

# Environmental Factors to get Nutritious Crops

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What is Quality?

Cultivar  
Selection

Lighting

Consumer  
Preferences

Today's Presentation

# Goal: To improve crop quality



## While maintaining yield

# What is quality?

1. Flavor
2. Nutrition
3. Post-harvest longevity
4. Appearance/Color

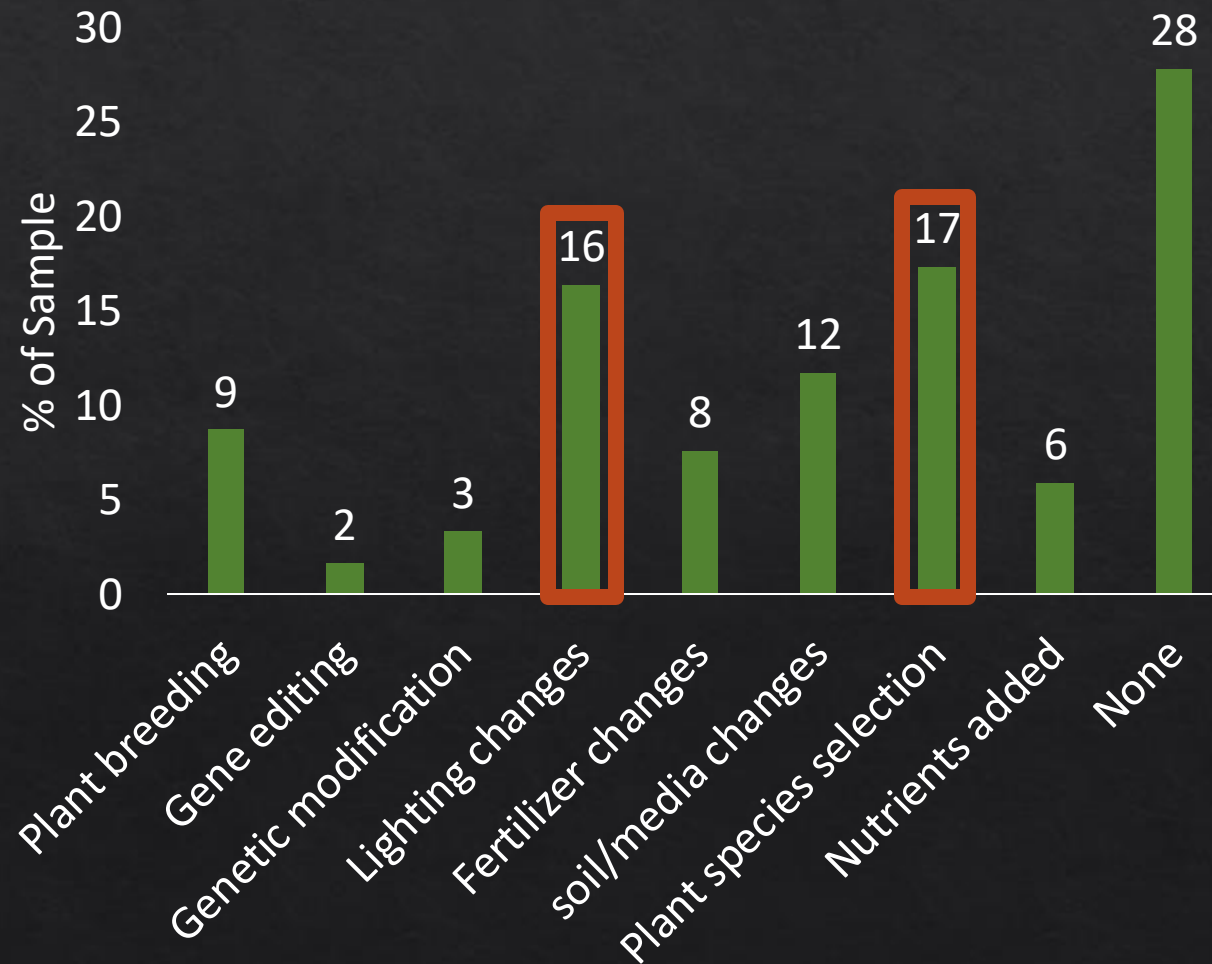




An Advantage of CEA



# Which of the following techniques do you perceive as being the best option to improve microgreen nutrition?





Cultivar Selection



# Modeling leafy greens physiological and biochemical responses to light intensity and successive harvest

Ethan Darby, Sarah Parker, and Kellie Walters



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# What are the “space” issues?

1. Diet deficient in certain nutrients  
(Cooper et al., 2017)
2. Health risks of radiation and microgravity
3. Degradation of compounds during long-term space flight



# Fresh produce as a solution

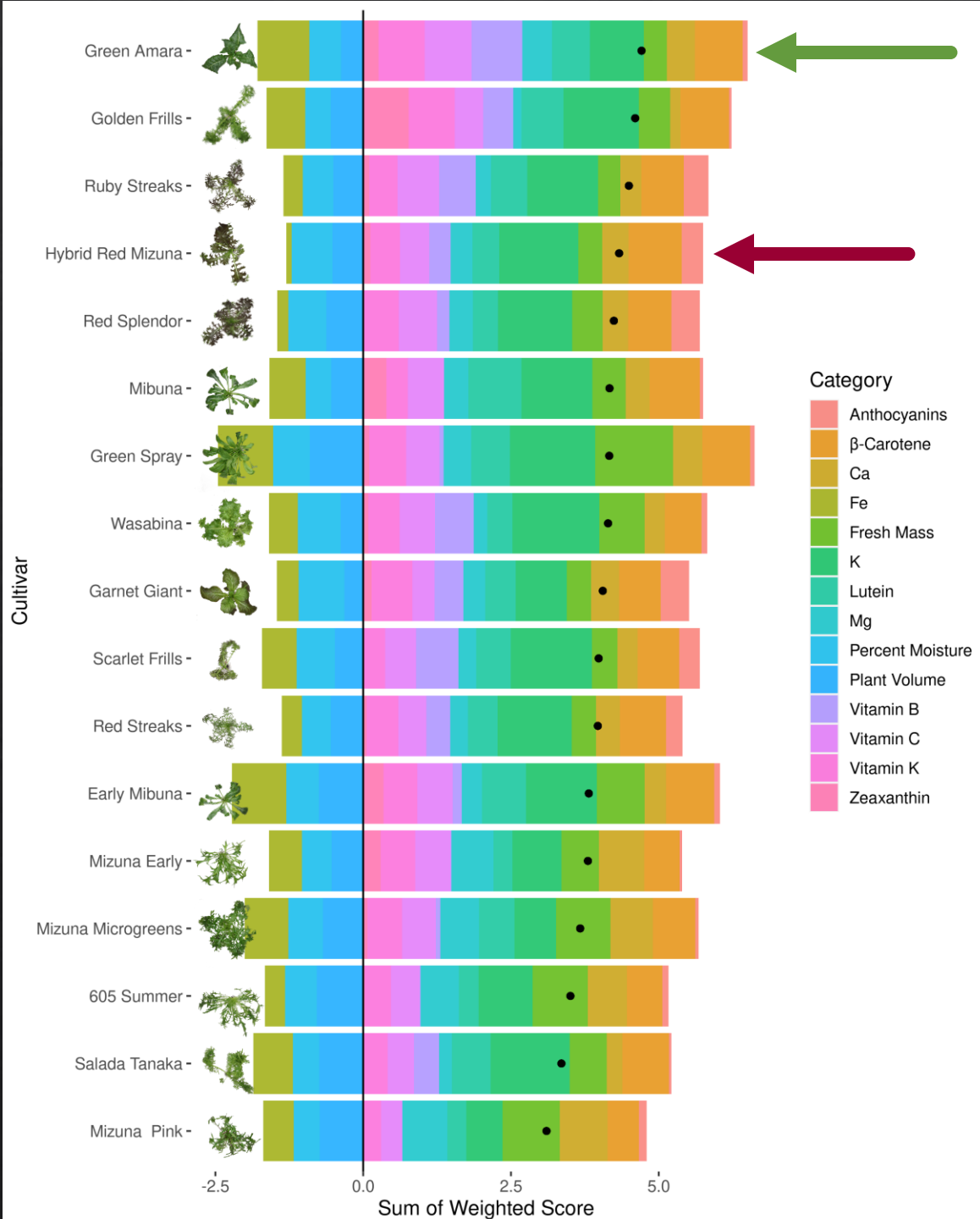
1. Actively synthesizes sensitive vitamins
2. No need for storage
3. Provides synergistic benefits and helps avoid potential over-accumulation
4. Mizuna identified as a promising candidate due to nutritional and flavor characteristics



# NASA Project

1. Cultivar
2. Light Intensity x Photoperiod





# Cultivar selection

1. Balancing positives and negatives
2. One size fits all? Building models

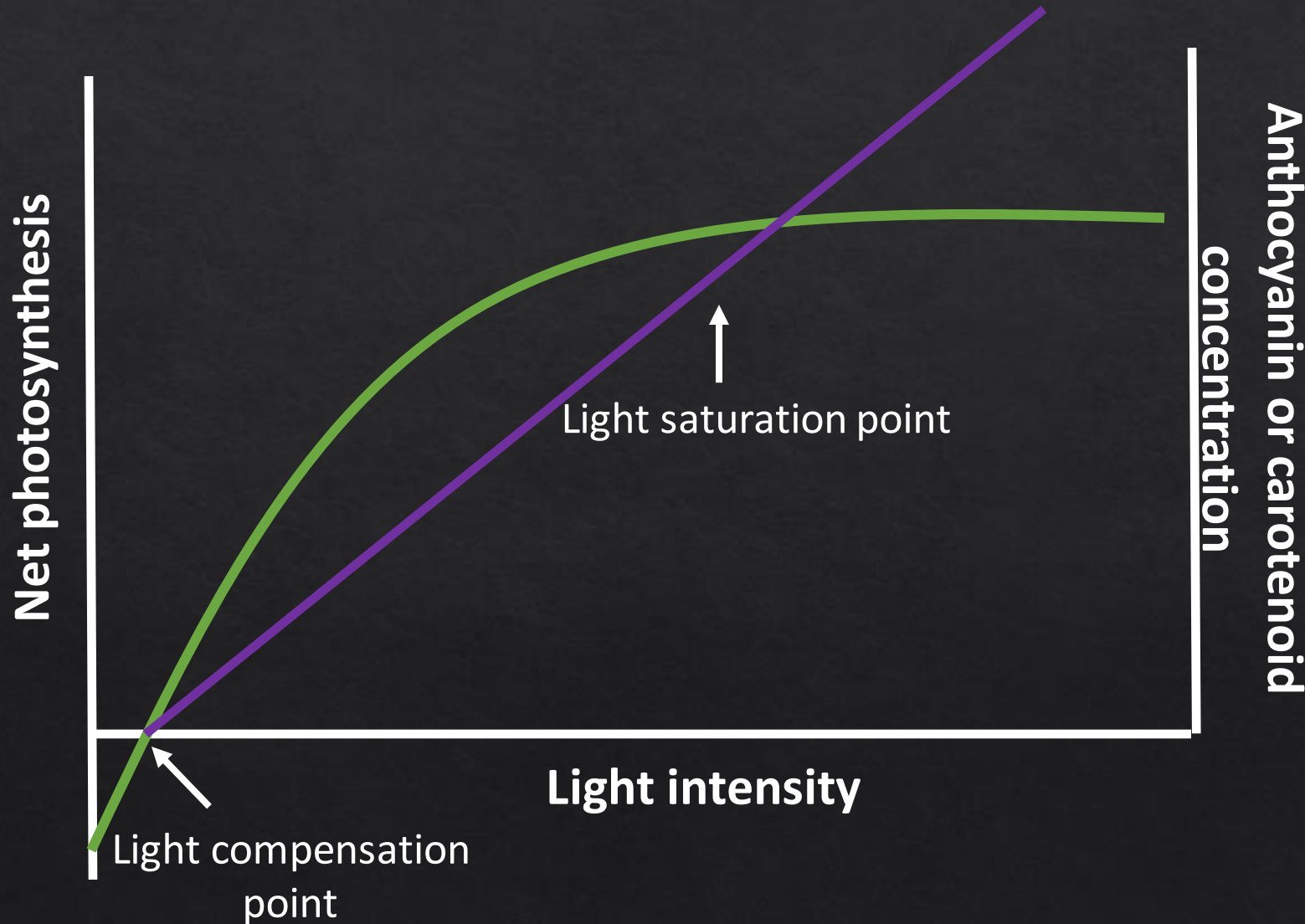


Submitted to Life Sciences in Space Research  
 Funding: NASA Space Biology 80NSSC22K0205

A close-up, top-down view of a large quantity of curly lettuce leaves. The leaves are a bright, healthy green color and have a ruffled, curly texture. They are packed closely together, filling the entire frame. A black horizontal bar is superimposed over the center of the image, containing the text "Focus on Light" in white, sans-serif font.

Focus on Light

# Manipulating Light Intensity



## Anthocyanins

### Importance in plants

- Photoprotection

### Importance to humans

- Purple pigmentation
- Potential antioxidant activity

## Carotenoids

### Importance in plants

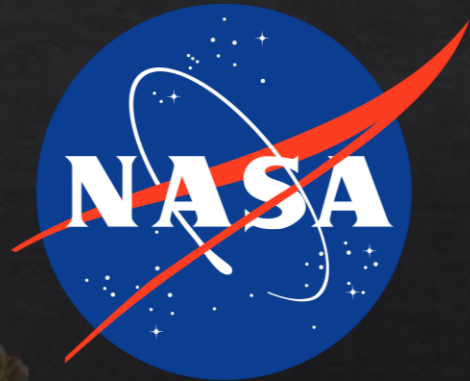
- Light harvesting
- Photoprotection
- Structural stabilization

### Importance in human diet

- Main dietary source of provitamin A
- Eye health
- Potential antioxidant activity

# Modeling leafy greens physiological and biochemical responses to light intensity and successive harvest

Ethan Darby, Sarah Parker, and Kellie Walters



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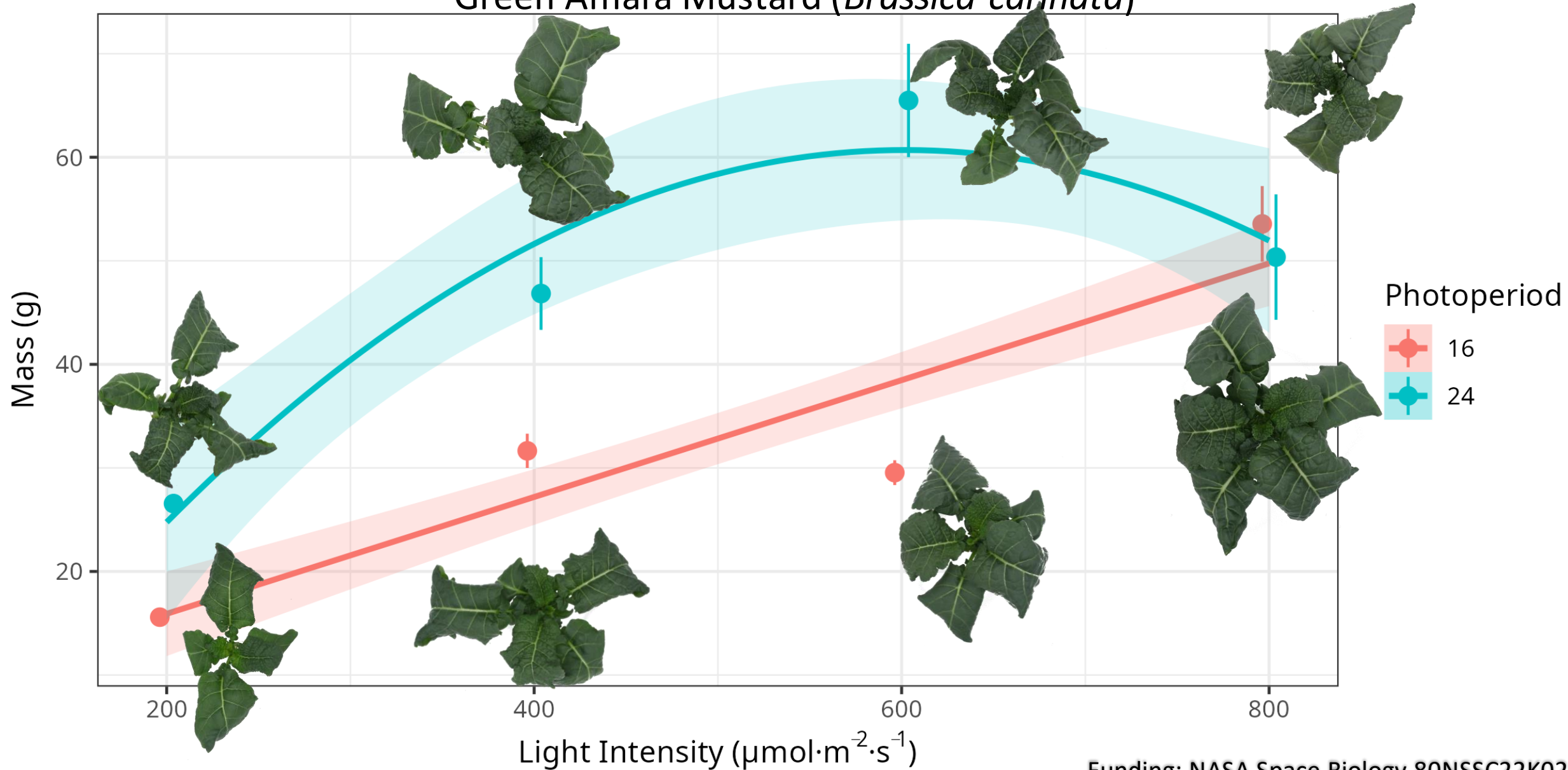
# Green Amara Mustard (*Brassica carinata*)

- Light intensity treatments:
  - 200, 400, 600, and 800  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
- Photoperiod treatments:
  - 16 and 24 hours



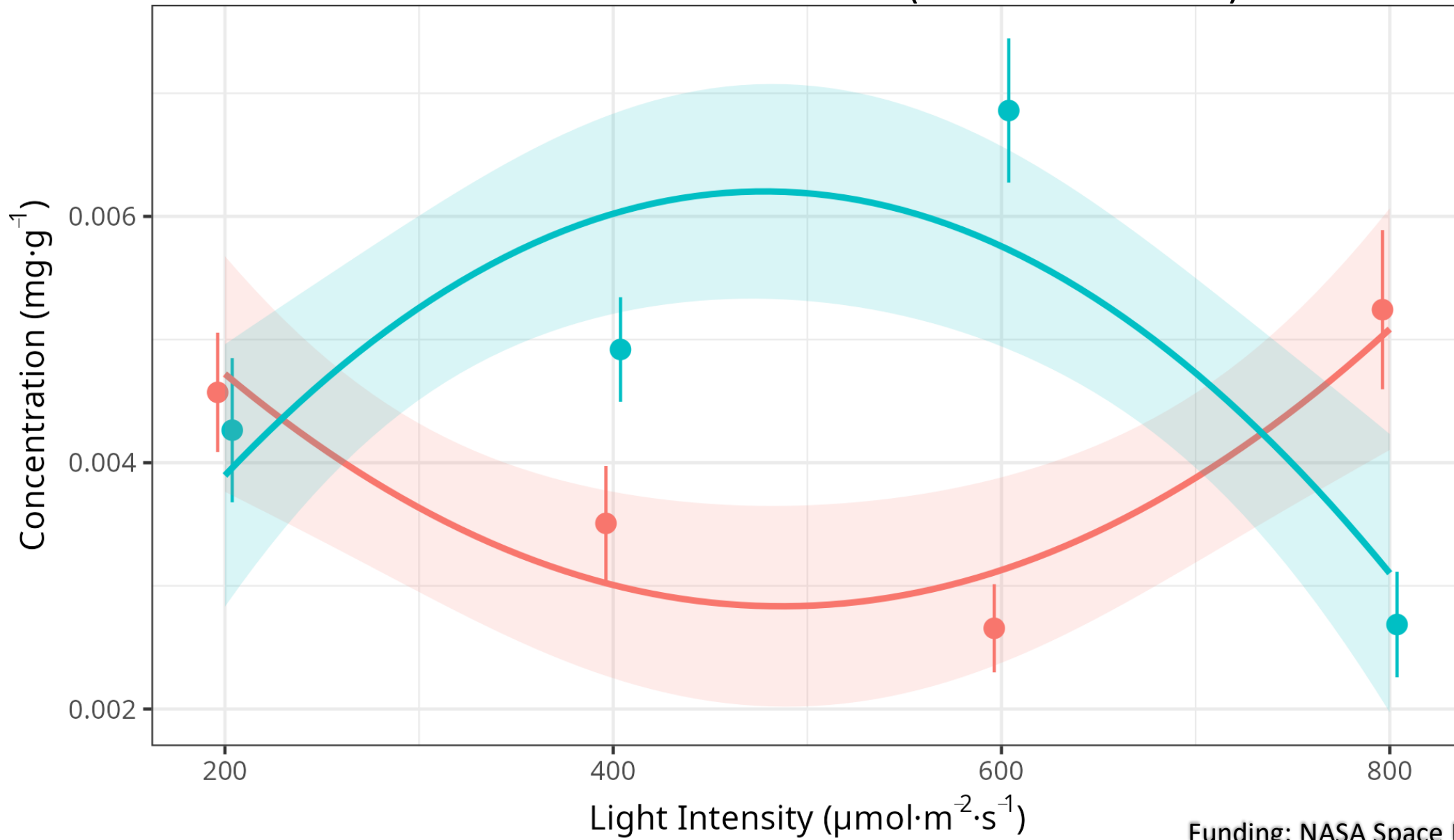
# Fresh Mass

Green Amara Mustard (*Brassica carinata*)



