRUIT GROWTH, VASCULAR DYSFUNCTION, AND BITTER PIT

Chayce Griffith, Randy Beaudry, and Todd Einhorn

THE BITTER PIT PROBLEM

- Bitter pit described in the 1860s
- Disorder results in corky lesions
- Up to 50% of fruit affected in some years
- 'Honeycrisp' particularly susceptible

A ONCE AND FUTURE PROBLEM


XI.—VARIETIES OF APPLE AFFECTED WITH BITTER PIT.

Any one who has carefully inspected an orchard at the proper season, where a number of varieties of apple trees are grown, must have been struck by the fact that not only are certain varieties much more liable to the disease than others, but that some of them are absolutely or practically free from it. And, when he extends his observations to other districts, and even to other States, he finds that this immunity or liability to the disease is not constant, but that a variety regarded as free in one district may be liable in another, and one slightly affected under one set of conditions may be badly affected under another. It is also well known that one season may be favorable to it, and another unfavorable, so that the season, the soil, and the locality may all have an influence on the result.

Confining our attention for the present to the Commonwealth of Australia, and compiling lists, as given by responsible authorities in each State, the principal varieties affected are as follows :—

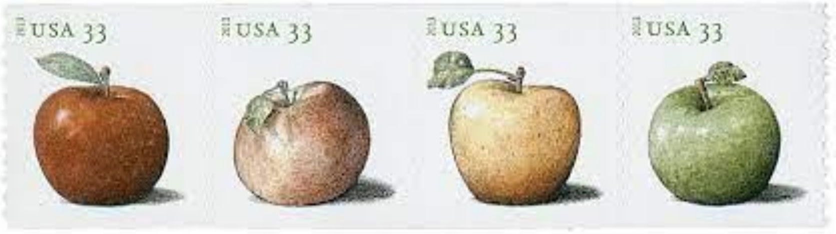
VICTORIA.

Very Bad to Bad.	*Medium.*	*Slight to Very Slight.*	
Annie Elizabeth.	Delicious.	Ben Davis.	Reinette de Canada.
Buncombe.	Duchess of Oldenburg.	Dumelow's Seedling.	Rome Beauty.
Cleopatra.	Esopus Spitzenberg.	Five Crown or London Pippin.	Rymer.
Cox's Orange Pippin.	Hoover.	Gravenstein.	Scarlet Nonpareil.
Lord Wolseley.	Nickajack.	Jonathan.	Statesman.
Magg's Seedling.	Perfection (Shepherd's).	Munroe's Favourite.	Stone Pippin.
Northern Spy.	Prince Alfred.	Pomme de Neige.	Winter Majetin.
Prince Bismarck.	Rokewood.		
Ribston Pippin.	Sturmer Pippin.		
Shockley.			

Ancestor of 'Honeycrisp'

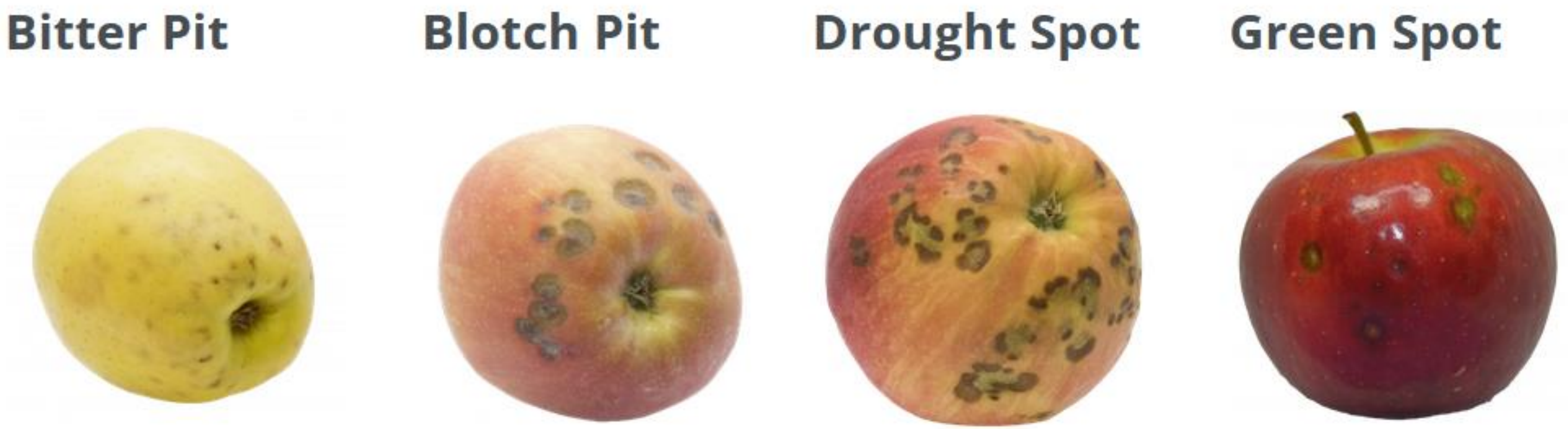
Ancestor of 'Gala'

Varying Cultivar Susceptibility



'Baldwin' 'Spy' 'Golden Delicious' 'Granny Smith'

DEFINING BITTER PIT



Courtesy of Washington State University

Lenticel Breakdown

Scab

BMSB

Leather Blotch

Courtesy of Cornell

WHAT ELSE CAN BE DONE?

- Maintain proper levels of Ca, Mg, and K in soil
- Avoid over fertilizing
- Spray foliar Ca
- Moderate cropload (6-7 fruit per cm^2 TCA)
- Plant resistant cultivars/choose resistant rootstocks

BITTER PIT AND CALCIUM DEFICIENCY

TABLE I

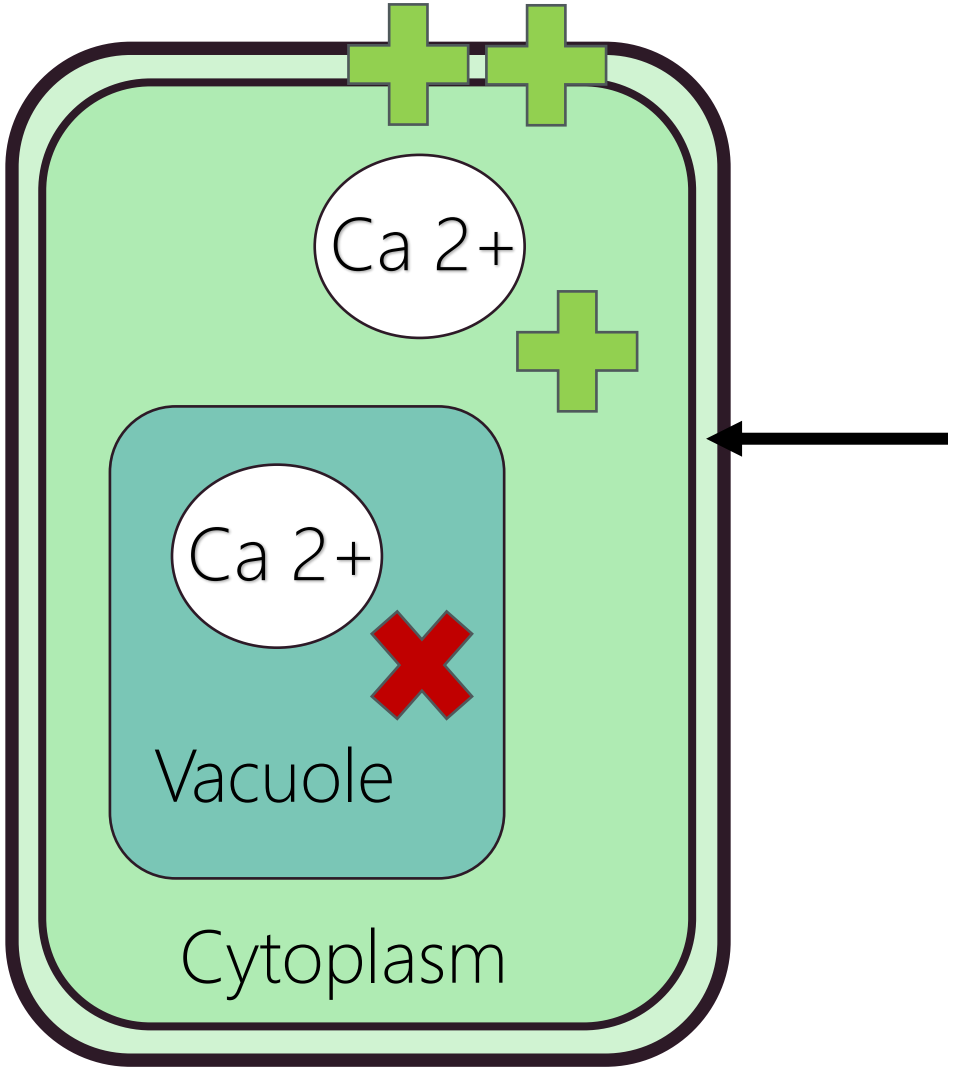
Ash analyses of Stark apples, A, B, C, affected with blotchy cork, D and E unaffected

