Supplemental LED Effects on Growth and Phytonutrients of 'Outredgeous' Lettuce

Matthew Mickens, Emilie J. Skoog, Gioia Massa, and Raymond Wheeler

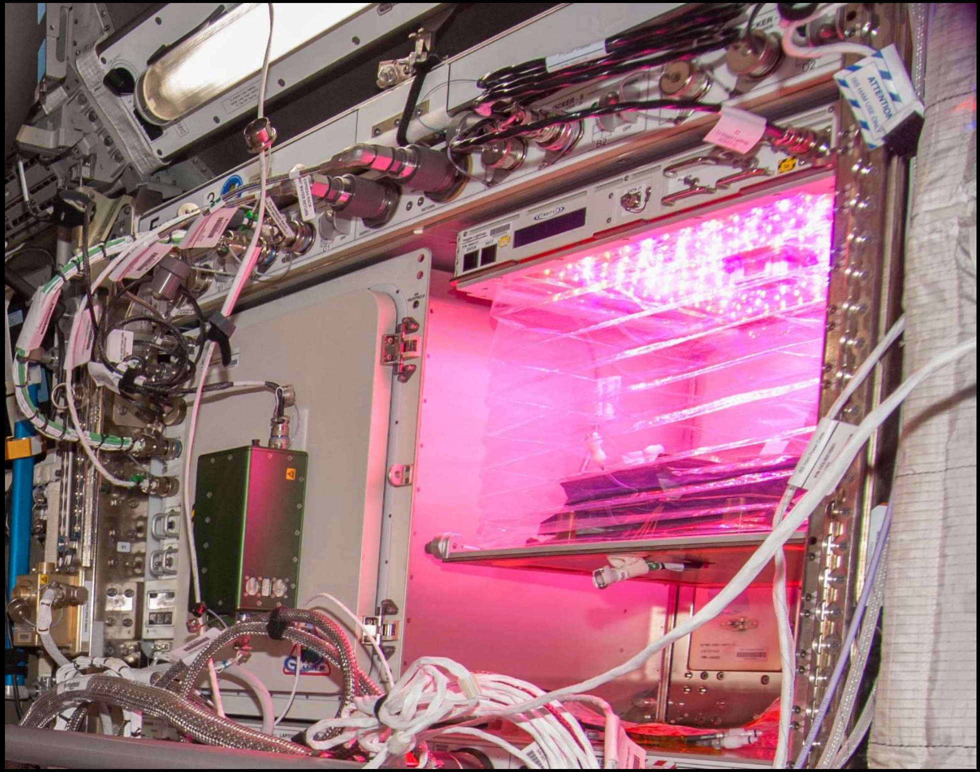
Kennedy Space Center

NASA Postdoctoral Program (NPP)

Exploration Research and Technology Programs

INTRODUCTION

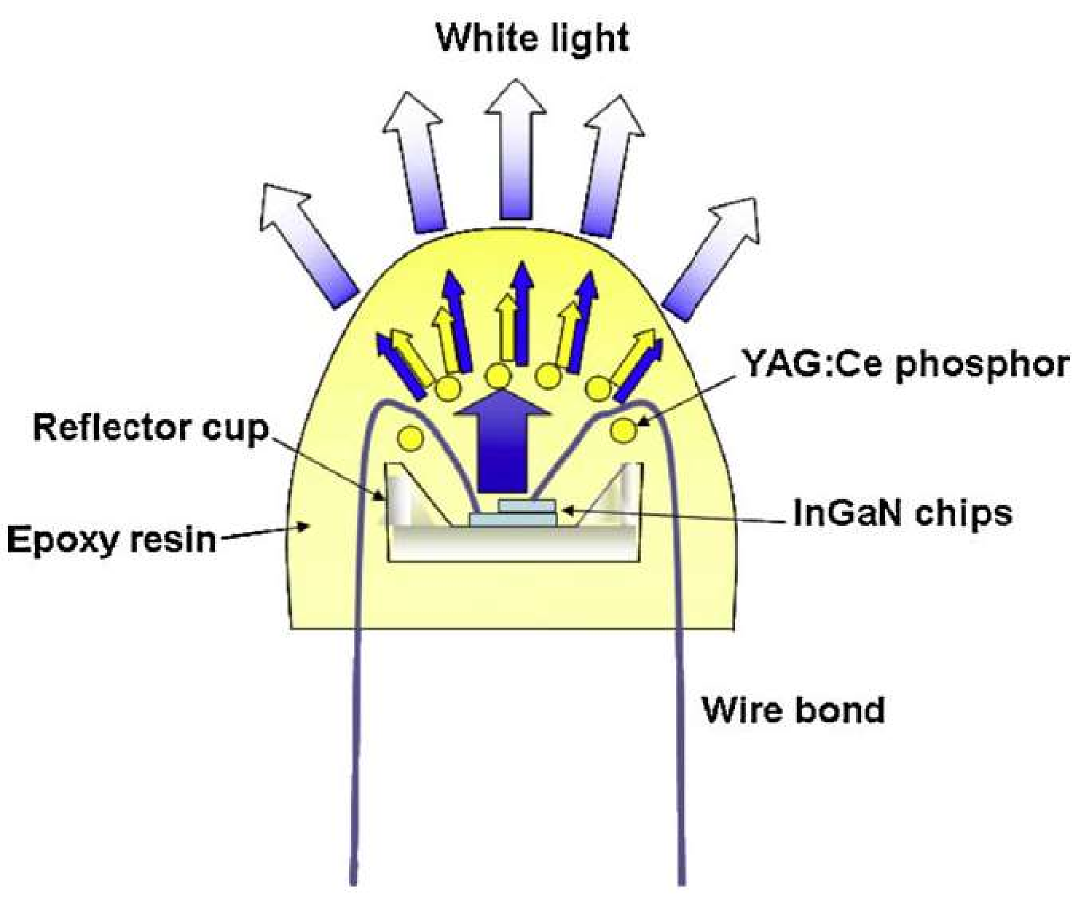
Is Red and Blue Light Enough?



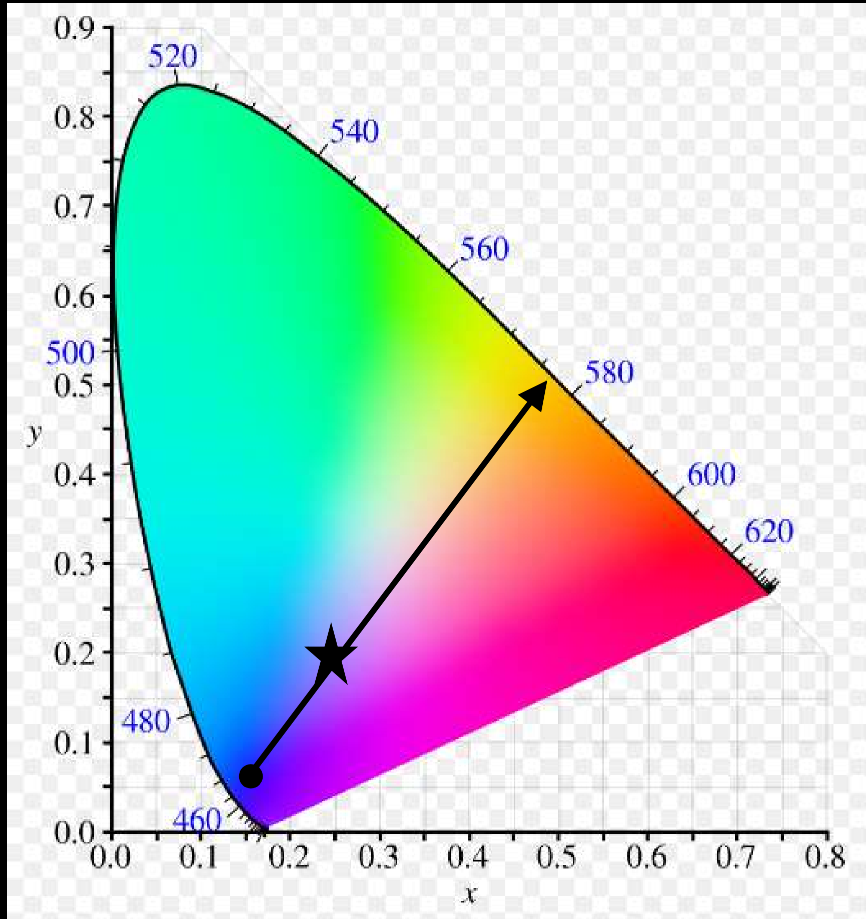
ISS VEGGIE Chamber
Flight Experiments

Kennedy Space Center
Ground Experiments

Using WLEDs for Plant Growth

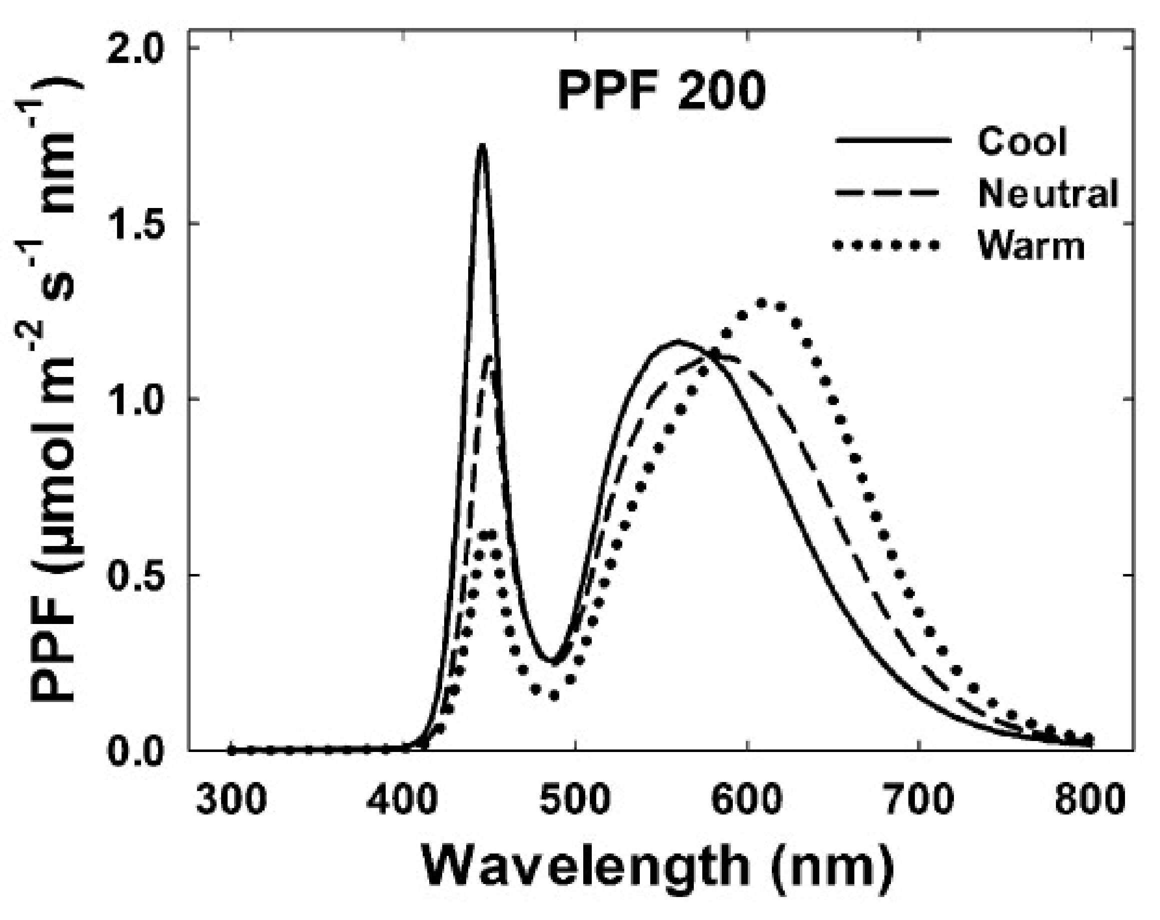


Phosphors in phosphor-converted white light-emitting diodes: Recent advances in materials, techniques and properties. S. Ye, F. Xiao, Y.X. Pan, Y.Y. Ma, Q.Y. Zhang. Mater. Sci. Eng. R 71 (2010) 1-34.



CIE Chromaticity Diagram

WLED Spectrum



Spectral Effects of Three Types of White Light-emitting Diodes on Plant Growth and Development: Absolute versus Relative Amounts of Blue Light

2013

Kevin R. Cope[1] and Bruce Bugbee

Department of Plants Soils and Climate, Utah State University, 4820 Old Main Hill, Logan, UT 84322-4820

Objectives:

1. To examine the effects of B, G, R, and FR LEDs on lettuce growth when supplemented with WLEDs as a background.

2. To identify an optimal combination that could be used for 'Outredgeous' lettuce grown in the future Advanced Plant Habitat (APH).

3. To determine any effects of these light treatments on phytonutrient accumulation (ongoing).

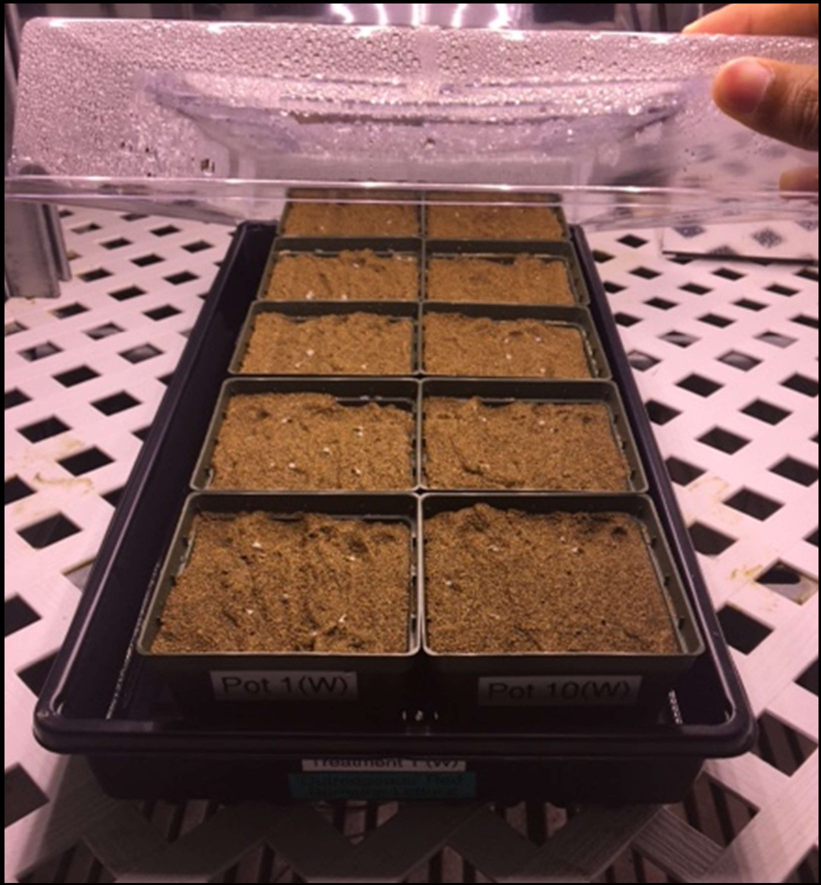
METHODS

Growth Measurements (14, 21, and 28 DAP)

- **Shoot Length**
- **Shoot Diameter**
- **Leaf Area**
- **Leaf Number**
- **Relative Chlorophyll (SPAD)**
- **Fresh and Dry Mass**

Cultural Conditions

- **Arcillite clay media (< 1 mm particle size)**
- **Nutricote controlled-release fertilizer (NPK=18:6:8, Type 70 day)**
- **Air Temperature: 23 °C**
- **CO_2: 1200 μmol·mol^{-1}**
- **RH: 70 %**
- **Pots rotated 3 times a week**
- **Photoperiod: 18 hr light/6 hr dark**