# Vitamin B<sub>1</sub> – Thiamine

## Green Amara Mustard (*Brassica carinata*)

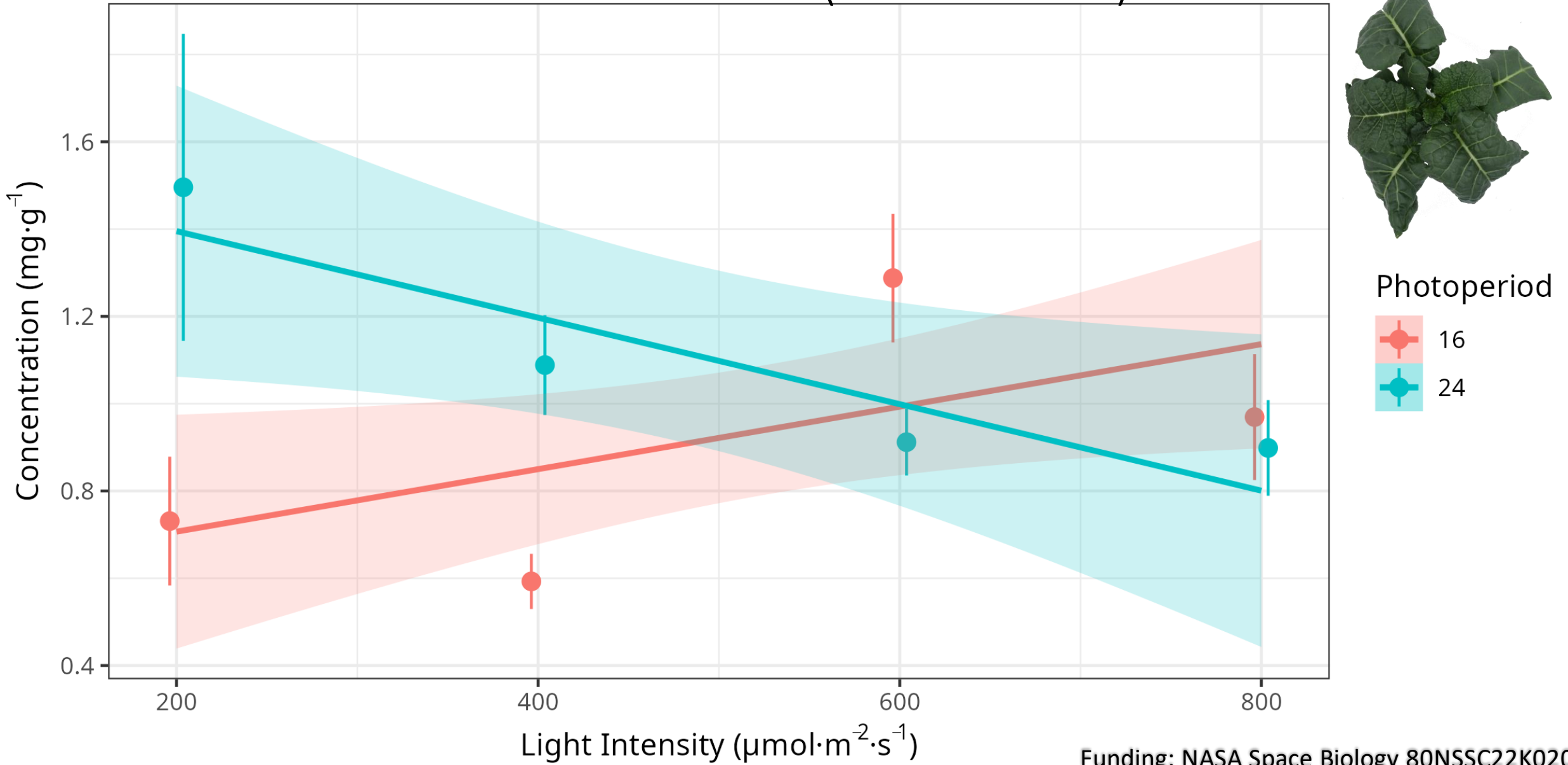


Photoperiod

- 16
- 24

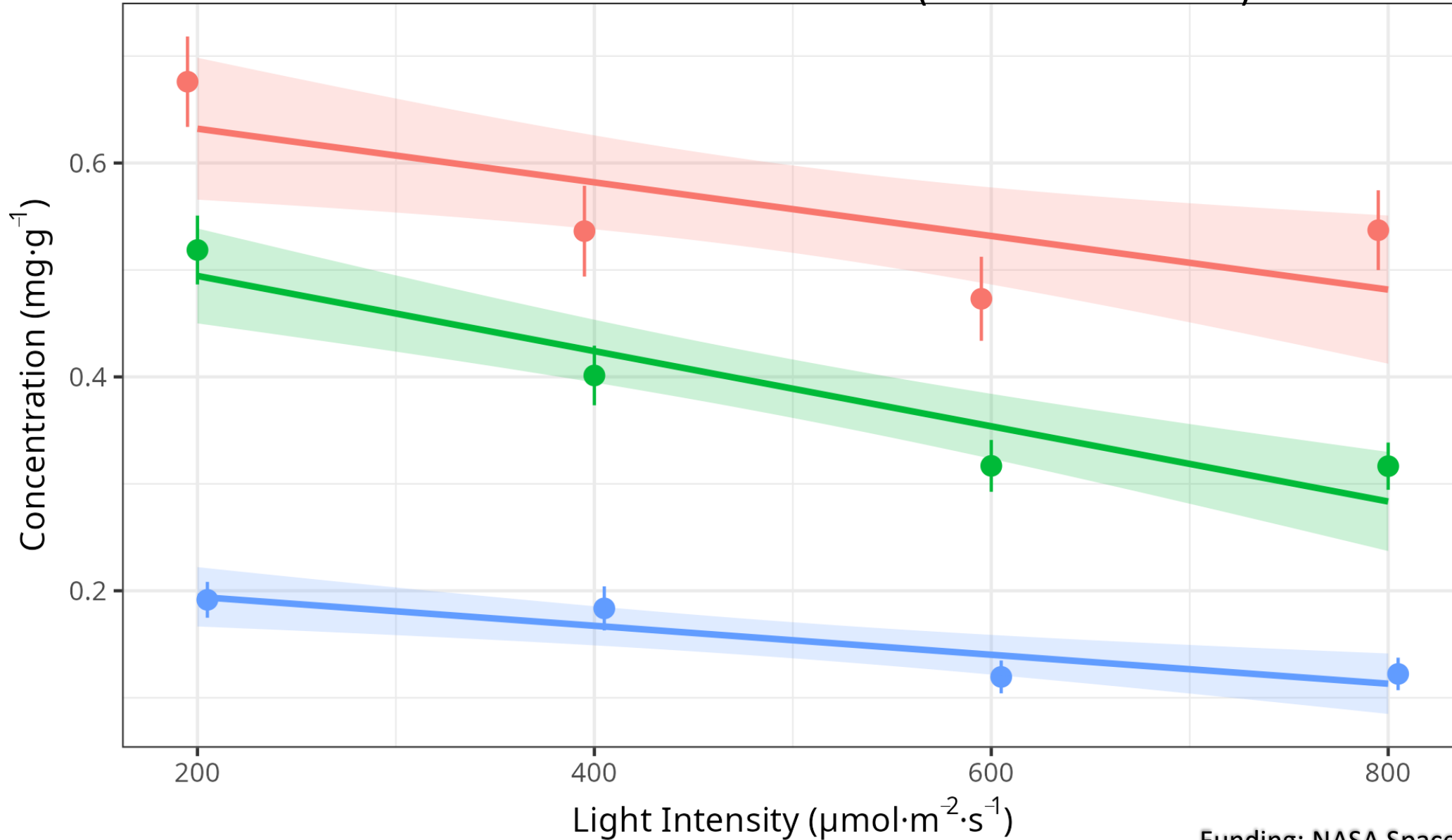
# Vitamin K<sub>1</sub> – Phylloquinone

## Green Amara Mustard (*Brassica carinata*)



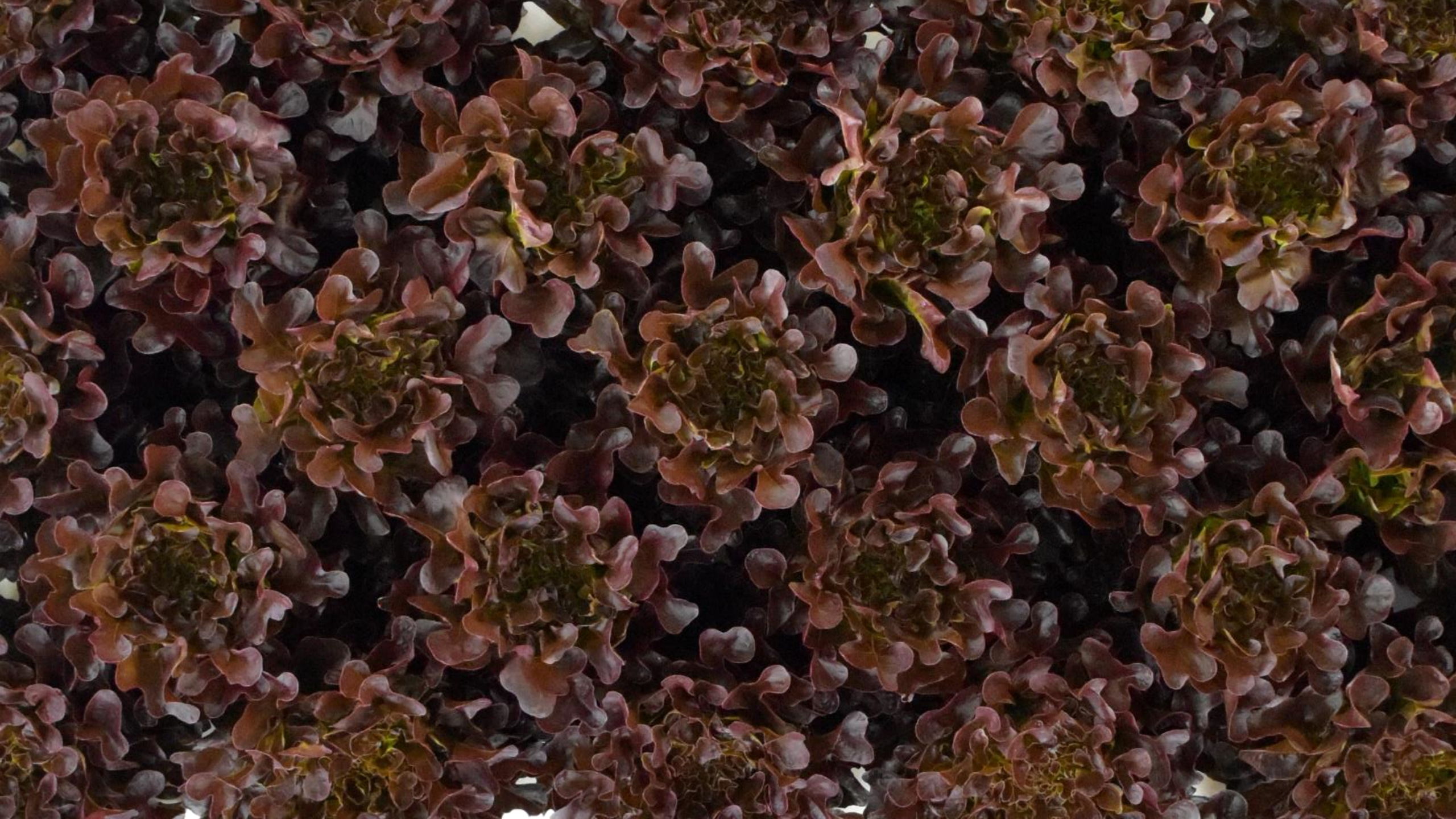
# Carotenoids

Green Amara Mustard (*Brassica carinata*)



## Carotenoids

- β-carotene
- Lutein
- Zeaxanthin





# Red Oakleaf Lettuce

Daily Light Integral ( $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ )

---

12.8



18.4



24.4



32.0



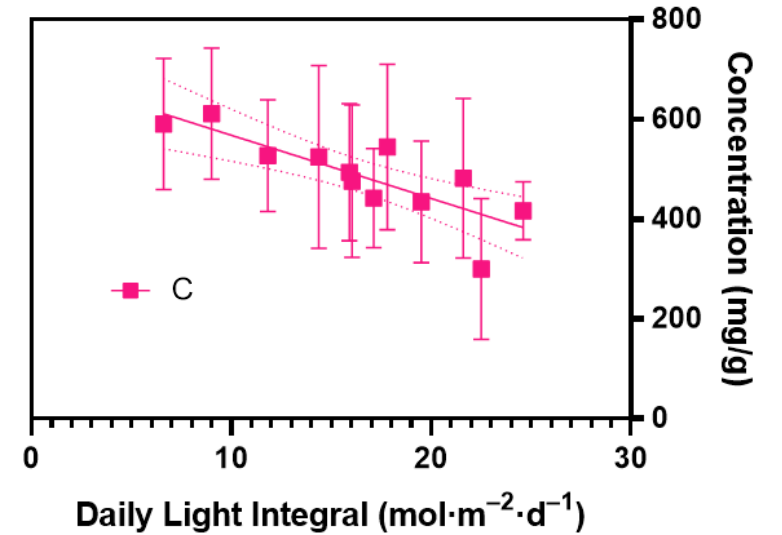
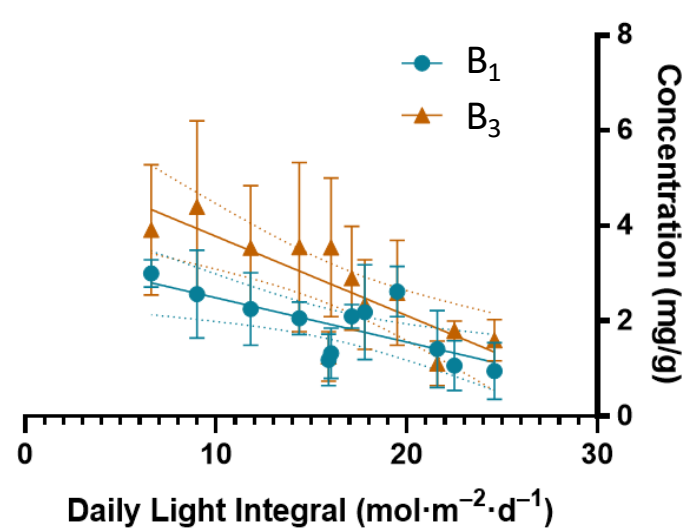
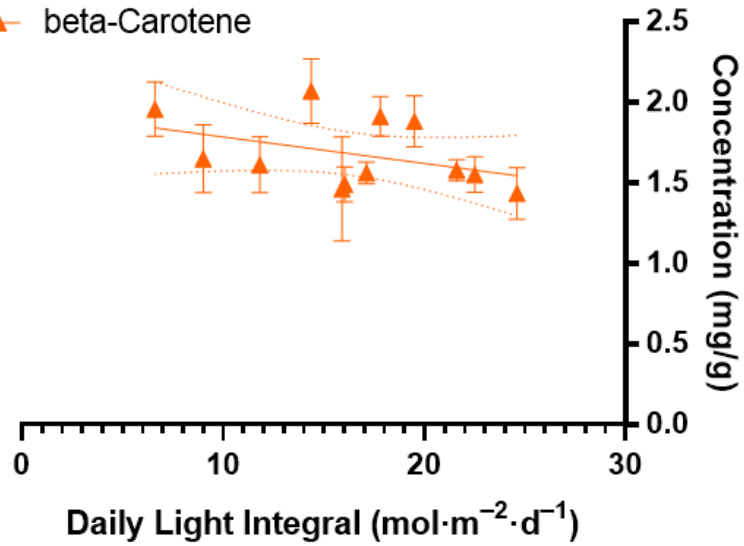
Photos taken 21 days after DLI initiation

In collaboration with  
Dr. Garrett Owen



# Red Oakleaf Lettuce

▲ beta-Carotene

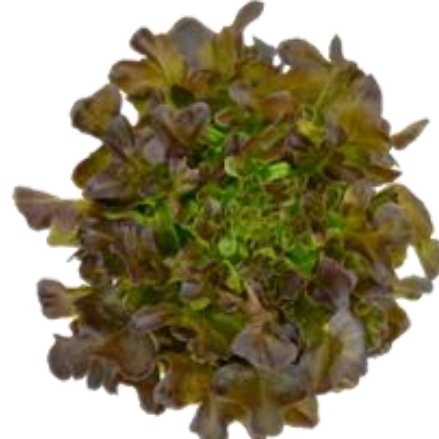


## Daily Light Integral ( $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ )

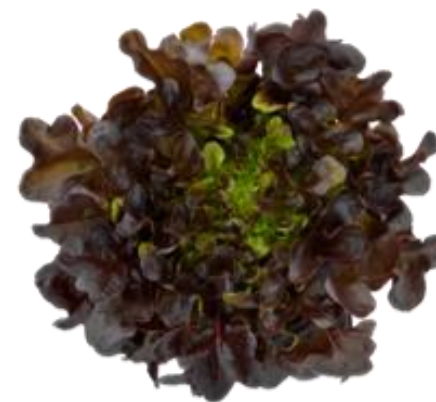
12.8



18.4



24.4



32.0



In collaboration with  
Dr. Garrett Owen

# Green Oakleaf Lettuce

Daily Light Integral ( $\text{mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ )

---

12.8



18.4



24.4



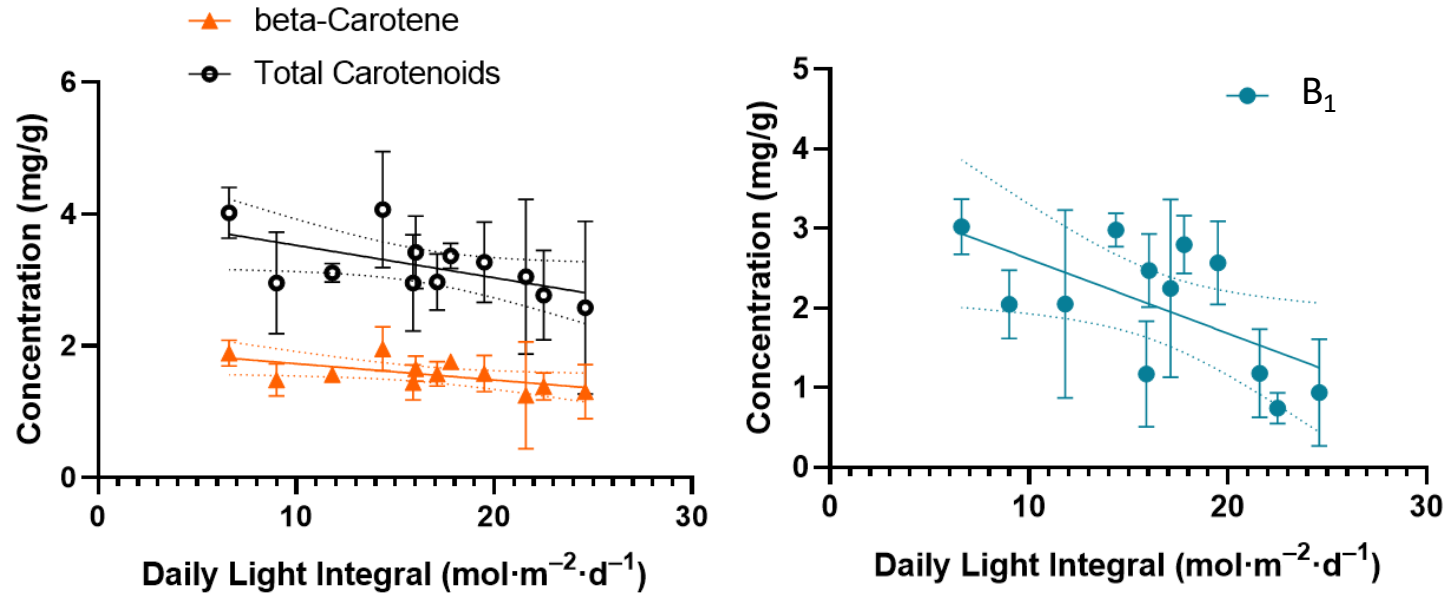
32.0



Photos taken 21 days after DLI initiation

In collaboration with  
Dr. Garrett Owen

# Green Oakleaf Lettuce



**Daily Light Integral (mol·m<sup>-2</sup>·d<sup>-1</sup>)**

**12.8**



**18.4**



**24.4**

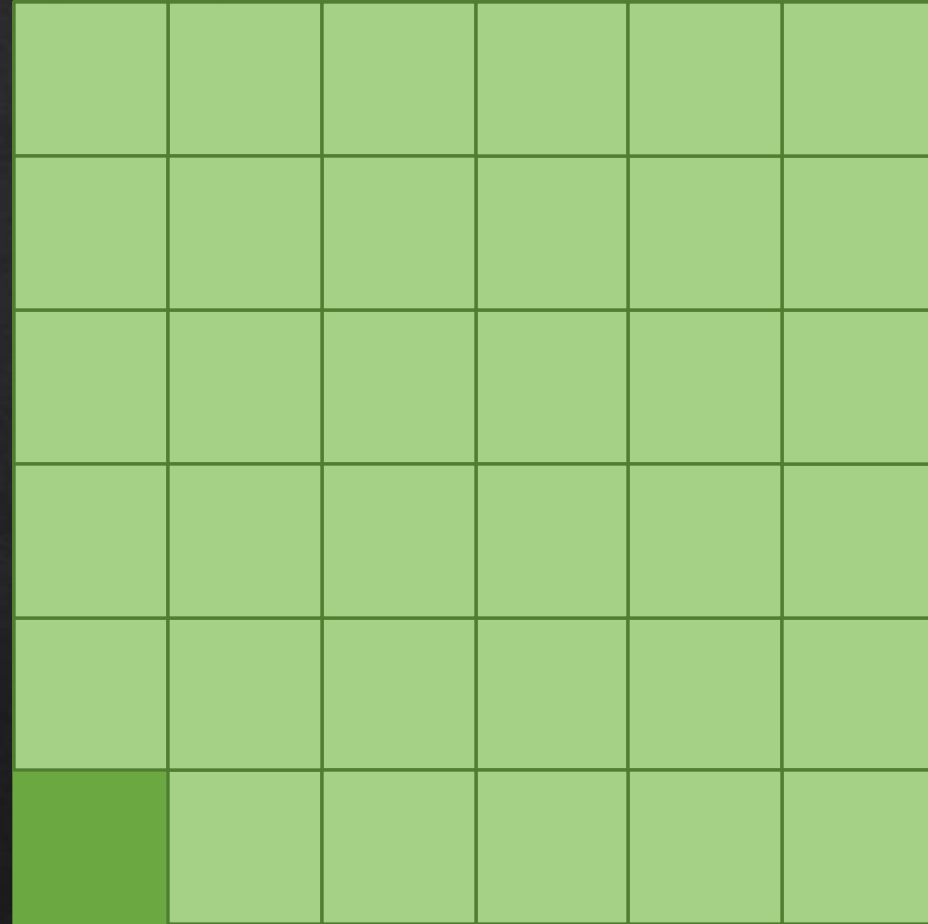


**32.0**



In collaboration with  
Dr. Garrett Owen

# Seedling Production vs. Finishing



# Seedling Production vs. Finishing



# Light intensity during lettuce seedling production



# Objectives

1. Determine the extent seedling light intensity influences:
  - Yield
  - Carotenoid, chlorophyll, and anthocyanin concentration
2. Will differences persist?
  - Finishing in a common greenhouse environment





