8th International Symposium on

Light in Hort

Program & Abstracts

Edited by Erik S. Runkle, Roberto G. Lopez, and Qingwu Meng

MICHIGAN STATE UNIVERSITY

May 22–26, 2016
East Lansing, Michigan, USA

8th International Symposium on Light in Horticulture

http://www.lightsym16.com

MICHIGAN STATE UNIVERSITY

Kellogg Hotel and Conference Center
East Lansing, Michigan, USA
May 22–26, 2016

ISHS

Symposium conveners: Erik S. Runkle and Roberto G. Lopez
Department of Horticulture, Michigan State University

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Symposium Information

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Roberto G. Lopez, Michigan State University (US)

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Erik S. Runkle, Michigan State University (US)

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Eiji Goto, Chiba University (JP)
Will Healy, Ball Horticultural Company (US)
Royal D. Heins, Dummen Orange (US)
Silke Hemming, Wageningen University (NL)
Ricardo Hernandez, North Carolina State University (US)
Ep Heuvelink, Wageningen University (NL)
Wim van Ieperen, Wageningen University (NL)
Meriam Karlsson, University of Alaska Fairbanks (US)
Ki Sun Kim, Seoul National University (KR)
Yoon Jin Kim, Seoul Women's University (KR)
Rod King, CSIRO - Plant Industry (AU)
Dean Kopsell, University of Tennessee (US)
Chieri Kubota, University of Arizona (US)
Roberto Lopez, Michigan State University (US)
Leo Marcelis, Wageningen University (NL)

Gioia Massa, NASA Kennedy Space Center (US)
Neil Mattson, Cornell University (US)
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Genhua Niu, Texas A&M University (US)
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Carl-Otto Ottosen, Aarhus University (DK)
Yujin Park, Michigan State University (US)
Erik Runkle, Michigan State University (US)
Carl Sams, University of Tennessee (US)
Sadanori Sase, Nihon University (JP)
Beth Scheckelhoff, Ohio State University (US)
Yosepha Shahak, Agricultural Research Organization (IL)
Hiroshi Shimizu, Kyoto University (JP)
Abhay Thosar, Philips Lighting (US)
Youbin Zheng, University of Guelph (CA)

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Joshua Craver, Purdue University
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Yujin Park, Michigan State University
Brian Poel, Michigan State University
Michaleh Reddan, Michigan State University
Kellie Walters, Michigan State University
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International Society for Horticultural Science

This symposium is held under the auspices of the International Society for Horticultural Science (ISHS), the world's leading independent organization of horticultural scientists. The following ISHS Working Groups are involved:

Commission Horticultural Engineering
Commission Protected Cultivation
Section Ornamental Plants
Workgroup Light in Horticulture
Workgroup Photoselective Netting (subgroup of Light in Horticulture)

The following are the ISHS symposia and proceedings on the subject of light in horticulture:

- Symposium on Electricity and Artificial Light in Horticulture, Littlehampton, England, March 1969; Acta Hortic. 22
- II International Symposium on Artificial Light in Horticulture, Conthey, Switzerland, September 1981; Acta Hortic. 128
- III International Symposium on Artificial Lighting in Horticulture, Noordwijkerhout, Netherlands, January 1994; Acta Hortic. 418

- IV International ISHS Symposium on Artificial Lighting, Québec City, Canada, November 2000; Acta Hortic. 580
- V International Symposium on Artificial Lighting in Horticulture, Lillehammer, Norway, June 2005; Acta Hortic. 711
- VI International Symposium on Light in Horticulture, Tsukuba, Japan, November 2009; Acta Hortic. 907
- VII International Symposium on Light in Horticultural Systems, Wageningen, Netherlands, October 2012, Acta Hortic. 956
- VIII International Symposium on Light in Horticulture, East Lansing, Michigan, USA; Acta Hortic. 1134

Symposium Venue

Kellogg Hotel & Conference Center
Michigan State University
219 S Harrison Road
East Lansing, MI 48824, USA
https://kelloggcenter.com

Symposium Hotels

Kellogg Hotel & Conference Center
Michigan State University
219 S. Harrison Road
East Lansing, MI 48824, USA

East Lansing Marriott at University Place
300 M.A.C. Avenue
East Lansing, MI 48823, USA

Symposium Registration Times and Locations (Kellogg)

Sunday, May 22: 15:00 to 20:00, Central Lobby
Monday, May 23: 07:30 to 12:00, Outside Big Ten Room C
Tuesday, May 24: 08:00 to 10:00, Outside Big Ten Room C
Wednesday, May 25: 08:00 to 10:00, Outside Big Ten Room C

Scientific Program

Sunday, May 22, 2016

Time	Event	Location
15:00 - 20:00	Set-up of posters Set-up of booths for prime and platinum sponsors	Big 10 Room A
18:30 - 21:30	Welcome reception, sponsored by Philips. Hors d'oeuvres and drinks provided.	Broad Art Museum. A bus will be available every 10-15 minutes to transport registered participants to and from the Kellogg Hotel and the museum. Please register first and wear your name badge for admission.

Monday, May 23, 2016

Time	Presenting Author & Affiliation	Title/Event	Abstr.
07:15 - 08:15	Continental breakfast, Centennial Room		
08:30 - 09:00	Erik Runkle and Roberto Lopez (Conveners); Doug Buhler (Dean, College of Agriculture & Natural Resources), Michigan State Univ. (US); Silke Hemming (ISHS representative)	Welcoming remarks and symposium introduction Big Ten Rooms B&C	
Oral Session 1: Light quality and optimization Big Ten Rooms B&C Moderated by Ep Heuvelink			
09:00 - 09:40	Bruce Bugbee, Utah State Univ. (US)	**Invited:** Toward an optimal spectral quality for plant growth and development	I1
09:40 - 10:00	Cary Mitchell, Purdue Univ. (US)	In search of an optimized supplemental lighting spectrum for greenhouse tomato production	O1
10:00 - 10:20	Theoharis Ouzounis, Wageningen Univ. (NL)	Phenotyping tomato genotypes for light use efficiency under different LED lighting regimes	O2
10:20 - 10:40	Coffee break, Big Ten Room A		
10:40 - 11:00	Marc van Iersel, Univ. of Georgia (US)	Using chlorophyll fluorescence to optimize supplemental lighting in controlled environment agriculture	O3
11:00 - 11:20	Anna-Maria Carstensen, Chalmers Univ. of Technology (SE)	Exploring the dynamics of remotely detected fluorescence transients from *Basil* as a potential feedback for lighting control in greenhouses	O4
11:20 - 11:40	Daniel Bånkestad, Heliospectra AB (SE)	LED spectrum optimisation using steady-state fluorescence gains	O5
11:40 - 12:00	Panel discussion (I1, O1-O5) moderated by Ep Heuvelink		
12:00 - 13:00	Lunch, Lincoln Room (buffet in Room 106) and Red Cedar Rooms A & B (buffet in Galaxy Room)		

Oral Session 2: Ultraviolet light in horticulture Big Ten Rooms B&C Moderated by Chieri Kubota			
13:10 - 13:50	Jason Wargent, Massey Univ. (NZ)	**Invited:** UV LEDs in horticulture: from biology to application	I2
13:50 - 14:10	Mark Bridgen, Cornell Univ. (US)	Using ultraviolet-C irradiation on greenhouse ornamental plants for growth regulation	O6
14:10 - 14:30	Eiji Goto, Chiba Univ. (JP)	Effect of UV light on phytochemical accumulation and expression of anthocyanin biosynthesis genes in red leaf lettuce	O7
14:30 - 14:45	Panel discussion (I2, O6-O7) moderated by Chieri Kubota		
14:45 - 15:45	**Poster Session #1 (posters ending with 1, 4, 7)** Sponsor displays and refreshments, Big Ten Room A Graduate student poster competition, round #1		
Oral Session 3: Light technologies for horticulture Big Ten Rooms B&C Moderated by Eiji Goto			
15:50 - 16:10	Leo Marcelis, Wageningen Univ. (NL)	LED it be: A road to 50% energy saving by the smart use of LEDs in greenhouse horticulture	O8
16:10 - 16:30	Anja Dieleman, Wageningen Univ. (NL)	Re-designing LED-based production systems: Using all features to reduce the carbon footprint	O9
16:30 - 16:50	Silke Hemming, Wageningen Univ. (NL)	Evaluation of diffusing properties of greenhouse covering materials and screens	O10
16:50 - 17:05	Panel discussion (O8-O10) moderated by Eiji Goto		