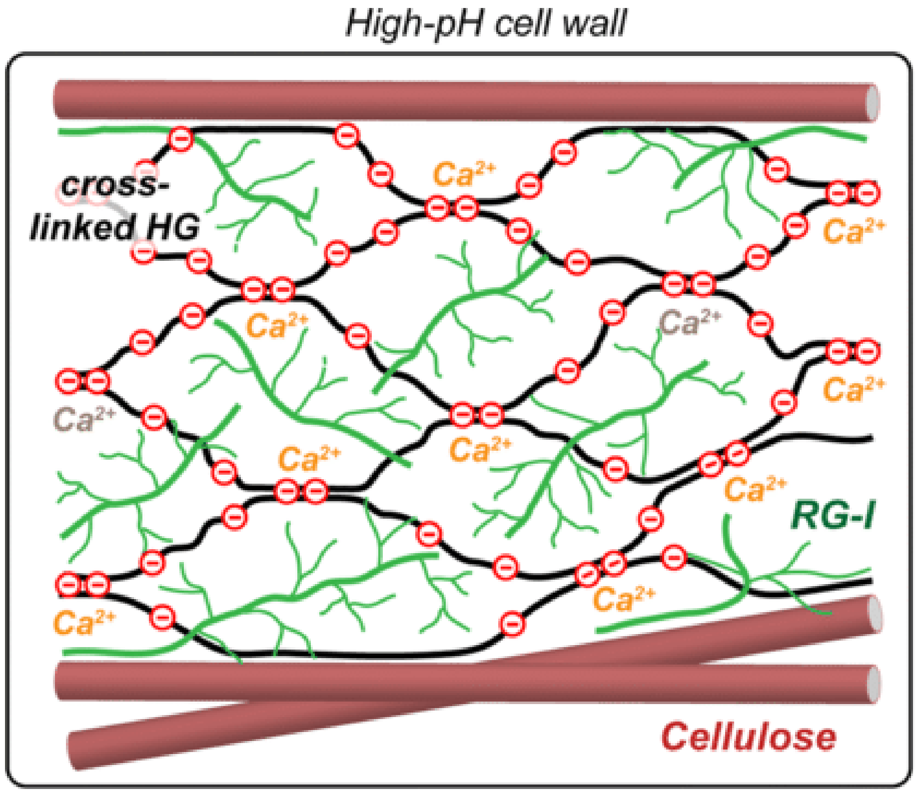
Sample	Ash in fresh weight	Percentage in the ash				Average fresh weight per apple
		P_2O_5	CaO	MgO	K_2O	
	%	%	%	%	%	gm.
	Analytical results on parings					
A	0.528	10.2	1.27	4.32	56.1	124.1
B	0.550	10.5	1.56	4.53	55.4	119.7
C	0.627	12.6	1.67	4.67	55.8	132.7
D	0.478	11.1	2.41	4.54	55.5	124.9
E	0.476	10.2	3.57	4.61	53.2	120.2
	Analytical results on flesh					
A	0.243	9.5	1.67	3.33	56.1	......
B	0.256	10.8	1.80	3.58	55.1	......
C	0.264	11.1	1.76	3.43	56.2	......
D	0.238	10.1	2.32	3.54	56.2	......
E	0.235	11.6	2.99	3.63	54.7	......

DELONG 1934

- Bitter pit was linked to Ca deficiency in 1934
- Walter DeLong observed Ca was lower in bitter pit-affected fruit
- Largest difference in Ca was observed in peels

CALCIUM DEFICIENCY DISORDER





Phyo et al. 2019

MORE CALCIUM, BUT WHERE?

Total fruit calcium?
Peel calcium?

~~Total tree calcium~~ (Martin et al. 1962)

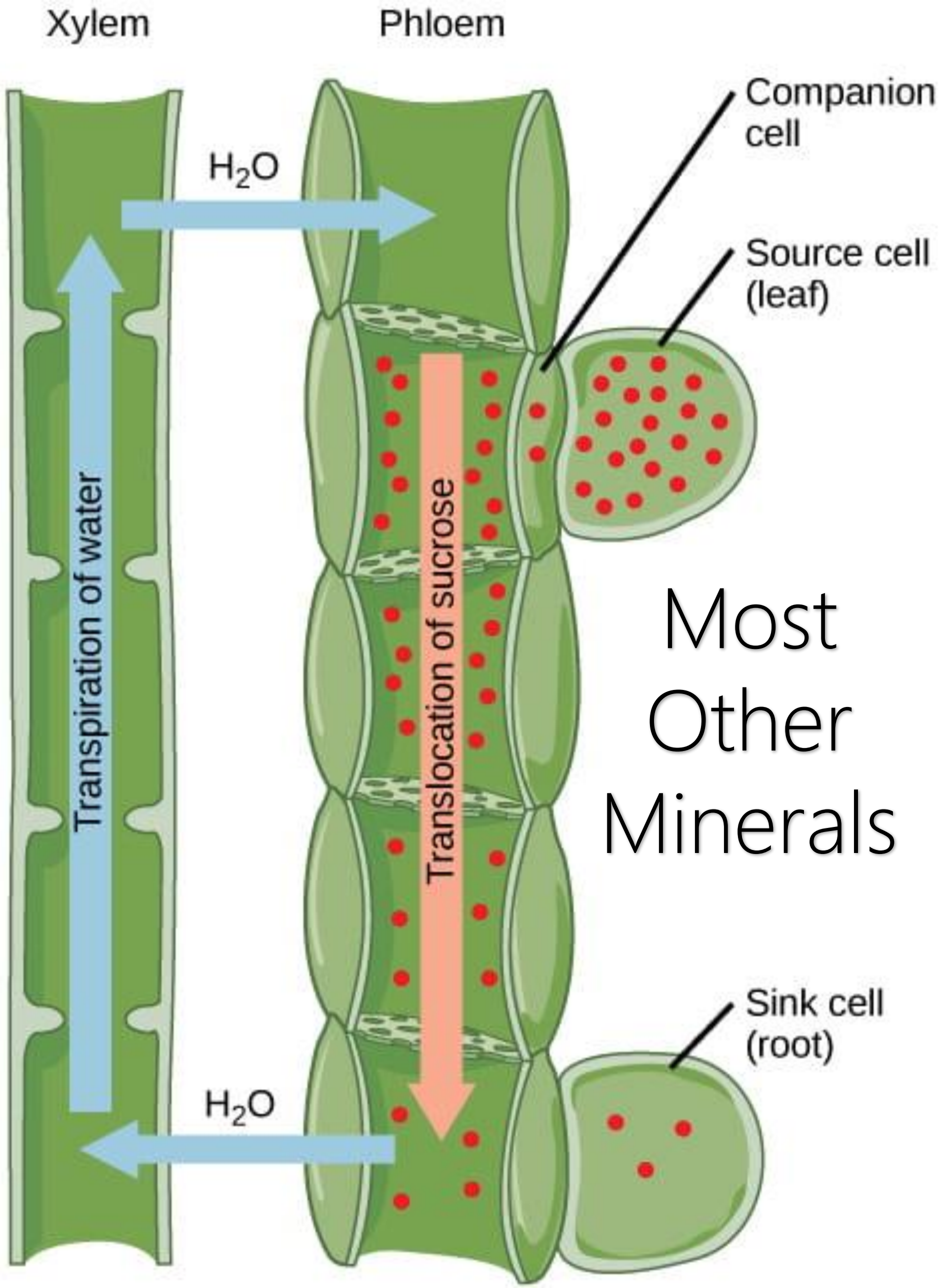
~~Soil calcium~~ (Fried and Shapiro 1961)