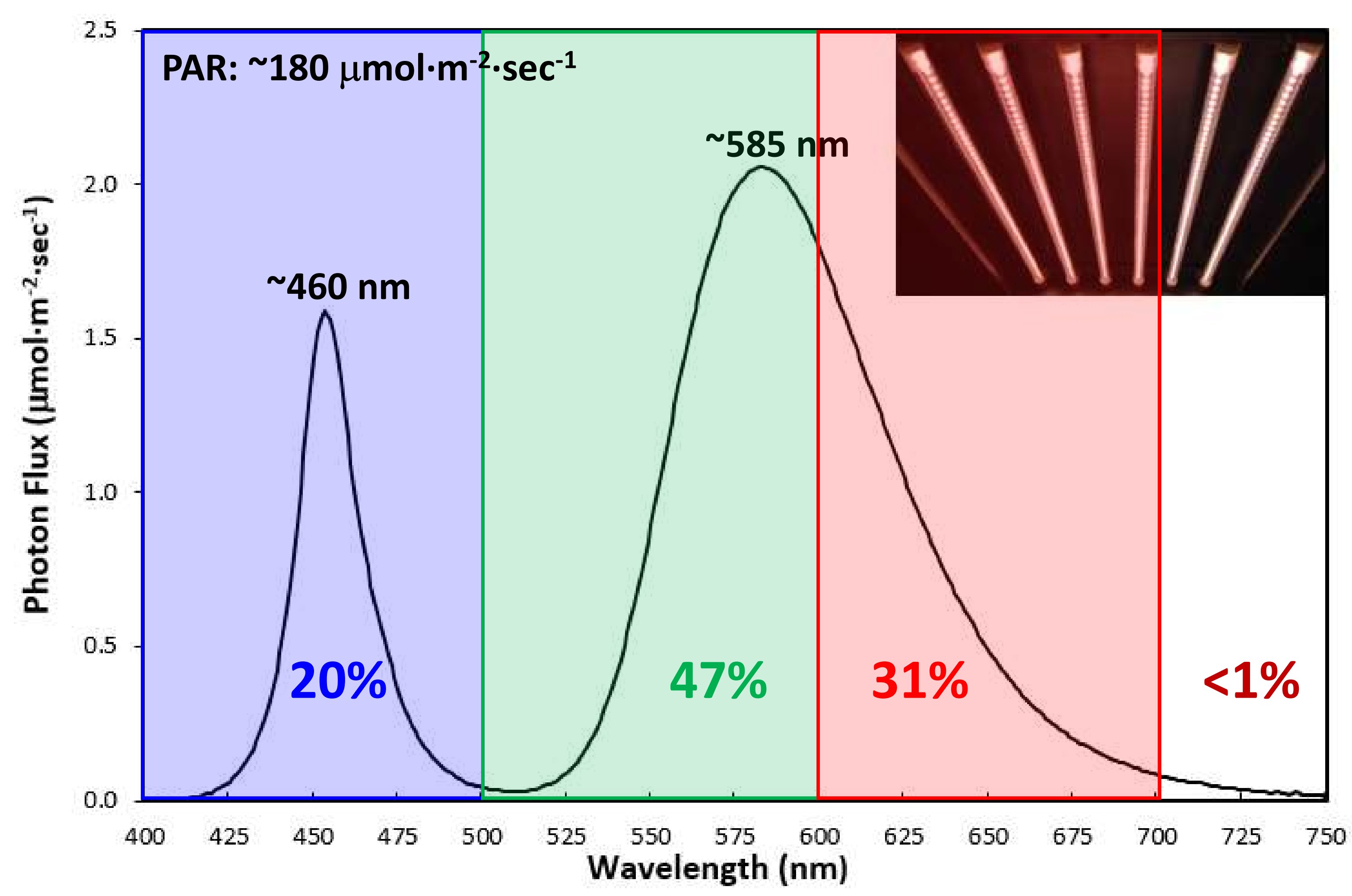


LIGHT TREATMENTS

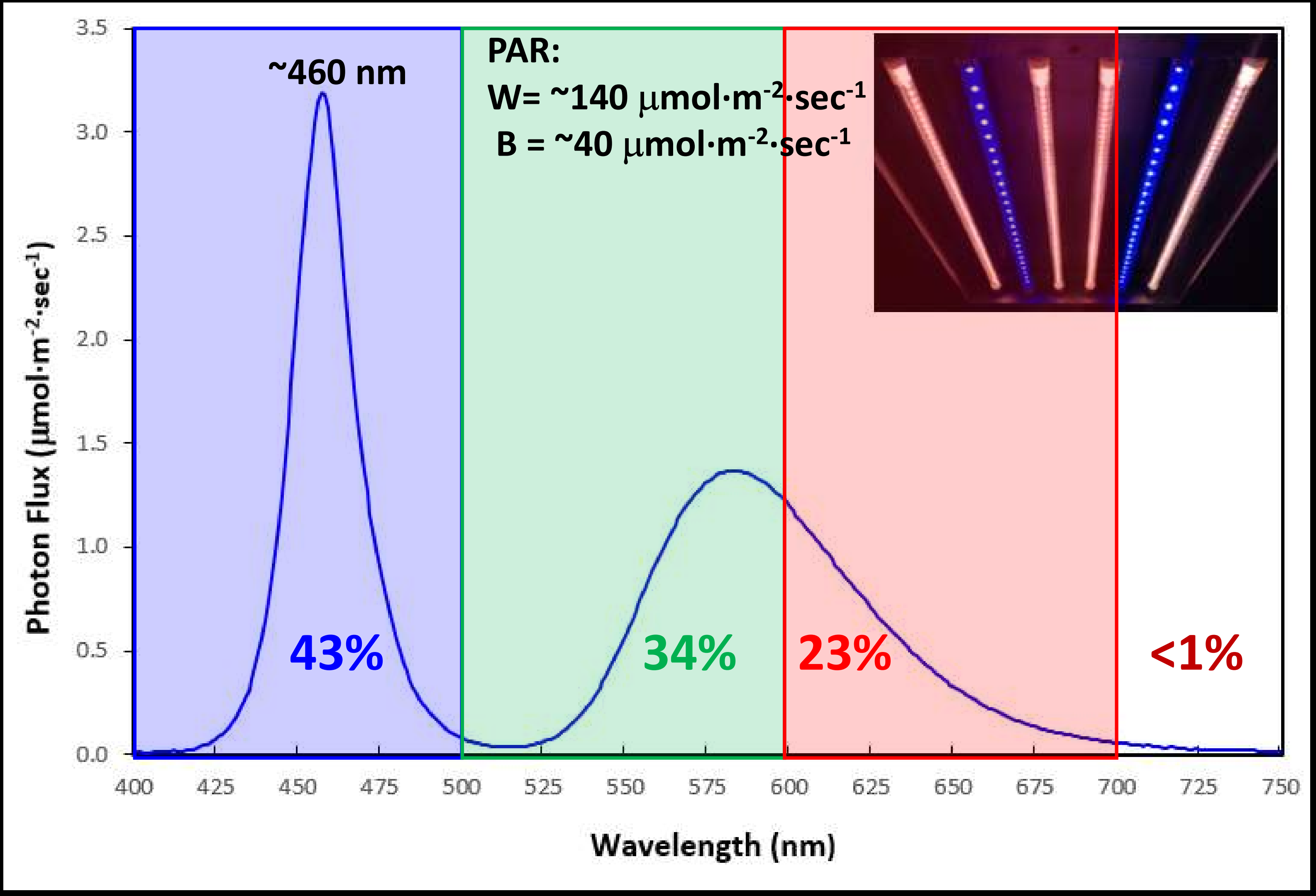
WLED Fixture

AIBC Full Spectrum Super T Panel (Ithaca, NY)

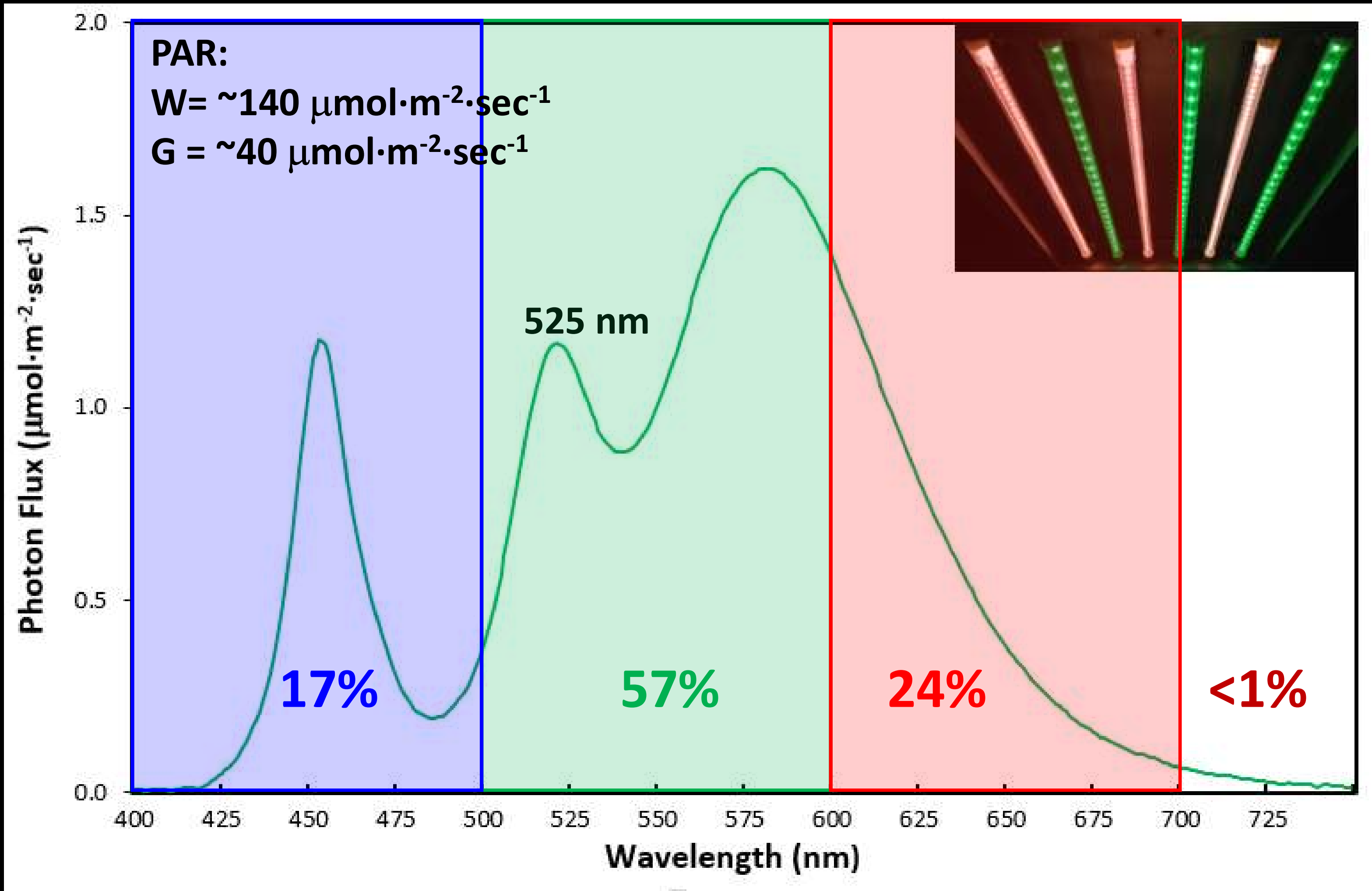
Treatment 1 (White Control)



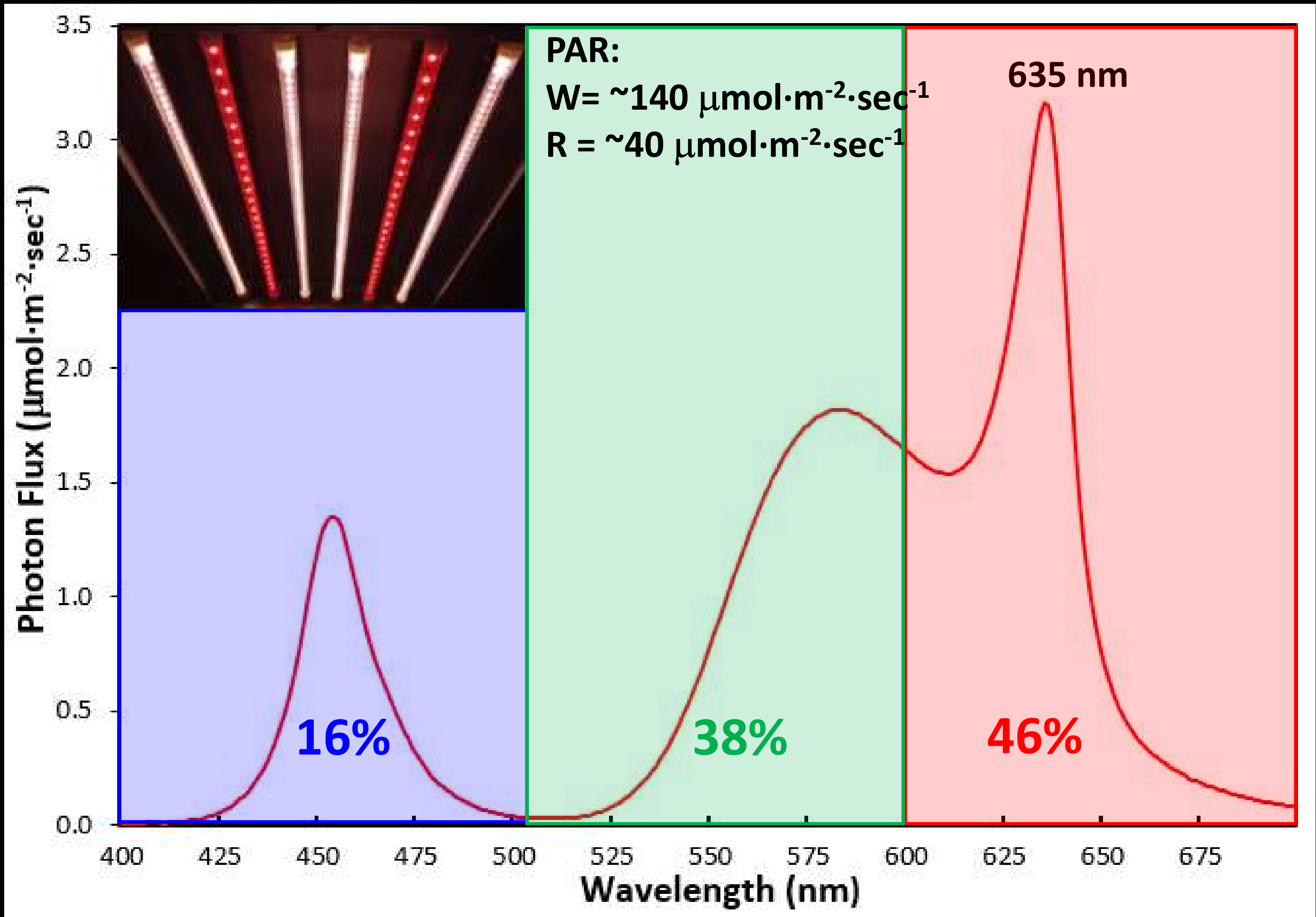
Treatment 2 (W + B)



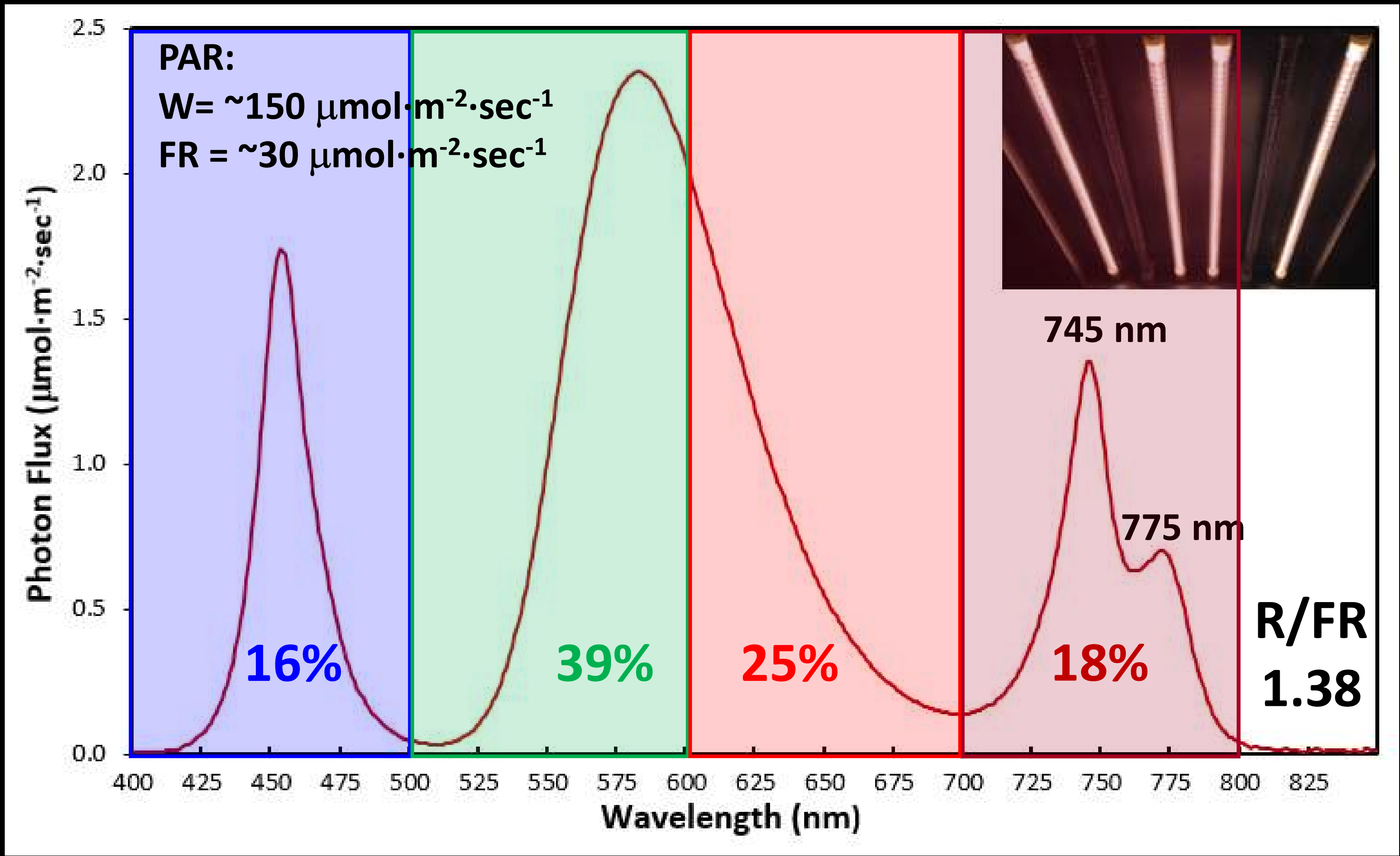
Treatment 3 (W + G)

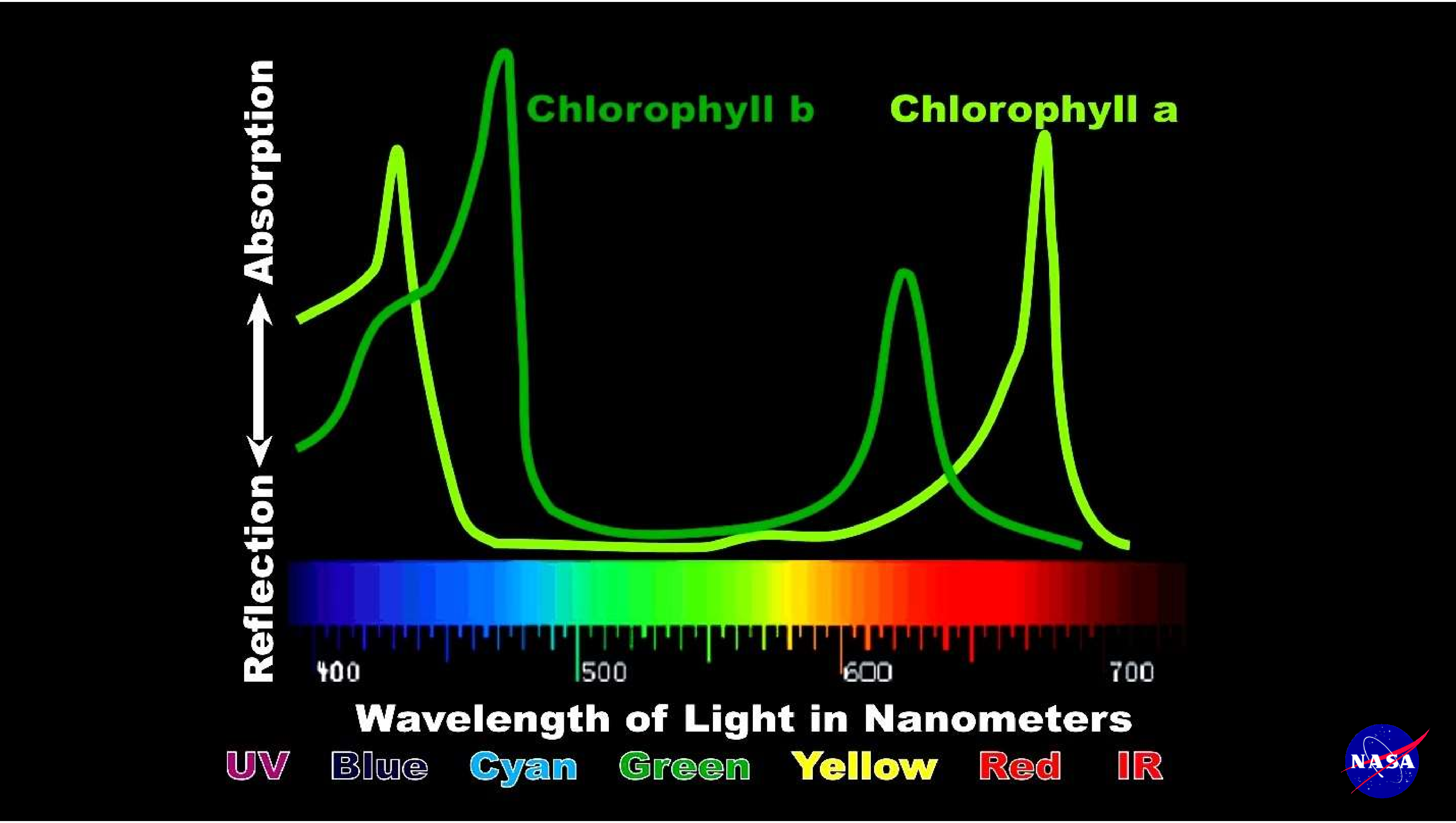


Treatment 4 (W + R)