# Seedling Stage



• **'Rex'** Green-leaf lettuce



• **'Teodore'** Purple-leaf lettuce



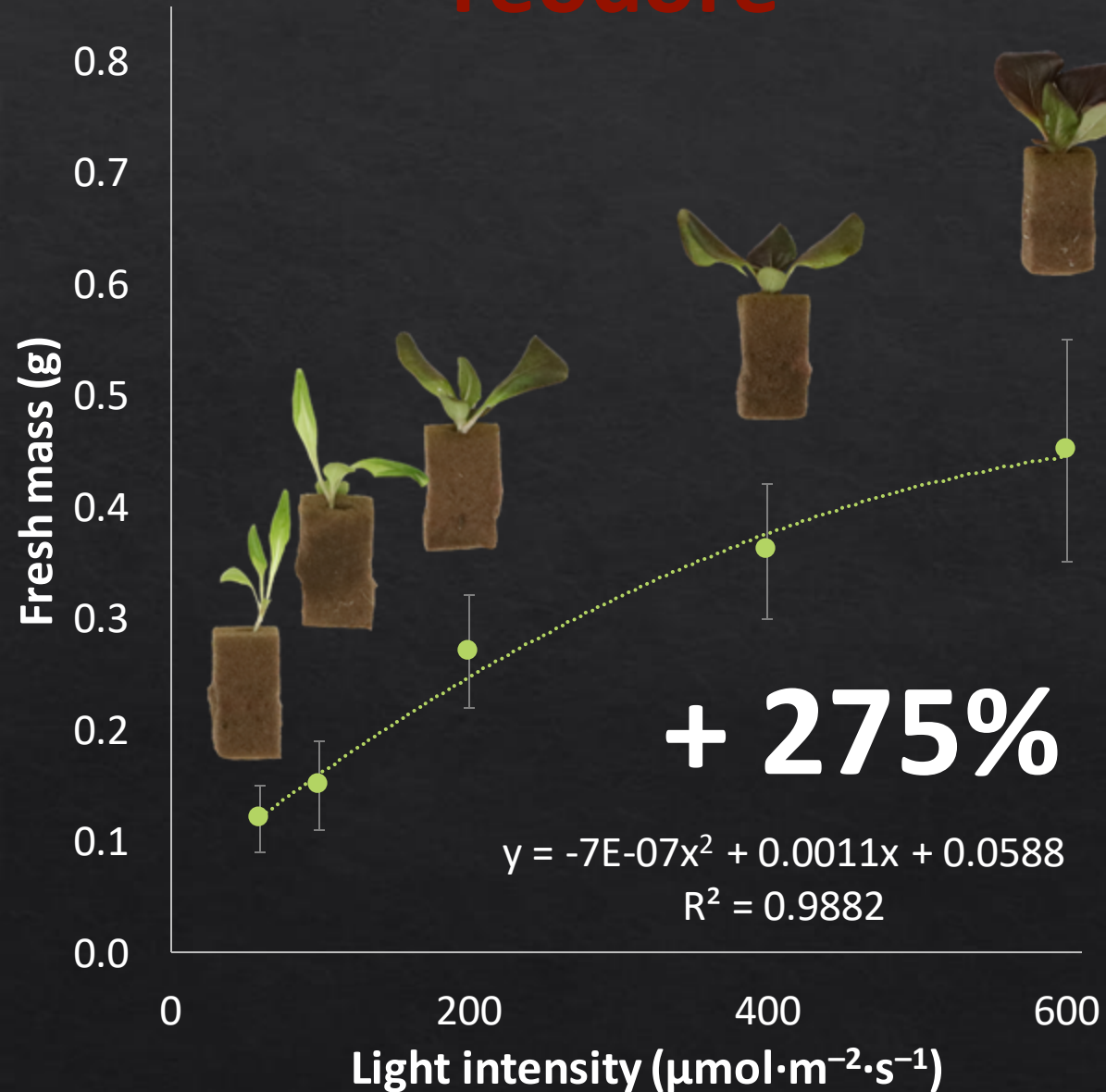


# Seedling Stage

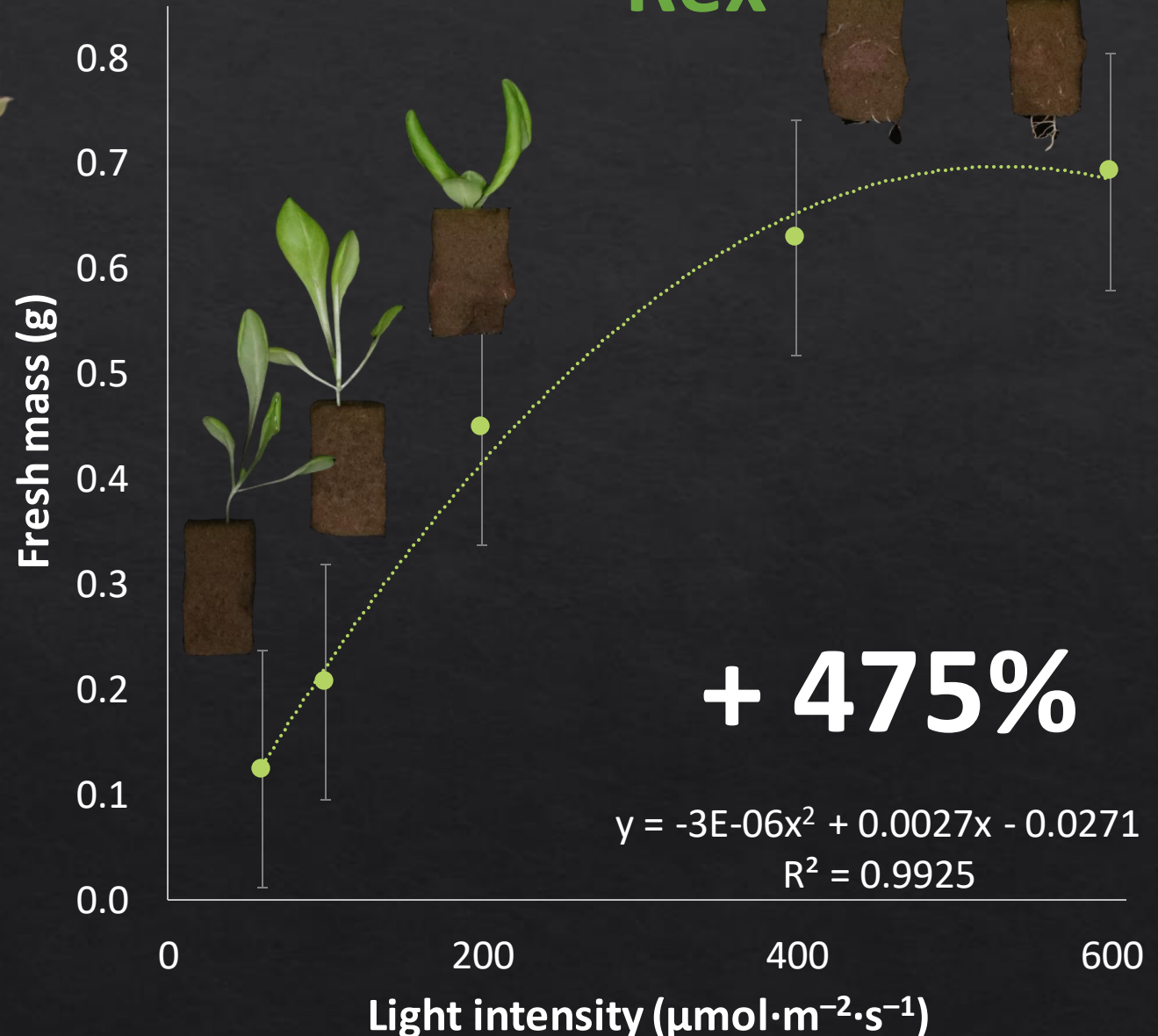
- Target light intensities
  - $60 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  ( $5 \text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ )
  - $100 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  ( $9 \text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ )
  - $200 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  ( $17 \text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ )
  - $400 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  ( $35 \text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ )
  - $600 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  ( $52 \text{ mol}\cdot\text{m}^{-2}\cdot\text{d}^{-1}$ )
- Photoperiod
  - 24 hrs
- Fluorescent lighting

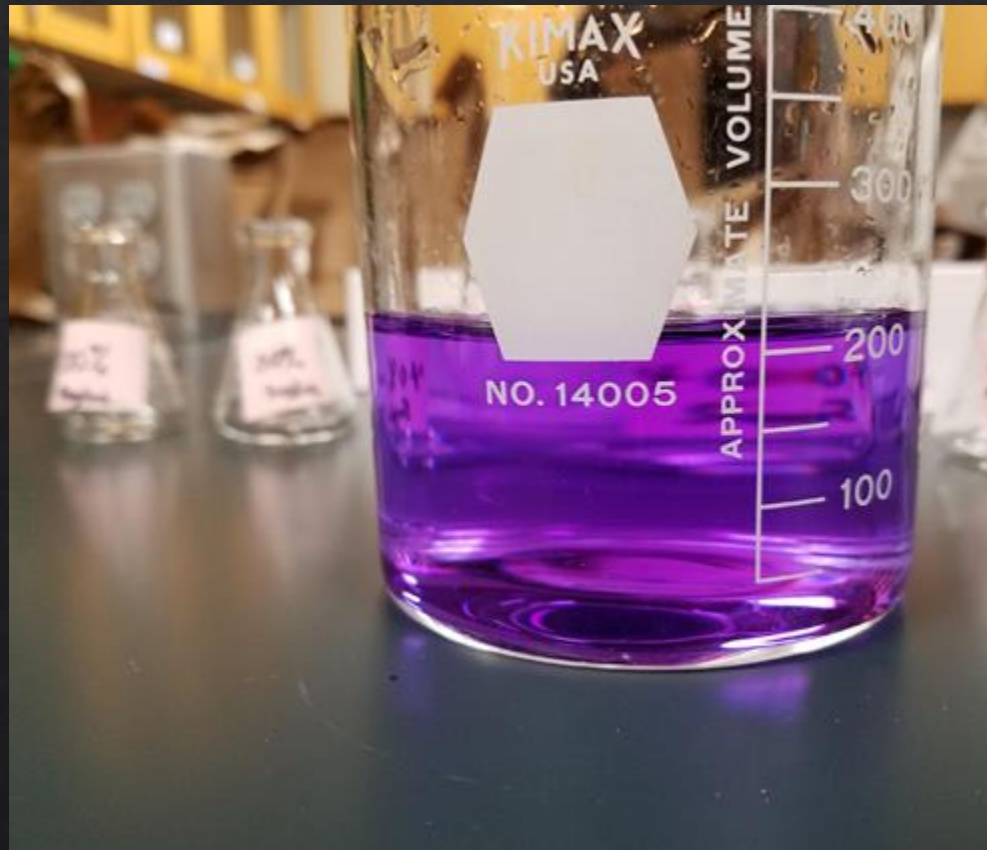
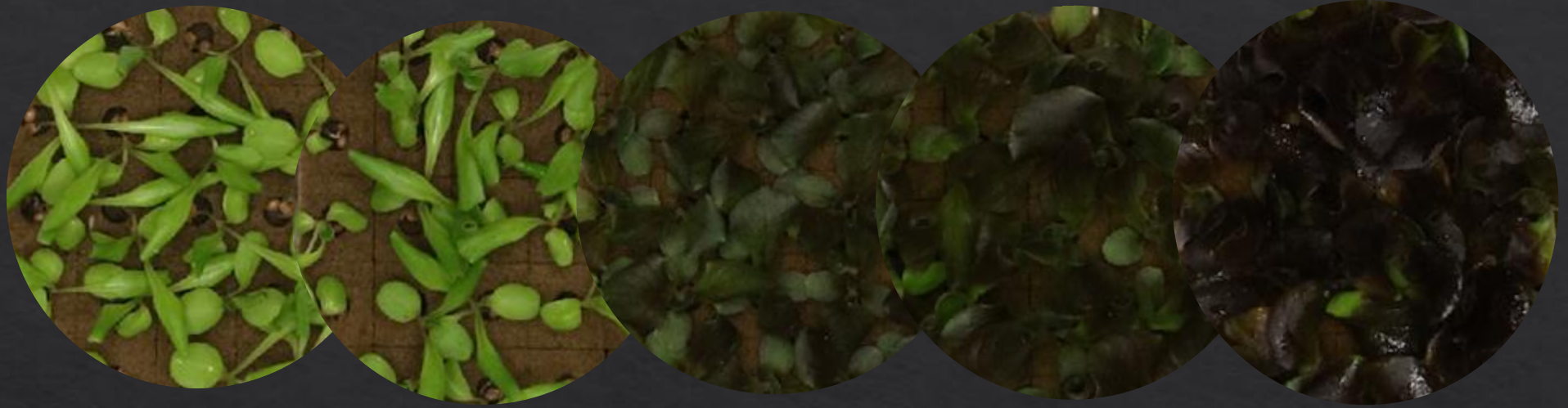
# Lettuce Seedling Fresh Mass

'Teodore'

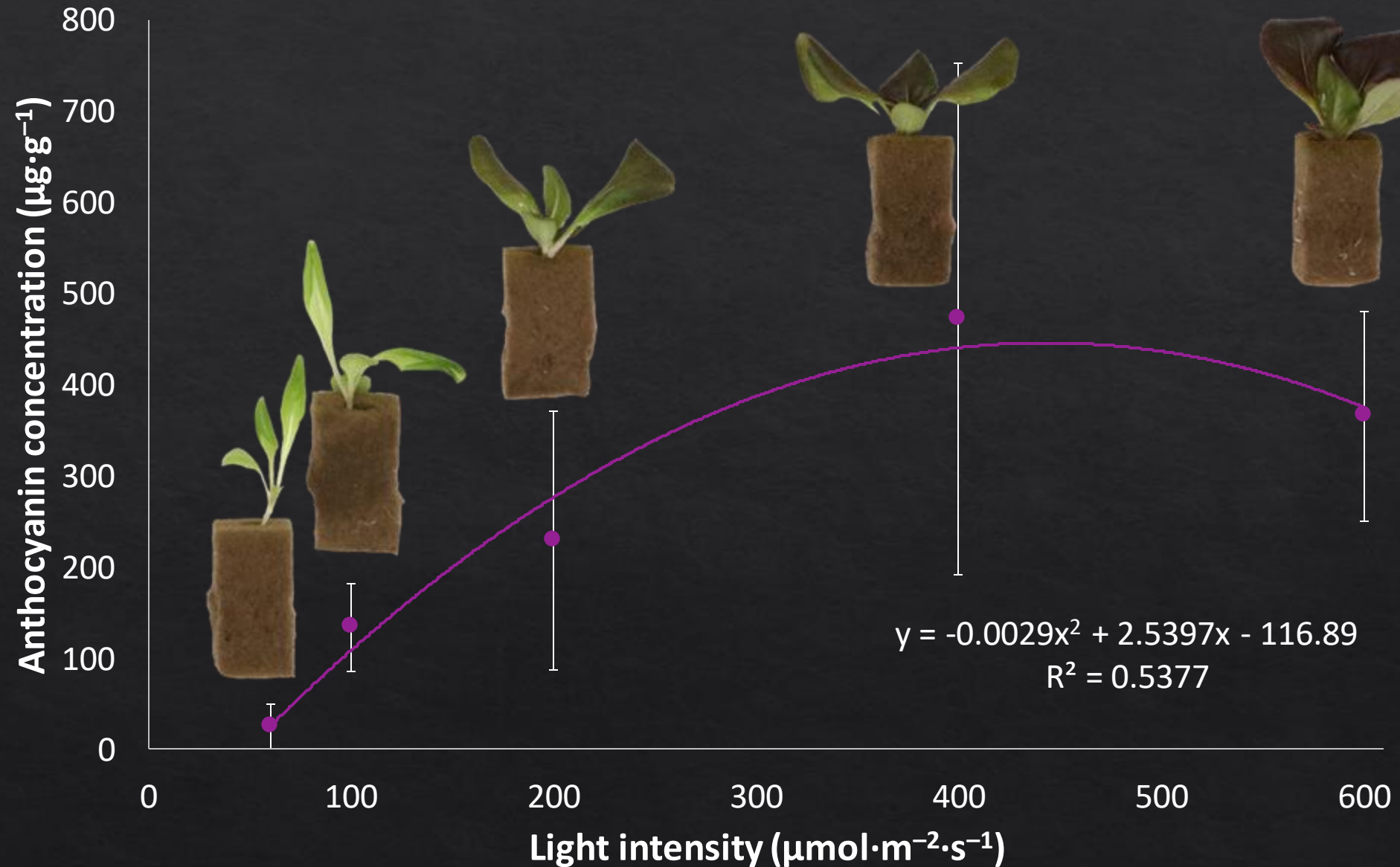


'Rex'