Tuesday, May 24, 2016

Time	Presenting Author & Affiliation	Title/Event	Abstr.
07:15 - 08:15	Continental breakfast, Centennial Room		
08:30 - 08:50	**Sponsor session #1** Big Ten Rooms B&C		
08:50 - 09:30	Kevin Folta, Univ. of Florida (US)	**Invited:** Controlling plant growth, development and metabolism with commands from the electronic canopy	I3
Oral Session 4 (Concurrent): Phytonutrients and growth control Big Ten Rooms B&C Moderated by Roberto Lopez			
09:40 - 10:00	Dean Kopsell, Univ. of Tennessee (US)	Genotype and the lighting environment impact petal tissue pigmentation in *Tagetes tenuifolia*	O11
10:00 - 10:20	Taro Fukuyama, Tamagawa Univ. (JP)	Improvement of vinblastine production by controlling light conditions in *Catharanthus roseus*	O12
10:20 - 10:40	Coffee break, Big Ten Room A		
10:40 - 11:00	Celine Nicole, Philips Research Laboratories (NL)	Plant growth and quality optimization in a plant factory	O13

11:00 - 11:20	Joshua Craver, Purdue Univ. (US)	Daily light integral and light quality from sole-source LEDs impacts nutrient uptake and anthocyanin content of *Brassica* microgreens	O14
11:20 - 11:40	Nikolaos Ntagkas, Wageningen Univ. (NL)	The effect of light intensity and spectral properties on vitamin C levels in tomato fruit	O15
11:40 - 12:00	Panel discussion (I3, O11-O15) moderated by Roberto Lopez		
Oral Session 5 (Concurrent): Supplemental lighting of vegetable crops Auditorium Moderated by Cary Mitchell			
09:40 - 10:00	Shalin Khosla, Harrow Research and Development Centre (CA)	Comparison of HPS lighting and hybrid lighting with top HPS and intra-canopy LED lighting for high-wire mini-cucumber production in a commercial greenhouse	O16
10:00 - 10:20	Todd Graham, Harrow Research and Development Centre (CA)	Response of greenhouse mini-cucumber to different vertical spectra of LED lighting under top high-pressure sodium and plasma lighting	O17
10:20 - 10:40	Coffee break, Big Ten Room A		
10:40 - 11:00	Rob Moerkens, Research Centre Hoogstraten (BE)	The added value of LED assimilation light in combination with high pressure sodium lamps in protected tomato crops in Belgium	O18
11:00 - 11:20	Xiuming Hao, Harrow Research and Development Centre (CA)	Far red LED improved fruit production in greenhouse tomato grown under high-pressure sodium lighting	O19
11:20 - 11:40	Elias Kaiser, Wageningen Univ. (NL)	Strongly increased stomatal conductance in tomato does not speed up photosynthetic induction in ambient nor elevated CO_2 concentration	O20
11:40 - 12:00	Panel discussion (O16-O20) moderated by Cary Mitchell		
12:00 - 12:20	Group photo		
12:20 - 13:20	Lunch, Lincoln Room (buffet in Room 106) and Red Cedar Rooms A & B (buffet in Galaxy Room)		
Oral Session 6 (Concurrent): Photoperiodism Big Ten Rooms B&C Moderated by Ki Sun Kim			
13:30 - 13:50	John Erwin, Univ. of Minnesota (US)	Temperature and irradiance affects photoperiodic flower induction	O21
13:50 - 14:10	Matthew Blanchard, Michigan St. Univ. (US)	Investigating reciprocity of intensity and duration of photoperiodic lighting to regulate flowering of long-day plants	O22
14:10 - 14:30	Karl-Johan Bergstrand, Swedish Univ. of Agricultural Sciences (SE)	Using short photoperiods and narrow-band lighting as a way of controlling growth in ornamental pot- and bedding plants	O23
14:30 - 14:50	Faline Plantenga, Wageningen Univ. (NL)	Regulating flower and tuber formation in potato with light spectrum and day length	O24
14:50 - 15:10	Panel discussion (O21-O24) moderated by Ki Sun Kim		

Oral Session 7 (Concurrent): Coverings and pests Auditorium Moderated by Silke Hemming			
13:30 - 13:50	Yosepha Shahak, Agricultural Research Organization Volcani Center (IL)	The wonders of yellow netting	O25
13:50 - 14:10	Katrine Heinsvig Kjr, Aarhus Univ. (DK)	Protecting organic apple trees from rain - Better fruit quality and maintenance of yield	O26
14:10 - 14:30	Beatrix Alsanius, Swedish Univ. of Agricultural Sciences (SE)	Ornamentals in new light - the story of the invisibles	O27
14:30 - 14:50	David Ben-Yakir, Agricultural Research Organization Volcani Center (IL)	The effects of UV radiation on arthropods: A review of recent publications (2010 - 2015)	O28
14:50 - 15:10	Panel discussion (O25-O28) moderated by Silke Hemming		
15:10 - 16:10	**Poster session #2 (posters ending with 0, 2, 5, 8)** Sponsor displays and refreshments, Big Ten Room A Graduate student poster competition, round #2		
16:15 - 17:15	Campus walking tour to Beal Botanic Garden, depart from East Patio		
17:30 - 18:15	ISHS Working Groups meeting Auditorium		

Wednesday, May 25, 2016

Time	Presenting Author & Affiliation	Title/Event	Abstr.
07:15 - 08:15	Continental breakfast, Centennial Room		
08:30 - 08:50	**Sponsor session #2** Big Ten Rooms B&C		
08:50 - 09:30	Wim van Ieperen, Wageningen Univ. (NL)	**Invited:** Plant growth control by light spectrum: Fact or fiction?	I4
Oral Session 8 (Concurrent): Light for ornamental crops Big Ten Rooms B&C Moderated by Erik Runkle			
09:40 - 10:00	Jim Faust, Clemson Univ.	Cyathia development and bract development of poinsettia have different critical night lengths	O29
10:00 - 10:20	Naoya Fukuda, Univ. of Tsukuba (JP)	Timing of blue and red light exposure and CPPU application during raising of seedlings can control flowering timing of petunia	O30
10:20 - 10:40	Coffee break, Big Ten Room A		
10:40 - 11:00	Yujin Park, Michigan State Univ. (US)	Investigating the utility of adding far-red radiation in the production of ornamental seedlings grown under sole-source lighting	O31
11:00 - 11:20	Annelies Christiaens, PCS Ornamental Plant Research (BE)	Far-red light stimulates rooting of ornamental cuttings in a closed multilayered system with LED light	O32
11:20 - 11:40	Tao Li, Chinese Academy of Agricultural Sciences (CN)	Responses of two anthurium cultivars to high daily integrals of diffuse light	O33