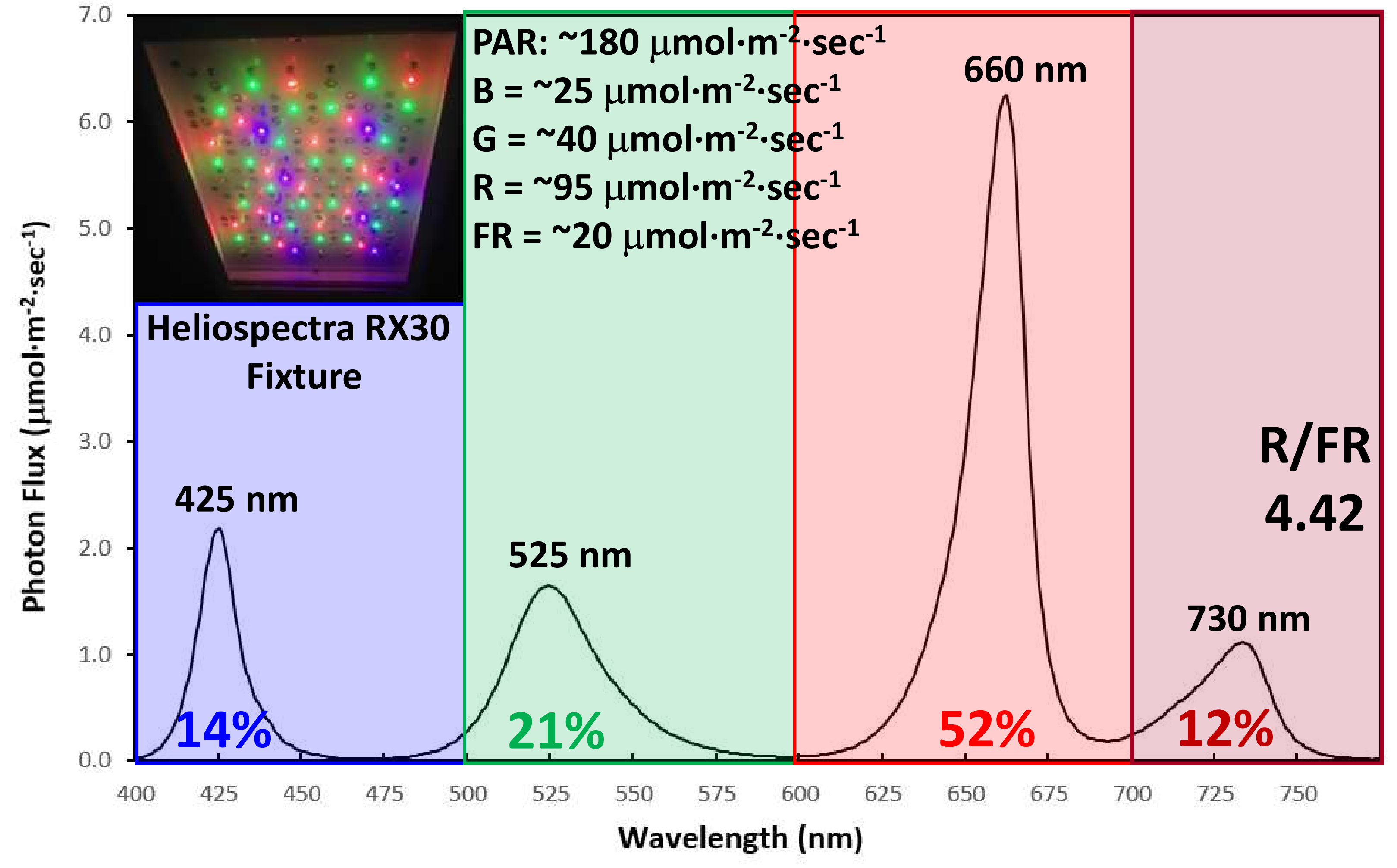
Treatment 5 (W + FR)

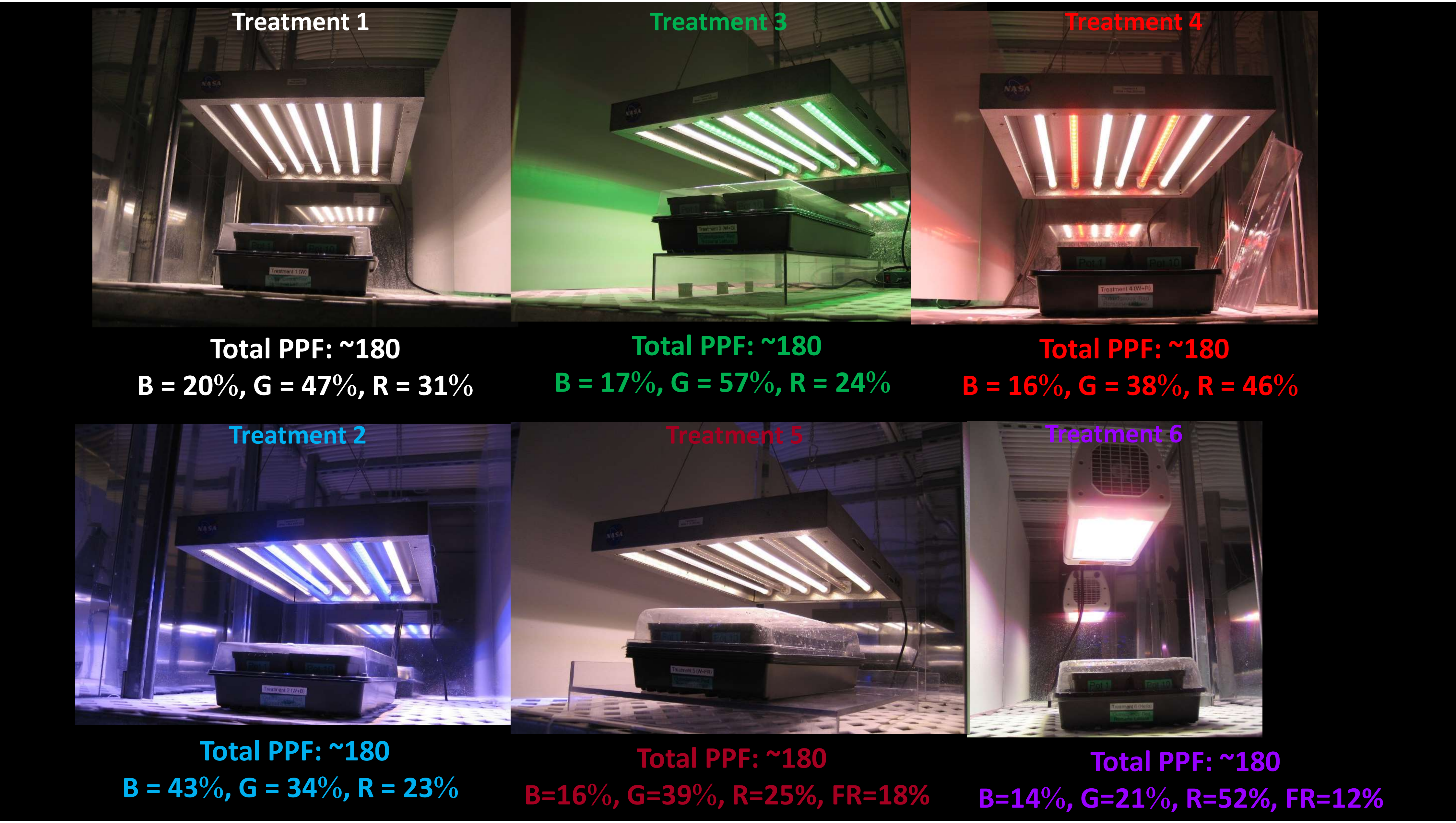




Chlorophyll b
Chlorophyll a
Absorption
Reflection
400
500
600
700
Wavelength of Light in Nanometers
UV
Blue
Cyan
Green
Yellow
Red
IR
NASA

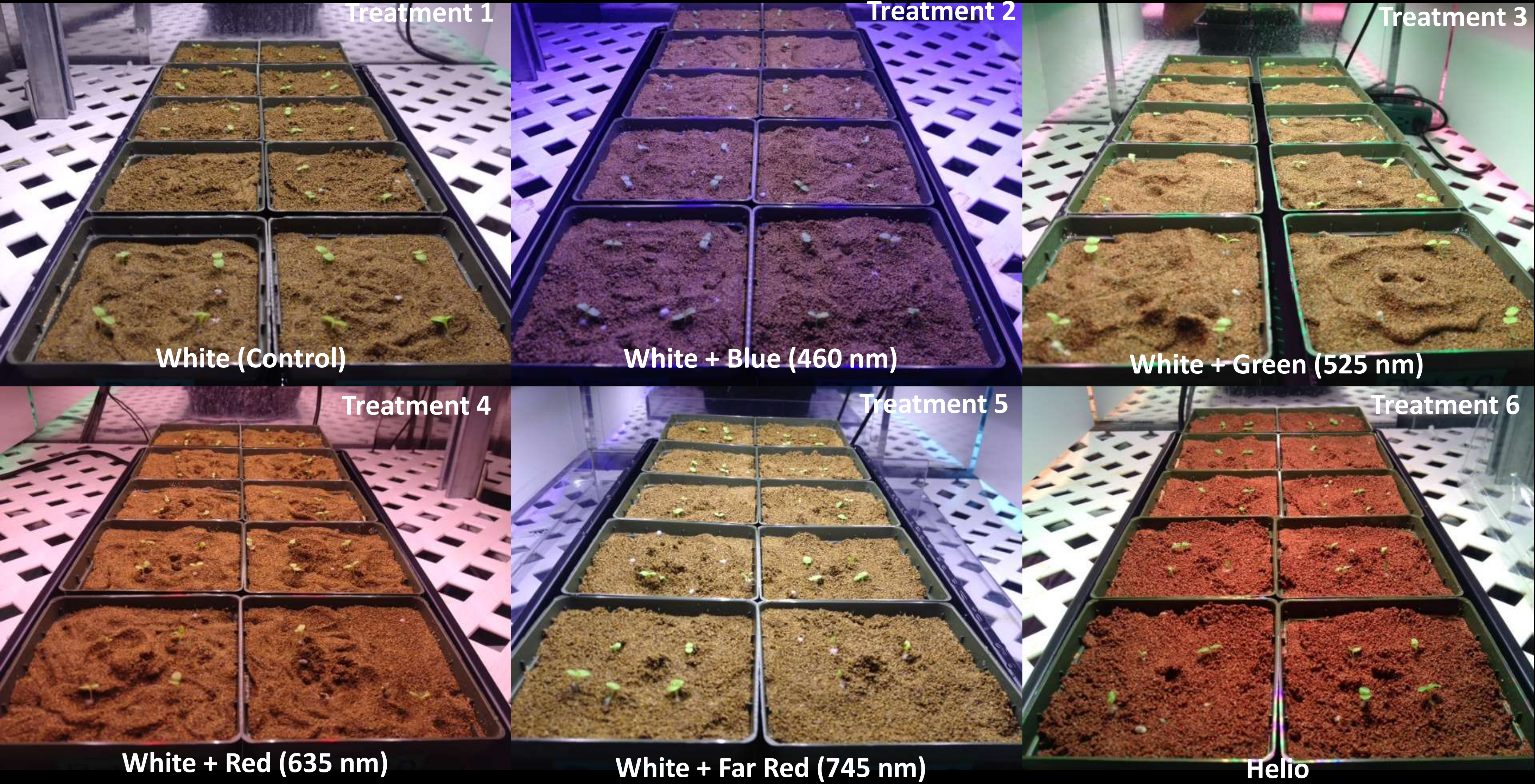
Treatment 6 (Helio)



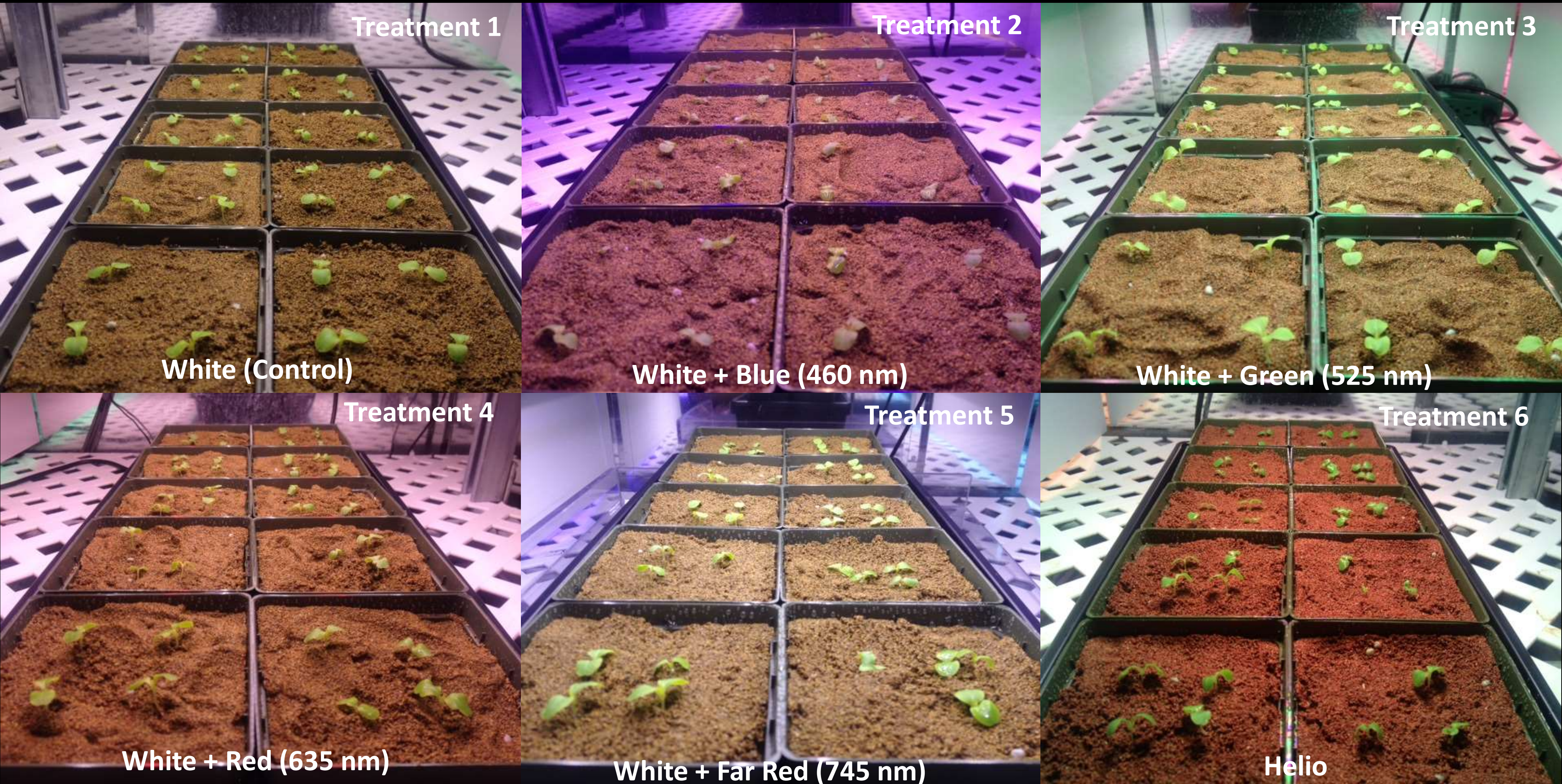

Treatment 1
Total PPF: ~180
B = 20%, G = 47%, R = 31%
Treatment 3
Total PPF: ~180
B = 17%, G = 57%, R = 24%
Treatment 4
Total PPF: ~180
B = 16%, G = 38%, R = 46%
Treatment 2
Total PPF: ~180
B = 43%, G = 34%, R = 23%
Treatment 5
Total PPF: ~180
B=16%, G=39%, R=25%, FR=18%
Treatment 6
Total PPF: ~180
B=14%, G=21%, R=52%, FR=12%

