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THE OHIO STATE UNIVERSITY
COLLEGE OF FOOD, AGRICULTURAL, AND ENVIRONMENTAL SCIENCES

Environmental disorders: Intumescence in tomato

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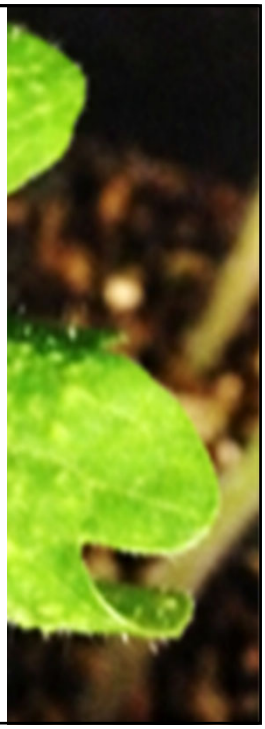


1

Producing tomatoes in indoor vertical farms

- Indoor commercial production of high flavor tomato has started in the U.S.
- High density year-round production
- Top lighting + interlighting
- Cultivar selection
  - High flavor
  - Good yield
  - Intumescence (oedema, edema) tolerance

2

Intumescence injury in tomato

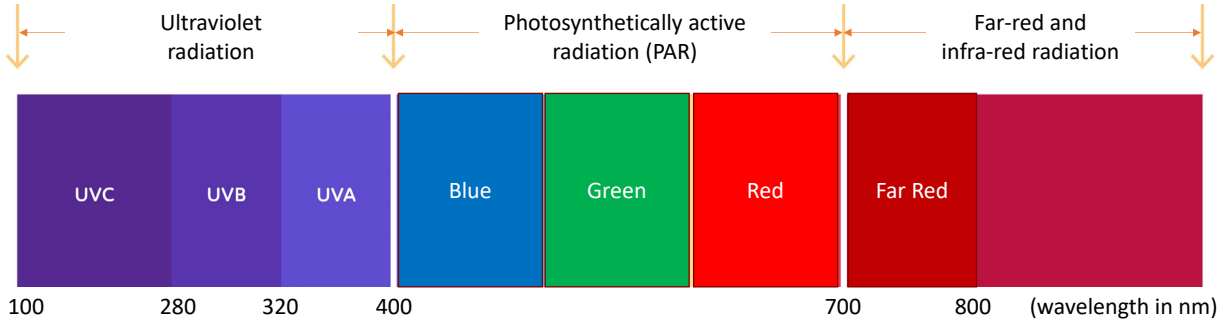
- Abnormal cell enlargement to develop callus-like tumor growths or necrosis due to their collapse (mainly over leaf blades)
- Sensitivity specific to cultivars
- Causes
  - Primary factor: Incident light quality
  - Secondary factor: High xylem pressure (relative humidity, watering)
- Growing systems with high incidences:
  - Greenhouses especially when covered with polycarbonate or UV-rated PE glazing
  - Indoor vertical farms

Photos: Zhao et al. (2008) Proc. Fla. State. Hort Soc. 121

Photos: T. Eguchi

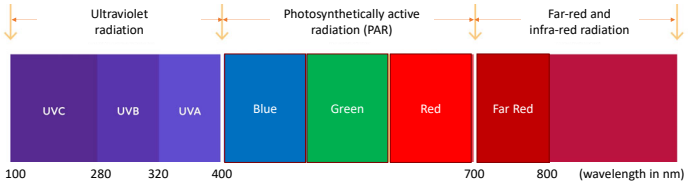
3

Light spectrum



4

Intumescence and light qualities



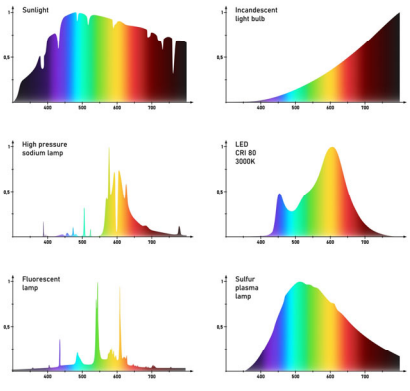
- Intumescence is caused by UV-B deficient light quality
- Under UV-B deficient light environment
  - Red light promotes intumescence [1-3]
  - Far-red light mitigates intumescence[2]
  - Blue light (high %) mitigates intumescence [4,5]

1) Lang and Tibbitts (1983), 2) Morrow (1987), 3) Morrow and Tibbitts (1988)
4) Wollaeger and Runkle (2014), 5) Hernandez et al., (2016)