CALCIUM AS A UNIQUE MACRONUTRIENT

Fruit, Leaves

Ca 2+ is only mobile in xylem

Roots



Most Other Minerals

PERIPHERAL XYLEM

XYLEM DYSFUNCTION

RESEARCH AT MSU, 2021-2022

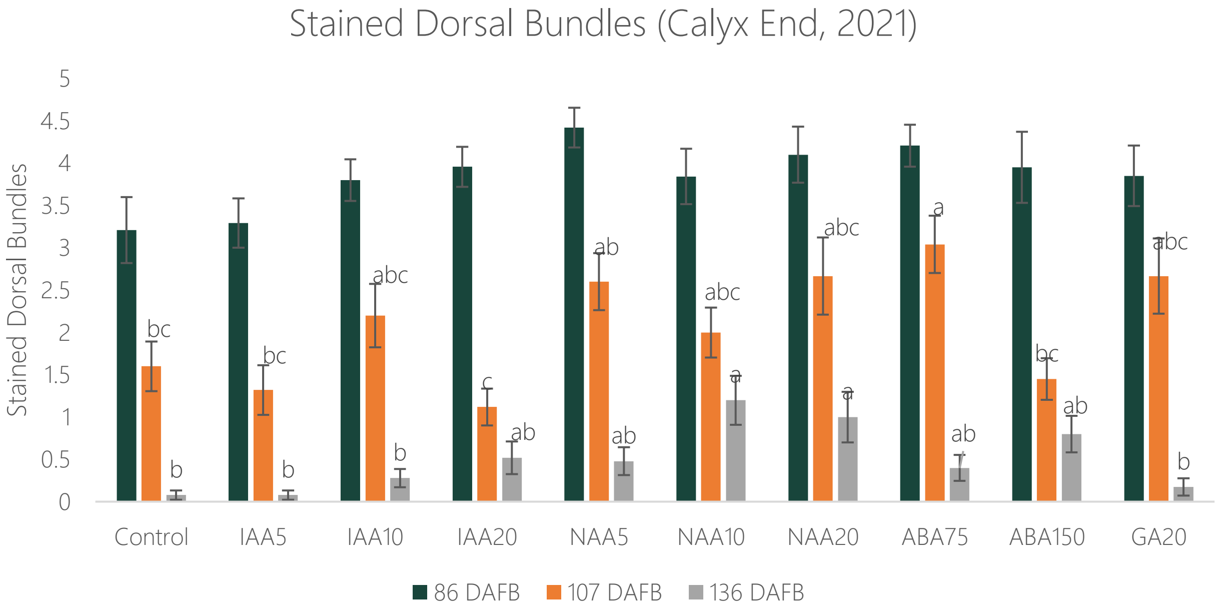
- 6th leaf 'Honeycrisp'/G.11 trees selected on trunk circ. and bloom
- RCBD, 5 replicates
- Three applications: 30, 45, 60 DAFB as whole-tree sprays

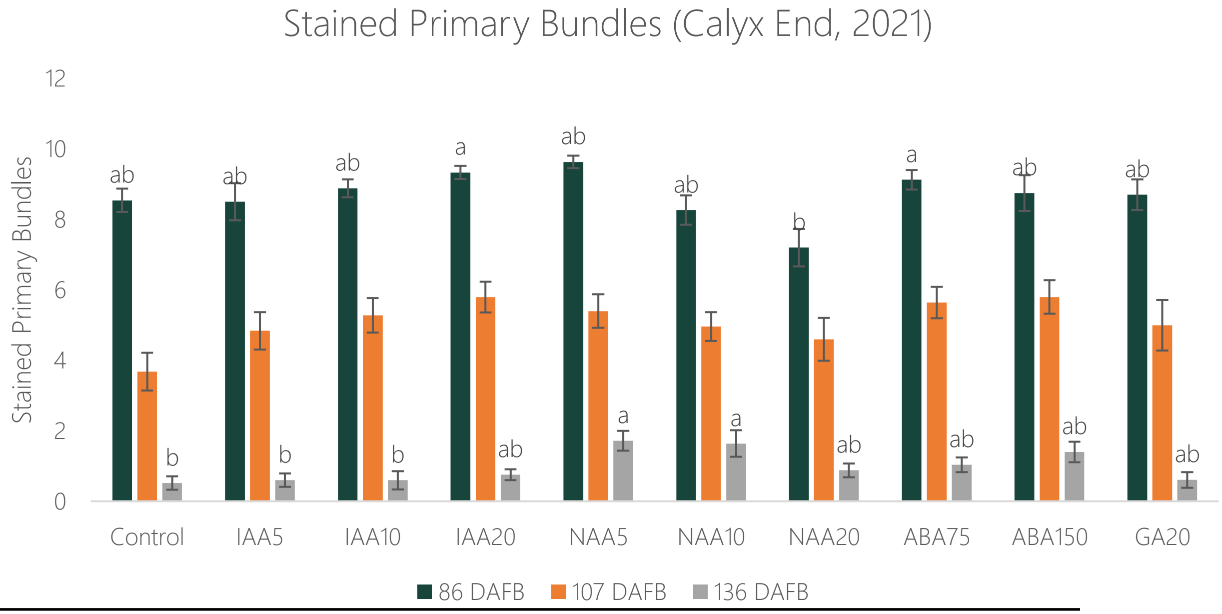
Active Ingredient	Formula or Product	Concentration of ai (ppm)
Control	-	-
IAA	Pure solid	5-40
NAA	Fruitone® L	2.5-20
ABA	Protone®	75-250

<u>Primary bundles</u> are the largest type of bundle and provide nutrients to the flesh (10 total)

<u>Dorsal bundles</u> are the primary suppliers of nutrients to deep flesh (5 total)

<u>Ventral bundles</u> rupture early and therefore were not assessed (10 total)





BITTER PIT RESULTS

Treatment		2021		2022	
AI	ppm	Harvest (%)	Storage (%)	Harvest (%)	Storage (%)
Control	-	32.9	45.2	28.6	34.9
IAA	20	7.3*	19.8*	18.8*	21.2*
NAA	10	17.6*	26.3*	20.1*	22.3*
ABA	125	-	-	21.0*	22.7*
	150	13.2*	31.3*	-	-

Significance (* = P < 0.5) calculated with binary logistic regression with tree, replicate, and cropload as random effects where significant differences between treatments were calculated with ANOVA.