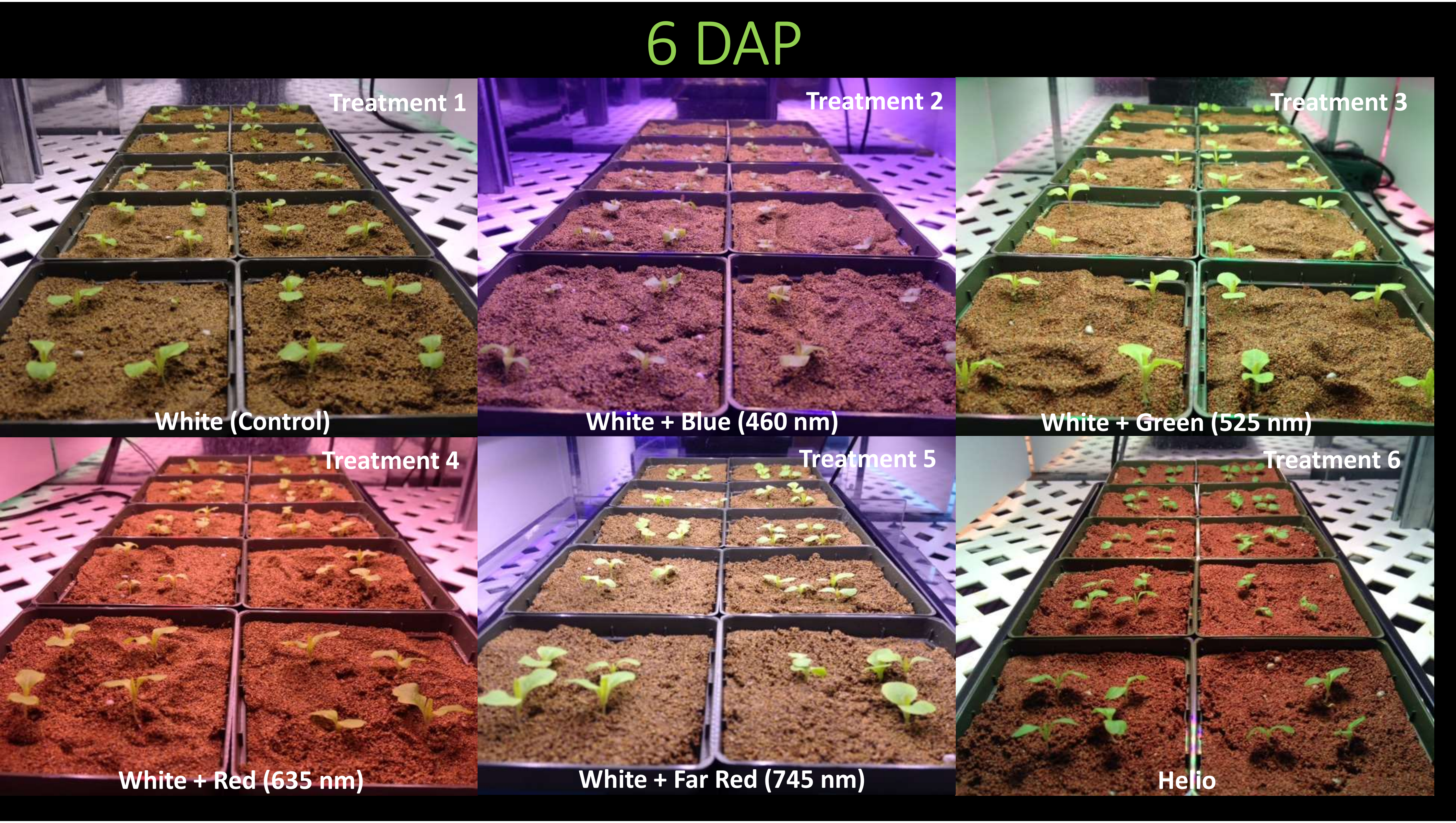
Growth

3 DAP

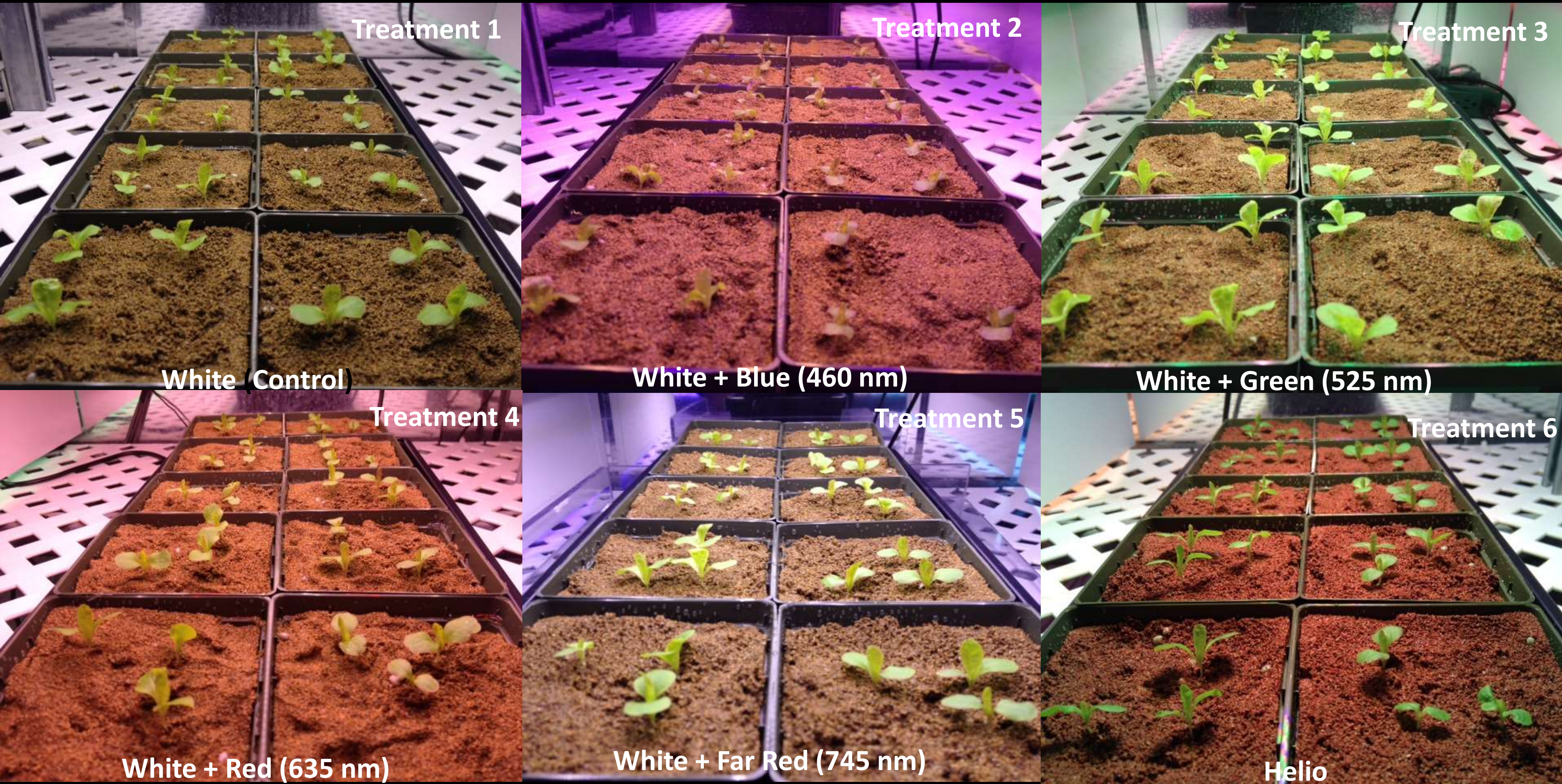

Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

5 DAP


Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio


6 DAP
Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

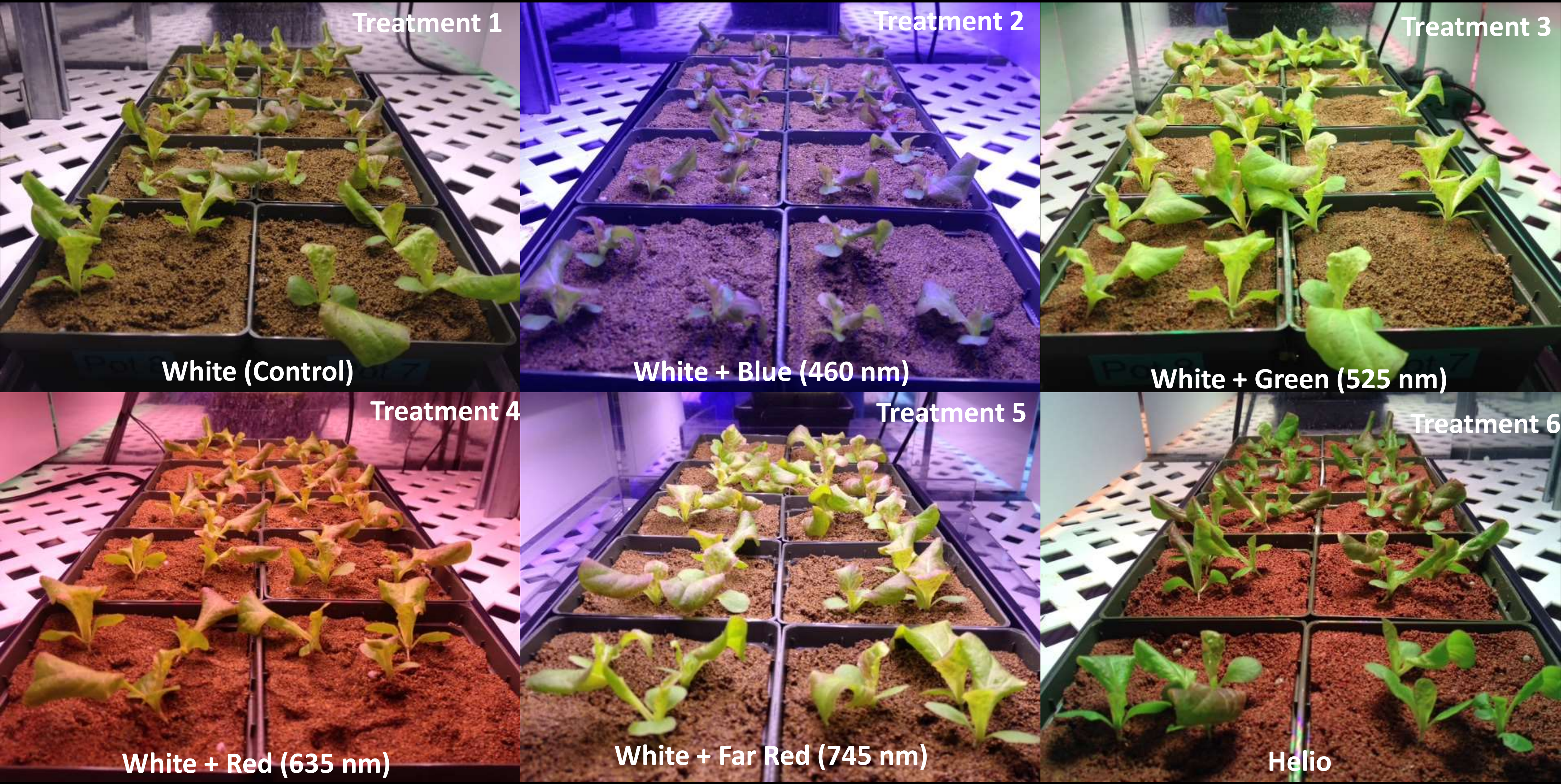
7 DAP


Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

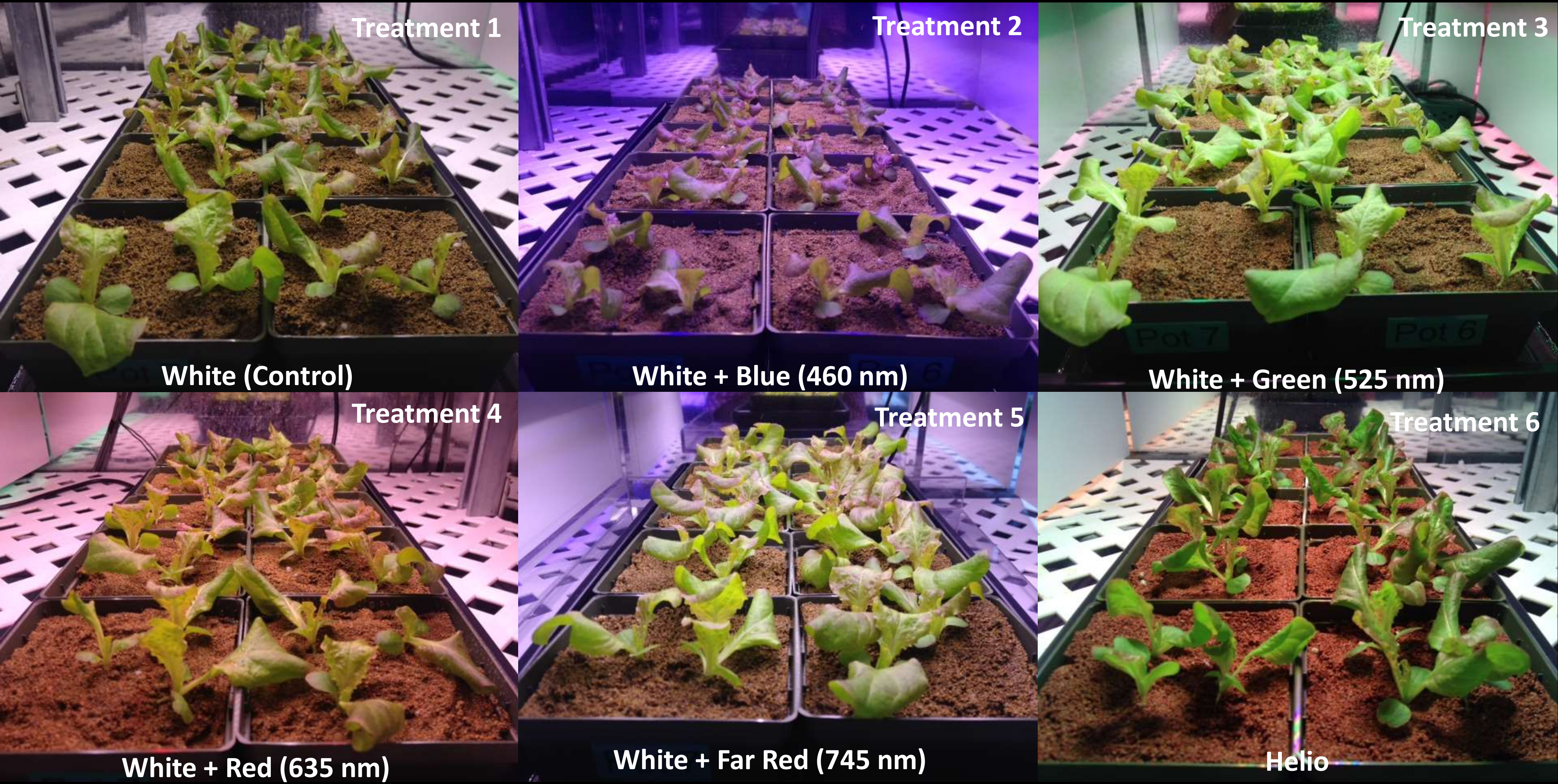
7 DAP (Initial Thinning)

1. White (Control)
2. W + B (460 nm)
3. W + G (525 nm)
4. W + R (635 nm)
5. W + FR (745 nm)
6. Helio (425 nm + 525 nm + 660 nm + 733 nm)