11:40 - 12:00	Panel discussion (I4, O29-O33) moderated by Erik Runkle		
Oral Session 9 (Concurrent): Sole-source lighting of vegetable crops Auditorium Moderated by Dean Kopsell			
09:40 - 10:00	Qichang Yang, Chinese Academy of Agricultural Sciences (CN)	Effects of continuous LED lighting on reducing nitrate content and enhancing edible quality of lettuce during pre-harvest stage	O34
10:00 - 10:20	Ricardo Hernández, North Carolina State Univ. (US)	Growth and morphology of vegetable seedlings under different blue and red photon flux ratios using LEDs as sole-source lighting	O35
10:20 - 10:40	Coffee break		
10:40 - 11:00	Chieri Kubota, Univ. of Arizona (US)	Combination of end-of-day far-red lighting and blue-rich light environment to mitigate intumescences on tomato seedlings	O36
11:00 - 11:20	Ausra Brazaityte, Lithuanian Research Centre for Agriculture (LT)	Light quality: growth and nutritional value of microgreens under indoor and greenhouse conditions	O37
11:20 - 11:40	Krishna Kumar Sugumaran, Kuwait Institute for Scientific Research (KW)	Influence of light quality on the growth and secondary metabolites content of *Catharanthus roseus* in a modular agricultural production system	O38
11:40 - 12:00	Panel discussion (O34-O38) moderated by Dean Kopsell		
12:00 - 13:00	Lunch, Lincoln Room (buffet in Room 106) and Red Cedar Rooms A & B (buffet in Galaxy Room)		
Oral Session 10 (Concurrent): Lighting technologies and energy consumption Big Ten Rooms B&C Moderated by Royal Heins			
13:10 - 13:30	Morgan Pattison, U.S. Dept. of Energy Solid State Lighting Program (US)	LED lighting technology status and research directions	O39
13:30 - 13:50	Li Kun, Chinese Academy of Agricultural Sciences (CN)	Improving light distribution of LEDs in plant factory by zoom lens for electricity savings	O40
13:50 - 14:10	Arend-Jan Both, Rutgers Univ. (US)	Evaluating operating characteristics of light sources for horticultural applications	O41
14:10 - 14:30	Kale Harbick, Cornell Univ. (US)	Comparison of energy consumption: greenhouses and plant factories	O42
14:30 - 14:50	Gioia Massa, Kennedy Space Center (US)	Large plant growth chambers on the International Space Station	O43
14:50 - 15:10	Panel discussion (O39-O43) moderated by Royal Heins		
Oral Session 11 (Concurrent): Supplemental greenhouse lighting Auditorium Moderated by Marc van Iersel			
13:10 - 13:30	Youbin Zheng, Univ. of Guelph (CA)	LEDs as supplemental lighting for greenhouse cut flower production at northern latitudes	O44
13:30 - 13:50	Ep Heuvelink, Wageningen Univ. (NL)	Regulation of axillary budbreak in a cut-rose crop	O45

13:50 - 14:10	Carl Sams, Univ. of Tennessee (US)	Light quality impacts on growth, flowering, mineral uptake and petal pigmentation of marigold	O46
14:10 - 14:30	Tom Van Delm, Research Centre Hoogstraten (BE)	Advancing the strawberry season in Belgian glasshouses with LED assimilation light	O47
14:30 - 14:50	Most Tahera Naznin, Harrow Research and Development Centre (CA)	Different ratios of red and blue LED to improve the growth of strawberry plants	O48
14:50 - 15:10	Panel discussion (O44-O48) moderated by Marc van Iersel		
15:10 - 16:10	**Poster session #3 (posters ending with 3, 6, 9)** Sponsor displays and refreshments, Big Ten Room A		
16:15 - 16:45	Erik Runkle and Roberto Lopez, Michigan State Univ. (US)	Announcements, acknowledgments, and closing remarks Big Ten Rooms B&C	
16:45 - 18:00	Take down of posters and sponsor booths	Big Ten Room A	
19:00 - 22:00	Symposium banquet dinner, sponsored by Osram Opto Semiconductors. Bar opens at 19:00, dinner starts at 19:30.	Lincoln Room Advance registration and additional fee required	

Thursday, May 26, 2016

Time	Event	Location
07:30 - 17:30	Post-conference tours, sponsored by Illumitex	Departure from Central Lobby, Kellogg Hotel Advance registration and additional fee required

Poster Session Overview

Session 1: Monday, May 23, 2016

P1 - The effect of diurnal light intensity distribution on plant productivity in a controlled environment
G.M. Bocheneka[1], I. Fällström[1]
[1]Heliospectra AB, Sweden

P4 - The role of condensation in greenhouses on light transmission
S. Hemming[1], G.L.A.M. Swinkels[1], F.L.K. Kempkes[1], V. Mohammadkhani[1]
[1]Wageningen UR, the Netherlands

P7 - Influence of shading screens on microclimate, growth and yield of cucumber
R. Ferreira[1], R. Bezerra[1]
[1]Federal University of Goiás, Brazil

P11 - Effects of high-pressure sodium top lighting, LED inter-lighting and their interaction with calcium supply in nutrient solution in greenhouse sweet pepper production
X. Hao[1], C. Little[1], J. Zheng[1]
[1]Greenhouse and Processing Crops Res. Ctr., Agriculture and Agri-Food Canada, Canada

P14 - Interactive effects of illumination time and nutrient solution on growth and quality of lettuce
H. Huang[1], H. Liu[2], S. Song, [1] G. Sun[1], R. Chen[1]
[1]Wushan Road 483, Guangzhou, China
[2]South China Agricultural University, China

P17 - Influence of light intensity on CO_2 net assimilation of several ornamental species suitable for indoor modular wall systems
M.E. Giorgioni[1], A. Martorana[1]
[1]University of Bologna, Italy

P21 - An algorithm for determining the sunlight distribution inside photovoltaic greenhouses
M. Cossu[1], A. Yano[1], L. Ledda[2], P.A. Deligios[2], F. Chessa[3], A. Sirigu[3], L. Murgia[2], A. Pazzona[2]
[1]Shimane University, Japan
[2]The University of Sassari, Italy
[3]Agris Sardegna, Italy

P24 - Response of greenhouse tomato to long photoperiod of LED interlighting at different top HPS photoperiods and temperature integration regimes
X. Hao[1], Y. Zhang[1], X. Guo[1], J. Zheng[1], C. Little[1], S. Khosla[1]
[1]Greenhouse & Proccess. Crops Res. Ctr., Agriculture and Agri-Food Canada, Canada

P27 - The spectral distribution of photoperiodic lighting regulates flowering: A summary of recent research
Q. Meng[1], E.S. Runkle[1]
[1]Michigan State University, USA

P31 - Different ratios of red and blue LED light effects on coriander productivity and antioxidant properties
M.T. Naznin[1], M. Lefsrud[1], V. Gravel[1], X. Hao[2]
[1]McGill University, Canada
[2]Harrow Research and Development Centre, Agriculture and Agri-Food Canada, Canada

P34 - A new quantum sensor for measuring photosynthetically active radiation
D. Magnusson[1], D. Johnson[1]
[1]LI-COR Biosciences, USA

P37 - Day/night temperature regime affects photosynthetic responses to irradiance and carbon dioxide, and mineral, vitamin and fiber content of several vegetable crops
J.E. Erwin[1]
[1]University of Minnesota, USA

P41 - Effect of light spectra on selected microorganisms associated to the phyllosphere of ornamental plants
S. Gharaie[1], S. Windstam[2], S. Khalil[3], K.J. Bergstrand[3], W. Wohanka[4], B.W. Alsanius[5]
[1]Swedish University of Agricultural Sciences, Sweden
[2]State University of New York at Oswego, USA
[3]Swedish University of Agricultural Sciences, Sweden
[4]Geisenheim University, Germany
[5]Swedish University of Agricultural Sciences, Sweden

P44 - Initial studies on increasing garlic bulb size through night-break treatment in the Philippines
R.E.G. Ragas[1], C.F.C. Guittap[1], F.B. Bongat[2], J.T. Lee[3], E.T. Rasco, Jr.[1]
[1]Philippine Rice Research Institute, Central Experiment Station, Philippines
[2]Philippine Rice Research Institute, Batac Satellite Station, Philippines
[3]Korean Project on International Agriculture, Maligaya Science City of Muñoz, Philippines

P47 - Comparative study of lettuce and radish grown under red and blue LEDs and white fluorescent lamps
M. Mickens[1], G. Massa[1], G. Newsham[1], R. Wheeler[1], M. Birmele[1]
[1]NASA Kennedy Space Center, USA

P51 - Vegetative growth of young *Phalaenopsis* 'Blanc Rouge' and *Doritaenopsis* 'Mantefon' plants under different artificial light sources
K.S. Kim[1], H.B. Lee[1], S.K. An[1], S.Y. Lee[1]
[1]Seoul National University, Korea

P54 - Does supplemental lighting make sense for my crop? – Empirical evaluations
C. Kubota[1], M. Kroggel[1], A.J. Both[2], J.F. Burr[3], M. Whalen[1]
[1]The University of Arizona, USA
[2]Rutgers University, USA
[3]Purdue University, USA

P57 - Growth and phytochemical contents of ice plant as affected by light sources and NaCl concentration in a closed-type plant production system
S.J. Hwang[1], H.M. Kim[1], Y.J. Kim[1]
[1]Gyeongsang National University, Korea

P61 - Emerson's enhancement effect revisited: Increasing photosynthetic rate and quantum yield of photosystem II with far-red LEDs
M. Van Iersel[1], S. Zhen[1]
[1]University of Georgia, USA