2023 EXPERIMENTAL DESIGN

Cropload

High

16 fruit per square cm of TCSA

PGR

IAA

NAA

ABA

TIBA

Control/ Moderate

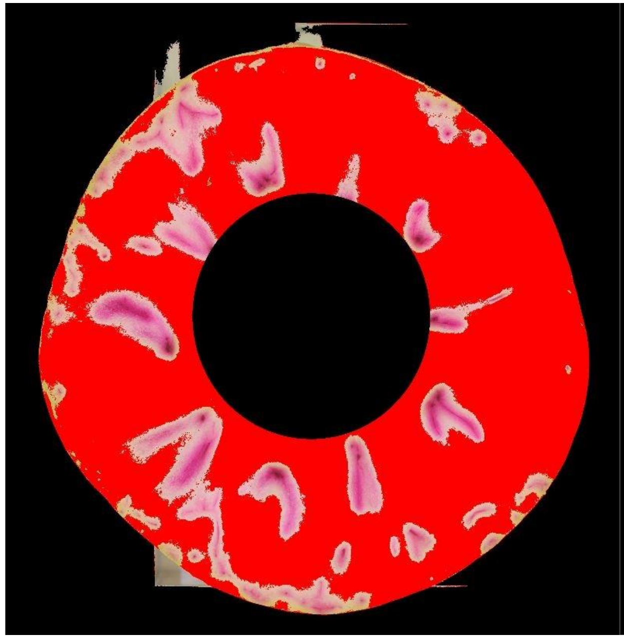
8 fruit per square cm of TCSA

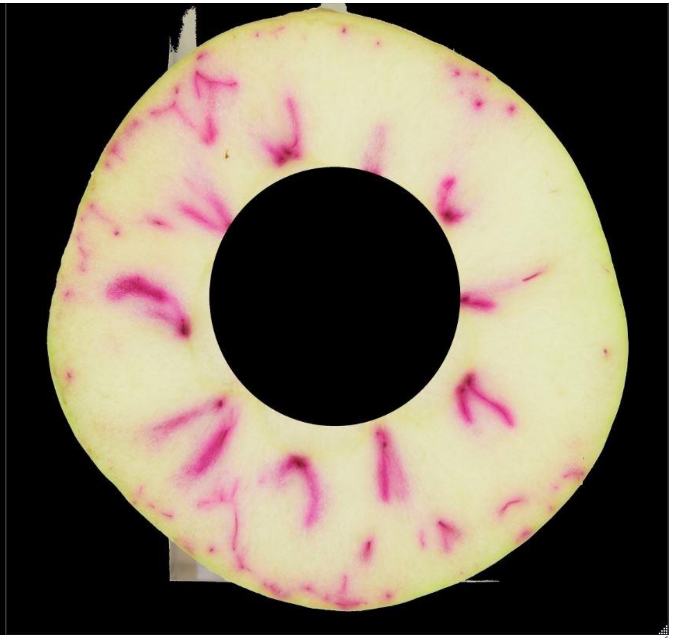
Low

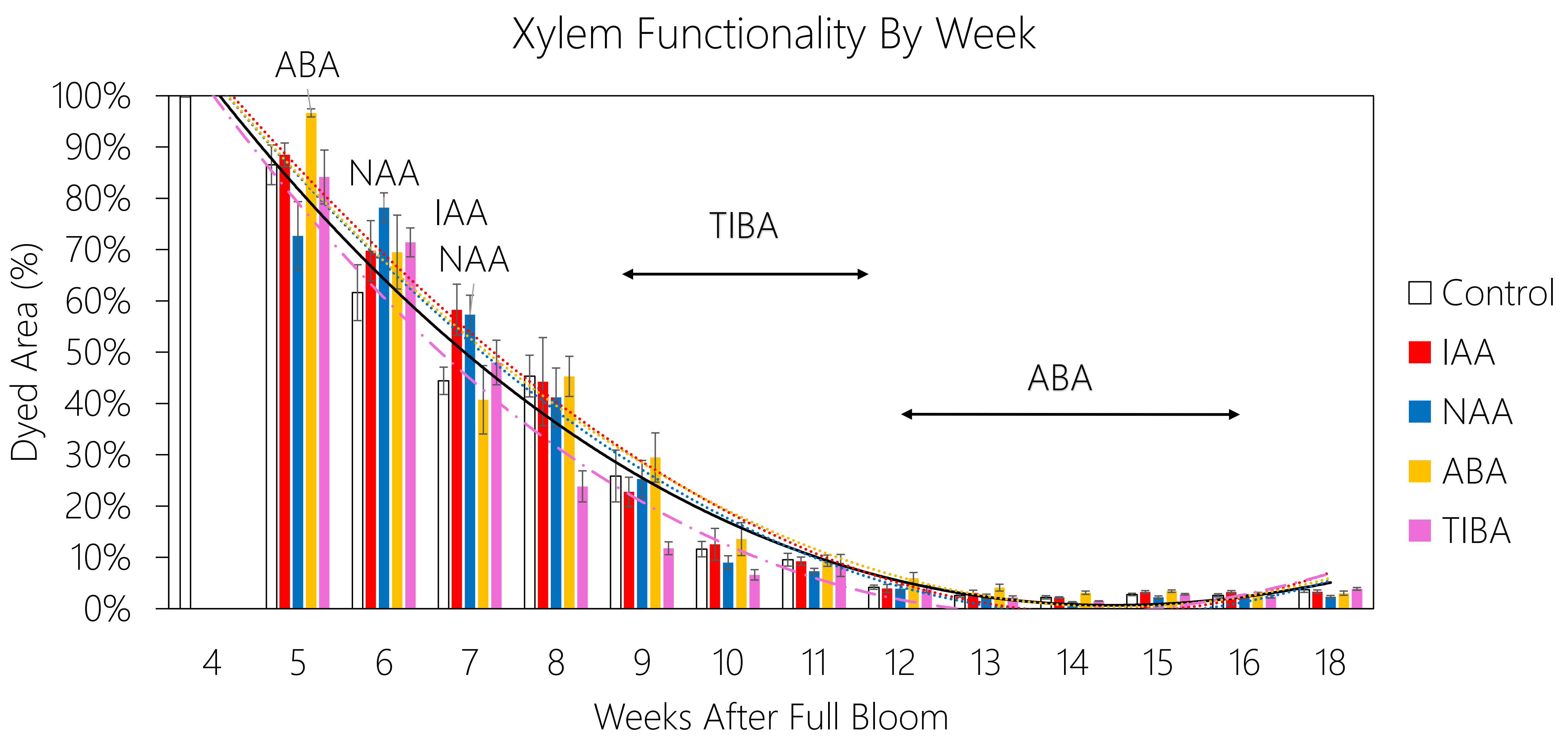
4 fruit per square cm of TCSA

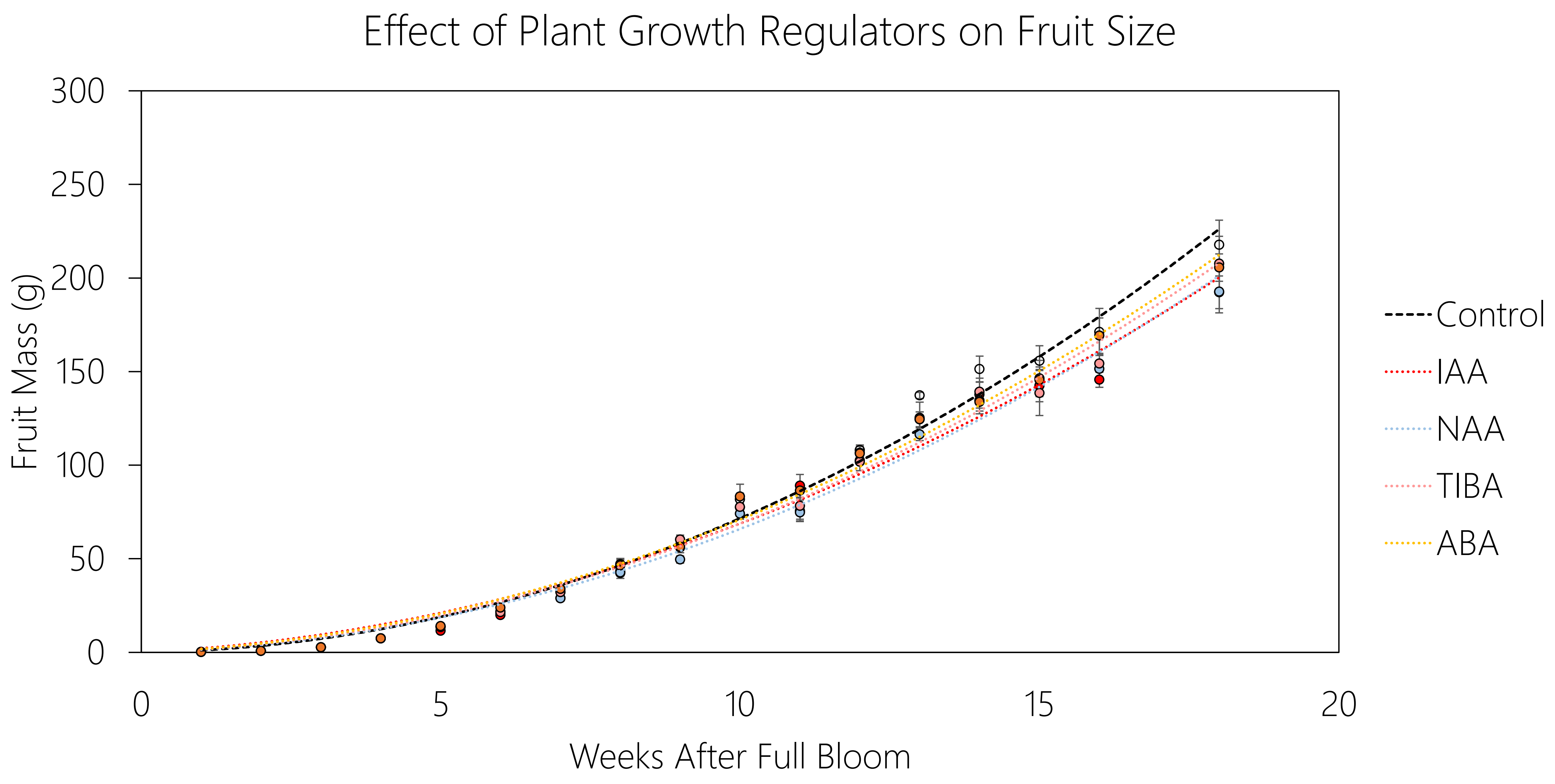
How do apple fruit change over time?