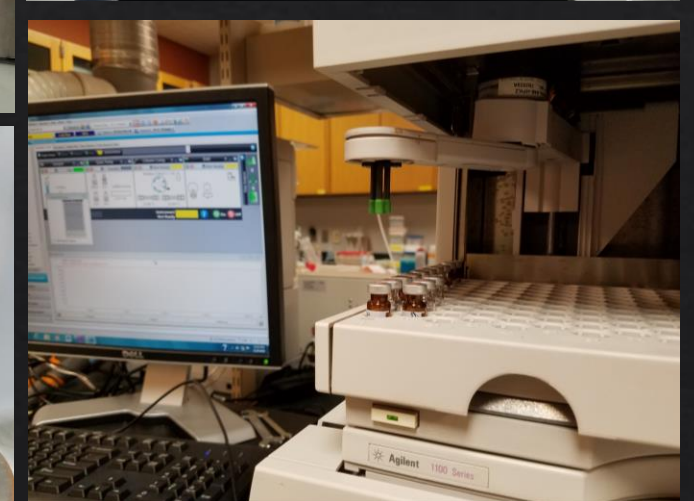




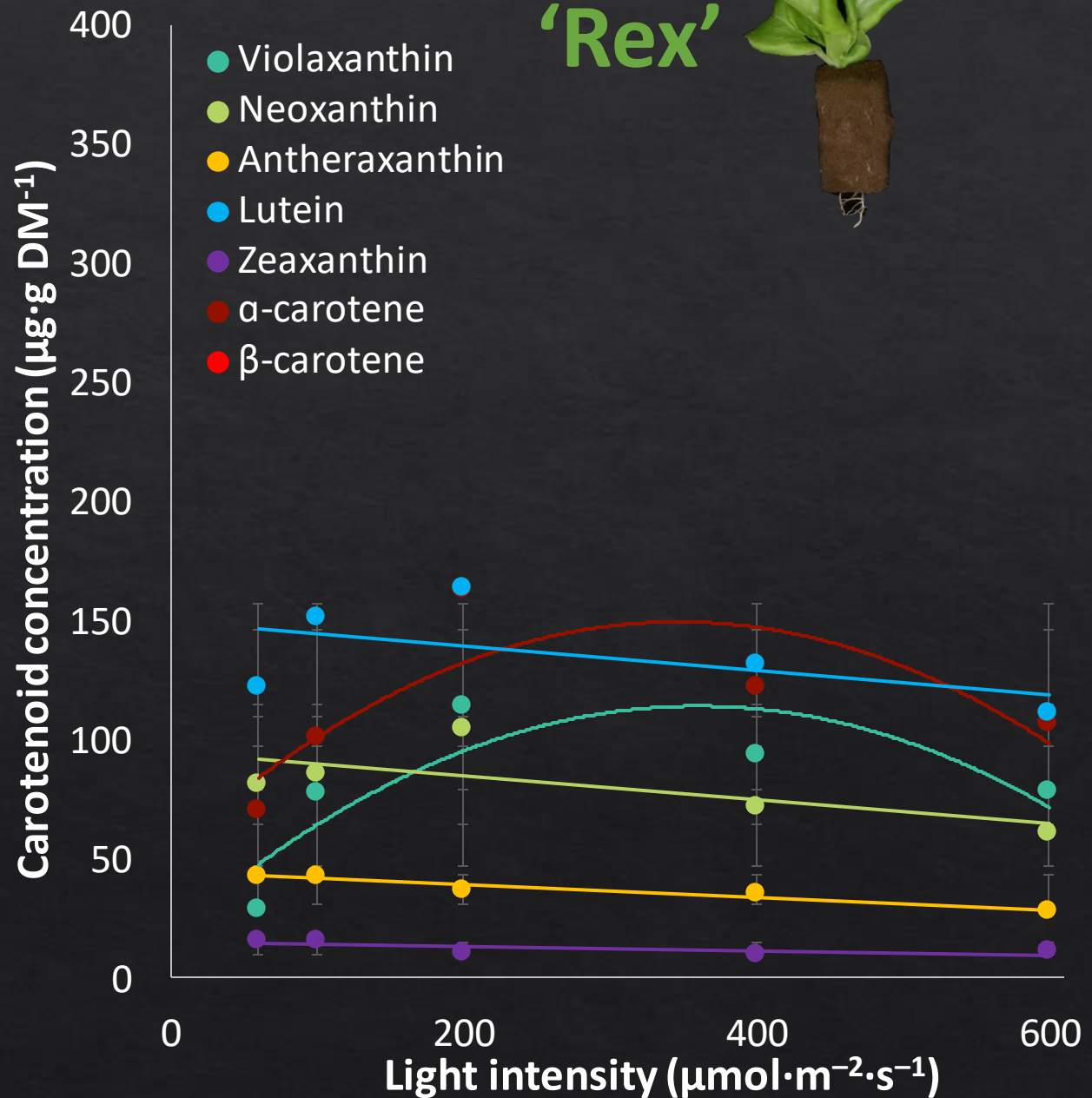
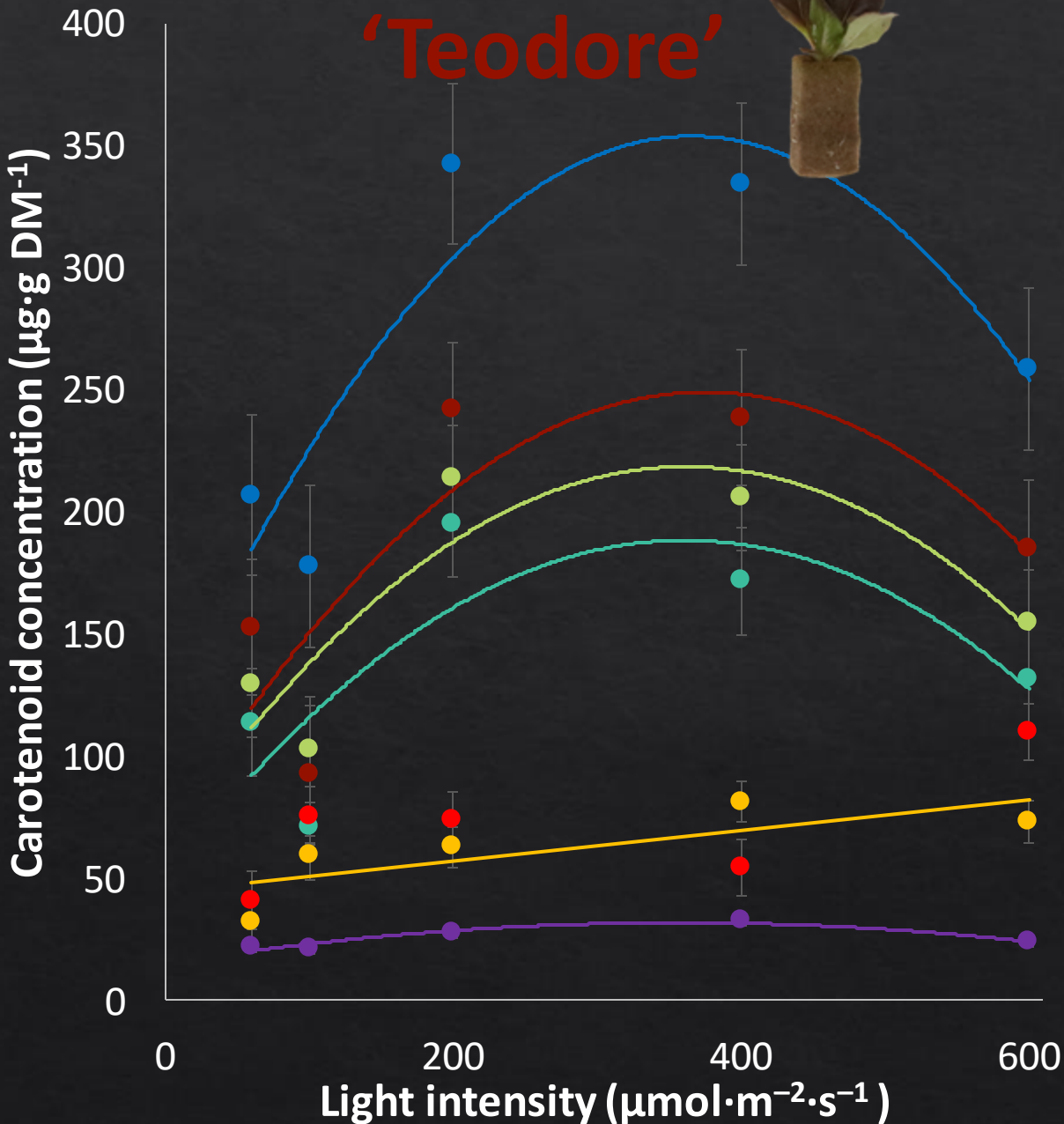
# Lettuce 'Teodore' Seedling Anthocyanin Concentration



# Carotenoid Extraction and Analysis



# Lettuce Seedling Carotenoid Concentration

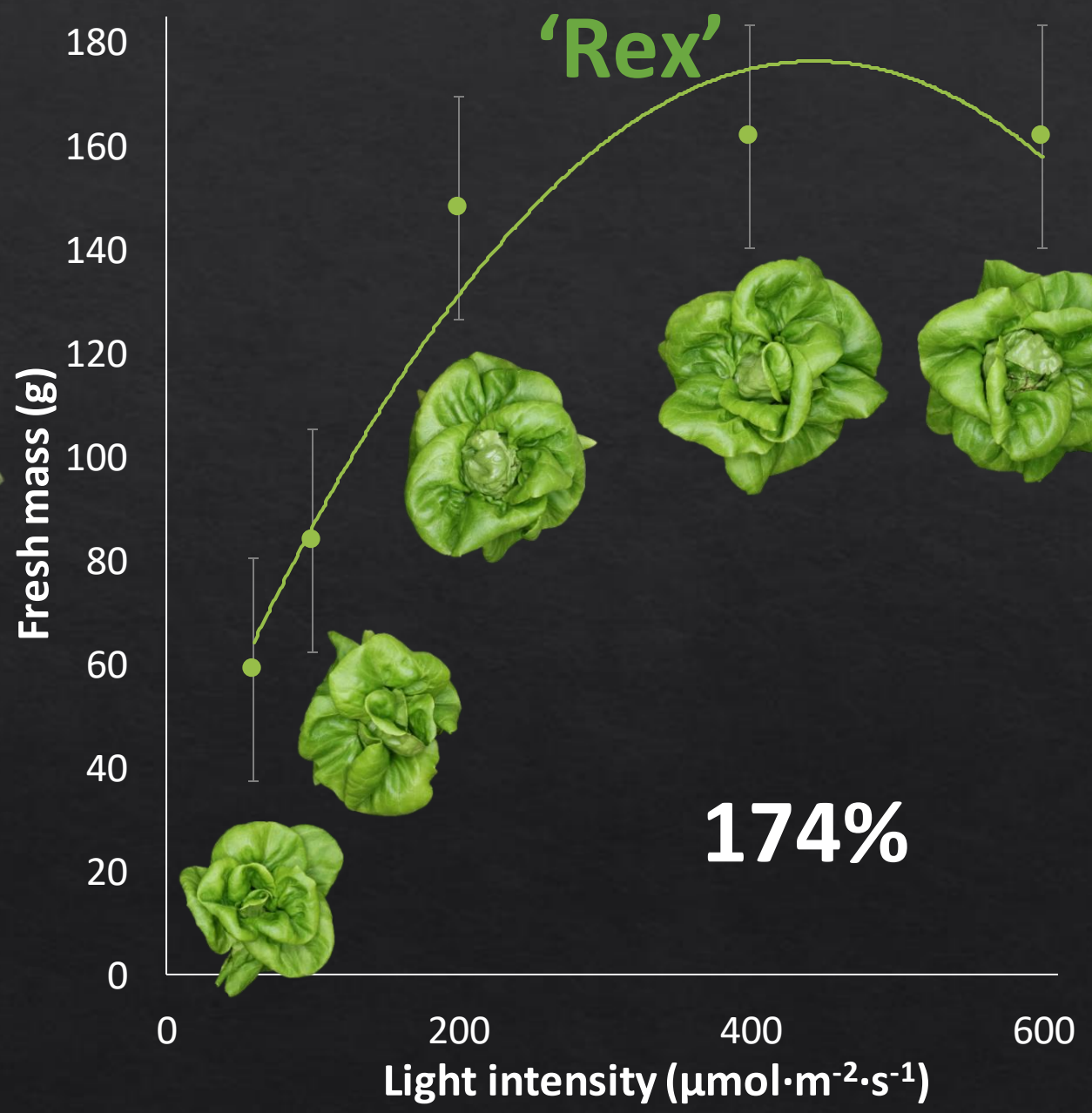
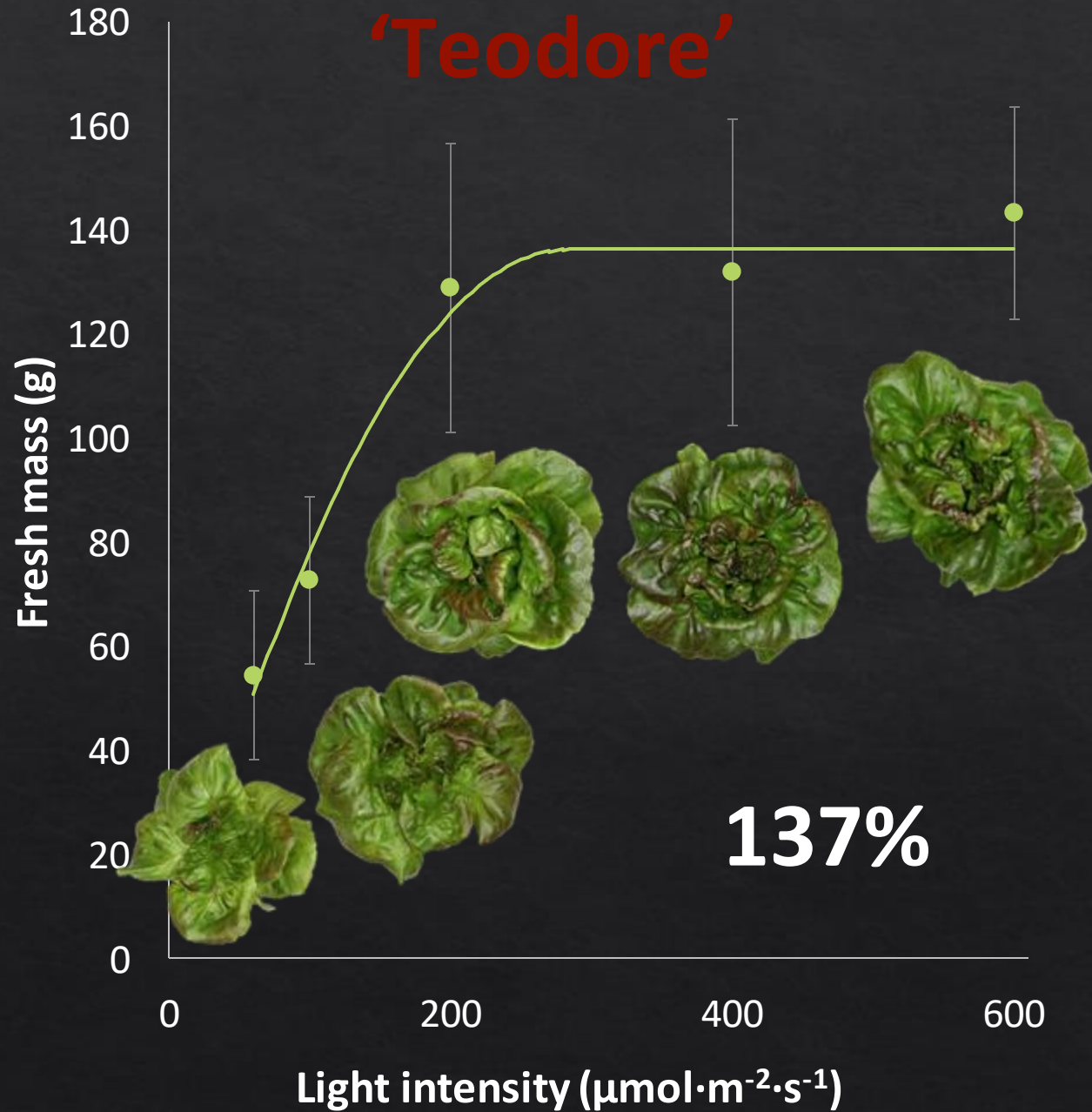




## Finishing Stage:

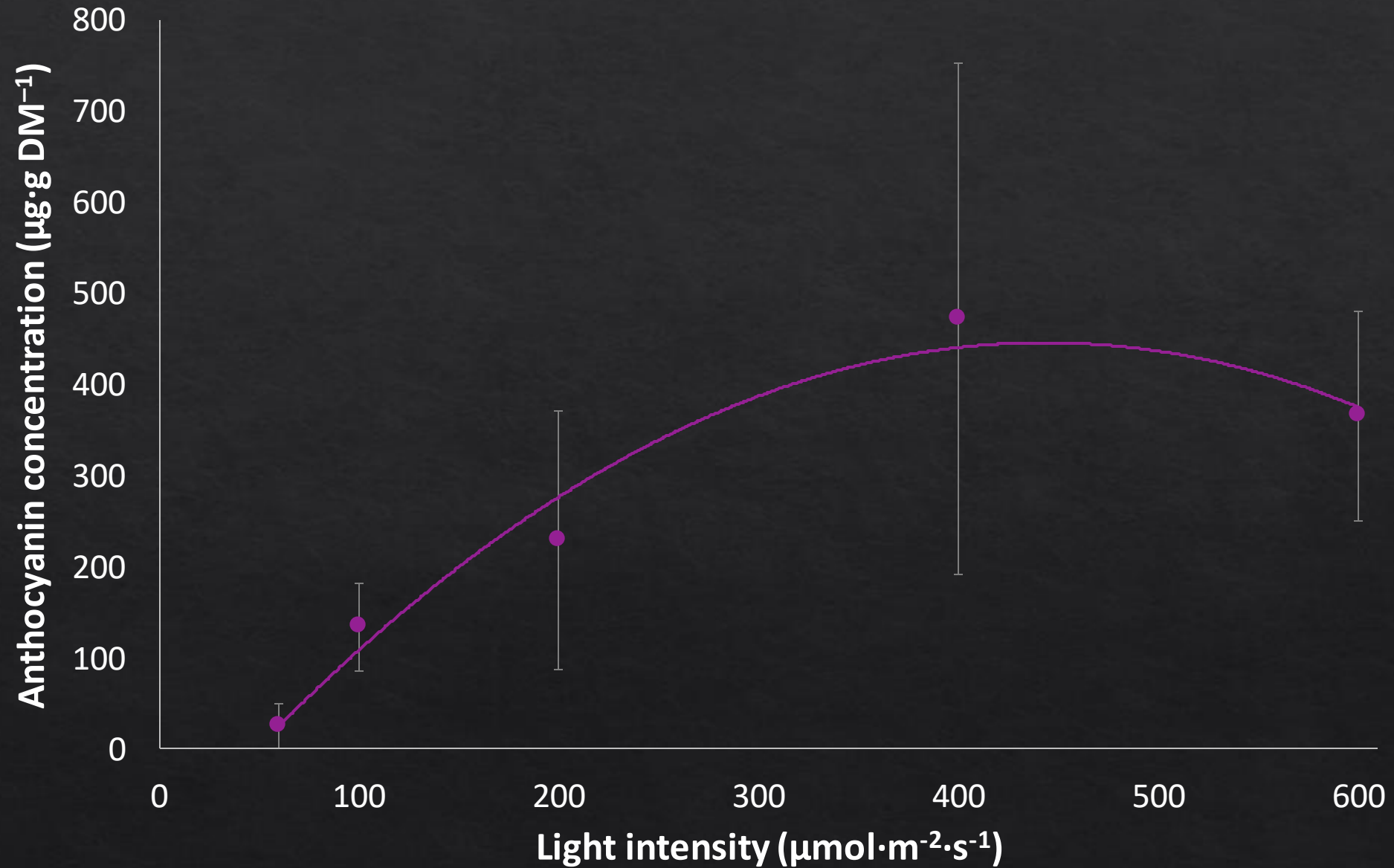
- 3 weeks
- Greenhouse
  - Raft hydroponic system
- Common growing environment