P64 - The impact of cultural parameters on growth of *Nicotiana benthamiana*
A. Gosselin[1], L. Gaudreau[1], J.C. Boulay[1], G. Marie-Claire[1], S. Pepin[1], D. Michaud[1], M. Martel[2]
[1]Université Laval, Canada
[2]Medicago Inc., Canada

P67 - Cultivar-specific differences of growth and head formation in iceberg lettuce under selected light intensities and LED light qualities
J.G. Lee[1], R.J. Lee[1], J.S. Jo[1], M.J. Lee[1], S.R. Bhandari[1], G.I. Lee[2], G.J. Lee[3], S.W. Jang[4], Y.H. Kim[1]
[1]Chonbuk National University, Korea
[2]National Academy of Agricultural Science, Rural Development Administration, Korea
[3]Chungbuk Agricultural, Research and Extension Service, Korea
[4]National Institute of Horticultural Herbal Science, Korea

P71 - Engineering modeling and analysis of sustainable indoor crop production systems in semi-arid climate I: Energy and resource use for independent production systems mushroom and lettuce
C. Hall[1], C. Kubota[1], B. Pryor[1]
[1]The University of Arizona, USA

P74 - Growth and the antioxidant phenolic content of dropwort grown under monochromatic and various combined ratios of red to blue light-emitting diodes
J-Y. Lee[1], Y-M. Jeon[1], K-H. Son[1], M-M. Oh[1]
[1]Chungbuk National University, Korea

P77 - The effect of light spectral quality on growth characteristics and cryopreservation success of potato (*Solanum tuberosum*) shoot tips in vitro
J. Edesi[1], A.M. Pirttilä[2], H. Häggman[2]
[1]Estonian Crop Research Institute ECRI, Estonia
[2]University of Oulu, Finland

Session 2: Tuesday, May 24, 2016

P2 - Diurnal fluctuations of nutritional compounds of three leafy vegetables under artificial condition
S. Hokosaka[1], E. Goto[1], M. Tanaka[1]
[1]Chiba University, Japan

P5 - Ambient UV manipulation in greenhouses: Plant responses and insect pest management in cucumber (*Cucumis sativus*)
E. Elfadly[1], H. Abd El-Aal[2], A. Rizk[2], W. Sobeih[3]
[1]Alexandria University, Egypt
[2]University of Sadat City, Egypt
[3]Aridagritec Ltd, Lancaster Environment Centre, Lancaster University, UK

P8 - Effects of light intensity and air temperature on lutein and beta-carotene content of spinach
E. Goto[1], S. Hikosaka[1], Y. Ishigami[1]
[1]Chiba University, Japan

P10 - Effects of red, blue, and white LED irradiation on root and shoot development of calibrachoa cuttings in comparison to high pressure sodium lamps
S. Olschowski[1], E.-M. Geiger[1], J. V. Herrmann[1], G. Sander[1], H. Grüneberg[2]
[1]Bavarian State Institute of Viticulture and Horticulture, Germany
[2]Humboldt University of Berlin, Albrecht Daniel Thaer-Institute of Agricultural and Horticultural Sciences, Germany

P12 - Using movable light-emitting diodes for electricity savings in a plant factory growing lettuce
L. Kun[1], Q. Yang[1]
[1]IEDA, Chinese Academy of Agricultural Sciences, China

P15 - Responses of leaf photosynthetic capacity of lettuce on different light quality
T. Li[1], J. Wang[1], Q. Yang[1], Y. Tong[1]
[1]IEDA, Chinese Academy of Agricultural Sciences, China

P18 - Does nighttime UV-B efficacy against powdery mildew depend on day length in cucumber?
S. Aruppillai[1], A. Stensvand[2], K.A. Solhaug[1], H.R. Gislerod[1]
[1]Norwegian University of Life Sciences, Norway
[2]Norwegian Institute for Bioeconomy Research, Norway

P20 - Growing dwarf sunflowers using light emitting diodes
E. Cook[1], M.G. Karlsson[1]
[1]University of Alaska Fairbanks, USA

P22 - Rooting of single-node *Pennisetum setaceum* 'Rubrum' culm cuttings is influenced by photosynthetic daily light integral and rooting medium temperature
W.G. Owen[1], R.G. Lopez[1]
[1]Purdue University, USA

P25 - Effects of light quality on the growth and essential oil production in Mexican mint
A. Noguchi[1], W. Amaki[1]
[1]Tokyo University of Agriculture, Japan

P28 - Increase in chlorogenic acid concentration in lettuce by overnight supplemental lighting and CO_2 enrichment
H. Yoshida[1], K. Sekiguchi[1], L. Okushima[2], S. Sase[3], N. Fukuda[1]
[1]University of Tsukuba, Japan
[2]National Institute for Rural Engineering, NARO, Japan
[3]Nihon University, Japan

P30 - Plant factory: hydroponic lettuce growth under light LED conditions - red, far-red and blue light irradiation
J. Grego[1], L.F. Ferreira[1]
[1]Escola Superior Agrária de Santarem, Portugal

P32 - Short term LED lighting effect on isoprenoid compounds in *Perilla frutescens* leaves
A. Virsile[1], A. Brazaityte[1], R. Sirtautas[1], S. Sakalauskiene[1], P. Duchovskis[1]
[1]Lithuanian Research Centre for Agriculture, and Forestry, Institute of Horticulture, Lithuania

P35 - Effects of plasma vs. high pressure sodium lamps on plant growth, microclimate, fruit yield and quality in greenhouse tomato production
X. Hao[1], X. Guo[1], J. Zheng[1], C. Little[1], S. Khosla[2]
[1]Greenhouse and Processing Crops Res. Ctr., Agriculture and Agri-Food Canada, Canada
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P38 - Daily light integral and plant density affect growth of green and purple sweet basil
K. Walters[1], C. Currey[1], C. Gamble[1]
[1]Iowa State University, USA

P40 - Effects of end-of-day irradiation on the growth and nicotine accumulation in tobacco
J. Ito[1], T. Fukuyama[1], W. Amaki[2], H. Watanabe[1]
[1]Tamagawa University, Japan
[2]Tokyo University of Agriculture, Japan

P42 - The connection between nitrate reduction and photosynthetic plant performance under red light treatment
G. Samuoliene[1], A. Virsile[1], S. Sakalauskiene[1], A. Bagdonaviciene[1], I. Odminyte[2]
[1]Kaunas str. 30, Babtai, Lithuania
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P45 - Effects of the irradiation patterns of red and blue led lights on plant growth
H. Shimizu[1], Y. Kuno[1], H. Namashima[1], J. Miyasaka[1], K. Ohdoi[1]
[1]Kyoto University, Japan

P48 - Growth and morphology of greenhouse bell-pepper transplants grown under supplemental LEDs and HPS lighting
R. Hernandez[1], P. Santana[2], C. Kubota[2]
[1]North Carolina State University, USA
[2]The University of Arizona, USA

P50 - Blue light-induced changes in scoparone as related to ethylene and reduced citrus postharvest disease
T. Lafuente[1], A.R. Ballester[1]
[1]Avda. Agustín Escardino 7, Spain

P52 - Maintaining different electron transport rates in lettuce: effects on quantum yield and non-photochemical quenching
M. Martin[1], E. Mattos[2], M. van Iersel[1]
[1]Department of Horticulture, University of Georgia, USA
[2]PhytoSynthetix LLC, USA

P55 - Effect of CO_2 enrichment on photosynthesis and growth characteristics of *Doritaenopsis* Queen Beer 'Mantefon'
Y.J. Kim[1], D.L. Yun[1], H.J. Kim[1]
[1]Seoul Women's University, Korea

P58 - Effect of different proportion of light intensity on glucosinolates and caroteniods in kale (*Brassica oleracea acephala*)
A.M. Valan[1], S-O. Chung[2], S.U. Park[2], S.H. Park[3], S-J. Kim[2]
[1]King Saud University, Saudi Arabia
[2]Chungnam National University, Republic of Korea
[3]National Institute of Horticultural and Herbal Science, Republic of Korea

P60 - Inter-lighting LED trial in greenhouse tomato production in Alberta, Canada
Z. Pan[1], J. Zhang[1]
[1]301 Horticultural Station Road East, Brooks AB, Canada

P62 - Seven dimensions of light in regulating plant growth
Y. Xu[1]
[1]Fujian Agriculture and Forestry University, China