XYLEM ASSESSMENT PROCEDURE

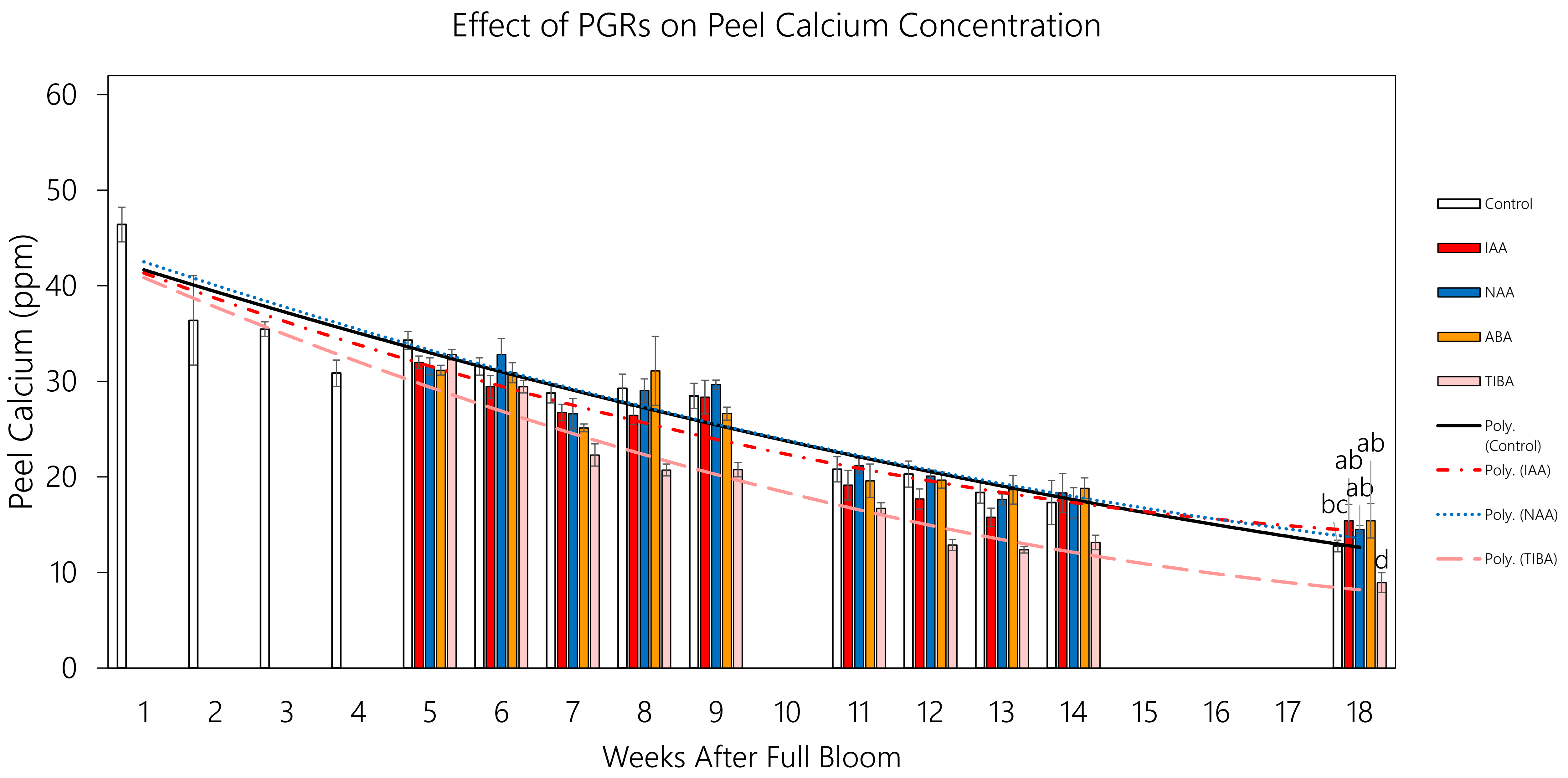





Xylem Functionality By Week
Dyed Area (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
ABA
NAA
IAA
NAA
TIBA
ABA
4
5
6
7
8
9
10
11
12
13
14
15
16
18
Weeks After Full Bloom
Control
IAA
NAA
ABA
TIBA

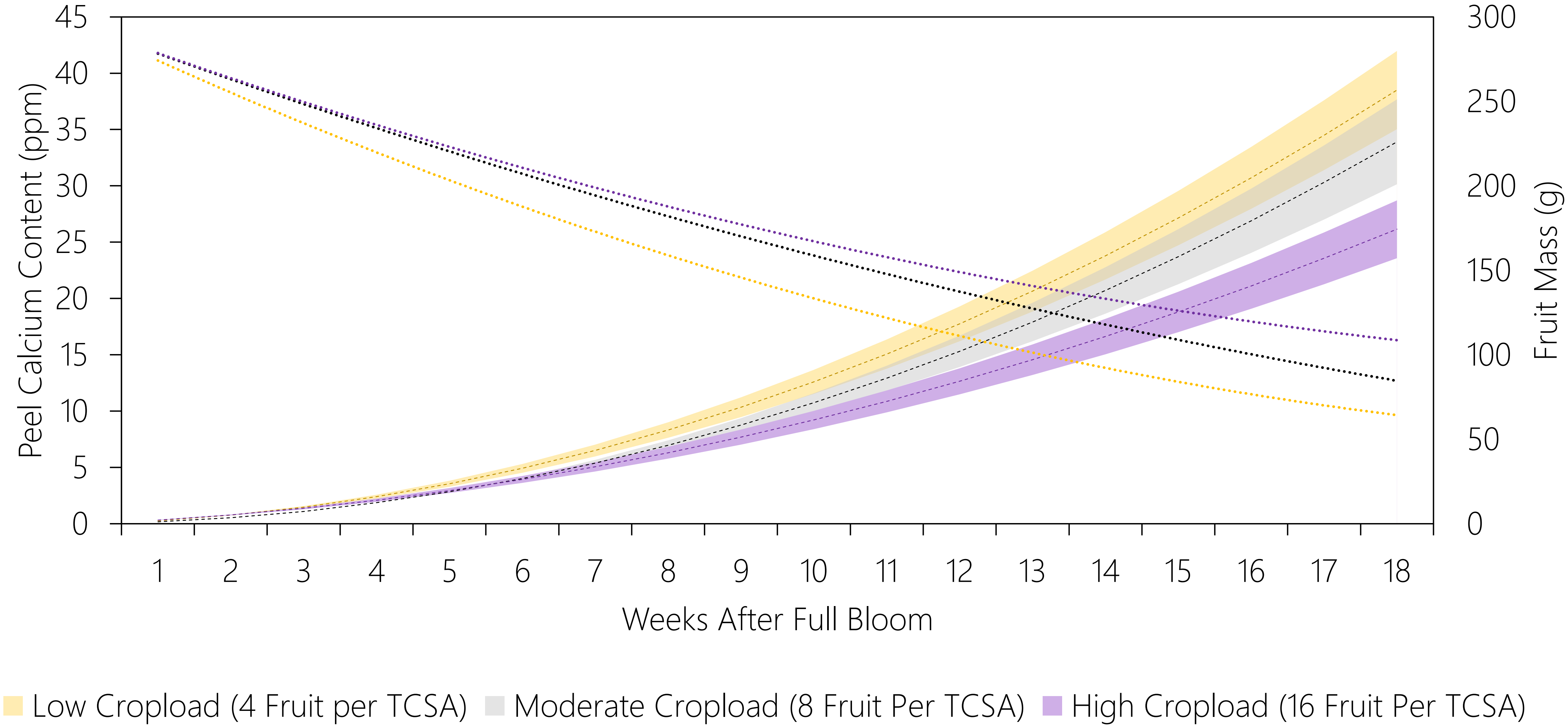


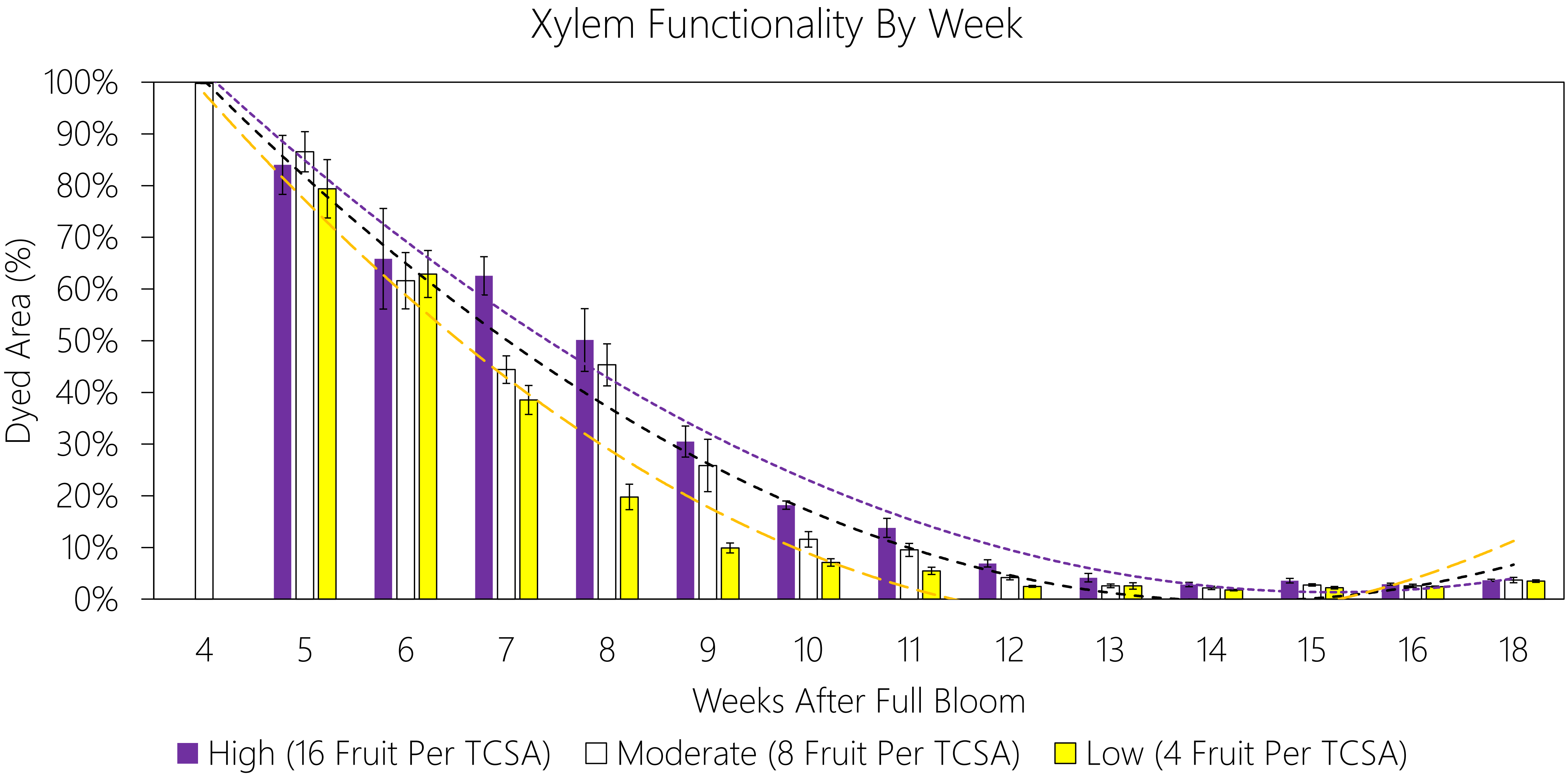
Effect of Plant Growth Regulators on Fruit Size
Fruit Mass (g)
300
250
200
150
100
50
0
0
5
10
15
20
Weeks After Full Bloom
Control
IAA
NAA
TIBA
ABA