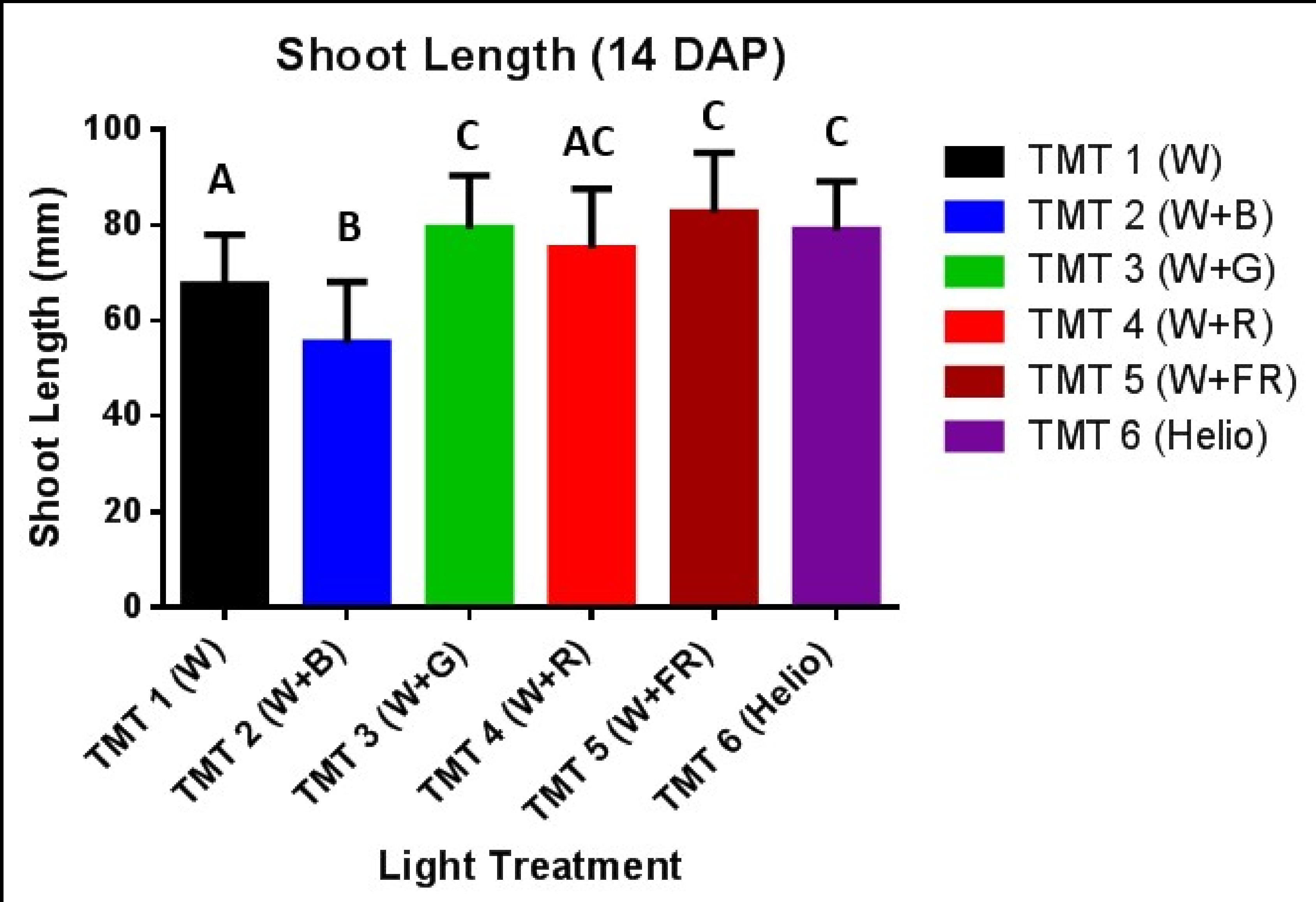
10 DAP


Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

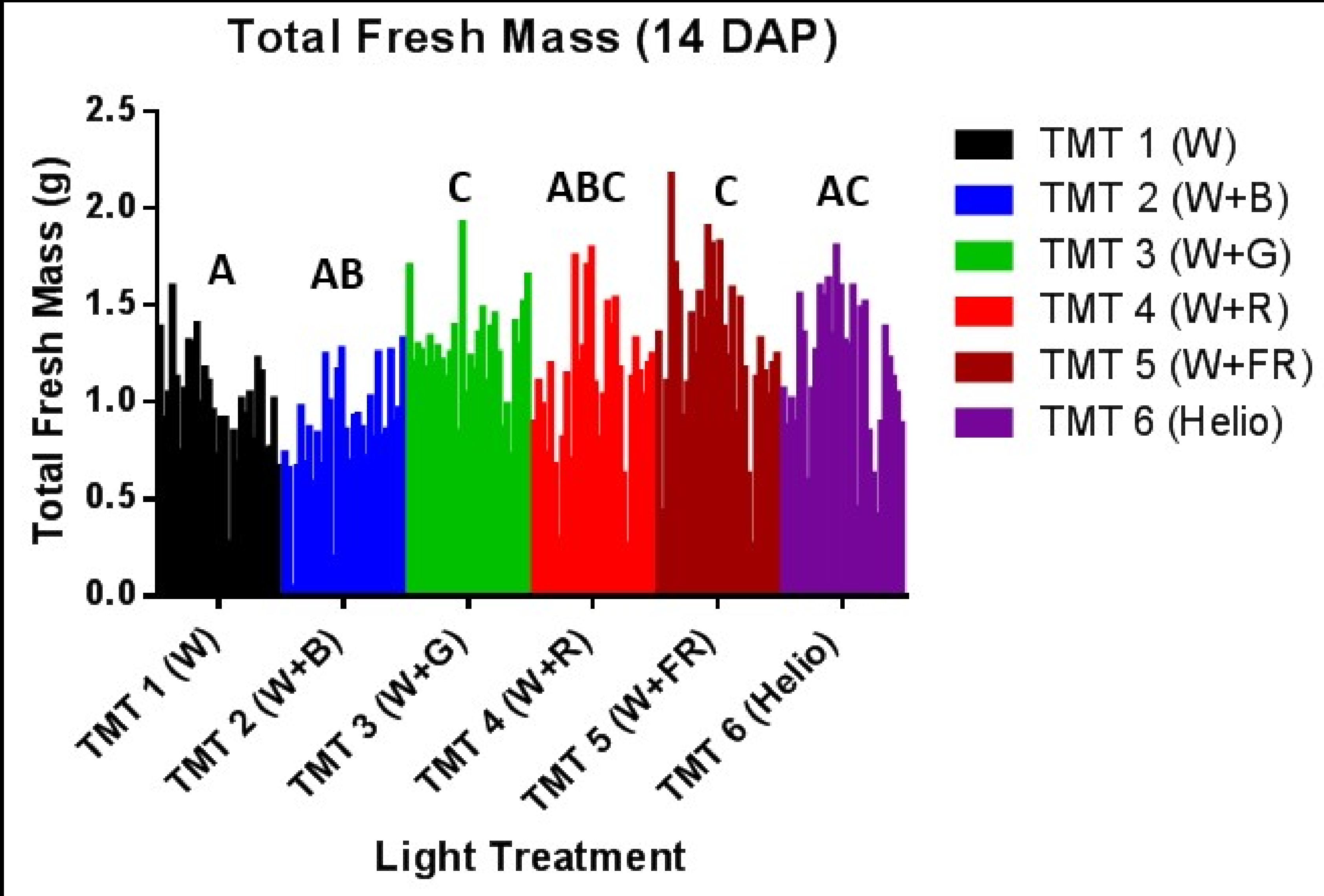
11 DAP


Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

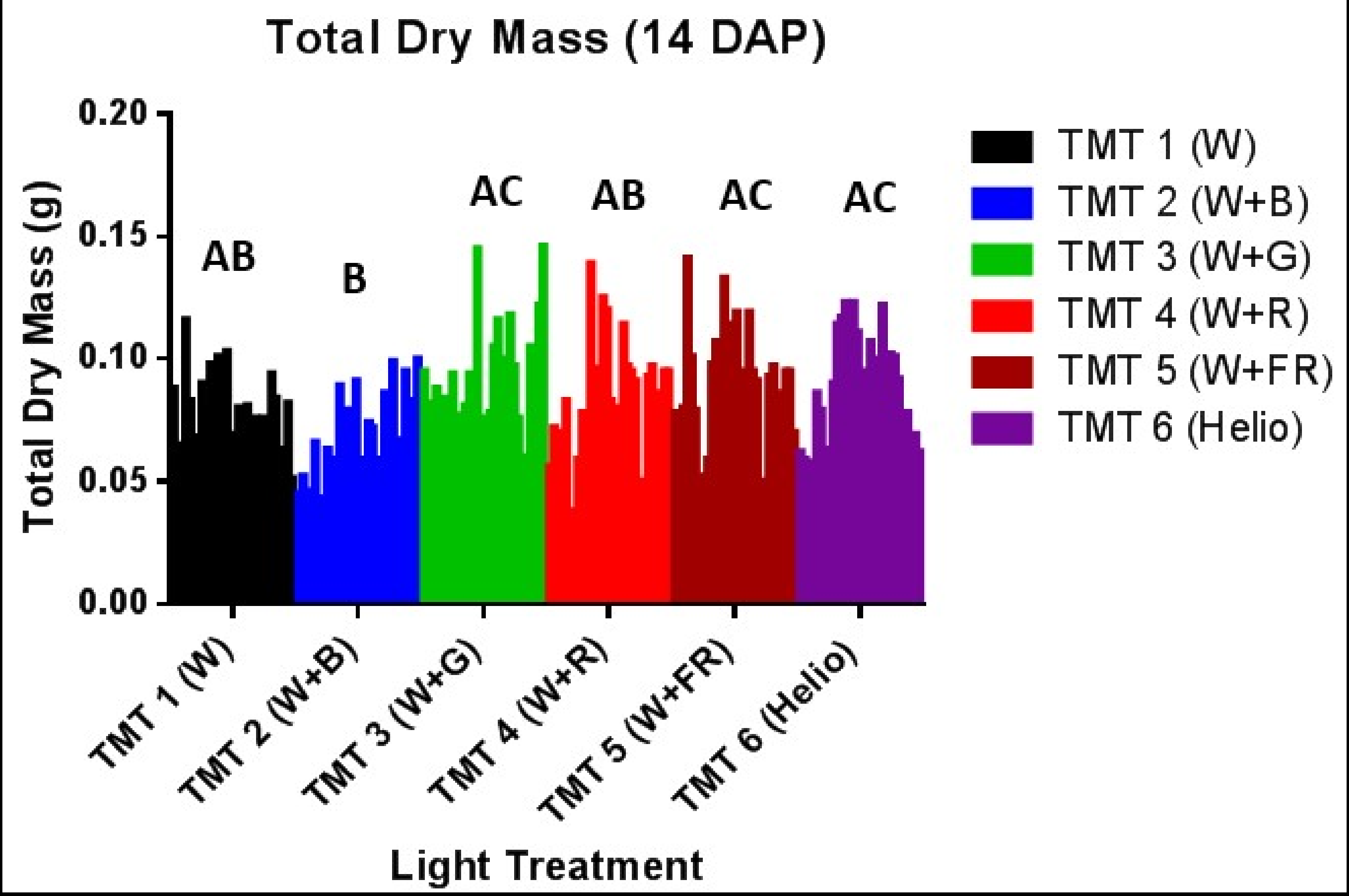
14 DAP RESULTS



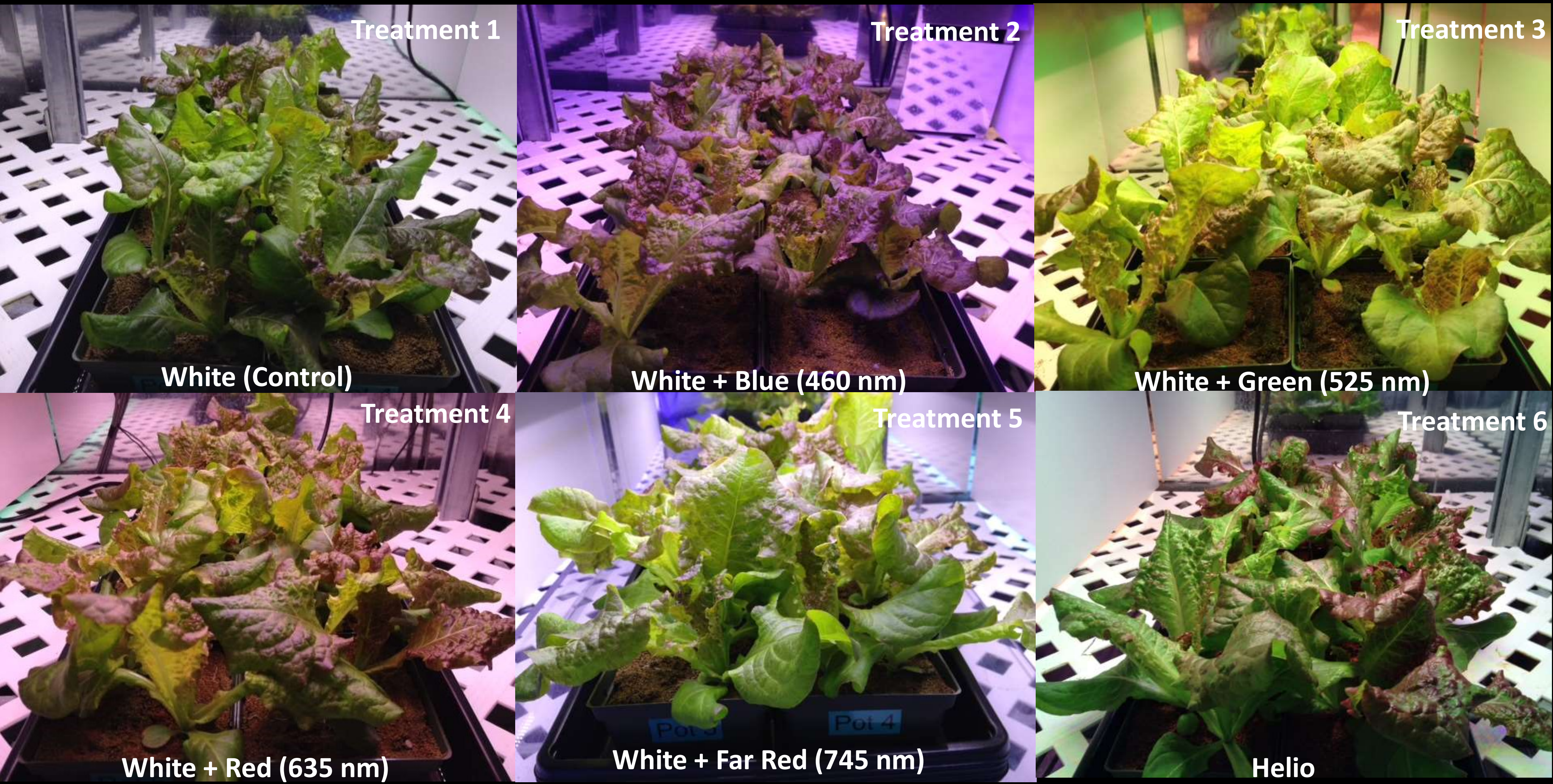
Shoot Length (14 DAP)
Shoot Length (mm)
100
80
60
40
20
0
A
B
C
AC
C
C
TMT 1 (W)
TMT 2 (W+B)
TMT 3 (W+G)
TMT 4 (W+R)
TMT 5 (W+FR)
TMT 6 (Helio)
Light Treatment



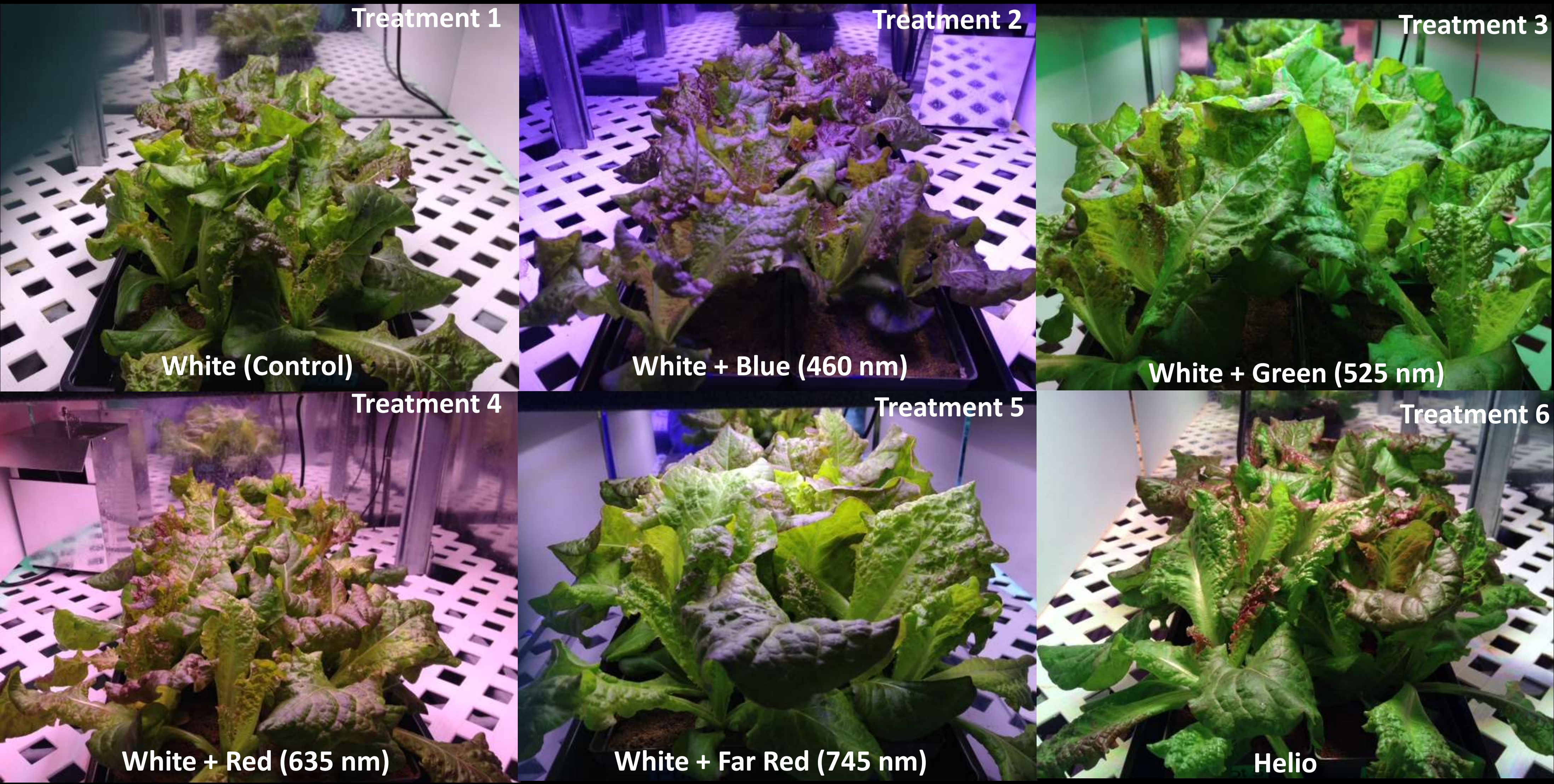
Total Fresh Mass (14 DAP)
Total Fresh Mass (g)
2.5
2.0
1.5
1.0
0.5
0.0
A
AB
C
ABC
C
AC
TMT 1 (W)
TMT 2 (W+B)
TMT 3 (W+G)
TMT 4 (W+R)
TMT 5 (W+FR)
TMT 6 (Helio)
Light Treatment


Total Dry Mass (14 DAP)
Total Dry Mass (g)
0.20
0.15
0.10
0.05
0.00
AB
B
AC
AB
AC
AC
TMT 1 (W)
TMT 2 (W+B)
TMT 3 (W+G)
TMT 4 (W+R)
TMT 5 (W+FR)
TMT 6 (Helio)
Light Treatment
TMT 1 (W)
TMT 2 (W+B)
TMT 3 (W+G)
TMT 4 (W+R)
TMT 5 (W+FR)
TMT 6 (Helio)