P65 - Blue LED light affects stress metabolites in chrysanthemum cultivars
L. Zheng[1], A. Christiaens[2], M.C. Van Labeke[1]
[1]Coupure Links 653, 9000 Ghent, Belgium
[2]PCS Ornamental Plant Research, Belgium

P68 - Smart LED-based lighting device for plant research
A. Virsile[1], G. Samuoliene[1], A. Brazaityte[1], P. Duchovskis[1], P. Vilemas[2]
[1]LRCAF Institute of Horticulture, Lithuania
[2]Energenas LLC, Lithuania

P70 - LED-it-be 50%: Spectrum effect of LED lighting on tomato (*Solanum lycopersicum*) fruit set
Y. Ji[1], L. Gao[1], L.F.M. Marcelis[1], E. Heuvelink[1]
[1]Wageningen University and Research Center, the Netherlands

P72 - Engineering modeling and analysis of sustainable indoor crop production systems in semi-arid climate II: Integration of mushroom and lettuce production systems
C. Hall[1], C. Kubota[1], B. Pryor[1]
[1]The University of Arizona, USA

P75 - Phytochemicals of *Crepidiastrum denticulatum* under continuous or short-term irradiation of far-red LEDs in a plant factory
J-H. Bae[1], M.-M. Oh[1]
[1]Chungbuk National University, Korea

P78 - Effects of bio-PM lamp treatments on whitefly adults in greenhouse

C. He[1], Y. Yan[1], Z. Zhang[1]
[1]Chinese Academy of Agricultural Sciences, China

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P3 - Effects of pulsed lighting based light-emitting diodes on the growth and photosynthesis of lettuce leaves
M. Kanechi[1], A. Maekawa[1], Y. Nishida[2], E. Miyashita[2]
[1]Graduate School of Agricultural Science, Kobe University, Japan
[2]Faculty of Agriculture, Kobe University, Japan

P6 - Effects of pre- and postharvest lighting on quality and shelf life of fresh-cut lettuce
E.J. Woltering[1,2], I.M. Witkowska[2]
[1]Wageningen University and Research Centre, Food & Biobased Research, Wageningen, the Netherlands
[2]Wageningen University, Horticulture & Product Physiology, the Netherlands

P9 - Effects of supplemental lighting on the growth and medicinal ingredient concentrations of Japanese honeysuckle (*Lonicera japonica*)
S. Hikosaka[1], N. Iwamoto[1], Y. Ishigami[1], E. Goto[1]
[1]Chiba University, Japan

P13 - Effects of light quality on growth and color of red-leaf lettuce
L. Ma[1], H. Liu[1], S. Song[1], G. Sun[1], R. Chen[1]
[1]South China Agricultural University, China

P16 - Can supplemental light quality influence the nutritional quality of greenhouse-grown tomatoes?
C. Mitchell[1], M. Dzakovich[1], M. Ferruzzi[1], C. Gómez[1]
[1]Purdue University, USA

P19 - How is the status: Spectral effects of LEDs on physiology and metabolites
C.O. Ottosen[1], E. Rosenqvist[2], T. Ouzounis[3]
[1]Aarhus University, Denmark
[2]Hoejbakkegaard Alle 9, 2630 Taastrup, Denmark
[3]Wageningen UR, the Netherlands

P23 - Efficiency of plastic cover types on essential oil composition and vegetative growth of dill (*Anethum graveolens*)
S.M. Hassan[1], Z.A. Abd Alhafez[2]
[1]Department of Vegetable, Faculty of Agriculture, Alexandria, Egypt
[2]Medicinal and Aromatic Plants Res. Department, Alexandria, Egypt

P26 - Effect of intracanopy lighting and/or root-zone temperature on high-wire tomato production under supra-optimal air temperature
C. Gómez[1], M. Clark[1], C.A. Mitchell[1]
[1]Purdue University, USA

P29 - In vitro organogenesis of *Anoectochilus formosanaus* under different sources of lights
S.M. Haquea[1], S.J. Nahar[1], K. Shimasaki[1]
[1]Kochi University, Japan

P33 - Effects of plasma vs. high pressure sodium lamps on plant growth, fruit yield and quality in greenhouse cucumber production
X.Guo[1], X. Hao[1], J. Zheng[1], C. Little[1], S. Kholsa[2]
[1]Greenhouse and Processing Crops Research Centre, AAFC, Canada
[2]Ontario Ministry of Agriculture Food and Rural Affairs, Canada

P36 - Effect of LED interlighting combined with overhead HPS light on fruit yield and quality of year-round sweet pepper in commercial greenhouse
X. Guo[1], X. Hao[1], S. Kholsa[2], K.G.S. Kumar[1], R. Cao[3], N. Bennett[4]
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[2]Ontario Ministry of Agriculture Food and Rural Affairs, Canada
[3]Guelph Food Research Centre, Agriculture and Agri-Food Canada, Canada
[4]Ontario Greenhouse Vegetable Growers, Canada

P39 - Effects of LED plant exposure on gustatory and health promoting compounds of greenhouse tomato
S. Pepin[1], M.J. Breton[1], M. Dorais[1], R. Bacon[1], A. Hell[1], K. Pedneault[2], P. Angers[1]
[1]Laval University, Canada
[2]Quebec Agrifood Development Center, Canada

P43 - Productivity and photosynthetic characteristics of heat-resistant and heat-sensitive recombinant inbred lines of *Lactuca sativa* in response to different durations of LED lighting
J. He[1], S.M. Kong[1], T.W. Choong[1], L. Qin[1]
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P46 - Reflected sunlight weed control capabilities of watermelon (*Citrullus lanatus*) in amaranth cropping system
D. Ojo[1], I.O.O. Aiyelaagbe[2]
[1]Horticultural Research Institute (NIHORT), Nigeria
[2]University of Agriculture, Nigeria

P49 - Effect of LED blue light on ethylene production of *Penicillium digitatum* and its capability to infect citrus fruits
T. Lafuente[1], F. Alférez[1]
[1]Avda. Agustín Escardino 7, Spain

P53 - Accumulation of phenylpropanoids and the growth of *Agastache rugosa* using different types of LEDs
J. Park[1], S. Kim[1], G. Bok[1], S. Kim[1], S. Park[1]
[1]Chungnam National University, Korea

P56 - Growth of ice plant as affected by light quality and light intensity in closed-type plant production system
S.J. Hwang[1], H.M. Kim[1], Y.J. Kim[1]
[1]Gyeongsang National University, Korea

P59 - Indoor cultivation of tomato transplants under various intensities of red and blue LED light
A. Brazaityte[1], A. Bagdonaviciene[1], J. Jankauskiene, [1] A. Virsile[1], A. Viskeliene[1], P. Duchovskis[1]
[1]Institute of Horticulture, Lithuania

P63 - Growth and development of *Ligularia fischeri* as affected by light source, photoperiod, and light intensity
B.R. Jeong[1], Y.G. Park[1], S. Kim[1], M. Abinaya[1], H. Wei[1], S. Muneer[1], S.J. Hwang[1]
[1]Gyeongsang National University, Korea

P66 - Effects of varying daily light integral and carbon dioxide concentration on the growth and nutritional characteristics of three microgreen species of the *Brassicaceae* family
J. Allred[1], N. Mattson[1]
[1]Cornell University, USA

P69 - Effect of CO_2 concentration, light intensity, and red/far-red ratio on growth of *Arabidopsis thaliana*
Y. Yang[1], B. Martindale[1], K. Curlee[1], D. Griffin[1], A. Perkett[1], R. Han[2]
[1]Dow AgroSciences, USA
[2]Cornell University, USA

P73 - Growth and bioactive compounds of lettuce under changing light quality created by red and blue light-emitting diodes during cultivation
K-H. Son[1,] M-M. Oh[1]
[1]Chungbuk National University, Korea