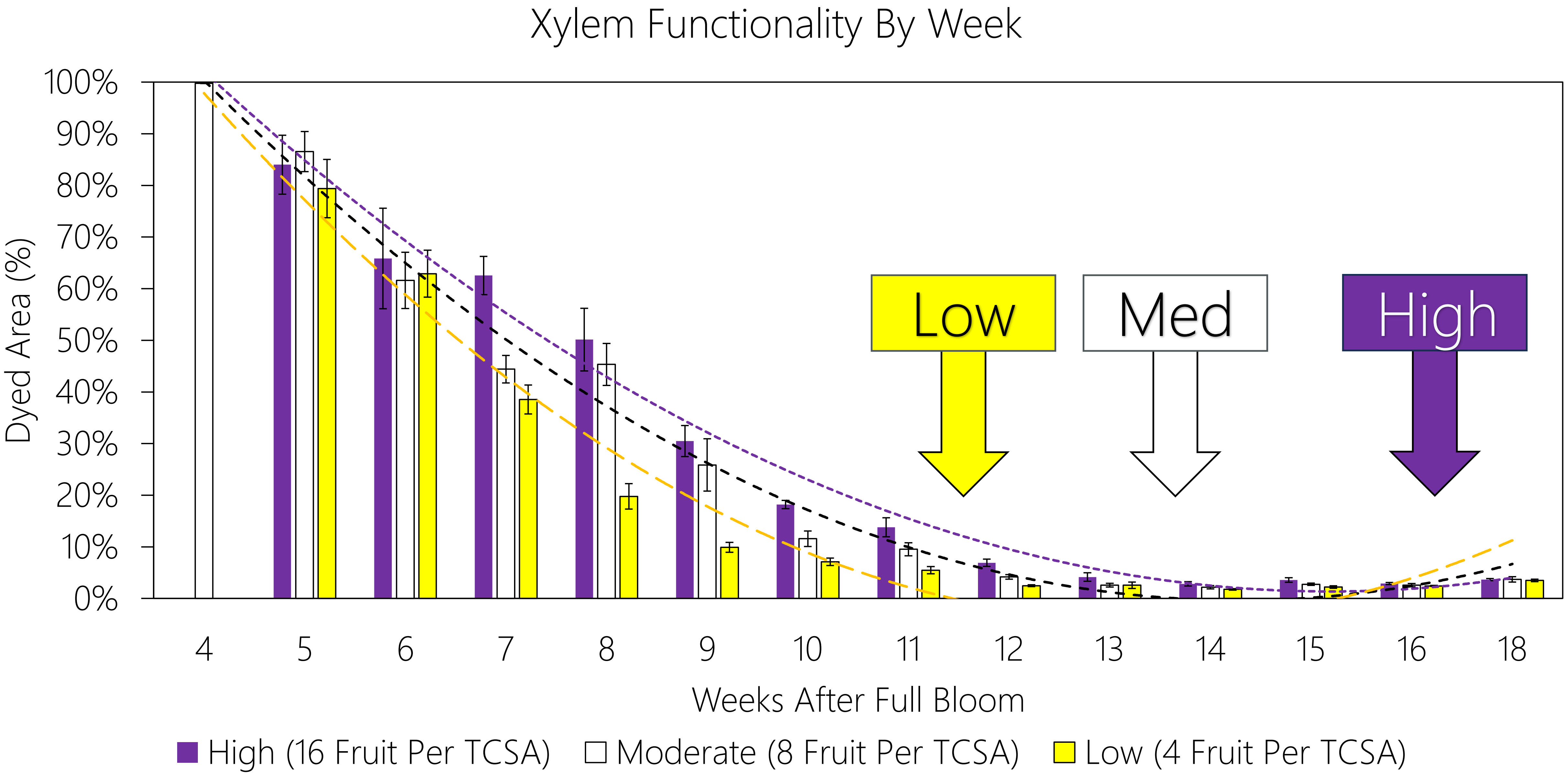
Effect of PGRs on Peel Calcium Concentration
Peel Calcium (ppm)
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Weeks After Full Bloom
bc
ab
ab
ab
d
Control
IAA
NAA
ABA
TIBA
Poly. (Control)
Poly. (IAA)
Poly. (NAA)
Poly. (TIBA)

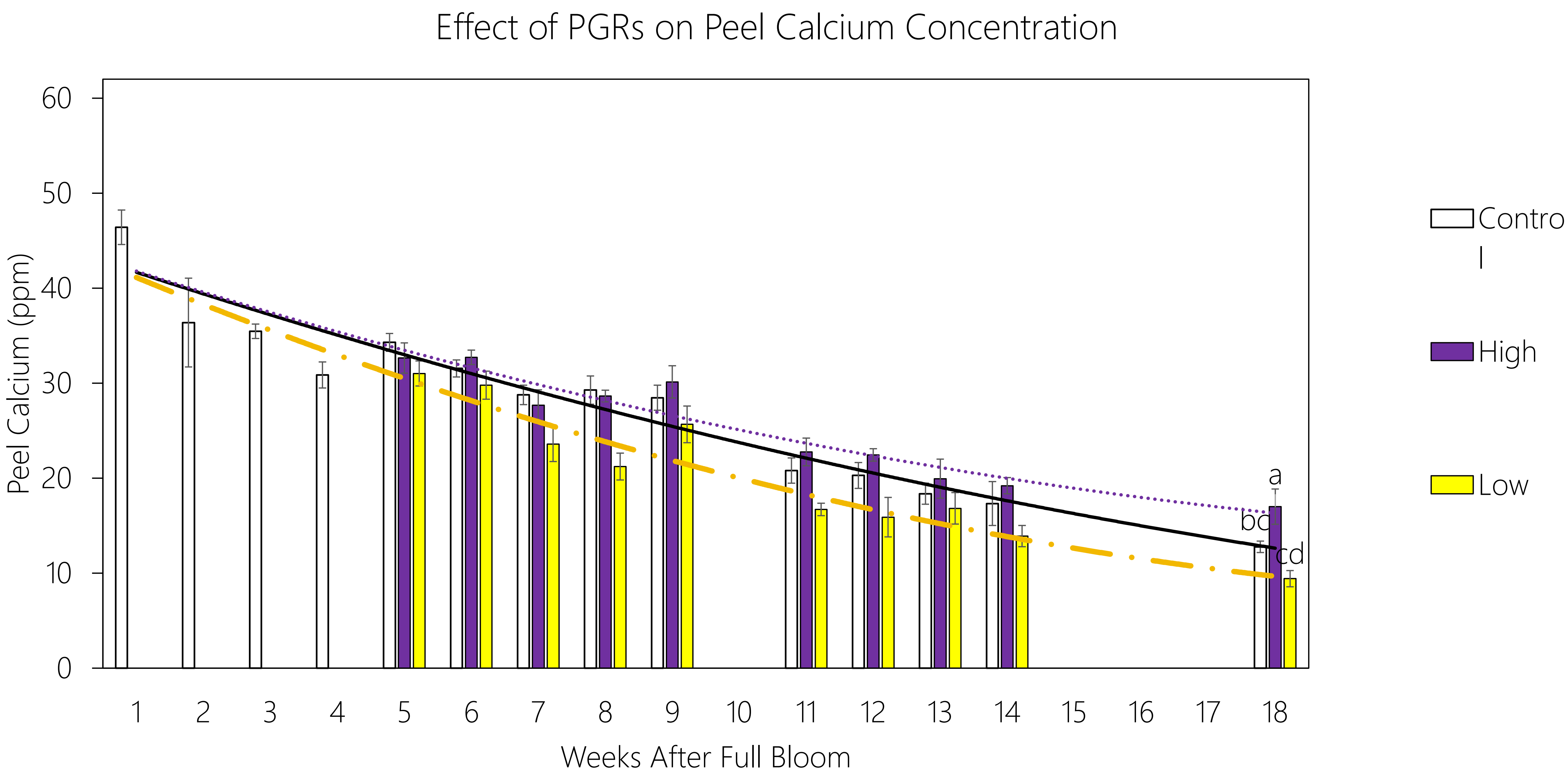
Fruit Growth Rate and Calcium Content by Cropload