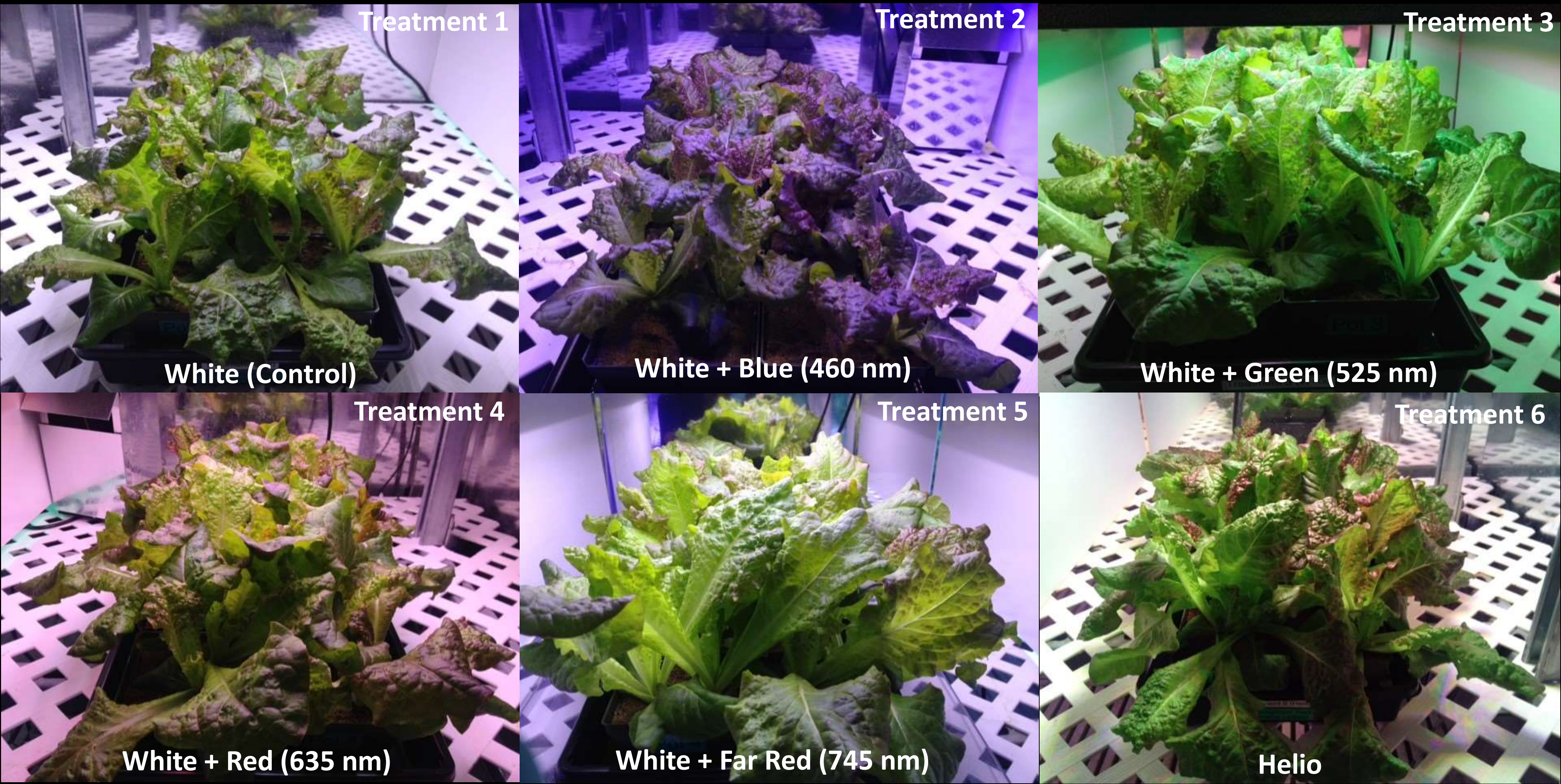
17 DAP


Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

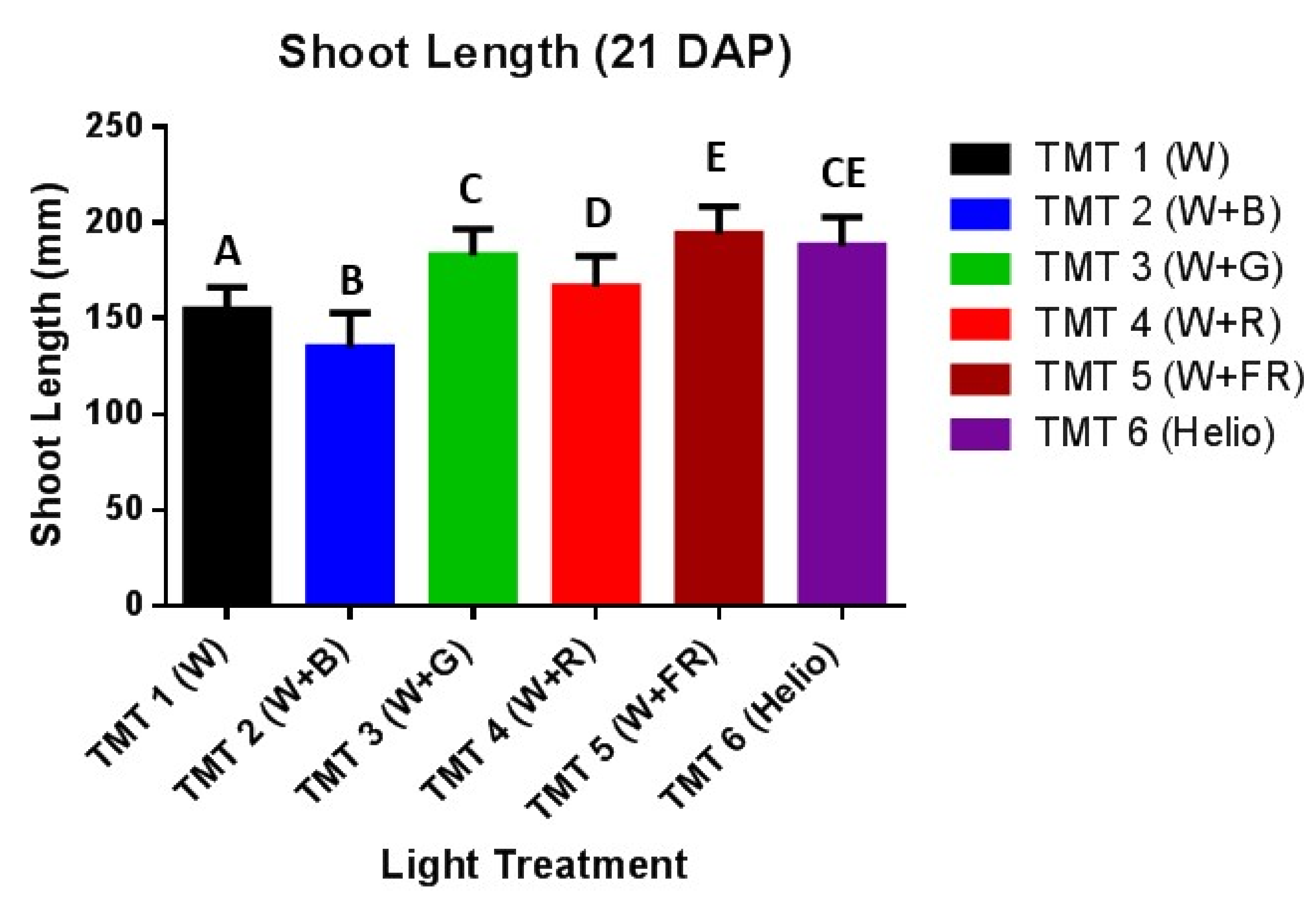
19 DAP


Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

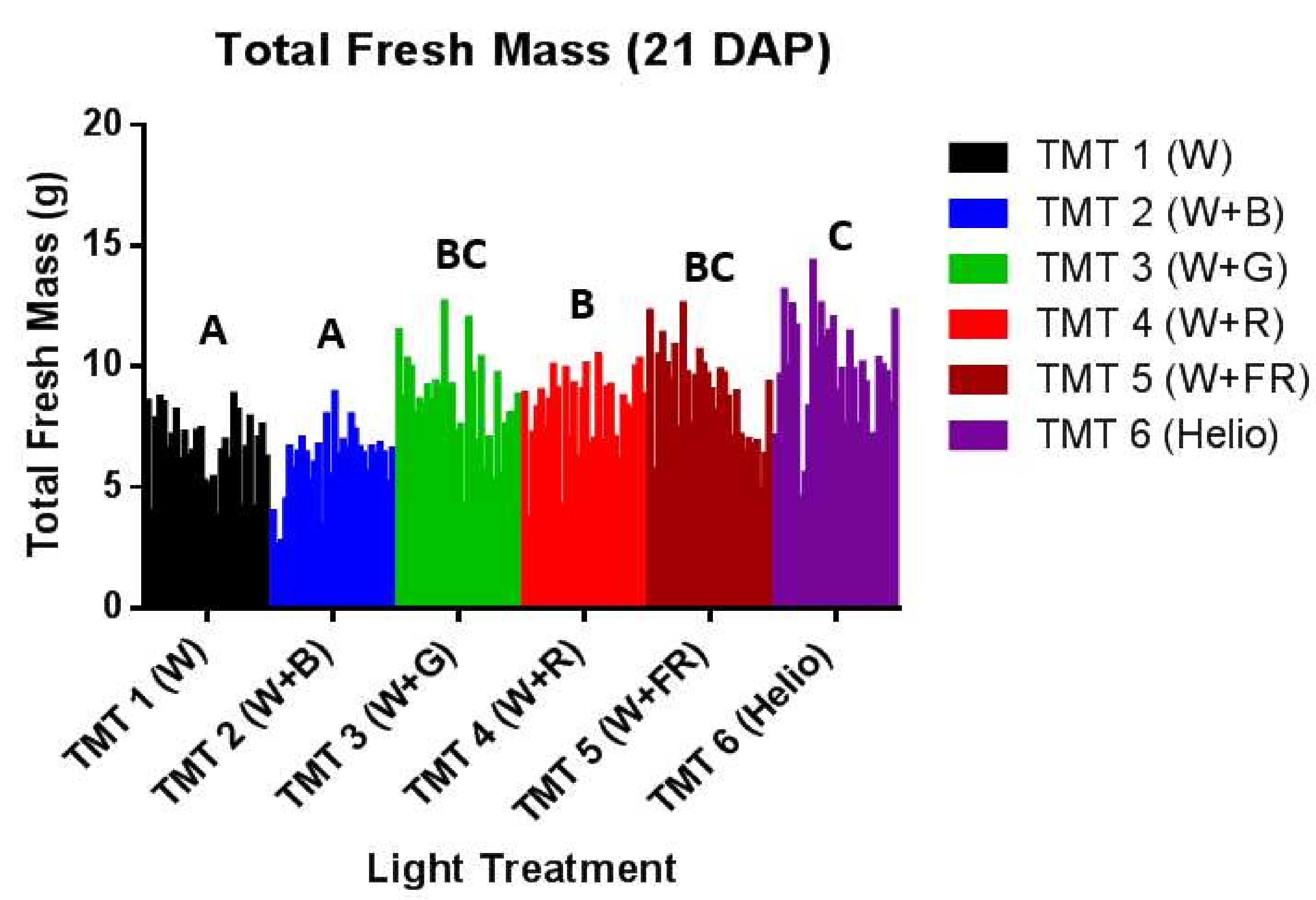
20 DAP

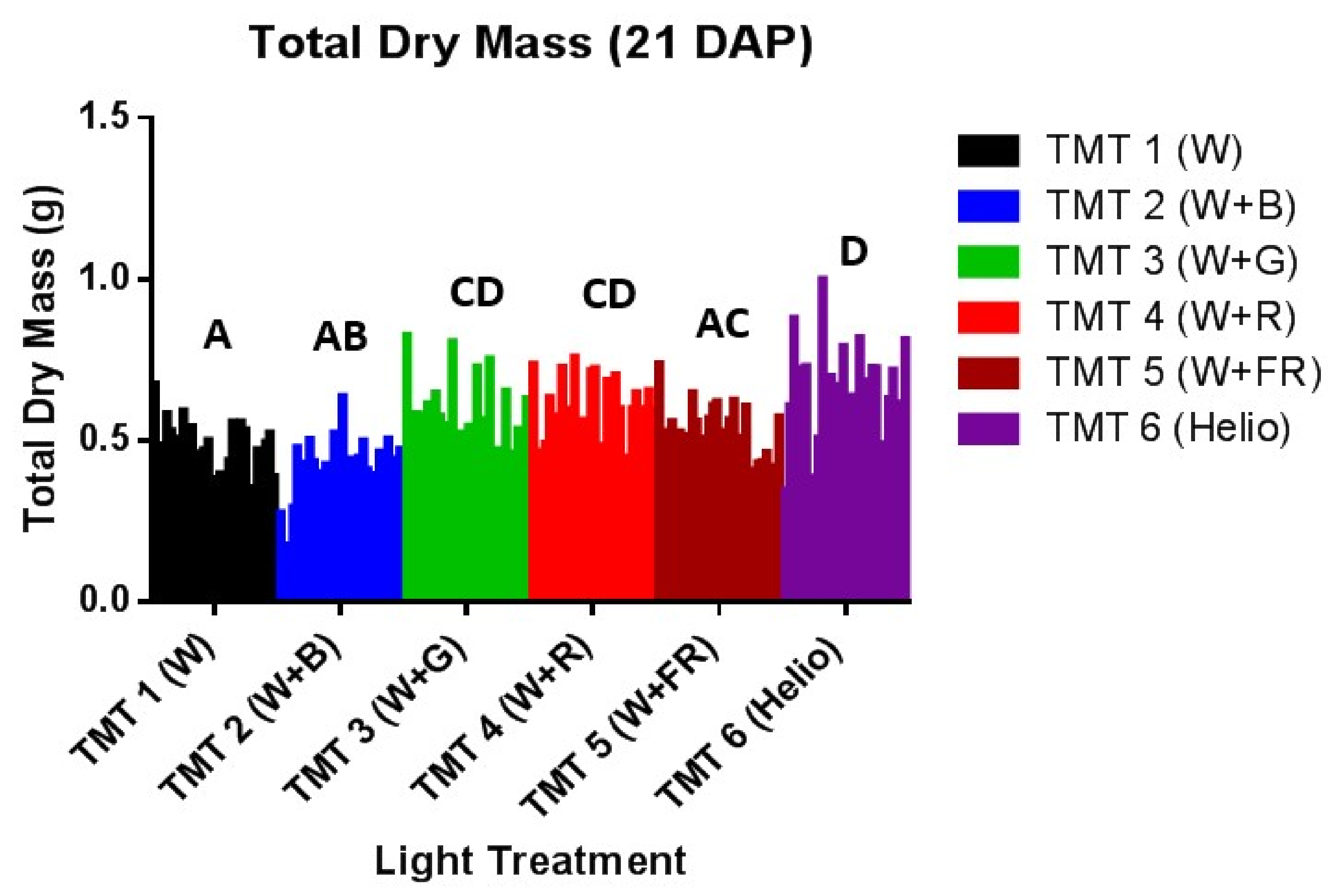

Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

21 DAP RESULTS



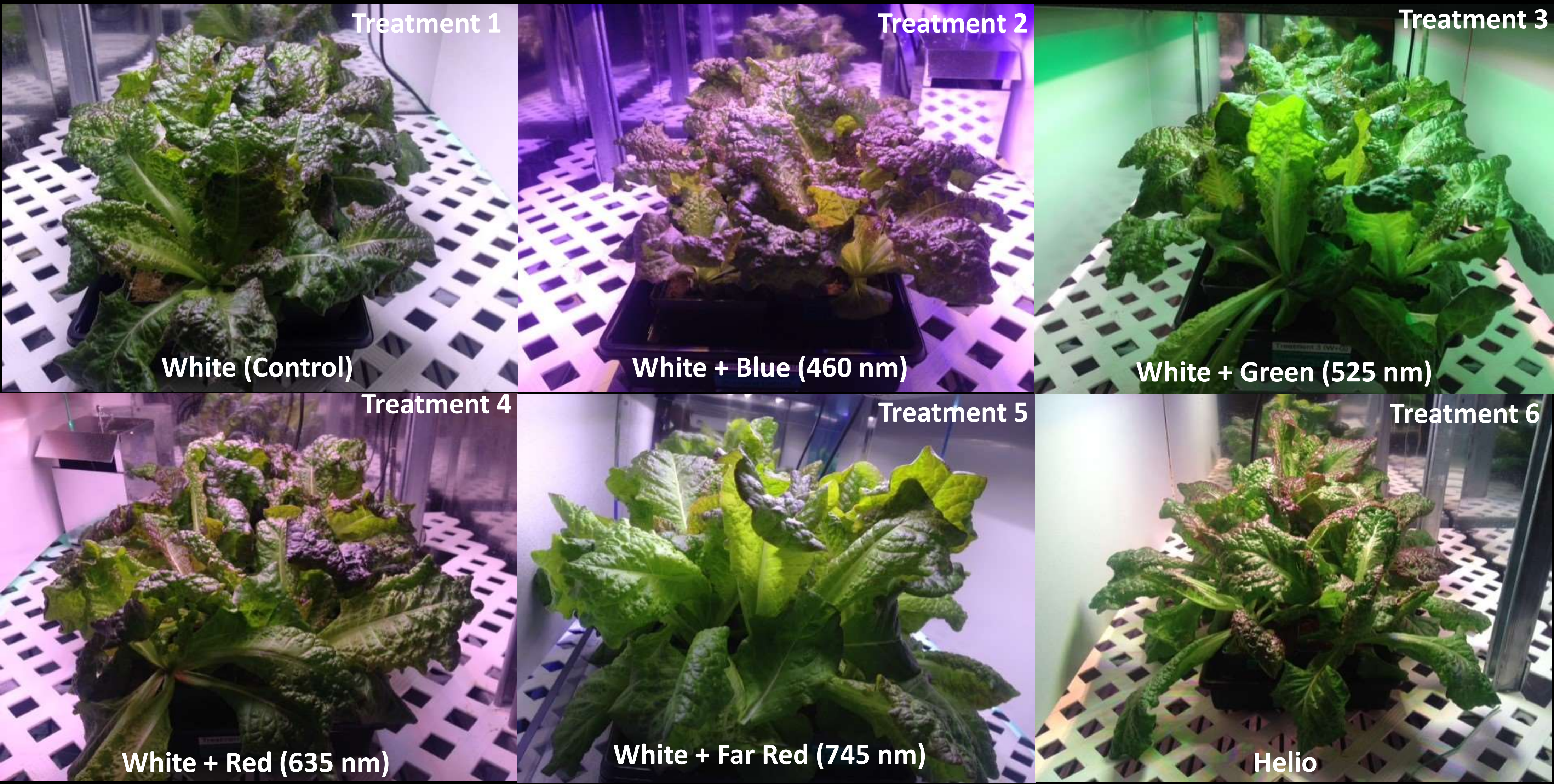
Shoot Length (21 DAP)
Shoot Length (mm)
250
200
150
100
50
0
A
B
C
D
E
CE
TMT 1 (W)
TMT 2 (W+B)
TMT 3 (W+G)
TMT 4 (W+R)
TMT 5 (W+FR)
TMT 6 (Helio)
Light Treatment


Total Fresh Mass (21 DAP)
Total Fresh Mass (g)
20
15
10
5
0
A
A
BC
B
BC
C
TMT 1 (W)
TMT 2 (W+B)
TMT 3 (W+G)
TMT 4 (W+R)
TMT 5 (W+FR)
TMT 6 (Helio)
Light Treatment

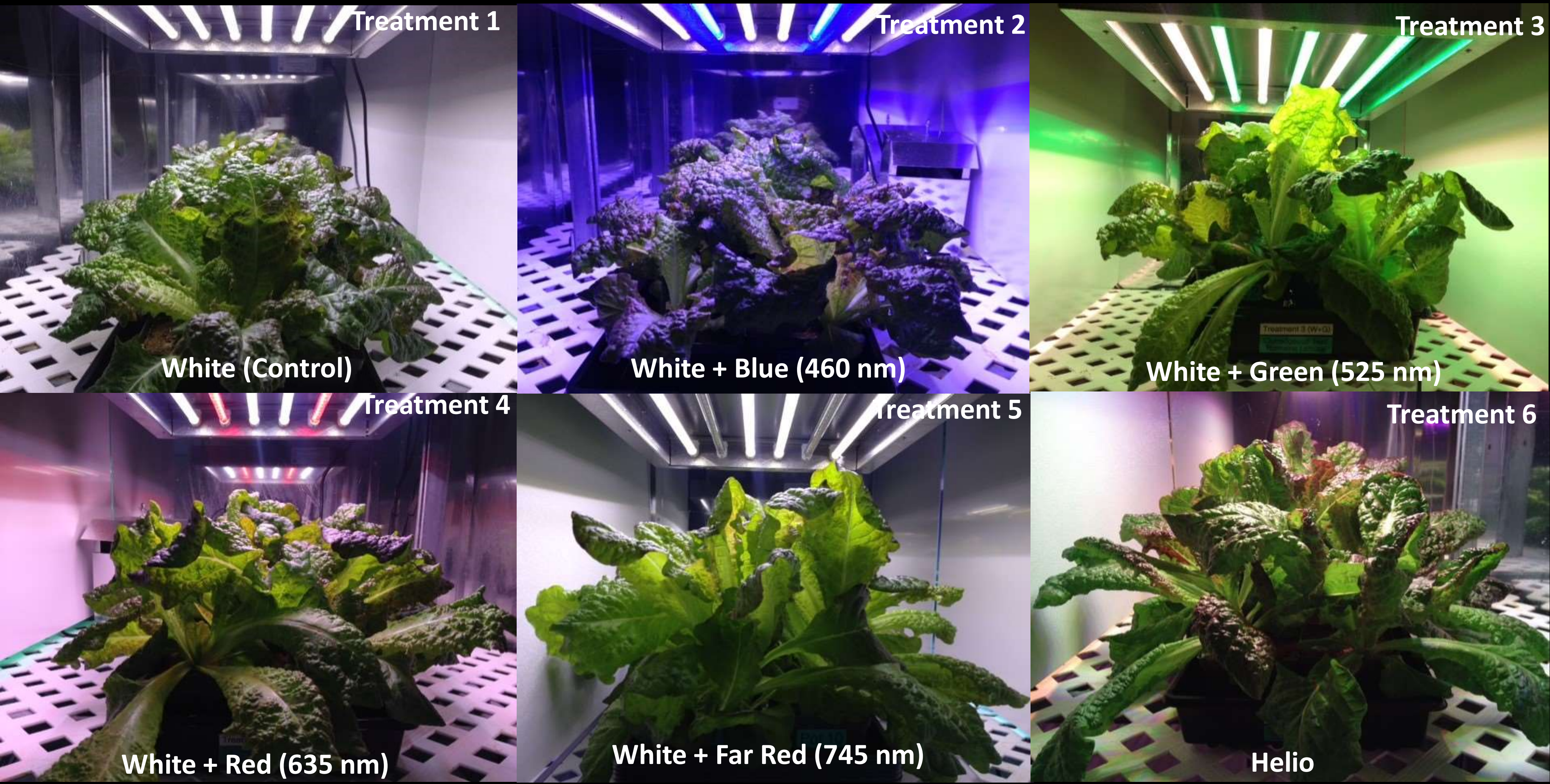


Total Dry Mass (21 DAP)
Total Dry Mass (g)
1.5
1.0
0.5
0.0
A
AB
CD
CD
AC
D
TMT 1 (W)
TMT 2 (W+B)
TMT 3 (W+G)
TMT 4 (W+R)
TMT 5 (W+FR)
TMT 6 (Helio)
Light Treatment