# Lettuce Harvest Fresh Mass

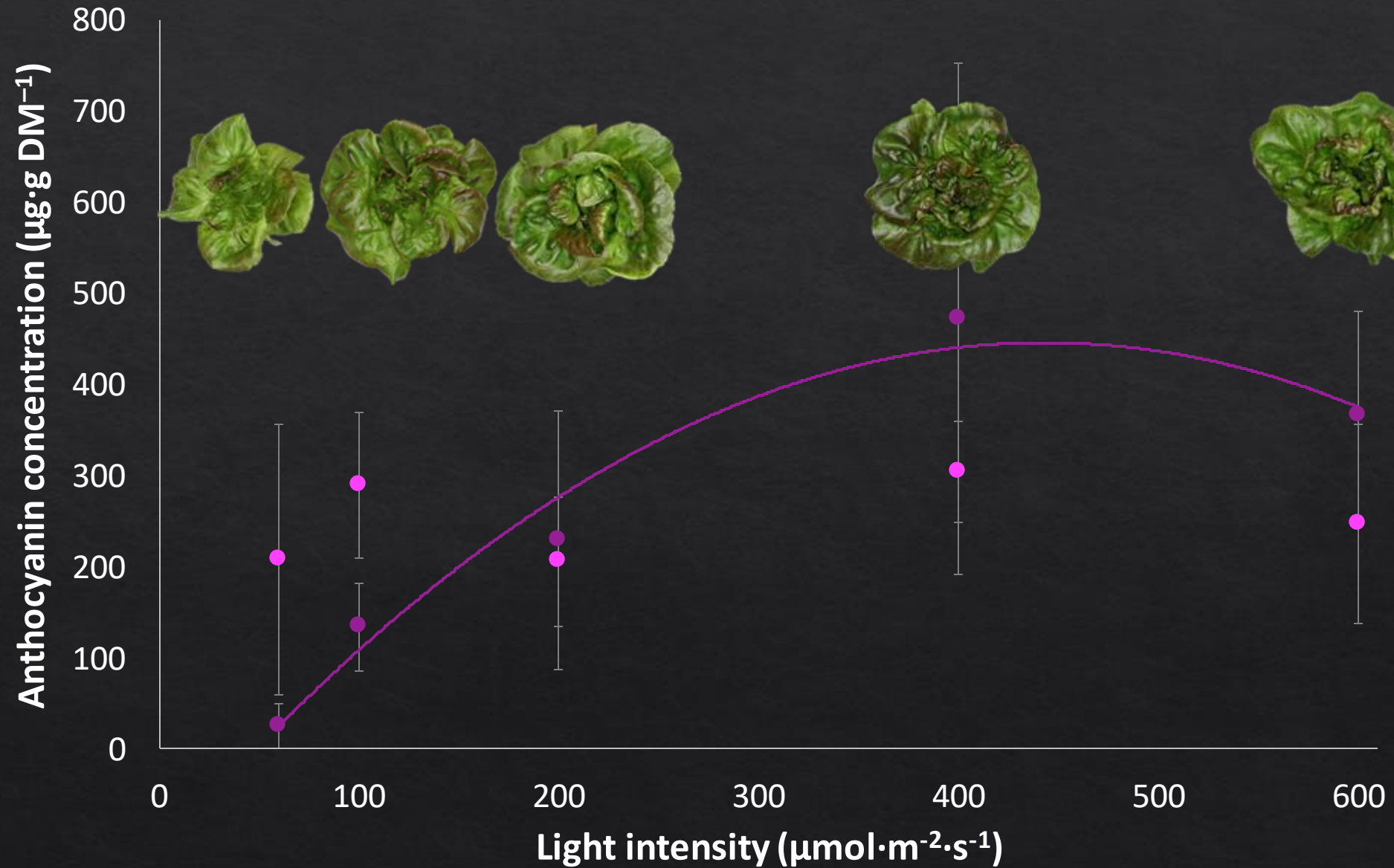




# Lettuce 'Teodore' Anthocyanin Concentration

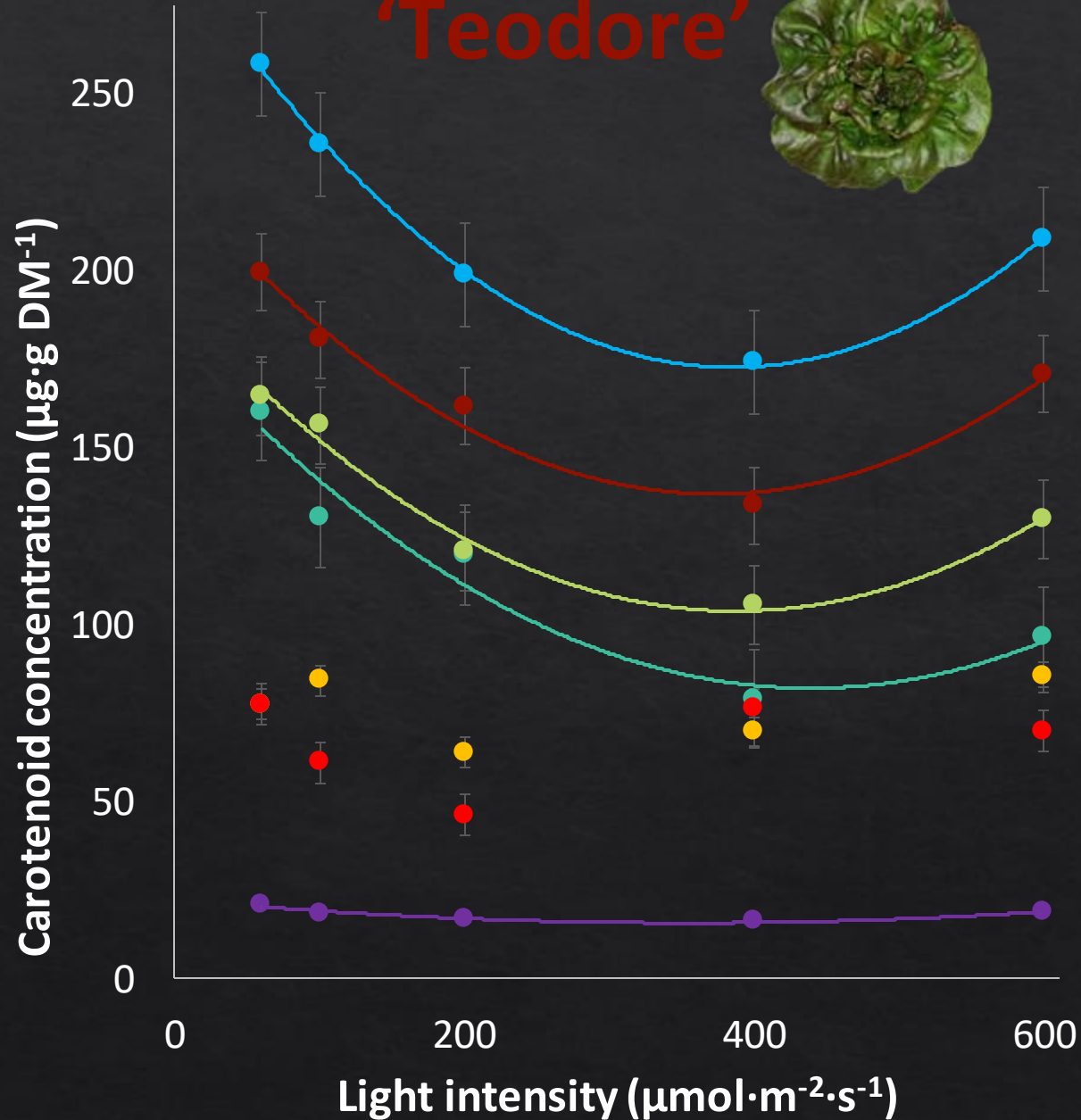


# Lettuce 'Teodore' Anthocyanin Concentration

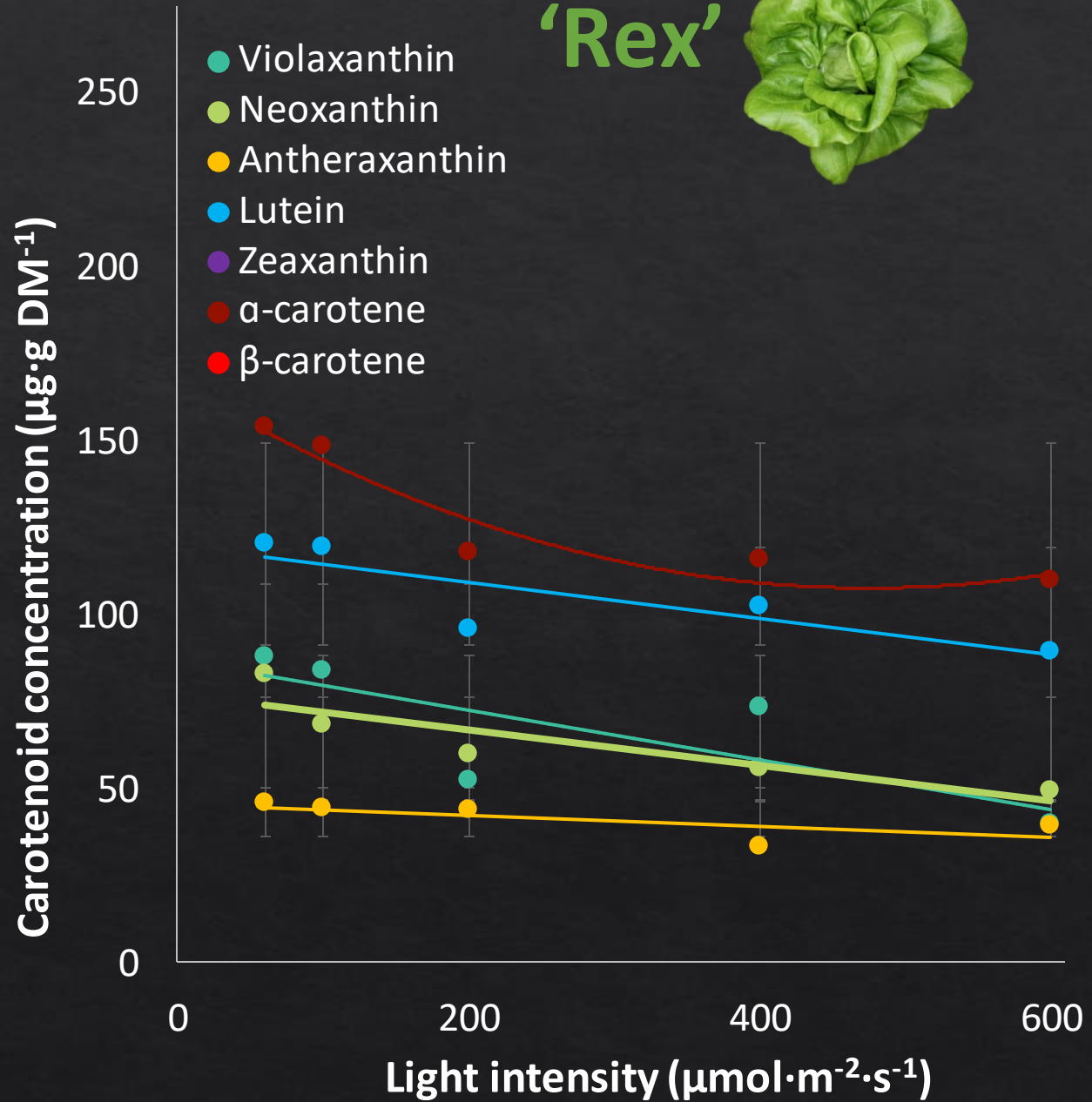


# Lettuce Harvest Carotenoid Concentration

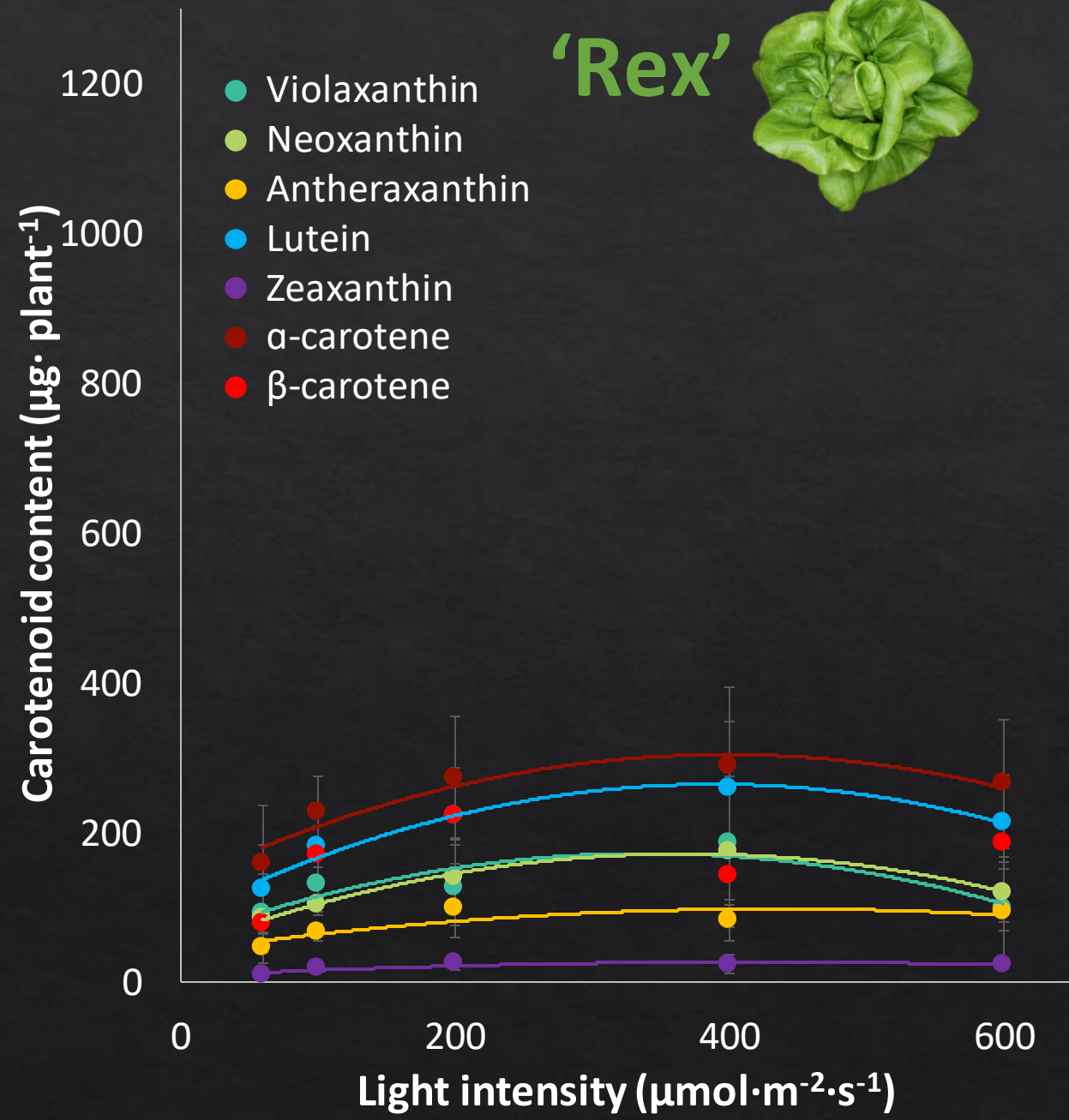
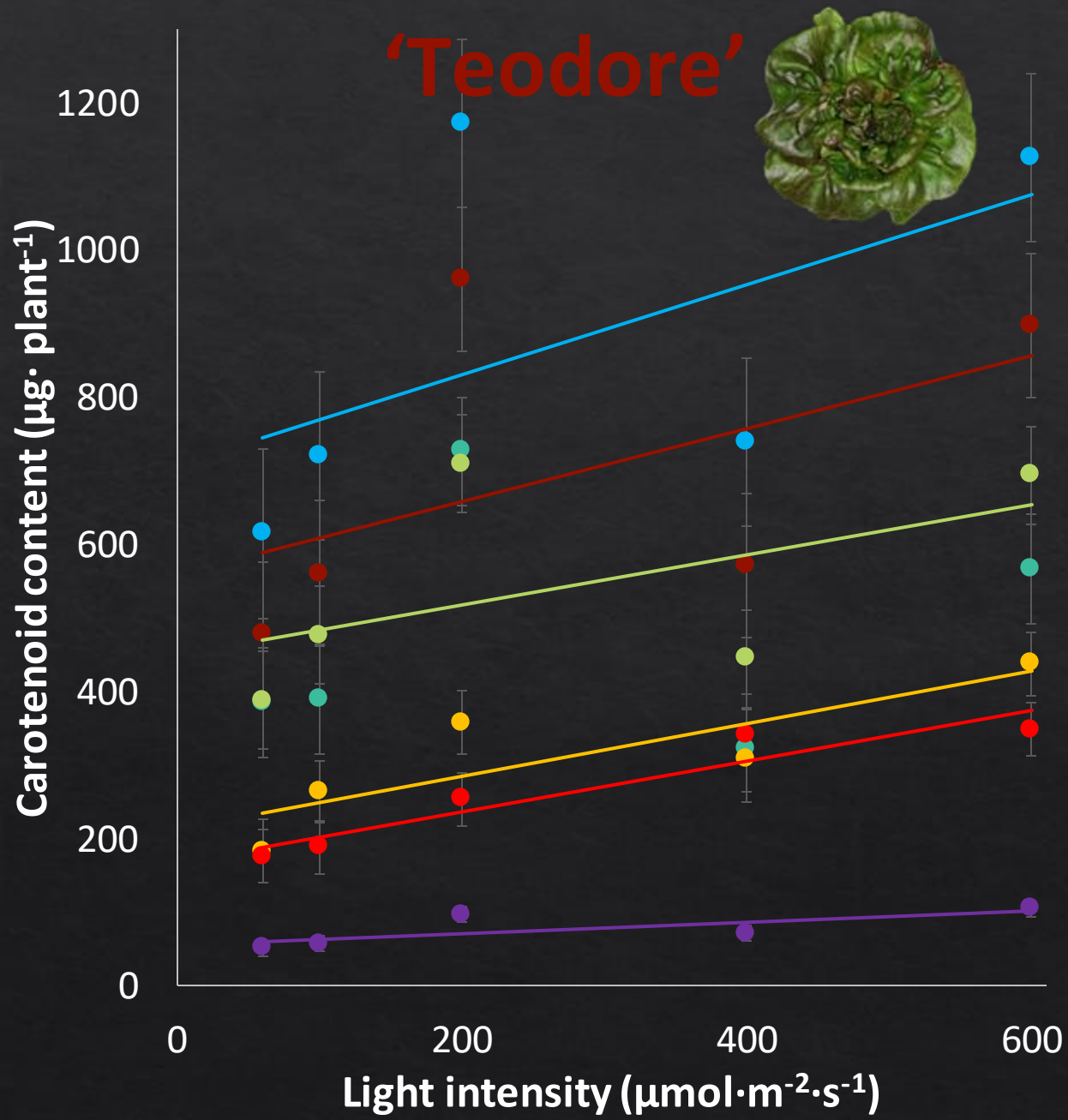
**'Teodore'**



**'Rex'**



# Lettuce Harvest Carotenoid Content



# Seedling Production vs. Finishing





## Seedling conclusions:

- Increasing light intensity to  $400 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ :
  - + fresh mass
  - + leaf number
  - + anthocyanin concentration ( $400 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ )
  - 'Rex' carotenoid concentration

Increasing light intensity to  $200 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ :  
+ 'Teodore' carotenoid concentration



## Harvest conclusions:

- Increasing light intensity to  $600 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ :
  - + leaf number
  - ns anthocyanin concentration
  - carotenoid concentration
  - + carotenoid content
- For greatest yield:
  - $\geq 200 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  ('Teodore')
  - $\geq 400 \mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$  ('Rex')

# Green Amara Mustard and Hybrid Red Mizuna

- Light intensity treatments:
  - 200, 400, 600, and 800  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
- Photoperiod treatment:
  - 16

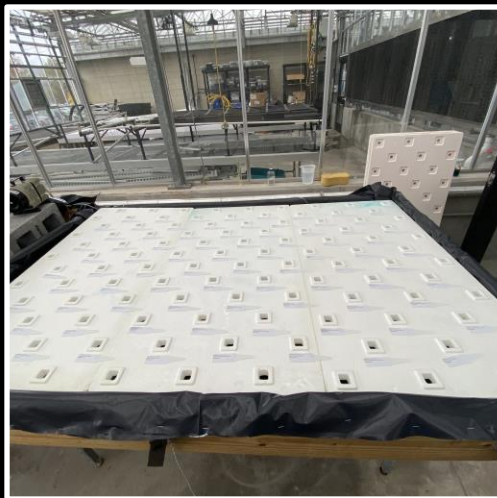
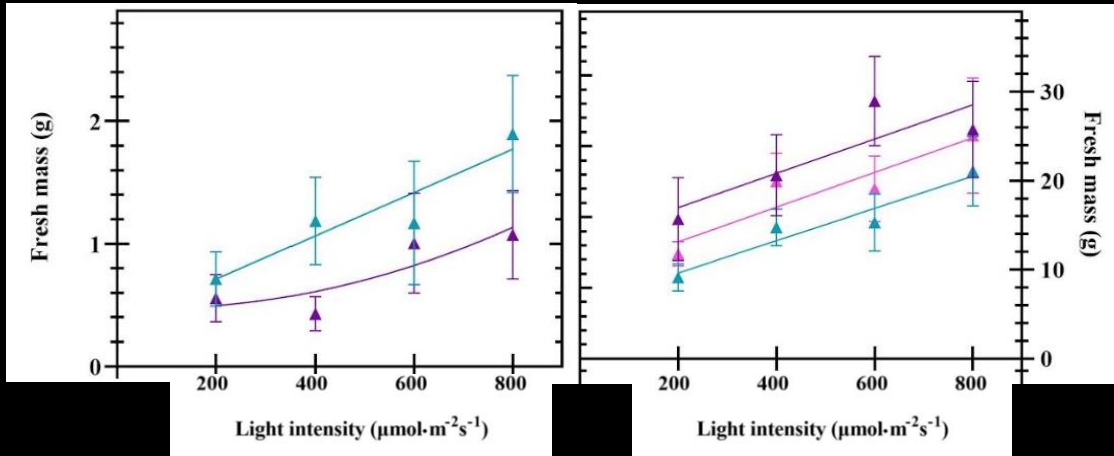




# The influence of light intensity during mizuna and mustard greens propagation

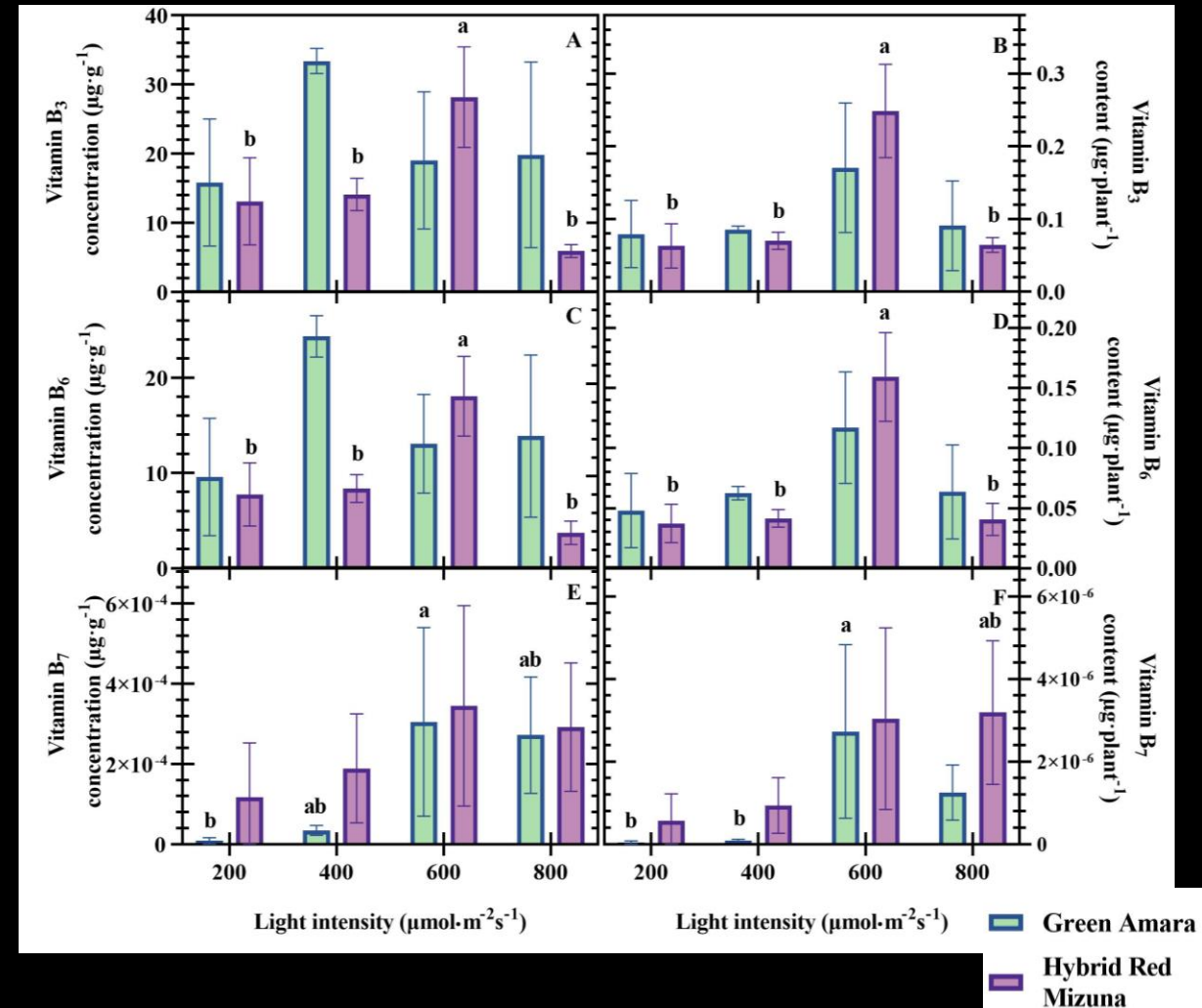
## Transplant

## Harvest



## Per g

## Per plant



A top-down view of a lush field of curly-leafed lettuce, likely a variety like 'Green Romaine' or 'Crisphead'. The leaves are a vibrant, healthy green and are densely packed together, creating a textured, repetitive pattern. The lighting is even, highlighting the natural curves and veins of the leaves.