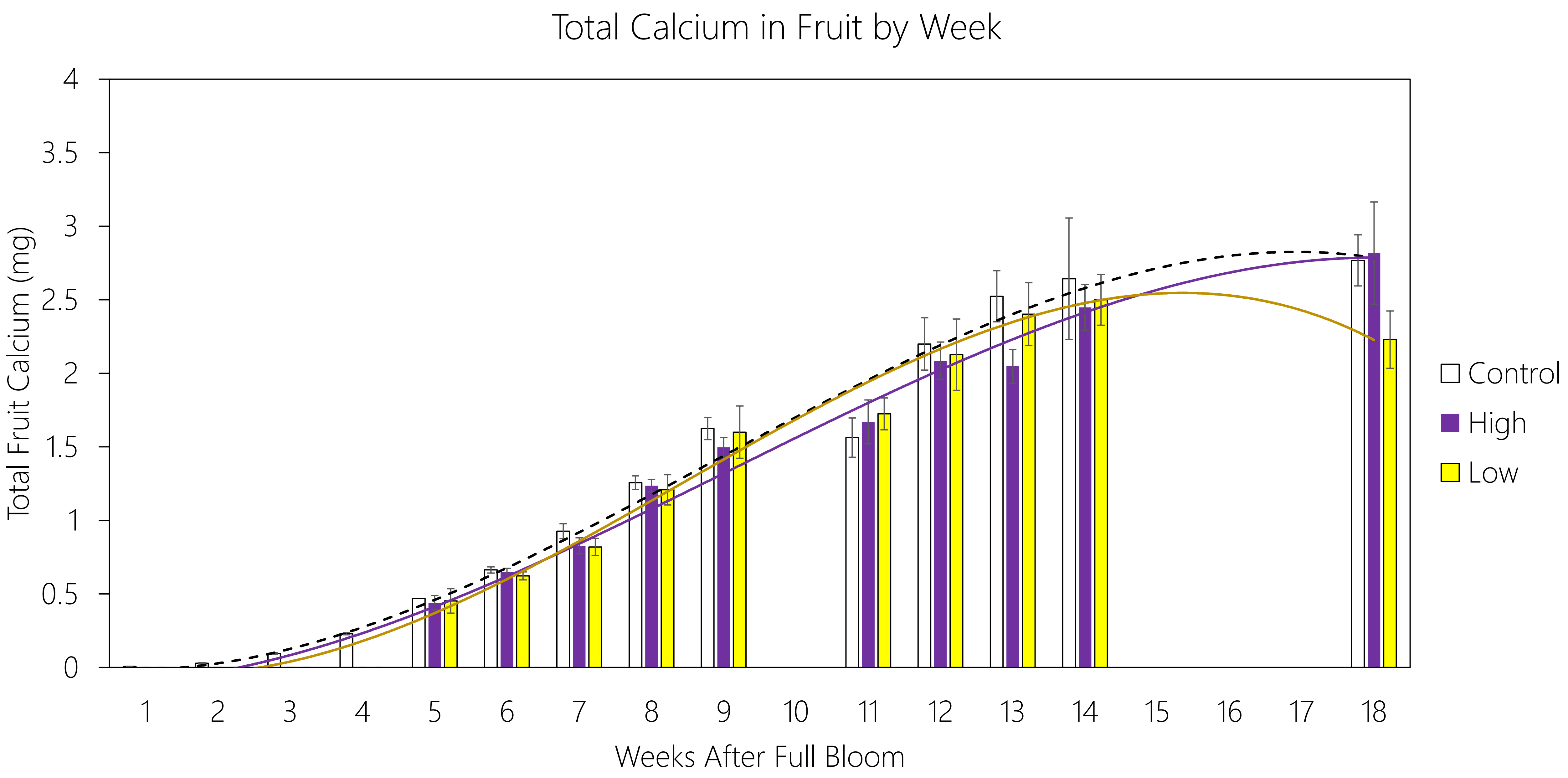




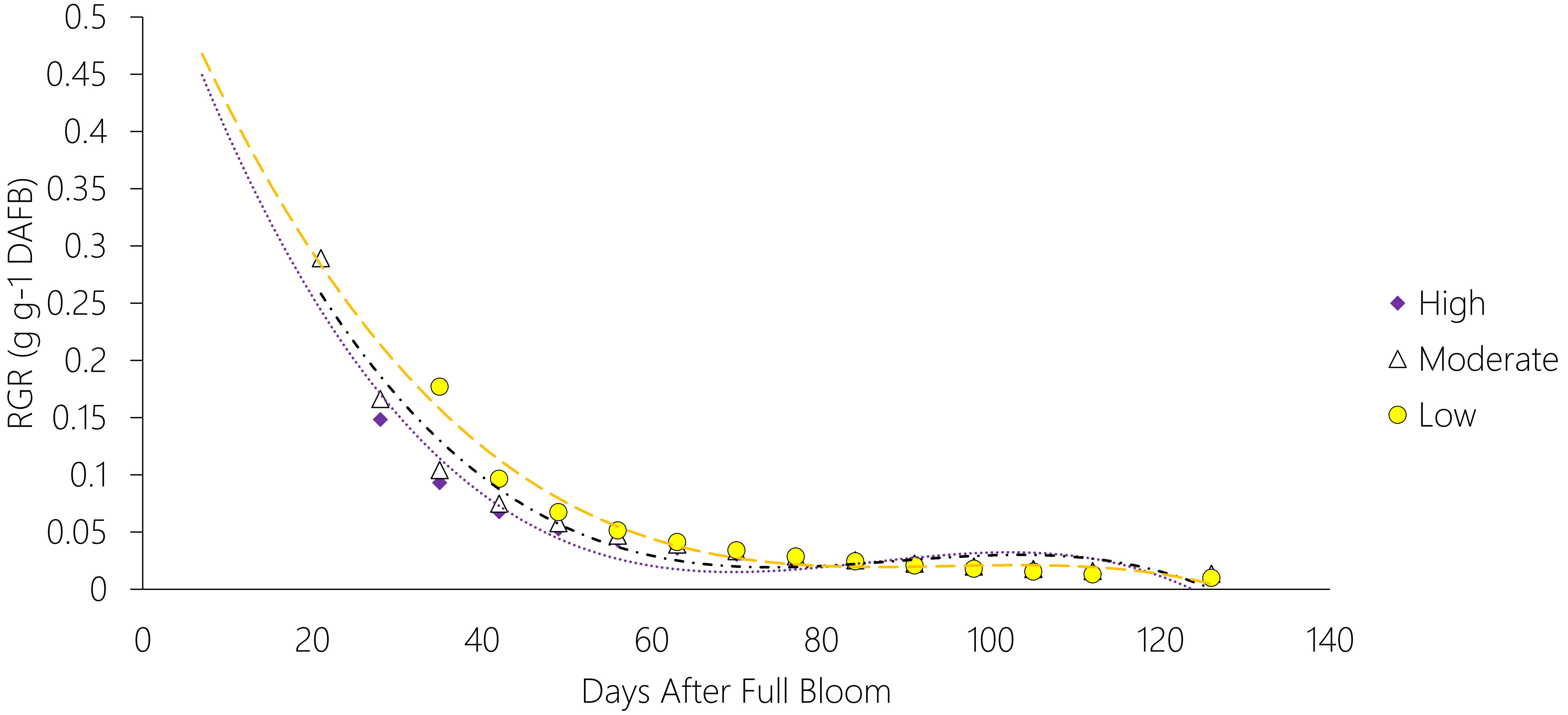
Xylem Functionality By Week
Dyed Area (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
4
5
6
7
8
9
10
11
12
13
14
15
16
18
Weeks After Full Bloom
High (16 Fruit Per TCSA)
Moderate (8 Fruit Per TCSA)
Low (4 Fruit Per TCSA)


Xylem Functionality By Week
Dyed Area (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Low
Med
High
4
5
6
7
8
9
10
11
12
13
14
15
16
18
Weeks After Full Bloom
High (16 Fruit Per TCSA)
Moderate (8 Fruit Per TCSA)
Low (4 Fruit Per TCSA)