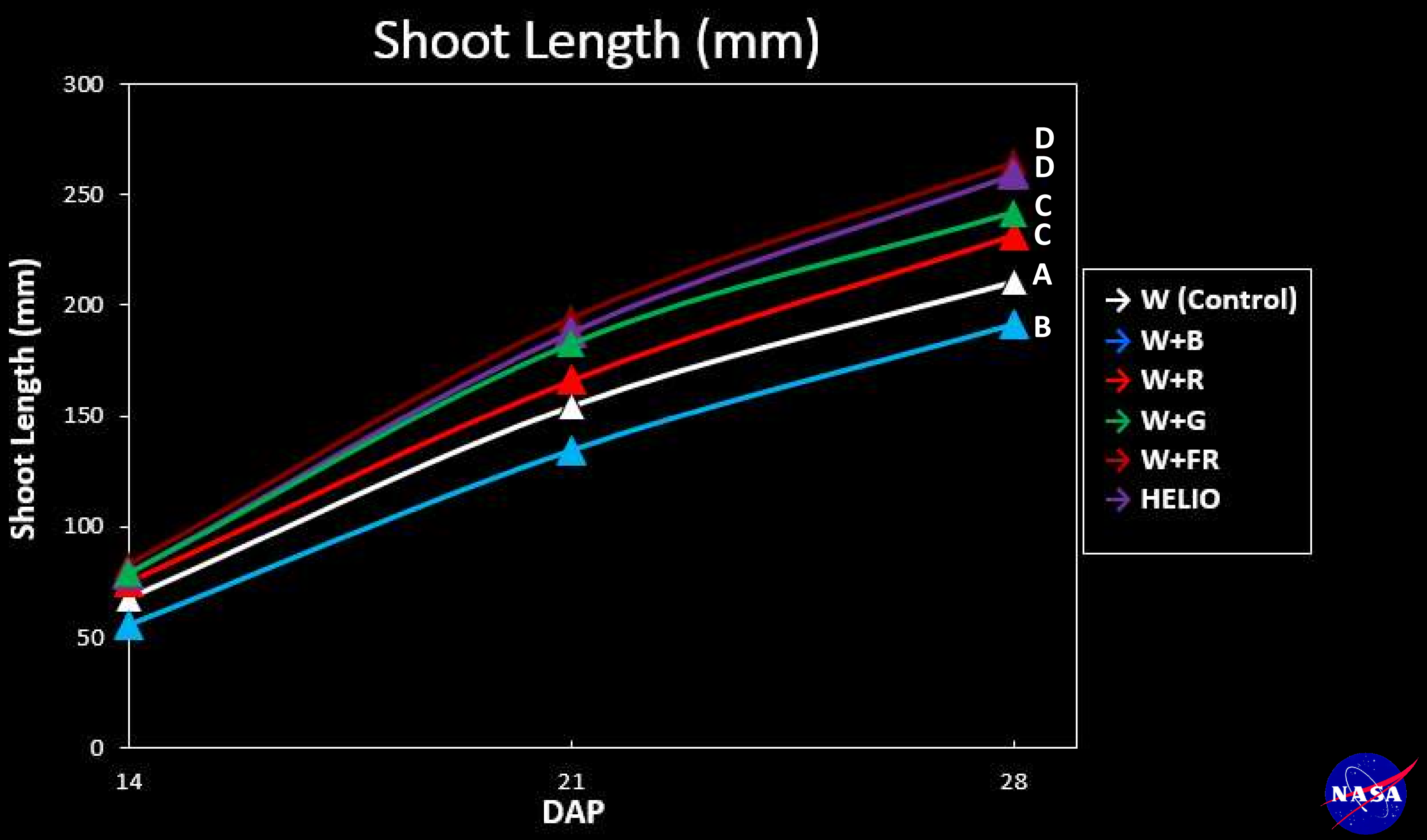
27 DAP

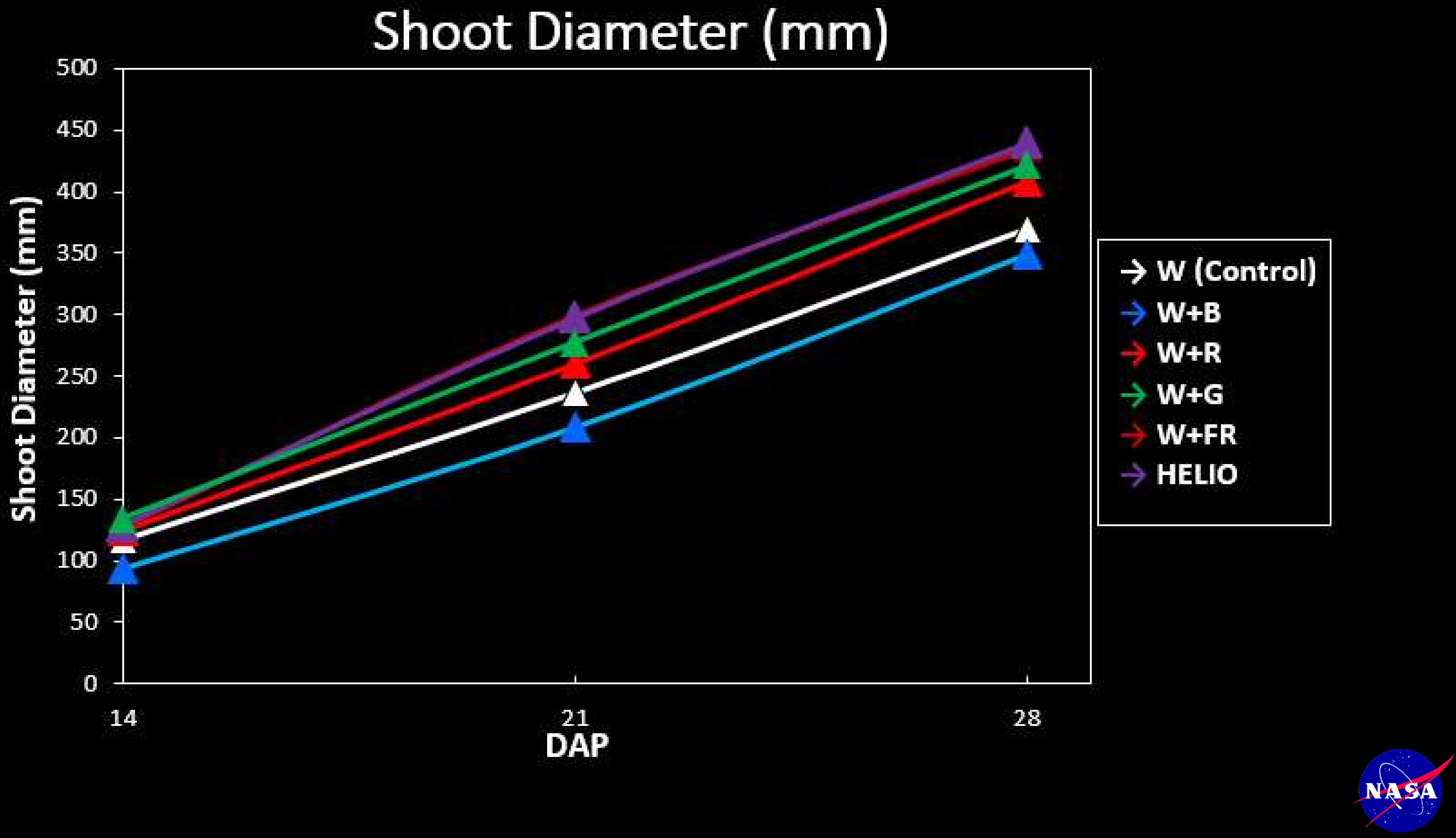

Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

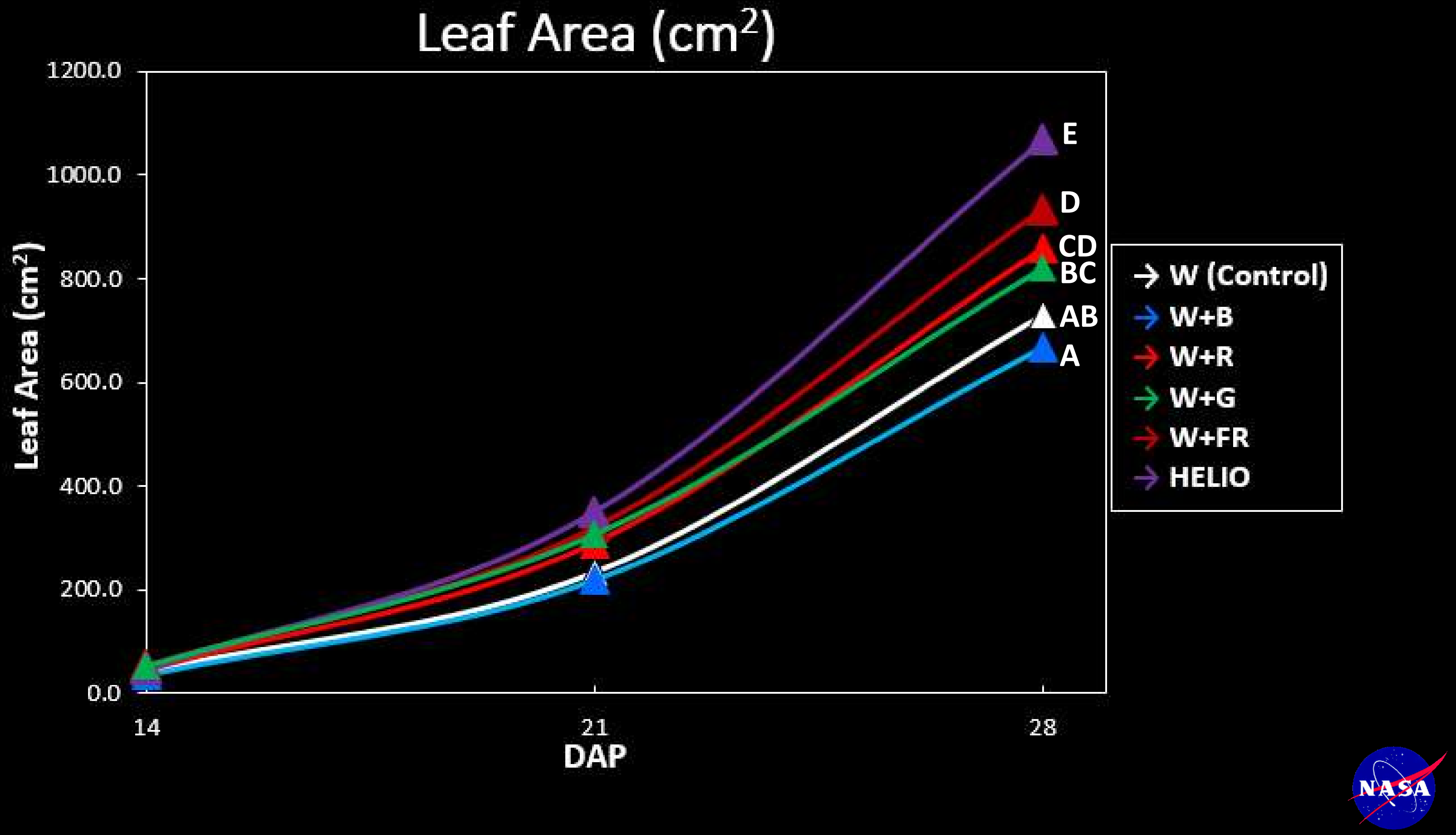
28 DAP

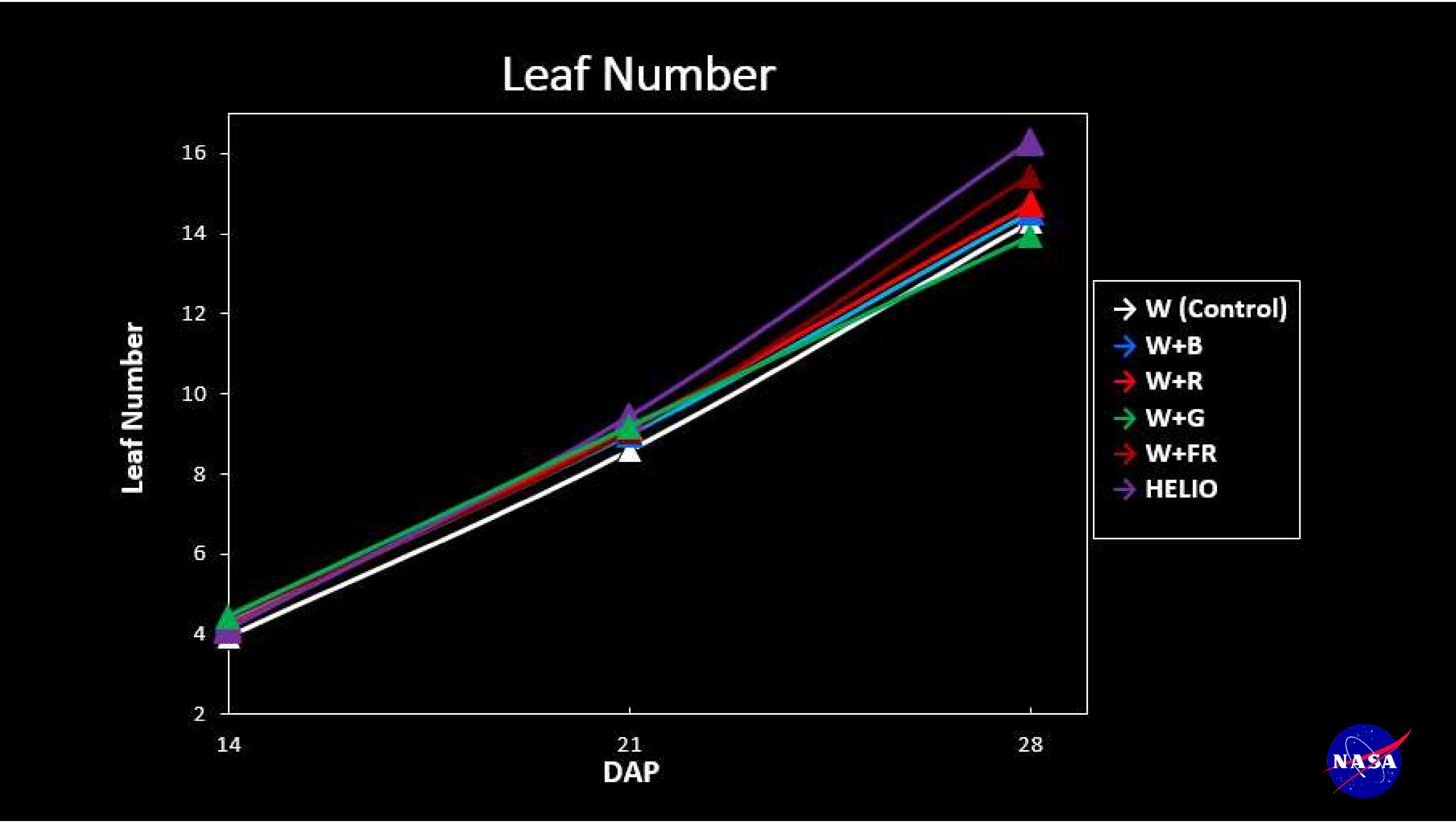

Treatment 1
White (Control)
Treatment 2
White + Blue (460 nm)
Treatment 3
White + Green (525 nm)
Treatment 4
White + Red (635 nm)
Treatment 5
White + Far Red (745 nm)
Treatment 6
Helio

28 DAP
RESULTS

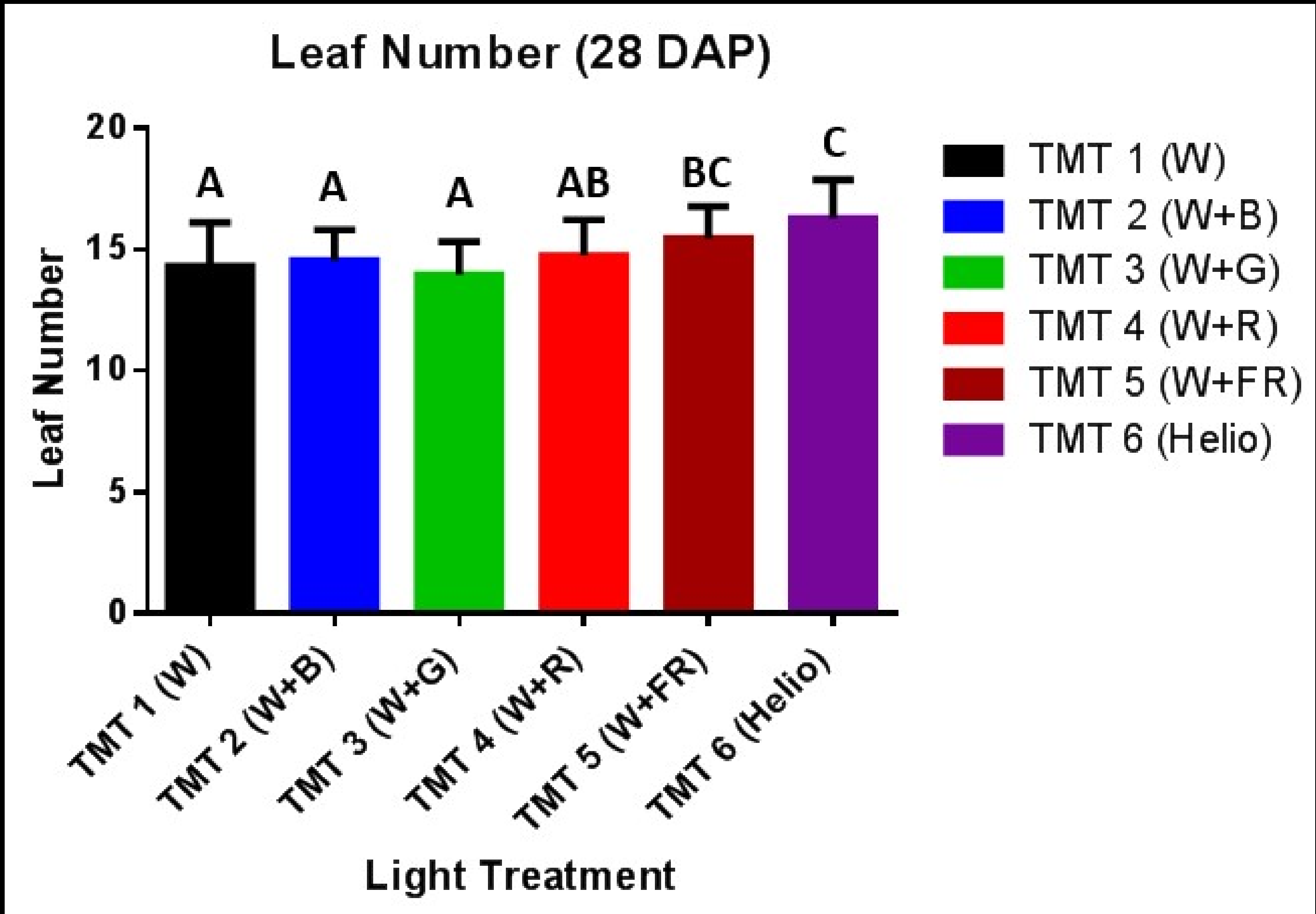

Shoot Length (mm)
300
250
200
150
100
50
0
Shoot Length (mm)
14
21
28
DAP
D
D
C
C
A
B
W (Control)
W+B
W+R
W+G
W+FR
HELIO
NASA


Shoot Diameter (mm)
Shoot Diameter (mm)
500
450
400
350
300
250
200
150
100
50
0
14
21
28
DAP
W (Control)
W+B
W+R
W+G
W+FR
HELIO
NASA

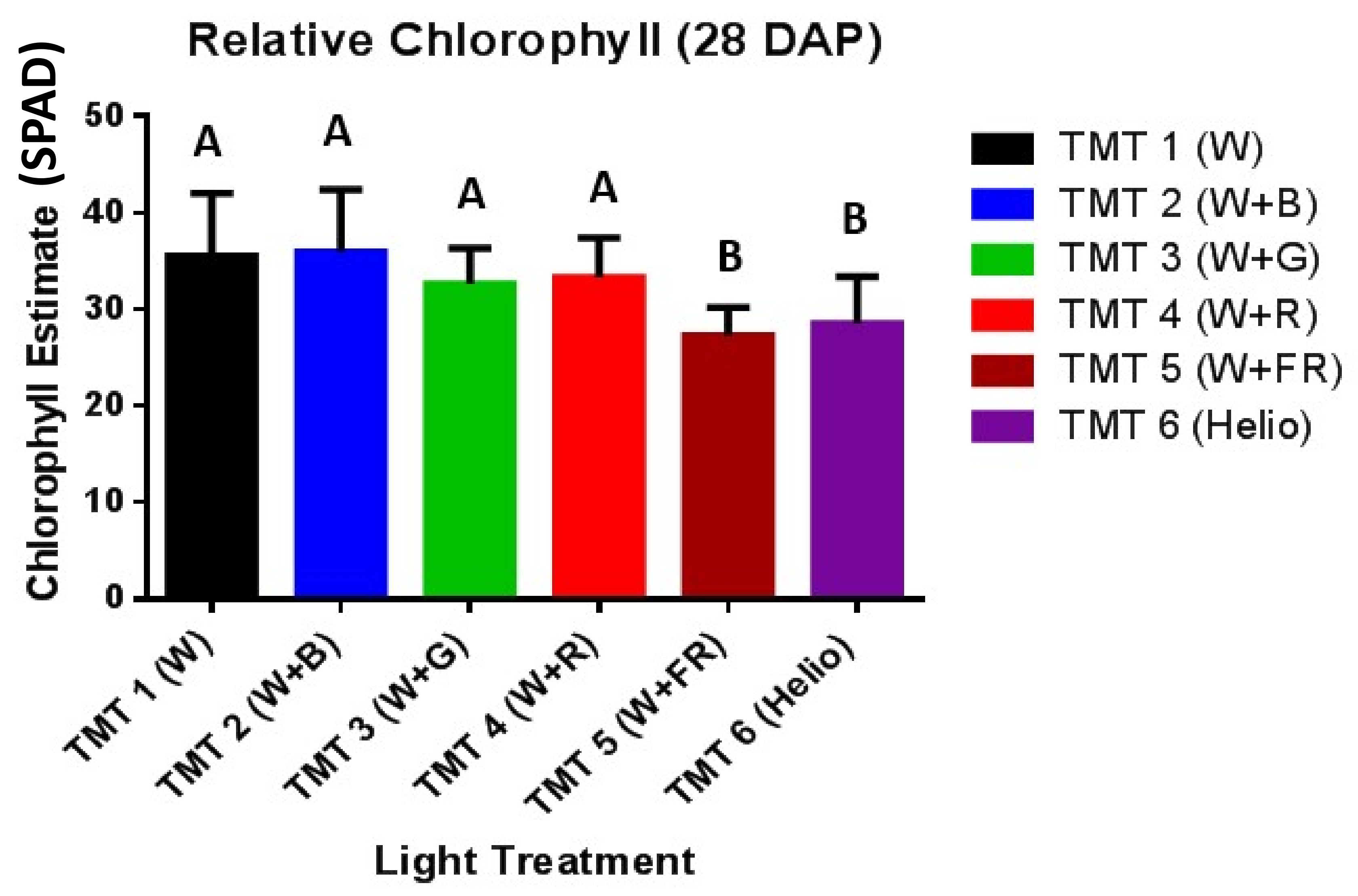

Leaf Area (cm2)
1200.0
1000.0
800.0
600.0
400.0
200.0
0.0
Leaf Area (cm2)
14
21
28
DAP
E
D
CD
BC
AB
A
W (Control)
W+B
W+R
W+G
W+FR
HELIO
NASA