P76 - Comparisons of photosynthetic and growth characteristics between plasma lighting systems and high pressure sodium lamp in horticultural crops
W. Oh[1], J.E. Son[2], J.K. Kwon[3], S.Y. Min[1], J-W. Lee[2], H.S. Seo[1], K.S. Park[3]
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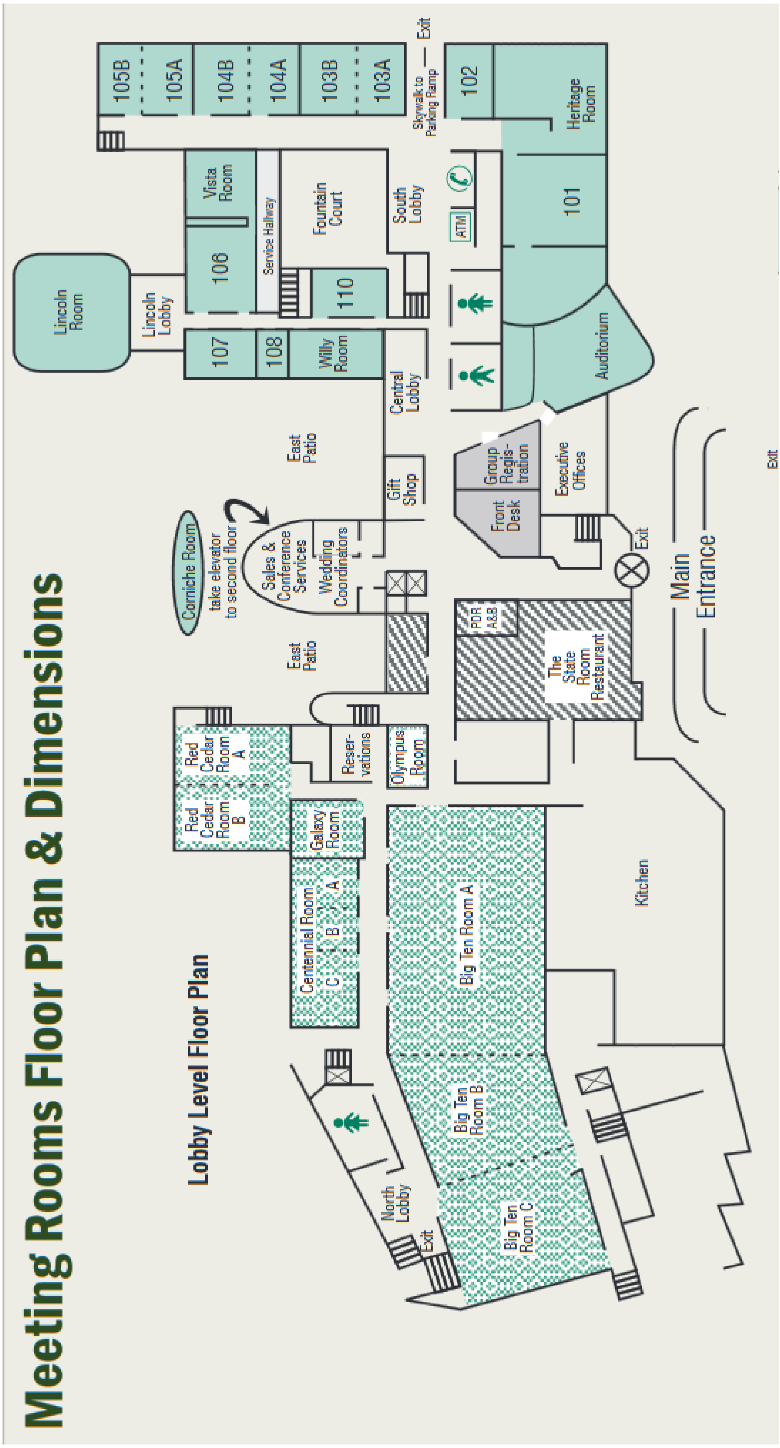
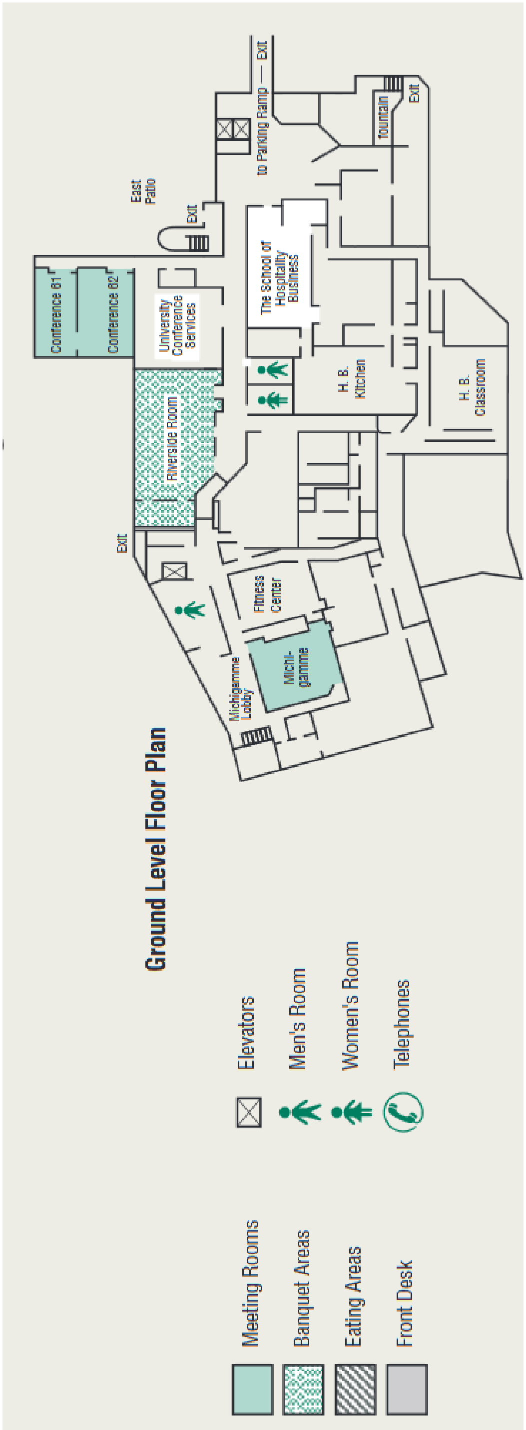
[2]Seoul National University, Korea
[3]National Institute of Horticultural and Herbal Science, Korea

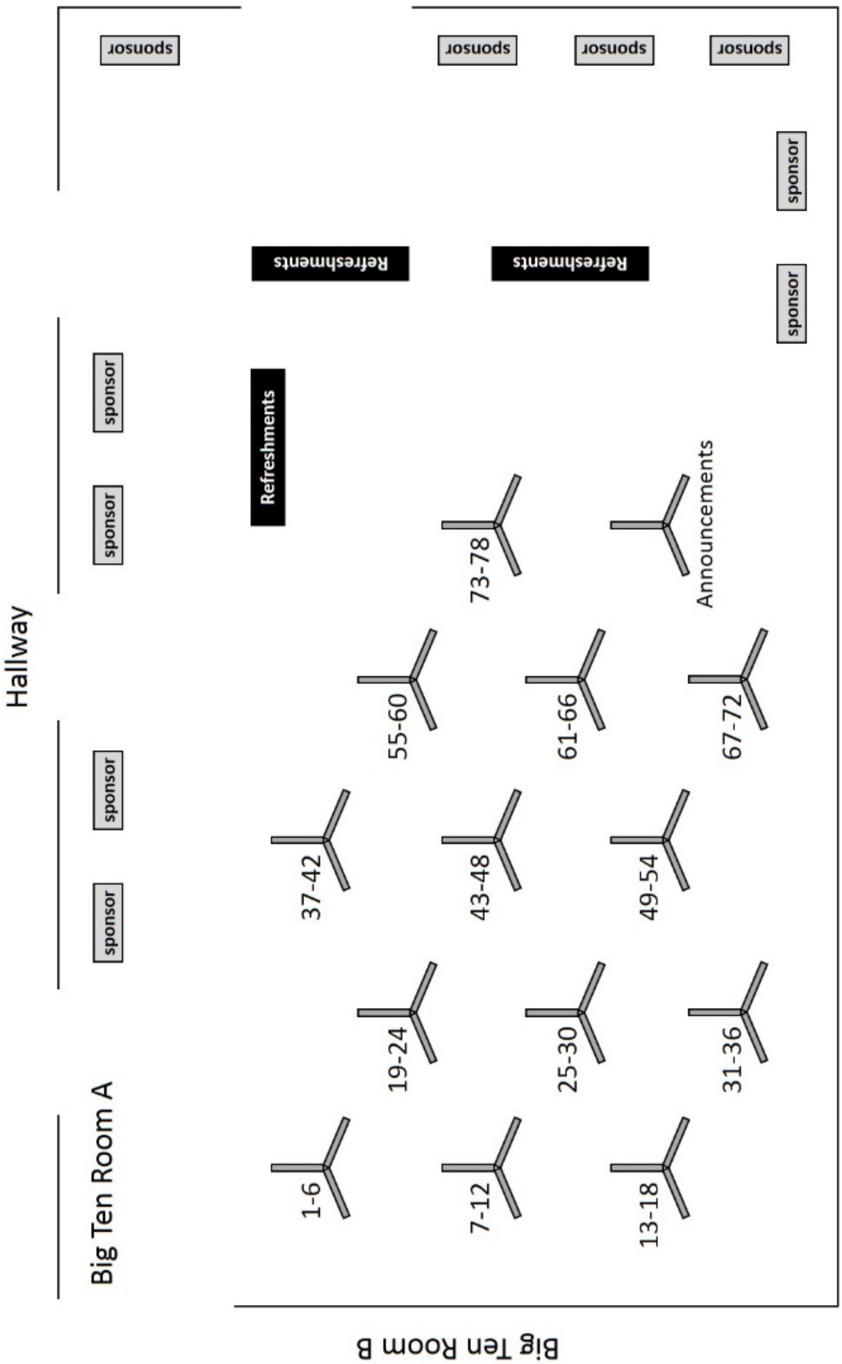
Kellogg Conference Center Floor Plan, Main/Lobby Level