Effect of PGRs on Peel Calcium Concentration
Peel Calcium (ppm)
0
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Weeks After Full Bloom
a
bc
cd
Contro
l
High
Low


Total Calcium in Fruit by Week
Total Fruit Calcium (mg)
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Weeks After Full Bloom
Control
High
Low

Relative Growth Rate of Apple Fruit



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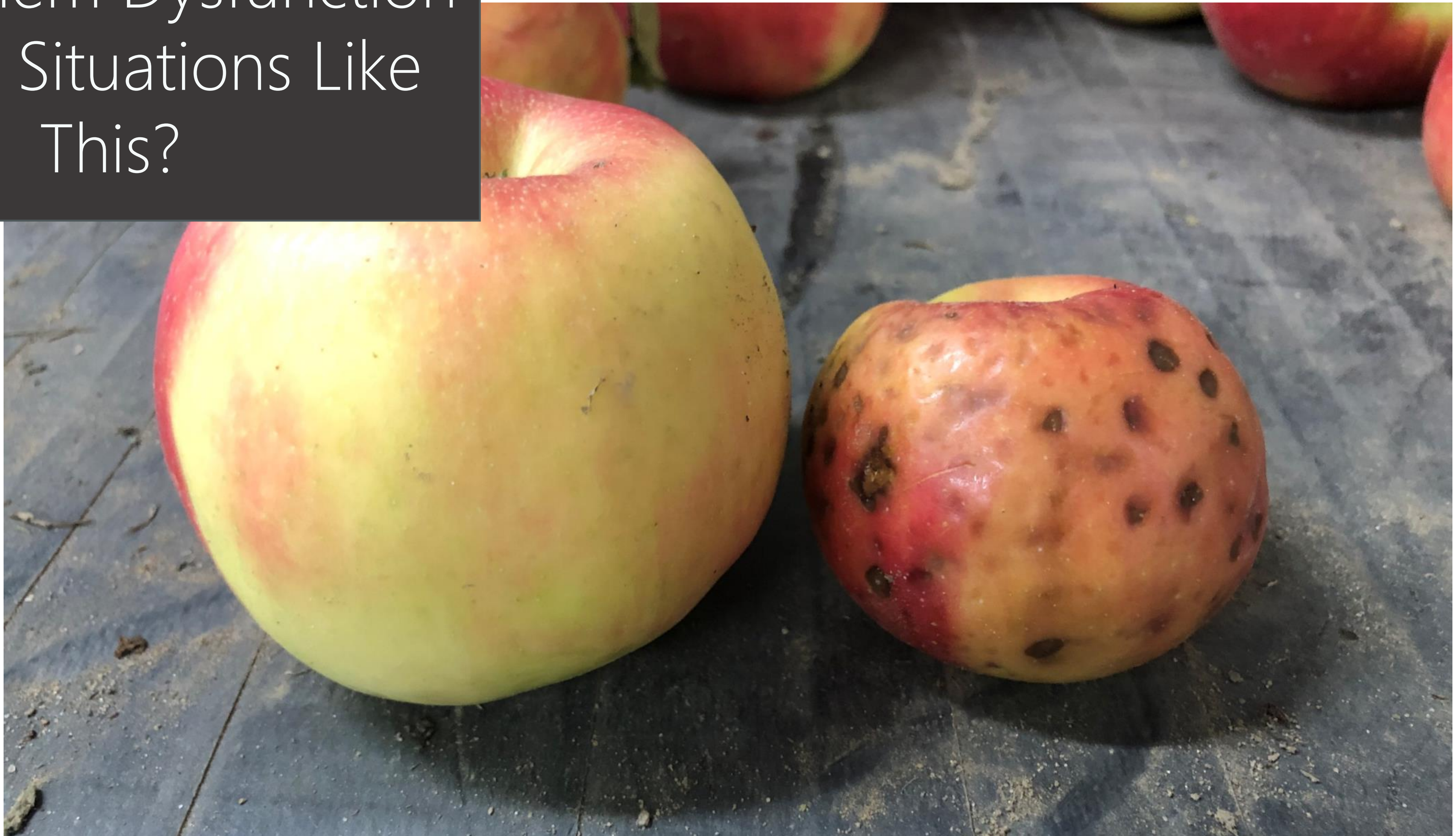
NAA	10	17.6*	26.3*	20.1*	22.3*	10.4	13.1
ABA	125	-	-	21.0*	22.7*	10.6	13.7
	150	13.2*	31.3*	-	-	-	-
TIBA	30	-	-	35.5	50.8	29.3*	36.4*
High	-	-	-	-	-	4.1*	4.8*
Low	-	-	-	-	-	27.3*	37.7*

Significance (* = $P < 0.5$) calculated with binary logistic regression with tree, replicate, and cropload as random effects where significant differences between treatments were calculated with ANOVA.

Does Xylem Dysfunction Explain Situations Like This?



FUTURE EXPERIMENT DIRECTIONS

FRUIT GROWTH RATE

Identify growth rate thresholds which cause xylem dysfunction

FINISHED

XYLOGENESIS

Identify genes responsible for xylogenesis in apple fruit and quantify expression changes caused by PGRS

2024

CALCIUM ALLOCATION

Determine changes in calcium allocation within cells caused by gene expression

2024

HORMONE MEASUREMENT

Measure hormone levels in growing apple tissues to determine baselines and how they respond to PGR treatment

2024

ADJUSTMENT OF PGR TIMINGS

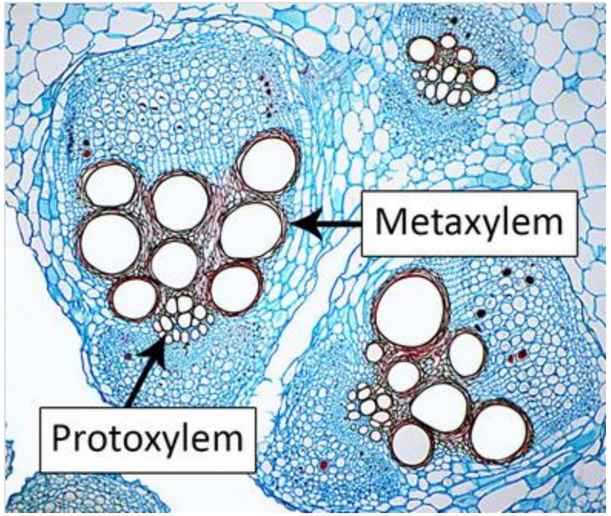
Plan ideal PGR spray timings based on calcium, gene expression, and hormone data.

2025

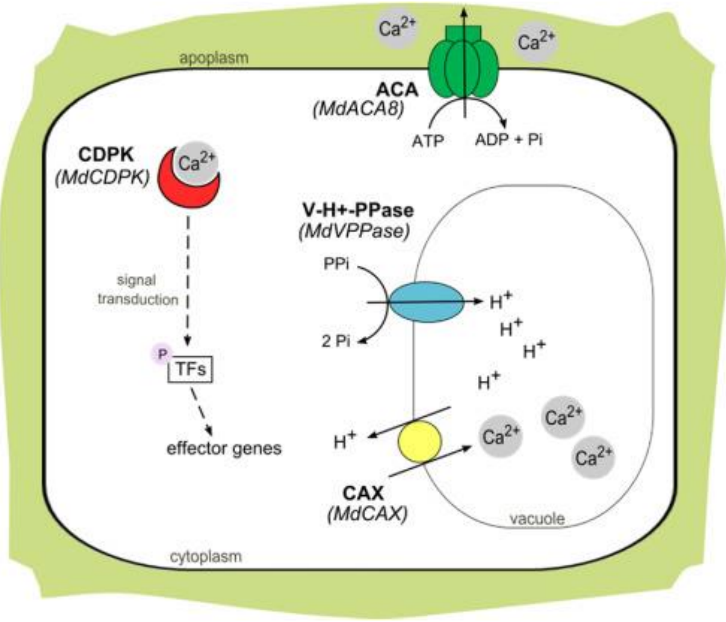
GENE EXPRESSION ANALYSIS

XYLOGENESIS

NAC-domain transcription factors determine xylem formation and transformation. How do PGRs affect these processes?



PROPG-UNIVERSITY OF FLORIDA



FALCHI ET AL. 2017

CALCIUM ALLOCATION

Ca allocation genes allow for the relative quantification of calcium throughout plant cells. How do auxins/TIBA interact with these transporters?

SUMMARY

Any mitigation of bitter pit would result in tremendous savings for 'Honeycrisp' growers. While cropload management is the most powerful bitter pit mitigation tool currently, PGRS demonstrate potential in mitigation of bitter pit by temporarily increasing xylem functionality. Future research is needed to determine the mode of action of these compounds.

THANK YOU

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Einhorn Lab