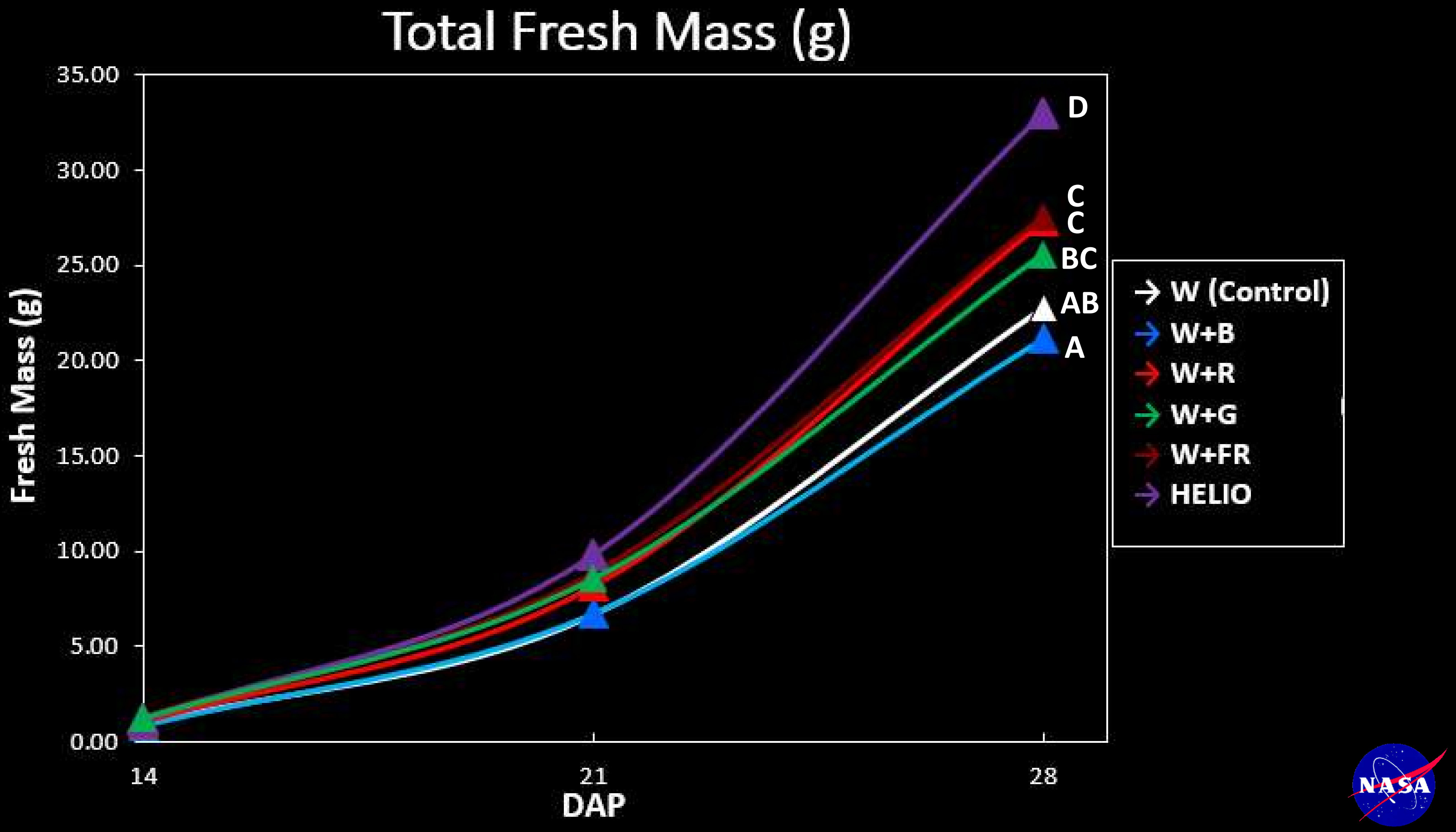
Leaf Number
Leaf Number
16
14
12
10
8
6
4
2
14
21
28
DAP
W (Control)
W+B
W+R
W+G
W+FR
HELIO
NASA

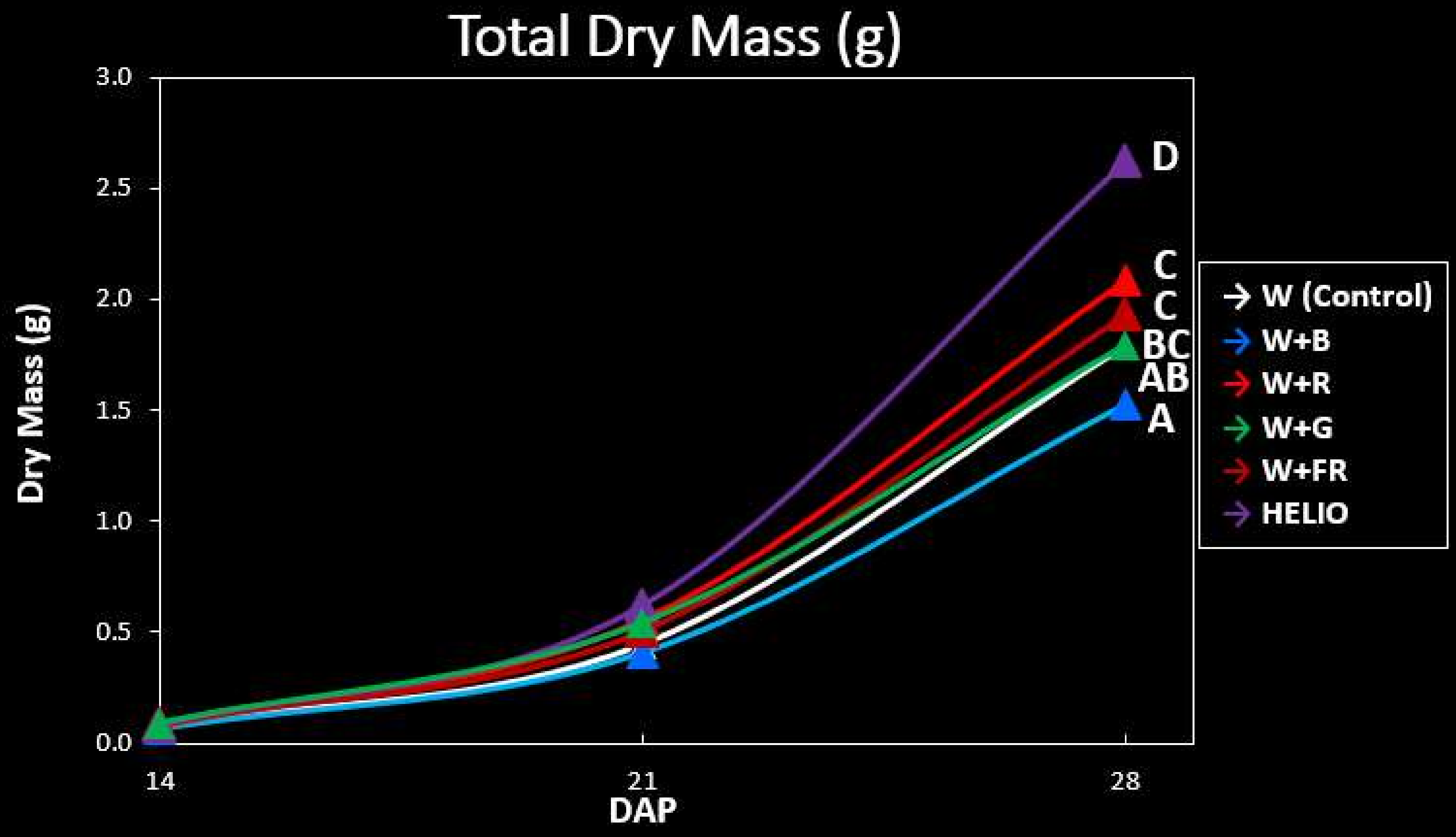


Leaf Number (28 DAP)
Leaf Number
20
15
10
5
0
A
A
A
AB
BC
C
TMT 1 (W)
TMT 2 (W+B)
TMT 3 (W+G)
TMT 4 (W+R)
TMT 5 (W+FR)
TMT 6 (Helio)
Light Treatment



Relative Chlorophyll (28 DAP)
Chlorophyll Estimate (SPAD)
50
40
30
20
10
0
A
A
A
A
B
B
TMT 1 (W)
TMT 2 (W+B)
TMT 3 (W+G)
TMT 4 (W+R)
TMT 5 (W+FR)
TMT 6 (Helio)
Light Treatment


Total Fresh Mass (g)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Fresh Mass (g)
14
21
28
DAP
D
C
C
BC
AB
A
W (Control)
W+B
W+R
W+G
W+FR
HELIO
NASA


Total Dry Mass (g)
Dry Mass (g)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
14
21
28
DAP
D
C
C
BC
AB
A
W (Control)
W+B
W+R
W+G
W+FR
HELIO


W
W+B
W+G
W+R
W+FR
Helio

DISCUSSION

2009

Green Light Drives Leaf Photosynthesis More Efficiently than Red Light in Strong White Light: Revisiting the Enigmatic Question of Why Leaves are Green

Ichiro Terashima[1,*], Takashi Fujita[1], Takeshi Inoue[1], Wah Soon Chow[2] and Riichi Oguchi[1,2,3]

[1]Department of Biological Sciences, Graduate School of Science, The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-0033 Japan

[2]Photobioenergetics Group, School of Biology, College of Medicine, Biology and Environment, The Australian National University, Canberra, ACT 0200, Australia

- **In strong white light, additional R and B light is likely dissipated as heat by upper chloroplasts, allowing lower chloroplasts to use G light more efficiently.**

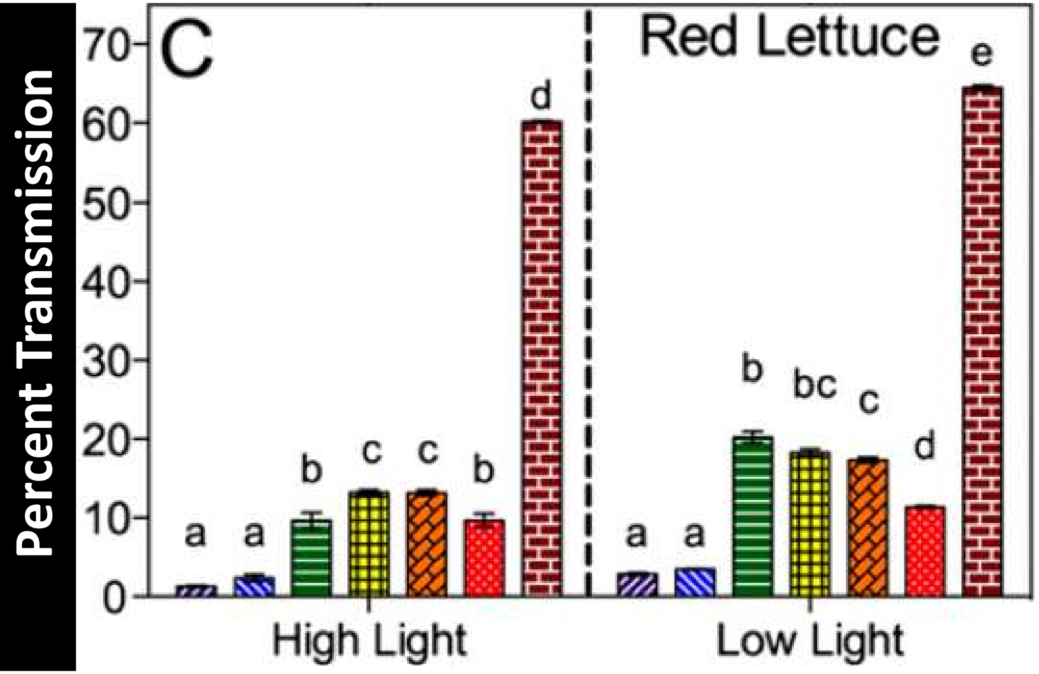
- **Green light penetrates deeper to reach chloroplasts on abaxial side of leaf.**

HortScience 50(3):501–506. 2015.

2015

Light-emitting Diode Light Transmission through Leaf Tissue of Seven Different Crops

Gioia Massa[1,2], Thomas Graham[1], Tim Haire, Cedric Flemming II, Gerard Newsham, and Raymond Wheeler
National Aeronautics and Space Administration, Kennedy Space Center, Merritt Island, FL 32899



Green Light Induces Shade Avoidance Symptoms[1][C][W][OA]

2011

Tingting Zhang, Stefanie A. Maruhnich, and Kevin M. Folta*

Horticultural Sciences Department (T.Z., K.M.F.) and Graduate Program in Plant Molecular and Cellular Biology (S.A.M., K.M.F.), University of Florida, Gainesville, Florida 32611

- **The possibility of green light reversing the effect of cryptochrome, but gene expression analysis did not support that.**

- **The green light shade avoidance could be due to secondary phytochrome or a undiscovered light receptor.**


HELIO

Plant Growth Regul (2015) 77:147–155
DOI 10.1007/s10725-015-0046-x

2015

ORIGINAL PAPER

Green light augments far-red-light-induced shade response

Yihai Wang · Tingting Zhang · Kevin M. Folta

- The shade response to G + FR together was greater in magnitude compared to either treatment alone (Aribidopsis).

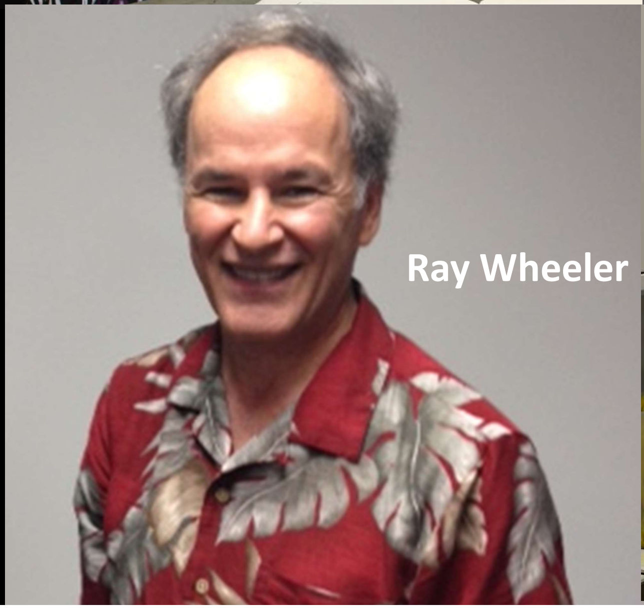
Conclusion

Supplementing WLEDs with equal amounts of light from various monochromatic LEDs caused differences in plant morphology and growth that depended on their age and progression during the cycle.

Treatment	Response compared to control
W+B	Dwarfed Plants, Increased pigment
W+G	Early leaf expansion, Shade avoidance
W+R	Delayed leaf area/biomass increase
W+FR	Maintained shade avoidance response
Helio	Optimal leaf expansion and biomass

Next Steps

1. **Phytonutrient analysis for anthocyanin and elemental analysis.**
2. **Comparing 2 Heliospectra lamps with Chl a and b wavelength targets.**
3. **Explore a treatment that switches W+G to W+R around 21 DAP**
4. **Testing species such as Chinese cabbage and dwarf tomatoes is underway.**



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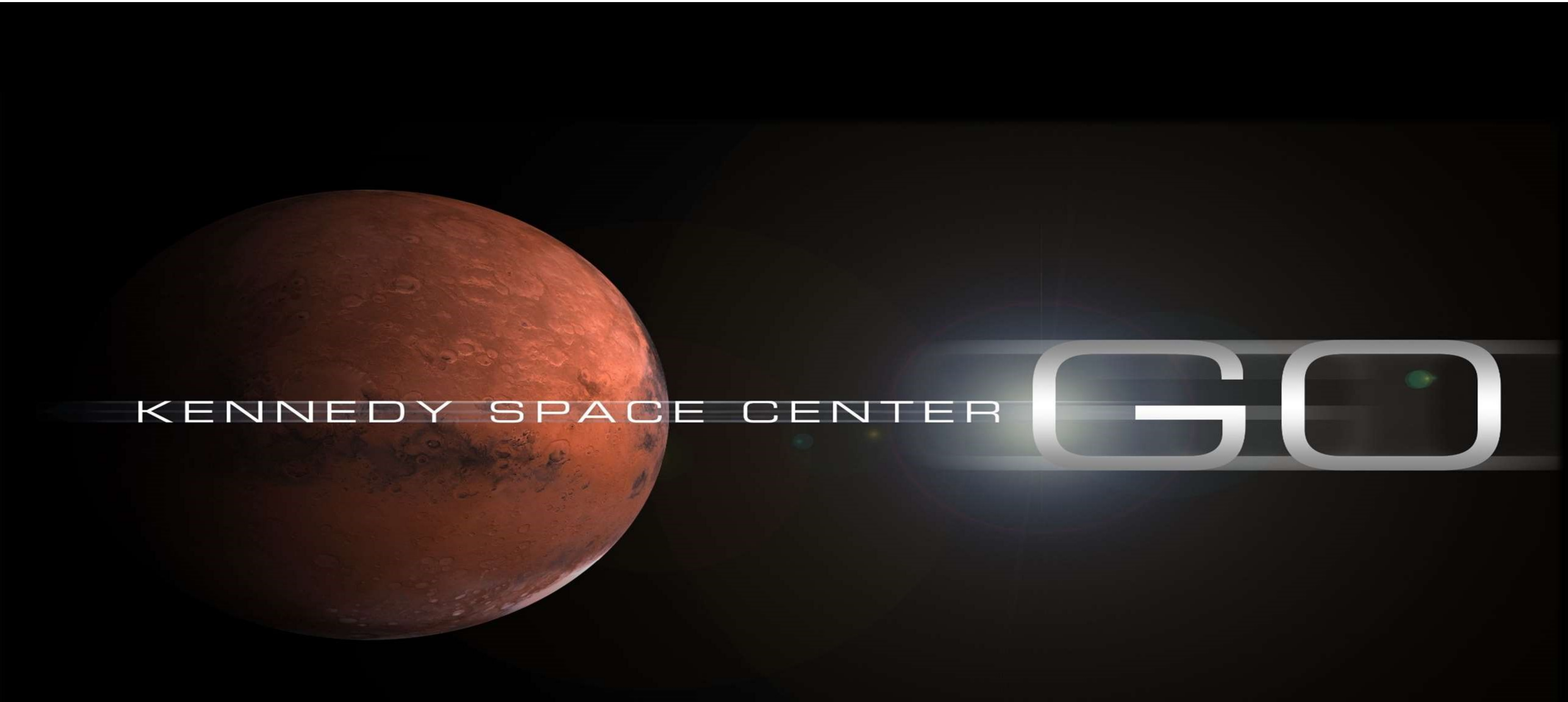

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