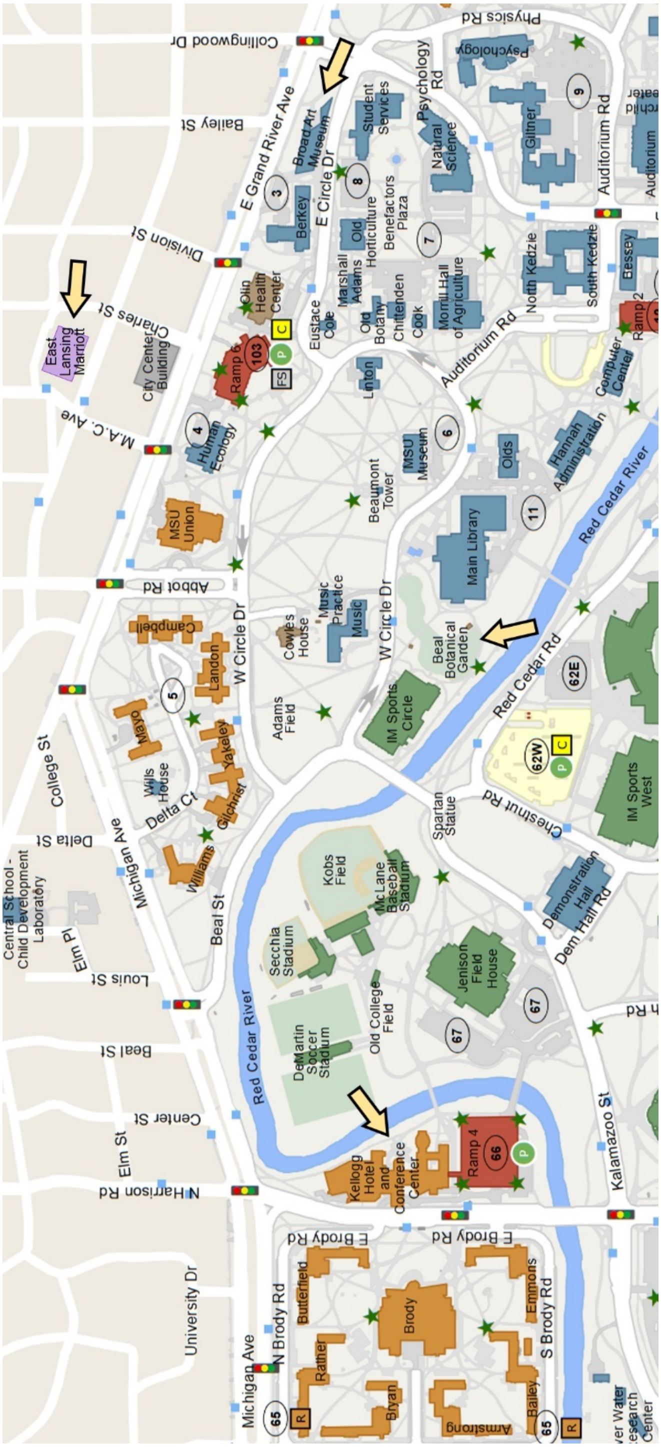
Kellogg Conference Center Floor Plan, Ground/Lower Level



Big Ten Room A – Posters, Sponsor Booths, and Refreshments



Michigan State University, Map of Northwest & North-Central Campus



Abstracts for Invited Oral Presentations

I1

TOWARD AN OPTIMAL SPECTRAL QUALITY FOR PLANT GROWTH AND DEVELOPMENT: THE IMPORTANCE OF RADIATION CAPTURE

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We have characterized the effects of individual wavelengths of light on single leaf photosynthesis but we do not yet fully understand the effects of multi-wavelength radiation sources on growth and whole-plant net assimilation. Studies with monochromatic light by Hoover, McCree and Inada nearly a half century ago indicated that blue and cyan photons are used less efficiently than orange and red photons. Contrary to these measurements, studies in whole plants have found that photosynthesis often increases with an increasing fraction of blue photons. Plant growth, however, typically decreases as the fraction of blue photons increases above 5 to 10 %. The dichotomy of increasing photosynthesis and decreasing growth reflects an oversight of the critical role of radiation capture (light interception) in the growth of whole plants. Photosynthetic efficiency is measured as quantum yield: moles of carbon fixed per mole of photons absorbed. Increasing blue light often inhibits cell division, cell expansion, and thus reduces leaf area. The thicker leaves have higher photosynthetic rates per unit area, but reduced radiation capture. This blue-light-induced reduction in photon capture is usually the primary reason for reduced growth in spite of increased photosynthesis per unit leaf area. This distinction is critical when extrapolating from single leaves to plant communities.

I2

UV LEDS IN HORTICULTURE: FROM BIOLOGY TO APPLICATION

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The opportunities within crop production presented by the continuing evolution of light emitting diode [LED] lighting technology are significant, with much attention currently focused on manipulation of visible wavelengths for supplementary and whole lighting systems in horticulture. However, our understanding of the importance of other components of the electromagnetic spectrum for plant development has expanded considerably over the last two decades, and such knowledge can now be exploited for agronomic gain. Ultraviolet [UV] radiation [280-400nm] is one such region beyond the visible, and is a biologically potent environmental cue to which plants acutely respond. With the recent discovery of the only known UV-B specific photoreceptor [UVR8], combined with the new paradigm of UV light as a plant-regulatory signal as opposed to a frequently injurious source of stress, the application of this new photobiological understanding is now possible. The arrival of UV LED technology is now offering possibilities to design UV lighting systems that can trigger desired outcomes in a range of crops. As with the arrival of visible LED lighting, UV LEDs can now generate a new range of research questions across all scales, from the molecular basis for UV photoperception and signal transduction, to the elucidation of horticultural UV treatments which can add value to a grower's operation, from induction of crop stress resilience, to regulation of traits linked to consumer acceptability.

I3

CONTROLLING PLANT GROWTH, DEVELOPMENT AND METABOLISM WITH COMMANDS FROM THE ELECTRONIC CANOPY

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The plant cell maintains a set of light sensors that are activated by discrete wavelengths. These sensors connect to integrate signal transduction pathways that ultimately drive changes in physiology, biochemistry and gene expression that adapt a plant to a specific light environment. These sensory pathways have traditionally been activated by broad-spectrum light mixtures from sun, white artificial light, or its polychromatic proxies. With the continued improvement of narrow bandwidth lighting, it is now possible to provide plants with discrete combinations of light to control specific aspects of plant product output. To illustrate proof of concept, we have focused on microgreens with substantial phenotypic plasticity. Work in Red Russian Kale and other seedlings demonstrates the synergistic and/or suppressive nature of specific wavelength combinations, and the ability to use light as a growth regulator to control pigmentation, size, flavor, nutraceutical accumulation and other traits in horticultural products.