End of Production?

# End-of-Production lighting increases kale coloration and quality



# Cultivars

'Redbor'

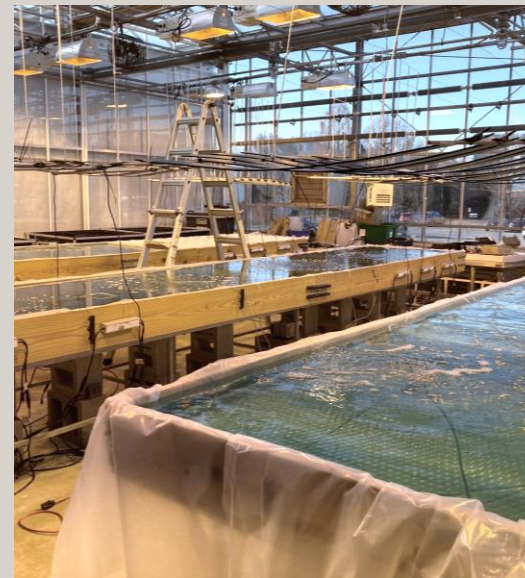


'Winterbor'



# Methods

- Ebb and flood
- Deep-water culture
- Target temperature: 22 °C  
21.8 ± 1.0 °C
- Target DLI: 11 mol·m<sup>-2</sup>d<sup>-1</sup>  
11.5 ± 4.7 mol·m<sup>-2</sup>d<sup>-1</sup>

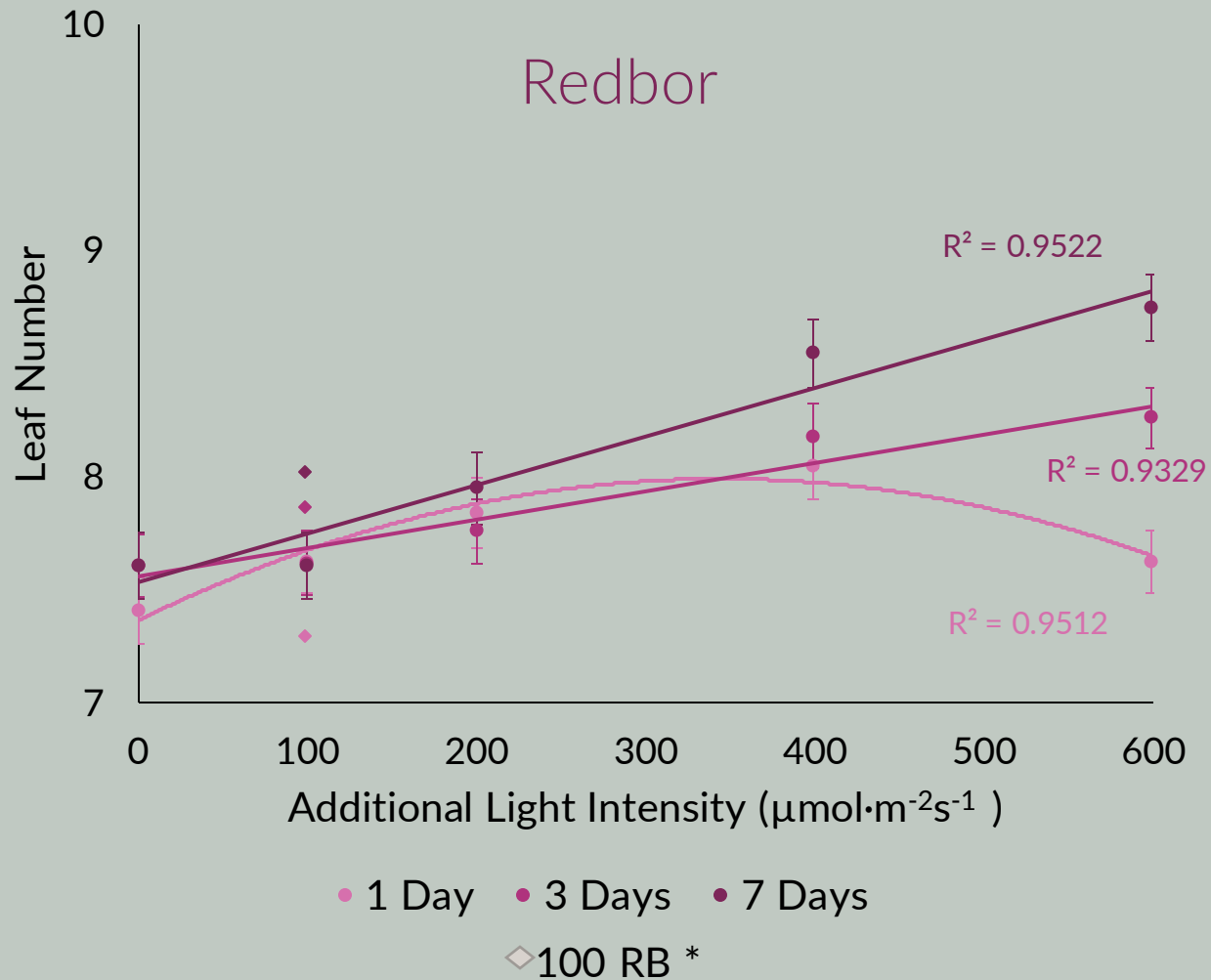




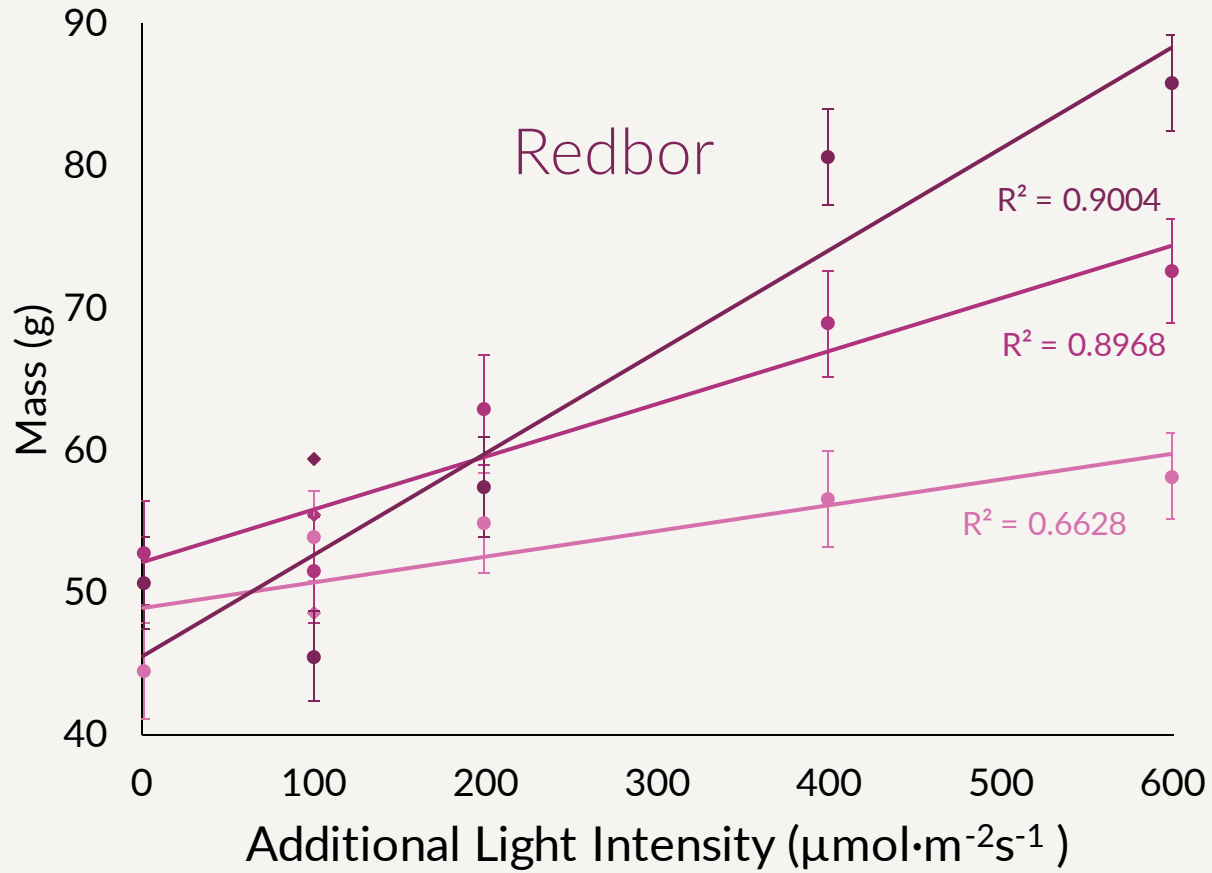
## End-of-production:

- 7 days, 3 days, 1 day before harvest
- DLI EOP Treatments
  - +100  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
  - +100 RB  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
  - +200  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
  - +400  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$
  - +600  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$