5

UV-B radiation in electric lighting

Lamp type	%UV-B (287-320 nm) of PPFD
Sunlight (noon, clear)	0.39-0.47
HPS	0.01
Metal Halide	0.13
T-12 Fluorescent	0.43-0.55
T-8 Fluorescent	0.30-0.40
T-5 Fluorescent	0.10-0.11
LEDs (white)	0.00
LEDs (Red/Blue mix)	0.00



(Data after Nelson and Bugbee, 2013)

6

UV-B irradiance to prevent intumescence

Species (reference)	Light source (UV-B)	Reported/Estimated UV-B irradiance (W/m^2)
Tomato (Eguchi et al., 2016)	T12 fluorescence lamps	0.09
Tomato (anecdotal sources)	T12 or similar lamps	0.17 – 0.55
Tomato (Lang and Tibbitts, 1983)	T12 fluorescence lamps	<0.51
Tomato (Rud et al., 2009)	UV-B lamps	0.72 – 2.29
Tomato (Eguchi et al., 2017)	UV-B lamps	0.12
-- (USDA UV-B)*	*Direct solar radiation in June & July (Tucson, AZ)*	*~2.7 (midday)*

*Predicted values at UV-B Monitoring and Research Program, http://uvb.nrel.colostate.edu/UVB/da_queryContourDailySums.jsf

7

UV-B radiation dose to prevent intumescence

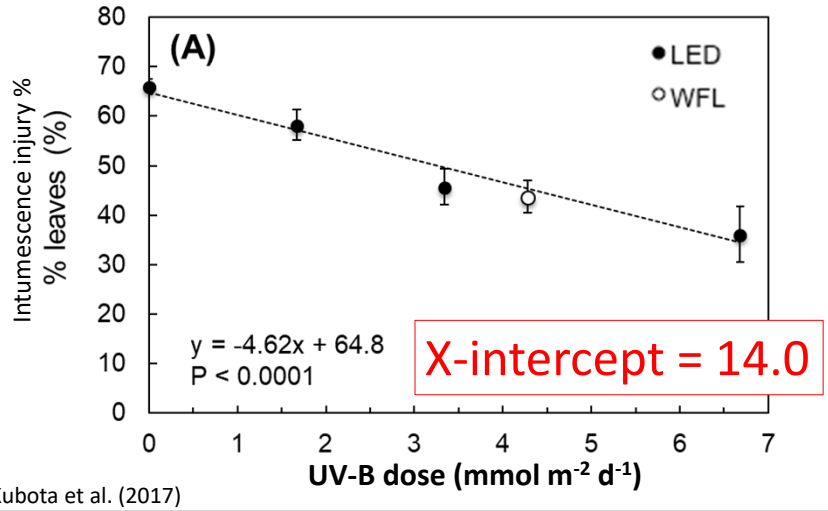
Species (reference)	Light source (UV-B)	Estimated UV-B dose ($mmol\ m^{-2}\ d^{-1}$)
Tomato (Eguchi et al., 2016)	T12 fluorescence lamps	15
Tomato (anecdotal sources)	T12 or similar lamps	26 – 77
Tomato (Lang and Tibbitts, 1983)	T12 fluorescence lamps	<74 (?)**
Tomato (Rud et al., 2009)	UV-B lamps	78 – 251 (?)**
Tomato (Eguchi et al., 2017)	UV-B lamps	14
-- (USDA UV-B)*	*Direct solar radiation in June & July (Tucson, AZ)*	*80 – 103*

*Predicted values at UV-B Monitoring and Research Program, http://uvb.nrel.colostate.edu/UVB/da_queryContourDailySums.jsf
** Estimated from reported irradiances and lamp types

8

UV-B dose response

Dose = intensity x duration



Kubota et al. (2017)

'Beaufort' tomato rootstock plants under Blue/Red LEDs (10% B)

No UV-B

UV-B 1.5 h (1.7 mmol m^{-2} d^{-1} or 0.6 kJ m^{-2} d^{-1})