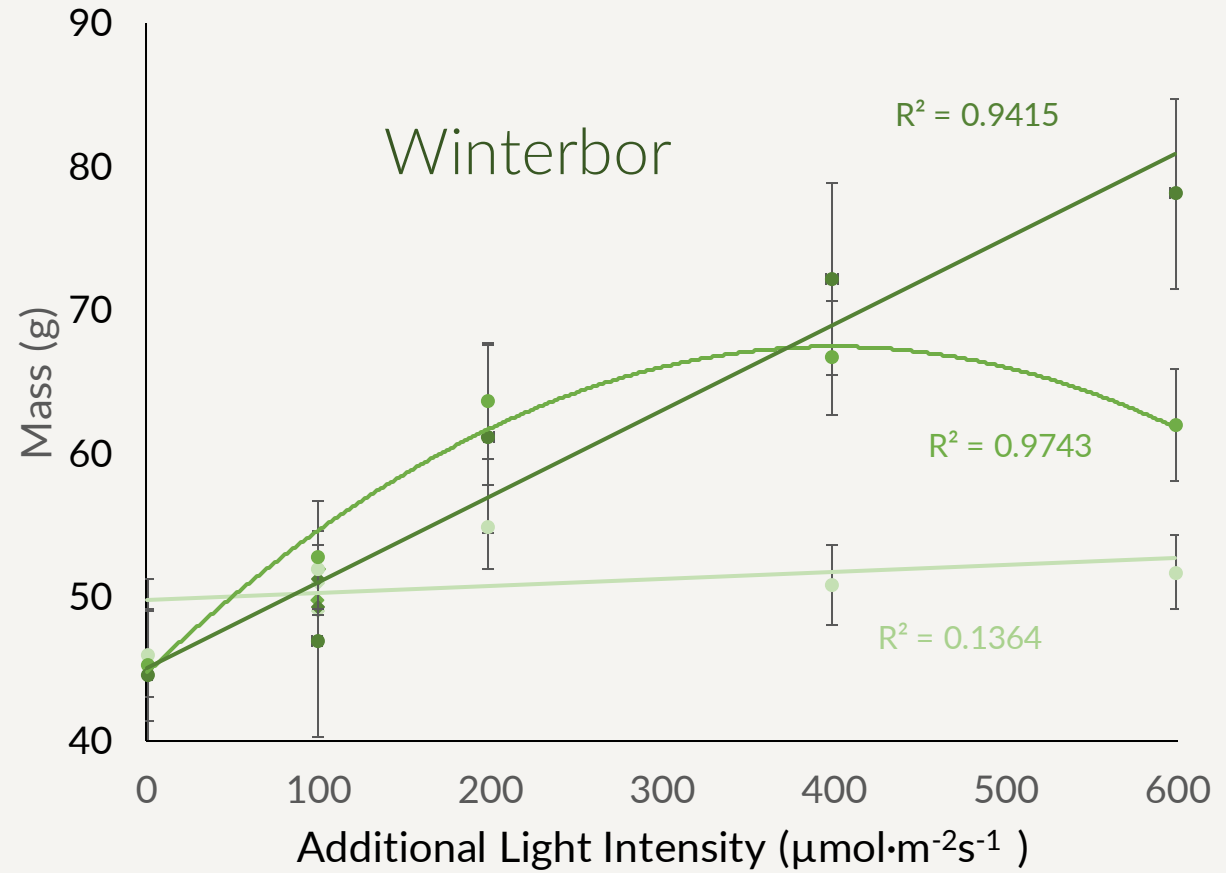
# Leaf Number



# Fresh Mass



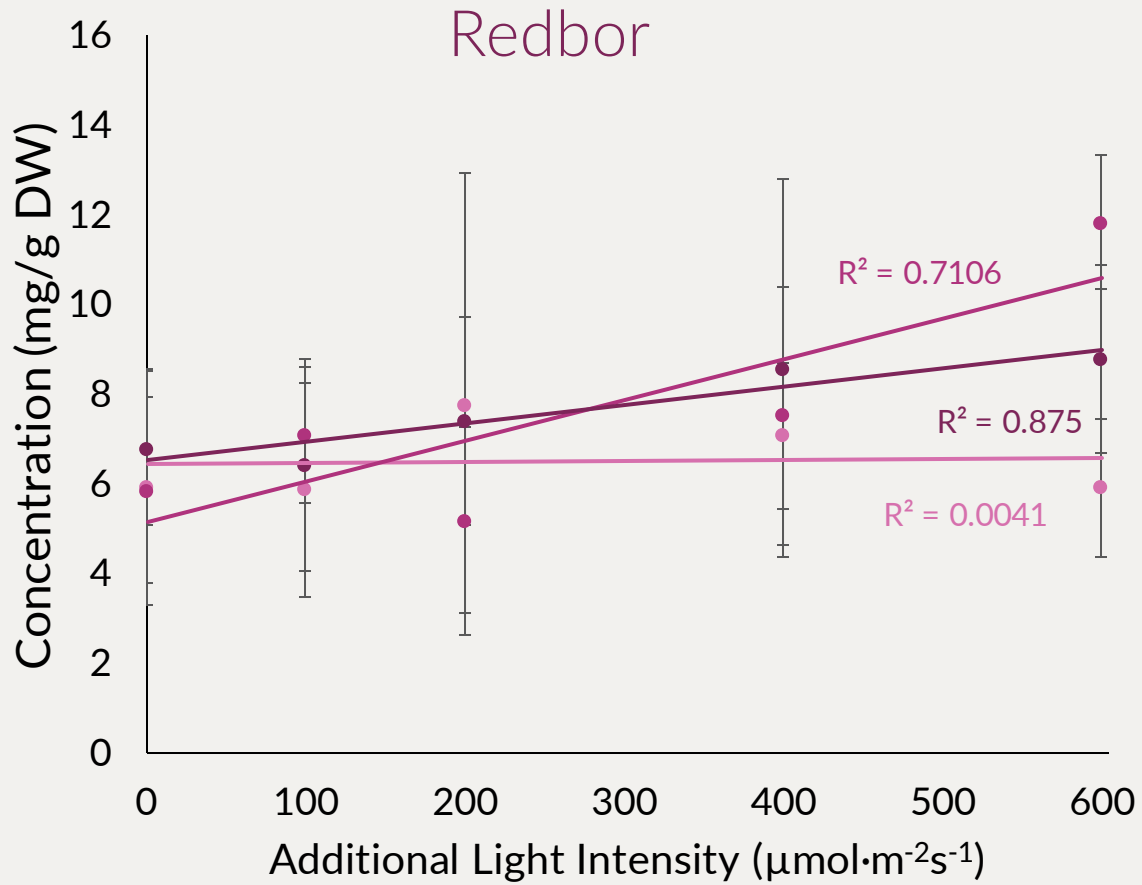
● 1 Day ● 3 Days ● 7 Days



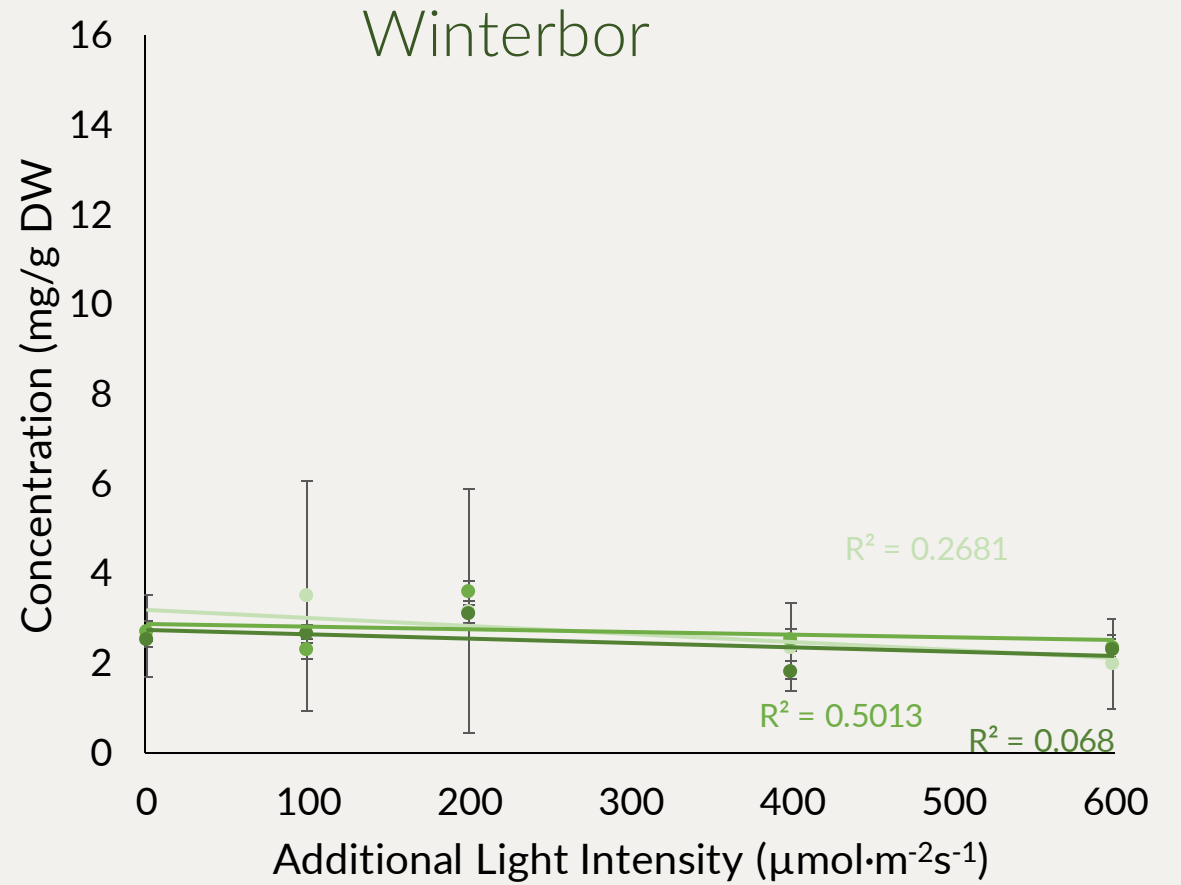
● 1 Day ● 3 Days ● 7 Days



# Anthocyanins



• 1 Day • 3 Days • 7 Days



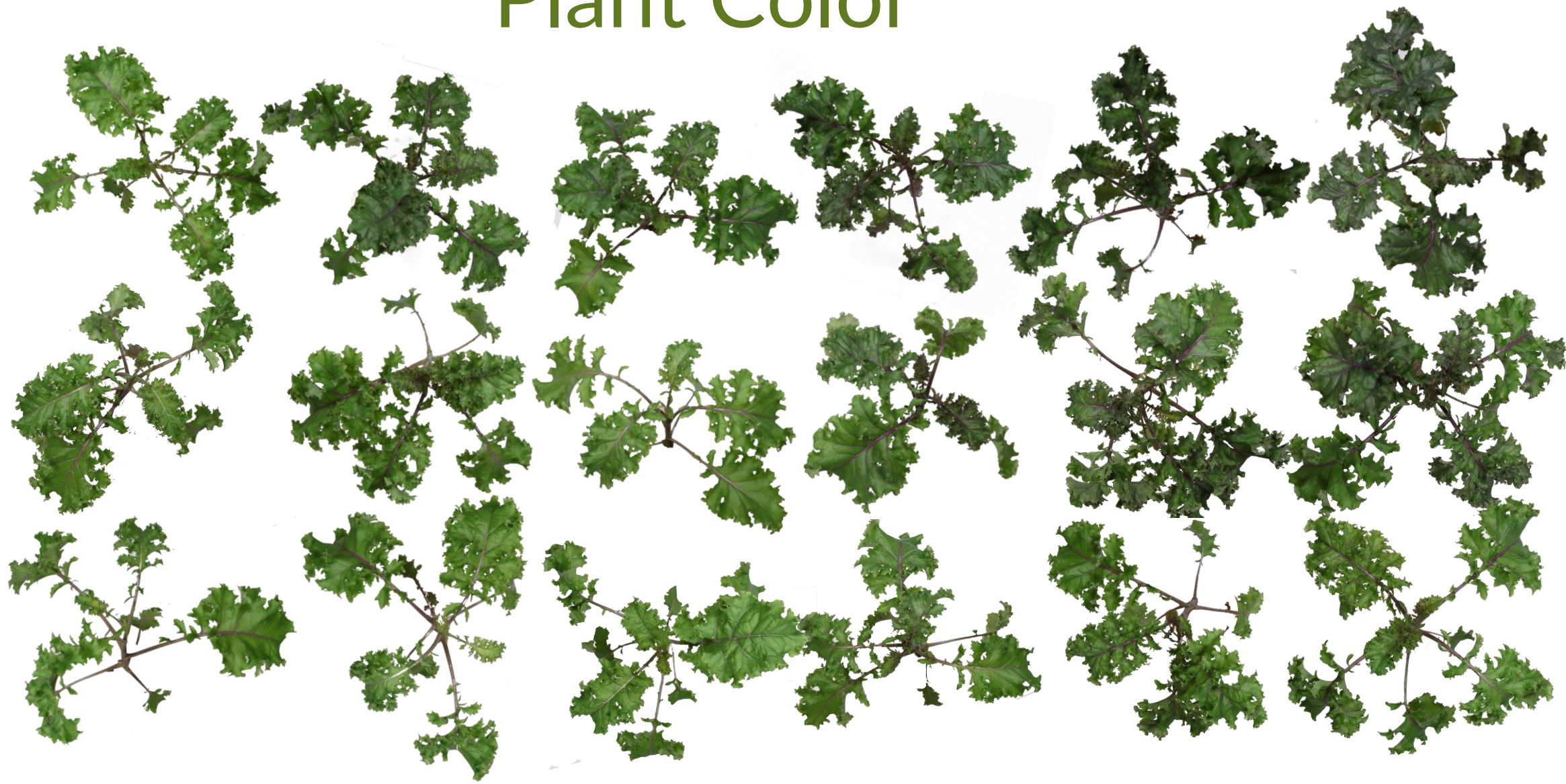
• 1 Day • 3 Days • 7 Days

# Plant Color

Day 7

Day 3

Day 1



+0

+100 RB

+100 W

+200 W

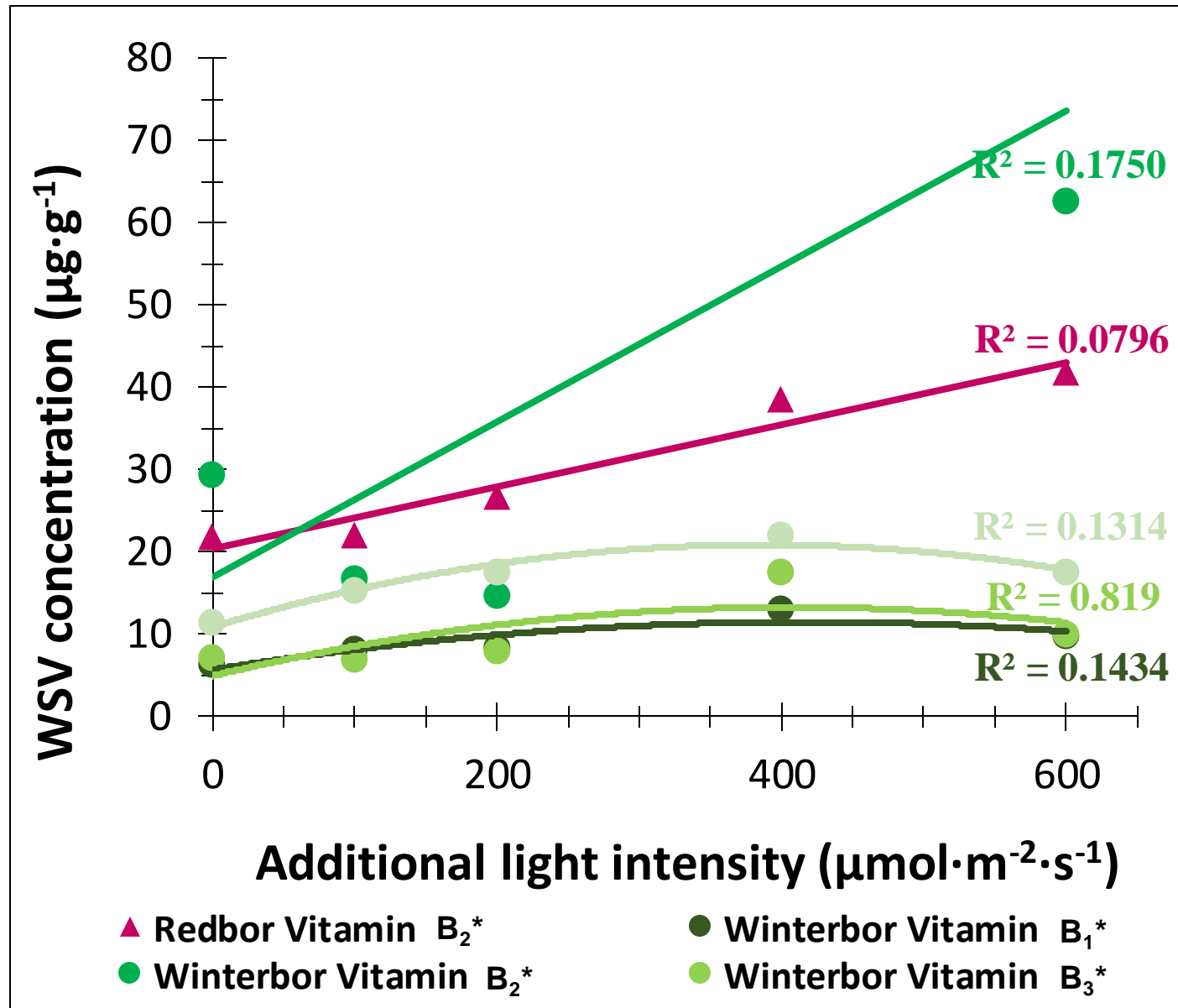
+400 W

+600 W

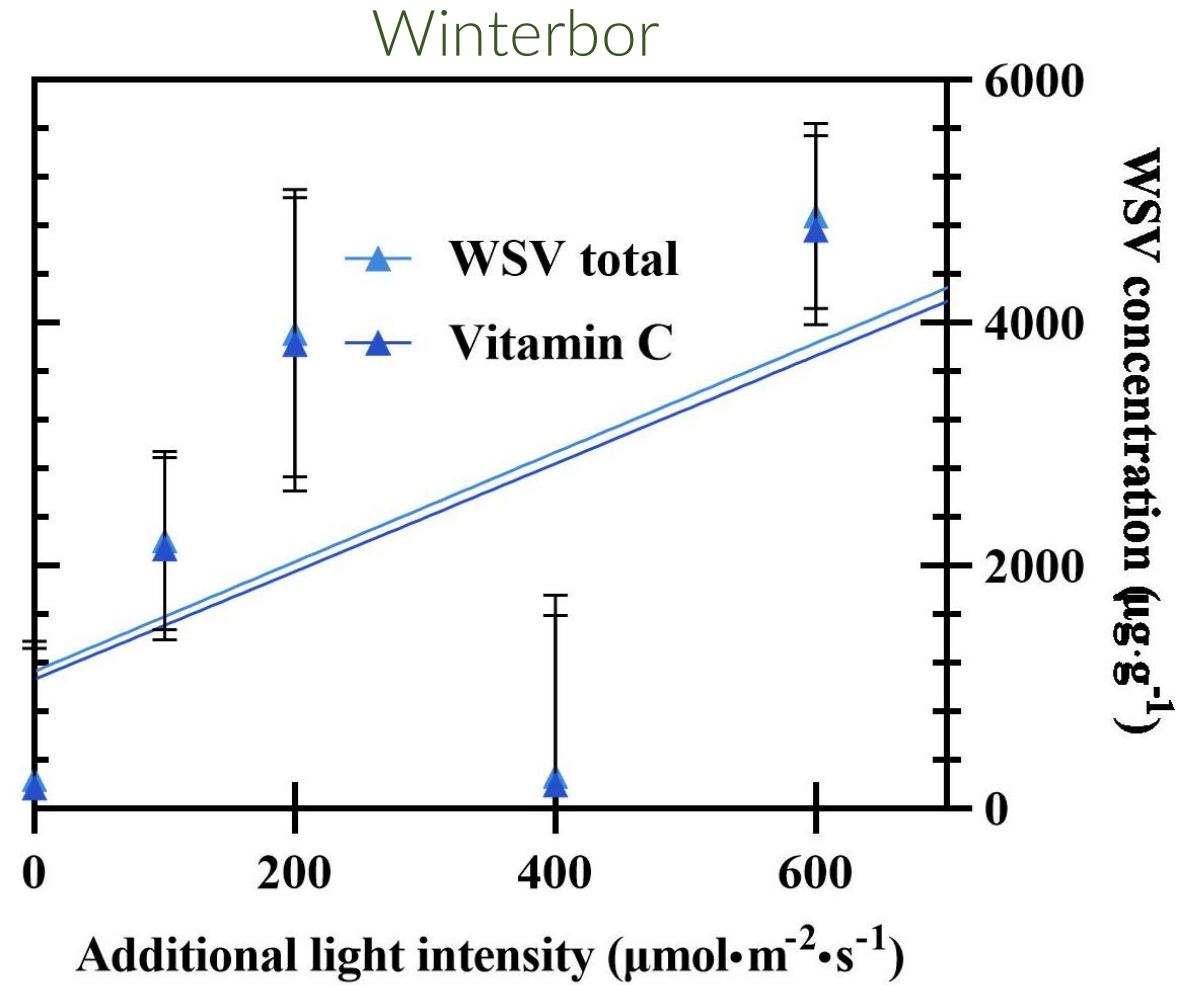
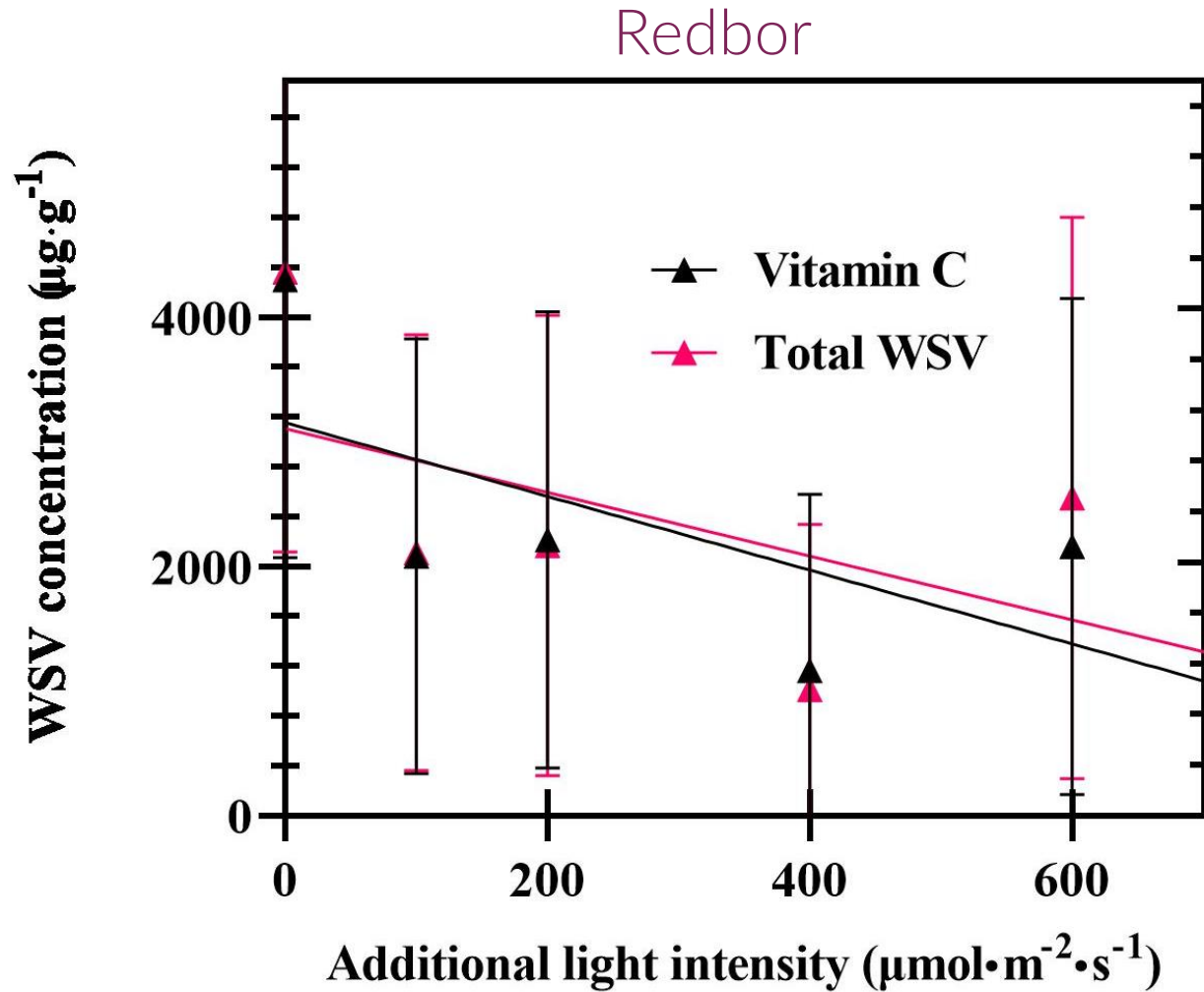
A close-up photograph of various leafy greens, including kale and chard, with some leaves showing purple veins. A black rectangular box is centered over the image, containing the text "What about indoors?".

What about indoors?

# Water-soluble Vitamins - Indoors



# Water-soluble Vitamins - Indoors





End-of-Production lighting:

A good strategy for coloration

More information is needed for  
consistent phytonutrients

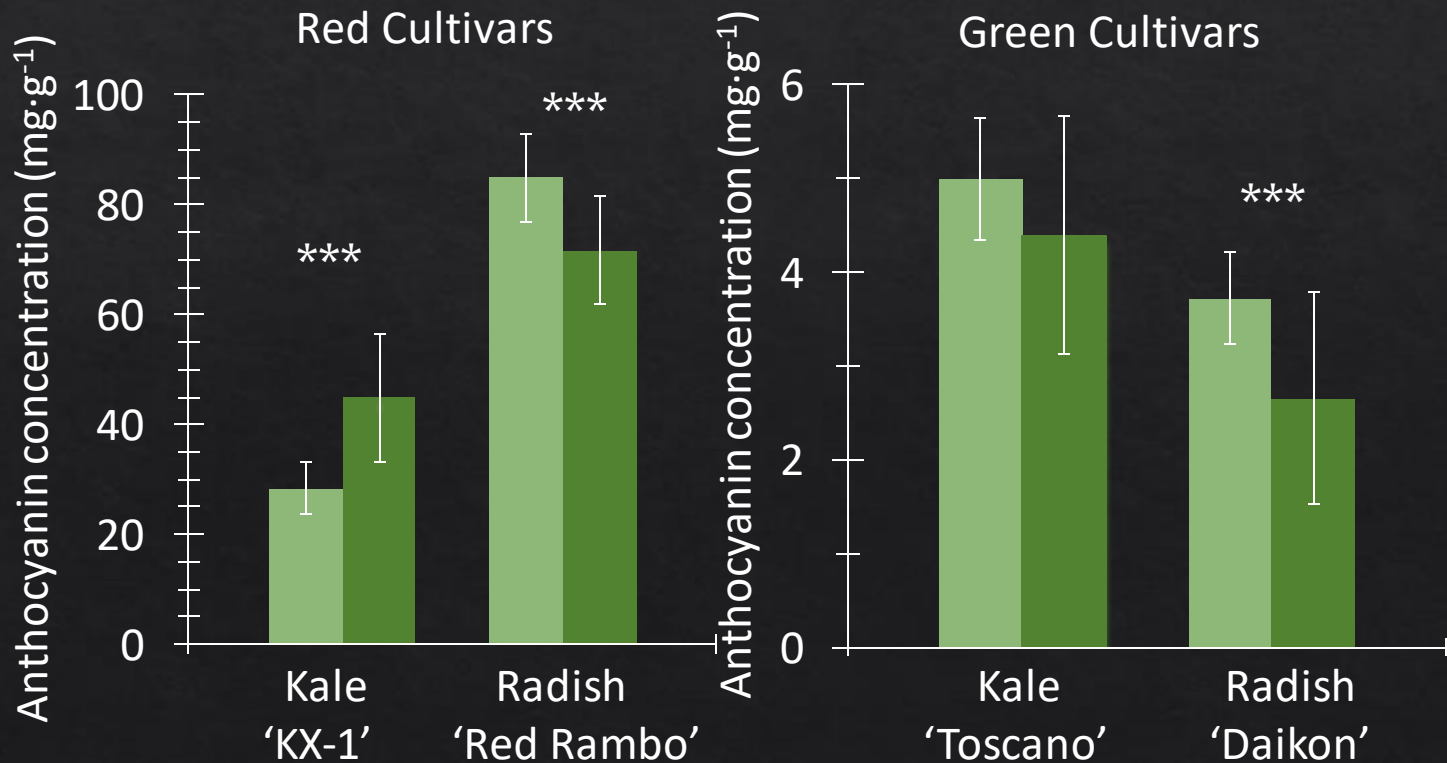
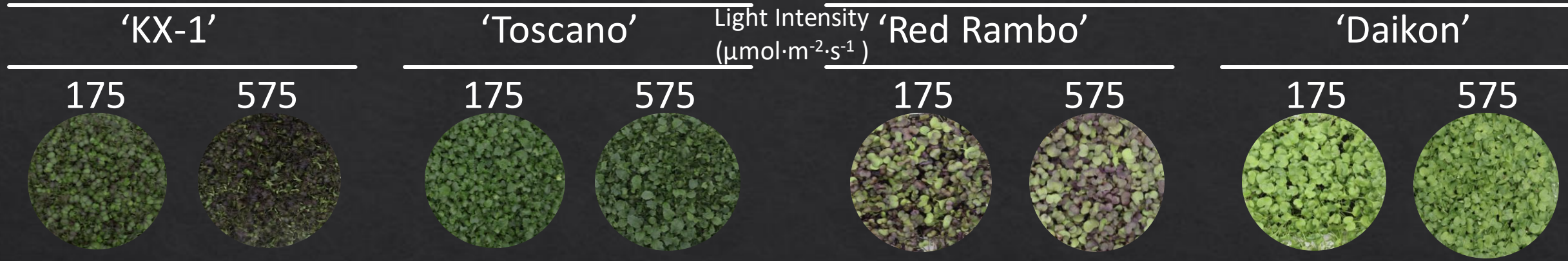
**What do consumers think?**

# Microgreens

175  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$   
 575  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$

Kale

Radish





# Microgreens

175  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$   
 575  $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$

Kale

Radish

'KX-1'

'Toscano'

Light Intensity  
 ( $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ )

'Red Rambo'

'Daikon'

175

575

175

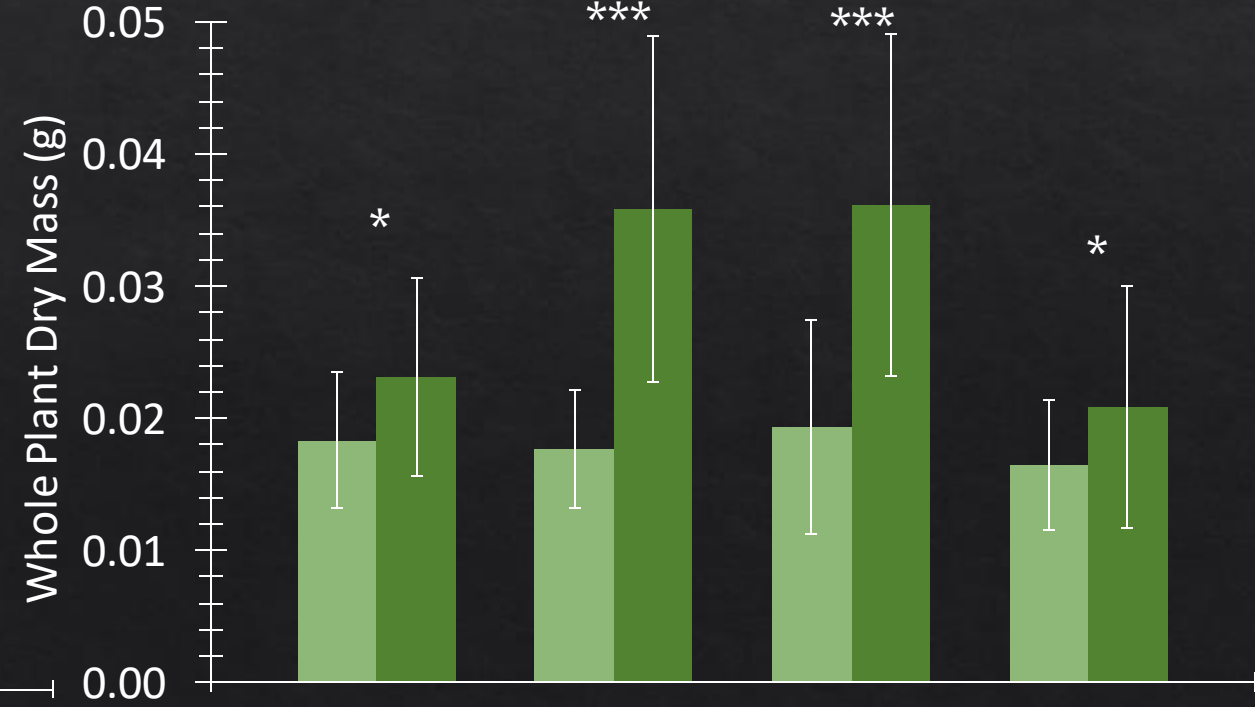
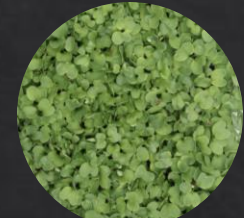
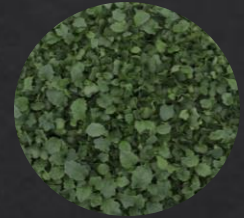
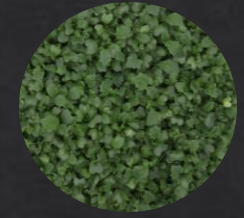
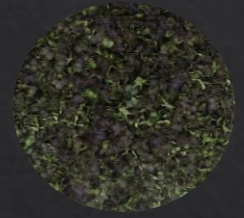
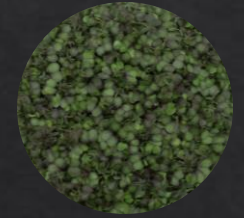
575