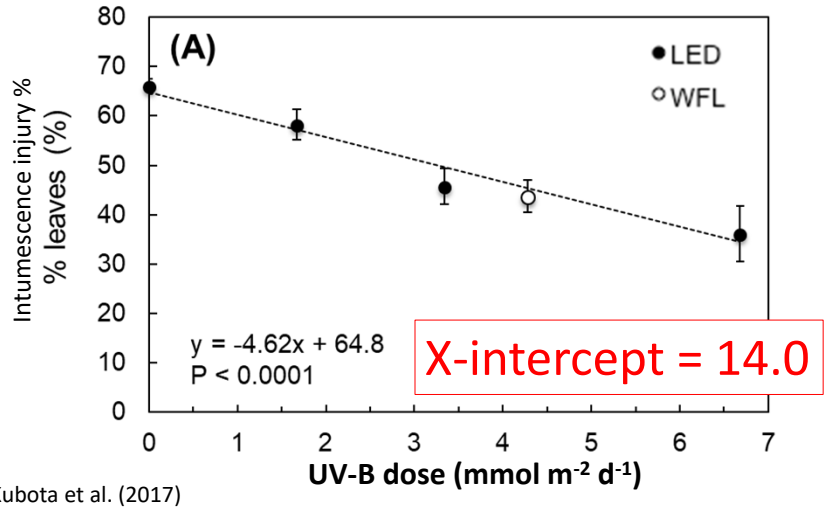
UV-B 3.0 h (3.3 mmol m^{-2} d^{-1} or 1.3 kJ m^{-2} d^{-1})

UV-B 6.0 h (6.7 mmol m^{-2} d^{-1} or 2.6 kJ m^{-2} d^{-1})

9

UV-B dose response

Dose = intensity x duration



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UV-B 3.0 h (3.3 mmol m^{-2} d^{-1} or 1.3 kJ m^{-2} d^{-1})

UV-B 6.0 h (6.7 mmol m^{-2} d^{-1} or 2.6 kJ m^{-2} d^{-1})

10

Target UV-B photon flux density and dose

Examples

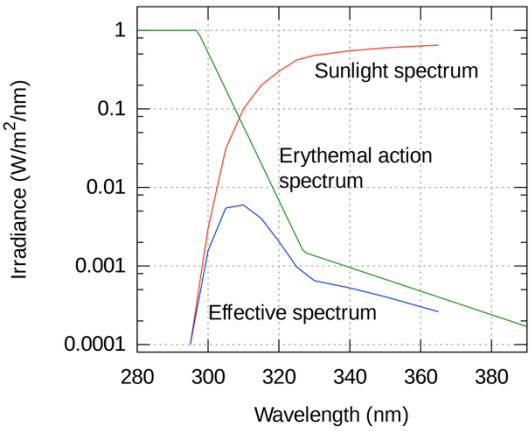
UV-B PFD (μmol m^{-2} s^{-1})	UV-B irradiance (W m^{-2})	Duration (h d^{-1})	Dose (daily, mmol m^{-2} d^{-1}) or (kJ m^{-2} d^{-1})
0.65	0.24	6 h	14 mmol m^{-2} d^{-1} (5.3 kJ m^{-2} d^{-1})
0.97	0.37	4 h	14 mmol m^{-2} d^{-1} (5.3 kJ m^{-2} d^{-1})
1.94	0.74	2 h	14 mmol m^{-2} d^{-1} (5.3 kJ m^{-2} d^{-1})

PFD X Hrs/day X 3600 s/h / 1,000 = Dose (mmol m^{-2} d^{-1})

11

UV-B dose for safety and human health

- WHO recommends sun (UV) protection at UV Index $\geq$ 3.
- A study suggests pathogenic MED (Minimum Erythema Dose) of UV-B radiation is 300-800 J m^{-2} depending on skin type (Welti et al., 2020).



Erythemal action spectrum (skin sensitivity) used for calculating UV index (Source: Wikipedia). UV index = erythemally weighted UV irradiance (W m^{-2}) x 40

12

How to implement UV-B application?

- Nighttime application (to minimize hazard)
  - Dose target at 14 mmol m^{-2} (5.3 kJ m^{-2}) every day (night)
- Moving light (high intensity x short duration)
  - Speed can be found from dose requirement and target PFD[1]
- Interlighting
- Light source: UV lamps (UV-B)

Lights on moving irrigation boom

1) Yang et al. (2012)

13

How to measure UV-B intensity?

- Measurement unit
  - µmol m^{-2} s^{-1}
  - W m^{-2}
- Spectroradiometer
  - Accuracy of UV-B (280-320 nm) range varies.
  - Low-cost spectroradiometers do not include UV-B range.
- UV sensor
  - UV-B needs to be separately detectable.
  - Low-cost UV sensor measures total UV (UV-A plus UV-B).

https://www.apogeeinstruments.com/lab-spectroradiometer/

14

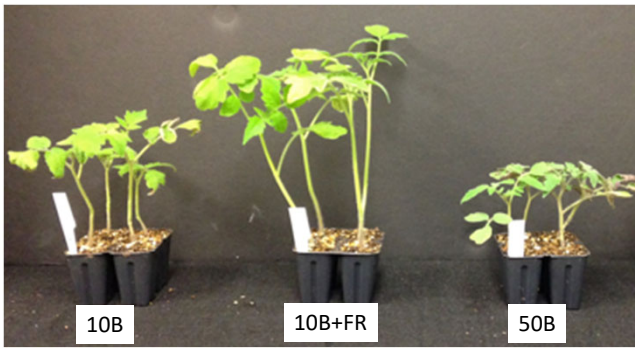
Other approaches to prevent intumescence in tomato

- End of day (EOD) far-red lighting
  - 6 μmol m^{-2} s^{-1} far-red lighting for 3 min every day (EOD)*
- High blue light
  - >50% blue photon flux over PAR**
- High green light
  - 50% green + 50% red mitigated intumescence injury***
- Combinations of above
  - 50% blue + 50% green eliminated intumescence***
  - EOD Far-Red + 50% blue (50% red) nearly eliminated intumescence*

* Eguchi et al. (2016)
**Hernández et al. (2016)
***Wollaeger and Runkle (2014)

15

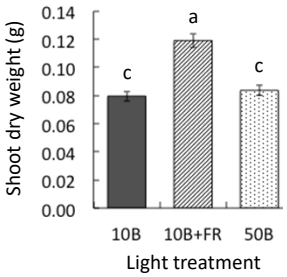
Synergistic response with high blue plus EOD FR

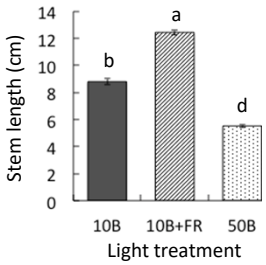


'Beaufort' tomato rootstock

EOD FR: 5 μmol m^{-2} s^{-1} FR for 3.3 min at every end of day

Eguchi et al. (2016)





16

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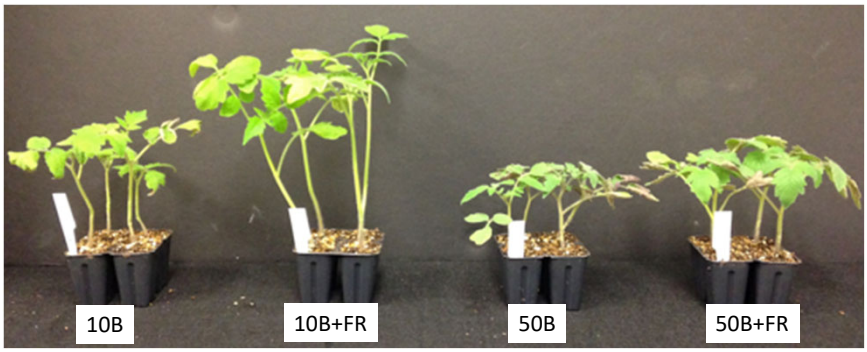

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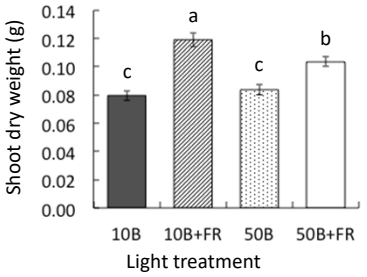

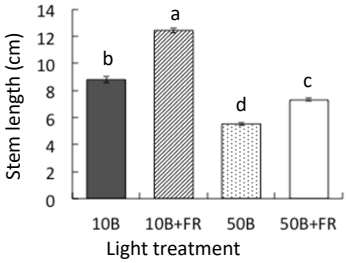

17

Summary – Intumescence control

- Tomato plants of sensitive cultivars need specific lighting recipe (UV-B, FR, G, and B)
- Nighttime UV-B application is likely the least expensive that does not require update of existing infrastructure
- "Tomato Light Recipe" to avoid intumescence must be developed: e.g., EOD-FR plus high blue
- Efficacy on mature plants needs to be examined.

18

Thank you!

For questions, please contact:
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'This lecture series is supported by Specialty Crop Research Initiative [grant no. 2019-51181-30017] from the USDA National Institute of Food and Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.'

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19