175

575

175

575

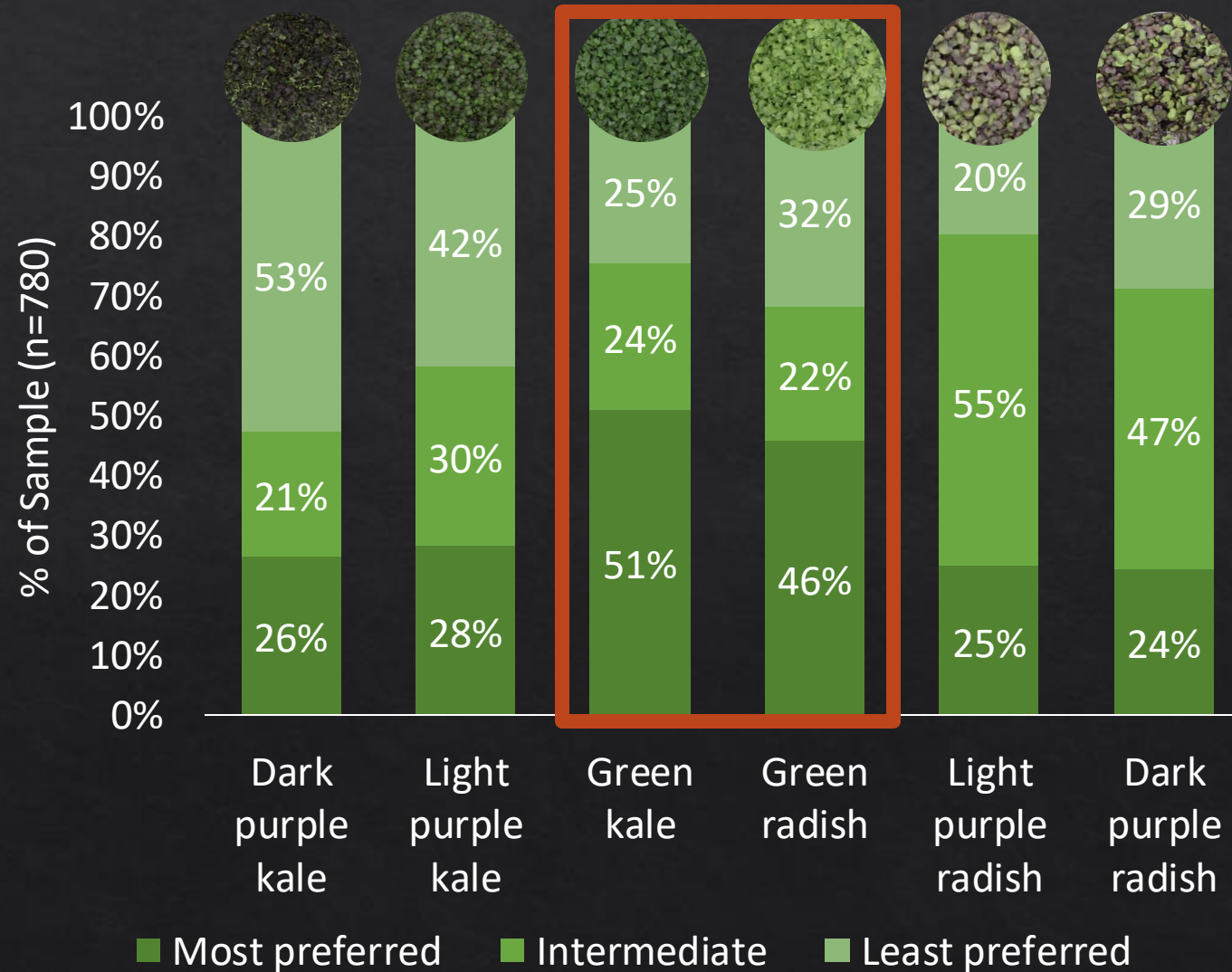


Kale 'KX-1'    Kale 'Toscano'    Radish 'Daikon'    Radish 'Red Rambo'

Kale 'KX-1'    Kale 'Toscano'    Radish 'Daikon'    Radish 'Red Rambo'

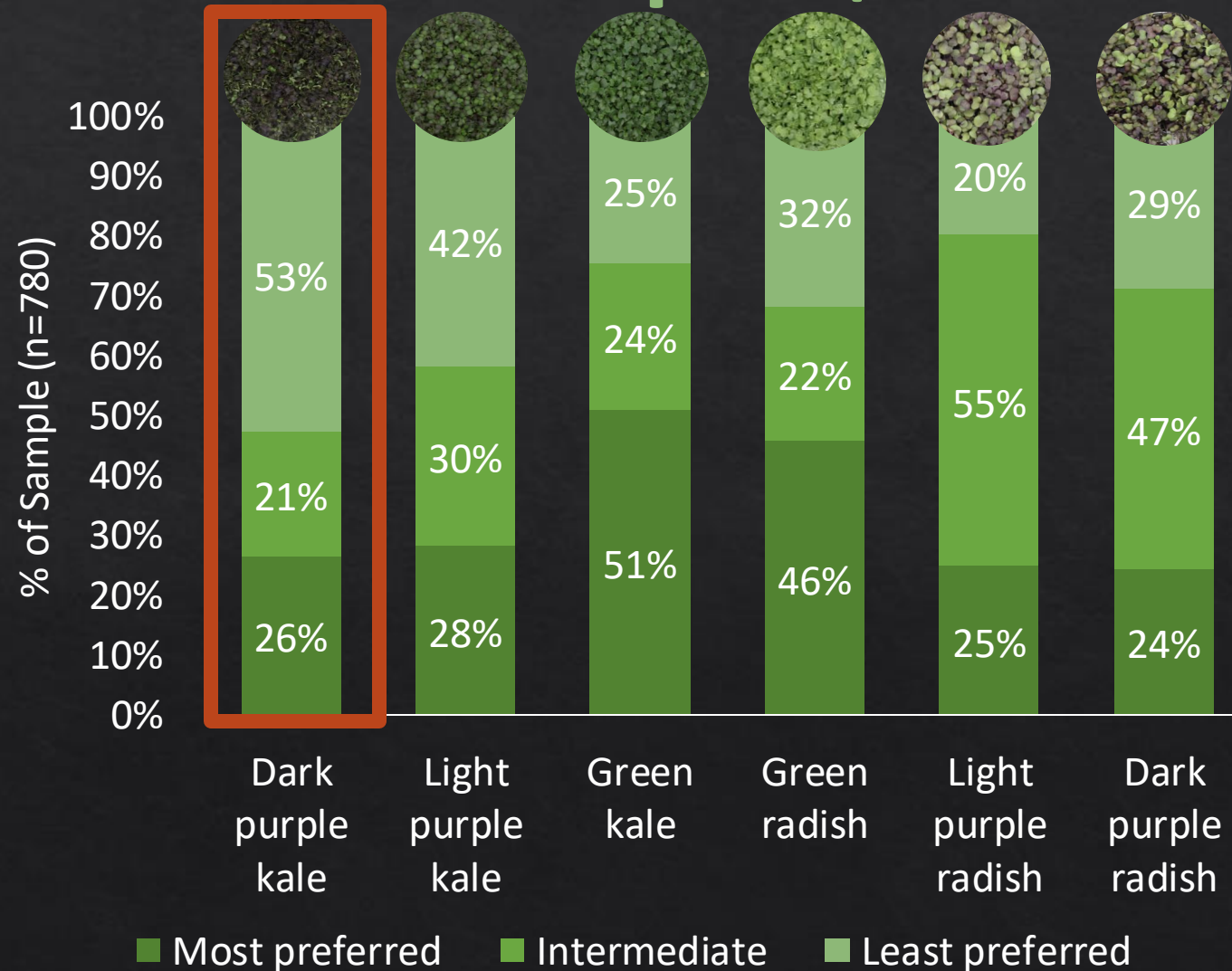
# Tennesseans' Preferences for Microgreens of a Different Color

Green +\$0.52 to \$0.66



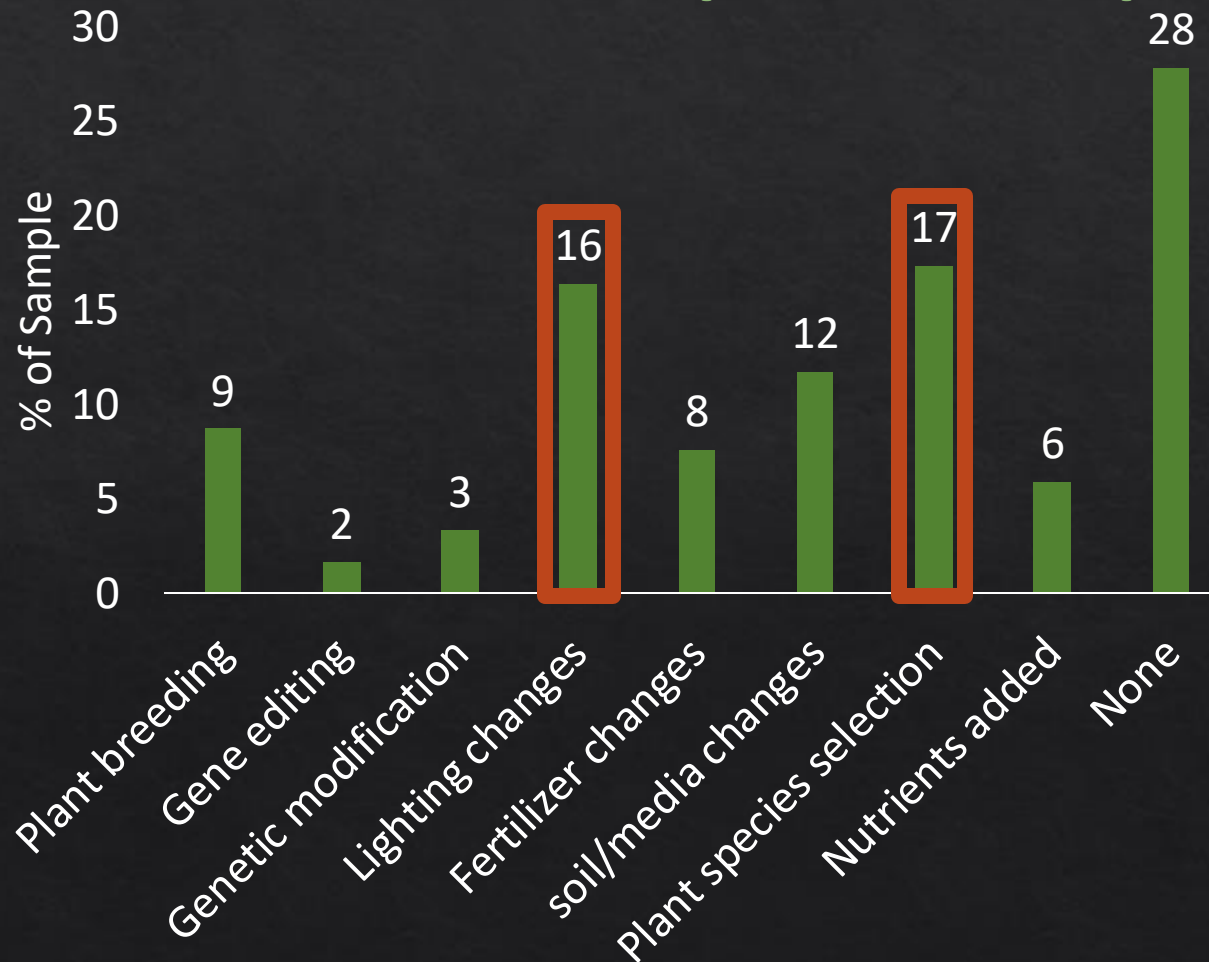
# Tennesseans' Preferences for Microgreens of a Different Color

## Dark Purple - \$0.50



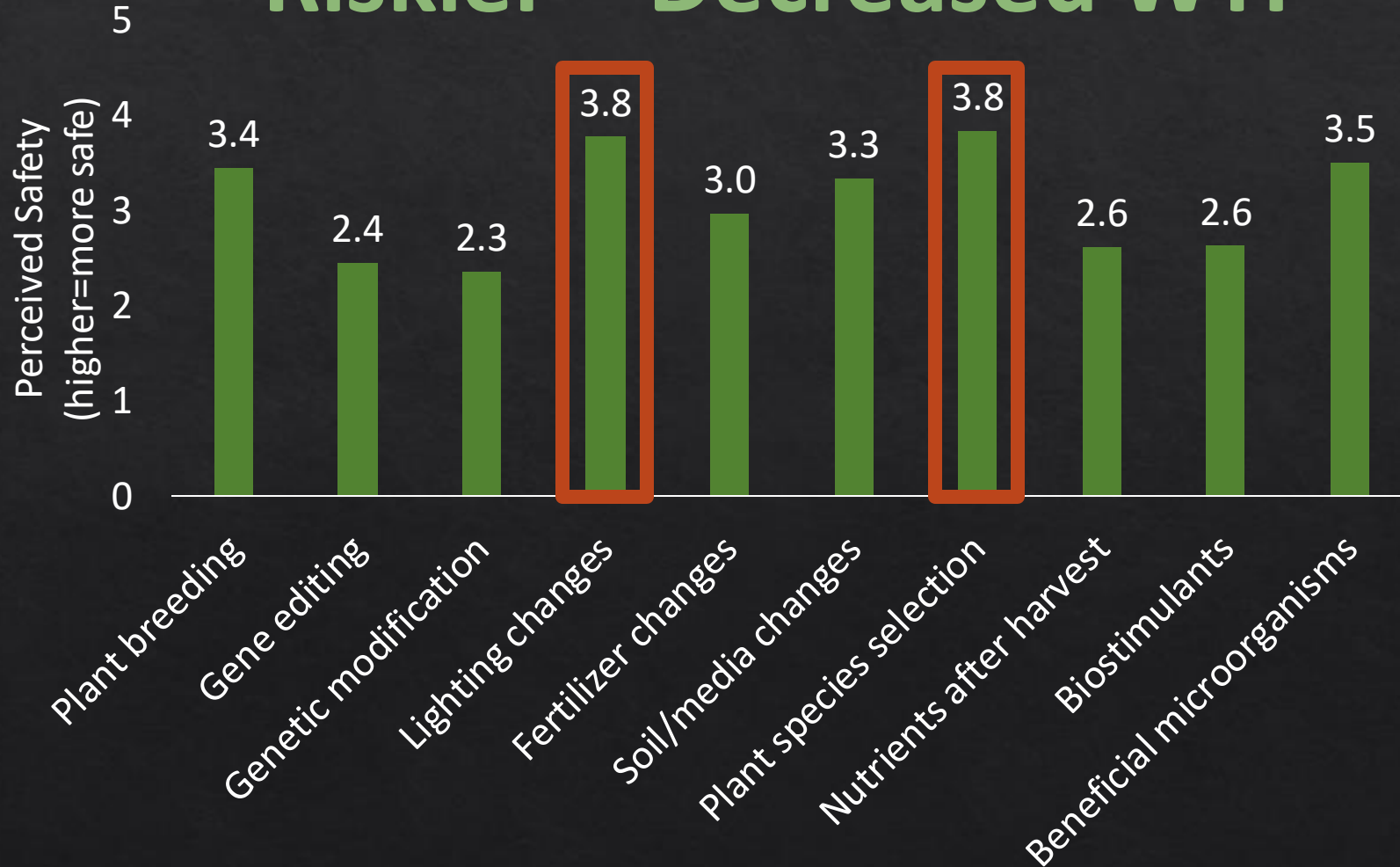
# Which of the following techniques do you perceive as being the best option to improve microgreen nutrition?

Light Enhanced +\$0.47 to \$0.79



If you were seeking nutritionally dense microgreens, how safe for consumption would you perceive the following methods of enhancing nutrition?

Riskier = Decreased WTP



**Controlled Environment Agriculture  
Great Challenges and Opportunities**

# Leafy Greens End-of-Production Strategies

Exploring the feasibility of end-of-production regimens to improve leafy greens nutritional content, appearance, and post-harvest longevity

1. Lighting Strategies
2. Temperature
3. Nutrient Solutions
4. Economic Feasibility
5. Training Resources



THE UNIVERSITY OF  
TENNESSEE  
KNOXVILLE



# CEA HERB:

Controlled Environment Agriculture Herb Extension and Research Base

## 1. Marketing and Economics

- Increase the demand and marketability of culinary herbs through marketplace feasibility studies of different production, sensory, and marketing characteristics.

## 2. Production, Post-harvest, Food Safety, and Plant Protection

- Increase and optimize herb growth, yield, disease management, and post-harvest quality through CE environmental and cultural control and develop CE curricula related to food safety.

## 3. Engage Stakeholders

- Develop new profitable and sustainable CE herb grower resources, protocols, and tools that lead to high-quality, safe-to-eat, flavorful, and nutritious herbs with an extended shelf-life.





# Acknowledgements

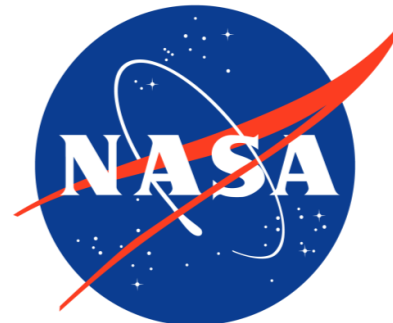
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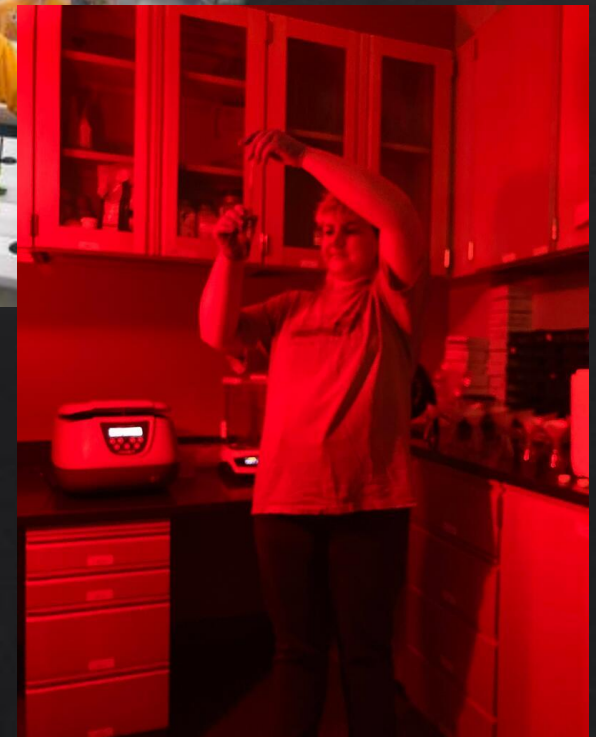
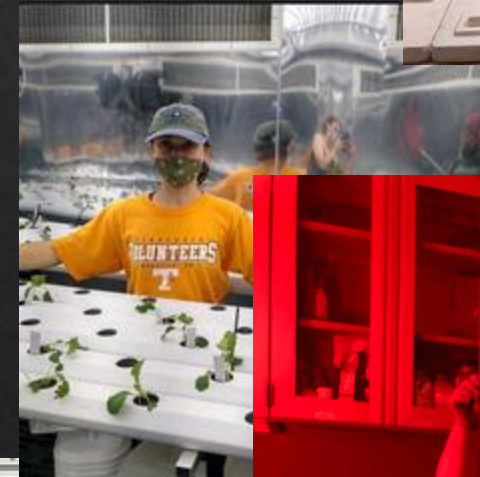
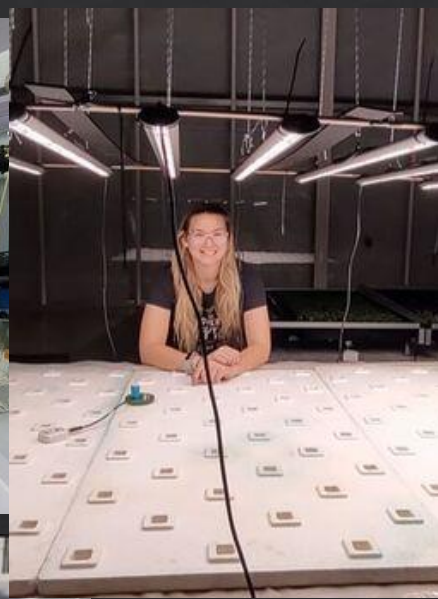
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