I4

PLANT GROWTH CONTROL BY LIGHT SPECTRUM: FACT OR FICTION?

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Plants are sessile organisms that have to cope with their environment as it is exposed to them in nature. To do so, they developed systems to sense environmental signals and to integrate these with endogenous developmental programs. As a result, they are well equipped to survive and flourish in very different environments, while it also ensures the timely production of offspring for survival in the long run. In horticulture, aims and environmental conditions for plant growth are often very different from nature. For growers, survival is associated with responding to market and societal demands, and with efficient and exact timed production of high quality plants and products at a minimum of costs (financial and environmental). Greenhouses and plant factories provide growers with means for extensive control of the growth climate, including the light environment. In nature, the light environment of plants is largely determined by the sun. Important characteristics of this natural light include intensity, length of the photoperiod, and the spectral composition, which are eventually modified by neighboring plants and or weather and provide the signals under which plants evolved their mechanisms to cope with their environmental conditions. Therefore, they have become genetically programmed to respond in accordance with these natural light signals. In horticulture, however, applied lighting can be very different from nature. Lengthening the photoperiod and increasing intensity with artificial lighting enabled the culture of plants at times and locations on earth, where this would never have been possible under the prevailing natural light climate. The introduction of LED’s as low-energy alternatives for conventional lamps, adds a new opportunity for control via the light spectrum, which is also not natural at all. Consequently, horticulture crops are now often exposed to light climates that they would never have experienced in nature. Applying lighting to plants beyond their natural comfort zone may also results in unexpected negative effects. This hampers the development of optimal lighting strategies in horticulture. In this paper, two examples of such negative effects on leaf photosynthesis are presented, aiming to induce a discussion on how genetic and physiological knowledge from natural systems may help to develop new lighting strategies for horticultural production in greenhouses and plant factories.

Abstracts for Oral Presentations

O1

IN SEARCH OF AN OPTIMIZED SUPPLEMENTAL LIGHTING SPECTRUM FOR GREENHOUSE TOMATO PRODUCTION WITH INTRACANOPY LIGHTING

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With anticipated energy-efficiency improvements and ever-improving light-distribution architectures, light-emitting diodes (LEDs) are a promising alternative to current supplemental lighting (SL) technologies for greenhouse crop production. Yet, significant questions remain regarding how to best optimize spectral-quality effects on plant growth and development using LEDs in the greenhouse. The objective of this study was to compare different spectra of intracanopy (IC) SL using LEDs for high-wire greenhouse tomato (*Solanum lycopersicum* cv. Merlice) production in a mid-northern climate during a winter-to-summer production cycle. Five lighting treatments were evaluated: solar light only (control); solar light + SL from IC-LED towers using different percentages of blue, red and/or far-red light: 10B-90R; 30B-70R; 25B-60R-15FR; or 80R-20FR, where B refers to blue (450 nm), R refers to red (627 nm), and FR refers to far-red (730 nm). A constant photon flux of 180 $\mu mol \cdot m^{-2} \cdot s^{-1}$ was provided to all plants grown with SL for 16 h d^{-1}. In general, light quality from SL did not affect weekly plant-growth measurements (leaf length and stem elongation), relative chlorophyll content (RCC), or plant productivity (fruit number and total fruit FW), but significantly altered leaf photosynthesis and abaxial stomatal density (SD) and index (SI). Although leaves grown with 25B-60R-15FR had higher stomatal conductance (g_s) than all other treatments, their abaxial stomatal features were only ~87% those of leaves grown with 10B-90R. Leaf chlorophyll content was up to 11% higher for plants grown under any kind of SL compared to unsupplemented controls. Similarly, total fruit yield was higher for SL treatments relative to the control. The consequences and perspectives of using different light-quality treatments in the SL spectrum will be discussed.

O2

BLUE AND RED LED LIGHTING EFFECTS ON PLANT BIOMASS, STOMATAL CONDUCTANCE, AND METABOLITE CONTENT IN NINE TOMATO GENOTYPES

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A collection of nine tomato genotypes was chosen based on their diversity, phylogeny, availability of genome information, and agronomic traits. The objective of the study was to characterize the effect of red and blue LED (light-emitting diode) lighting on physiological, morphological, developmental, and chemical parameters. Two LED light treatments were imposed: (1): 100% red and (2): 88% red/12% blue (peak emission at 662 and 456 nm for red and blue light, respectively). The combination of blue and red LED lighting increased total dry matter in seven of the nine genotypes compared to red. Upward or downward leaf curling was observed in all genotypes in the 100% red treatment. Stomatal conductance was not affected much by additional blue light, but blue light increased chlorophyll and flavonol contents in three genotypes. The exposure of tomato plants to a combination of red and blue LEDs alleviated leaf morphological abnormalities and enhanced plant biomass, and variably affected stomatal conductance and secondary metabolism compared to red light alone.

O3

USING CHLOROPHYLL FLUORESCENCE TO CONTROL LIGHTING IN CONTROLLED ENVIRONMENT AGRICULTURE

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[2]PhytoSynthetix LLC, USA
[3]University of the Virgin Islands, USA

Supplemental lighting is often needed for crop production in controlled environments. Such supplemental lighting can be expensive and inefficient. Chlorophyll fluorescence is a valuable tool for monitoring light use efficiency in plants and can be used to determine the quantum yield of photosystem II (ϕ_{PSII}) and the electron transport rate through photosystem II (ETR). Combining chlorophyll fluorescence measurements with light emitting diodes (LED), whose intensity can be easily and automatically adjusted, provides an unexplored opportunity to control lighting based on the physiology of the plants. We describe here how a chlorophyll fluorescence-based biofeedback system can be used to maintain steady ϕ_{PSII} or ETR by adjusting the duty cycle of the LEDs. Although the biofeedback system was capable of maintaining a stable ϕ_{PSII} of lettuce (*Lactuca sativa*), it did so by gradually down-regulating the photosynthetic photon flux density (PPFD), resulting in very low ETR and thus low photosynthetic rates. Maintaining stable ETR appears to be more promising: the biofeedback system was capable of maintaining a range of different ETRs over 12-h periods. To do so, the PPFD had to be gradually upregulated, because of a steady decrease in ϕ_{PSII}. This decrease in ϕ_{PSII} is likely due to an upregulation of non-photochemical quenching and possibly photoinhibition induced by the saturating pulses from the fluorometer. The next phase in this research is to determine how to use the biofeedback system to optimize energy efficiency and growth. Optimal control algorithms for biofeedback of lighting may need to take into account ϕ_{PSII}, ETR, and non-photochemical quenching.

O4

EXPLORING THE DYNAMICS OF REMOTELY DETECTED FLUORESCENCE TRANSIENTS FROM BASIL AS A POTENTIAL FEEDBACK FOR LIGHTING CONTROL IN GREENHOUSES

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[2]Heliospectra AB, Sweden
[3]Rensselaer Polytechnic Institute, USA

Optimizing artificial lighting control in industrial scale greenhouses has a potential for increased crop yields, energy savings and production timing. One possible component in controlling greenhouse lighting is continuous and accurate measurement of plant photosynthetic performance. A widely used tool for measuring photosynthetic performance non-invasively is chlorophyll fluorescence. For the purpose of automatic control, remote sensing of fluorescence is favourable, since it provides an aggregated measure for a large canopy area. However, adaptation of traditional fluorescence methodologies to remote sensing is problematic since they are based on the analysis of fluorescence intensities and therefore sensitive to distance and morphology. Other problems with using traditional methods remotely in a greenhouse are a need for dark adaption and use of saturating light. This paper presents a novel concept for the detection of photosynthetic performance based on the dynamics of remotely sensed light induced fluorescence signals. The dynamics of the fluorescence signal is insensitive to distance and morphology and hence provide a good basis for remote detection of photosynthetic performance. Through experiments we have

explored how the dynamics of the time-varying fluorescence signal from basil plants was affected by light intensity, light acclimation and light induced stress. This was done by first identifying a dynamic model by transient analysis and then applying frequency analysis on the model. We conclude that the capacity of basil plants to use a certain light intensity was reflected by how fast and how complex the dynamics are. These results show that an identified resonance peak frequency is a potential indicator of plants' ability to adapt to light, which could be a valuable feedback signal for lighting control in greenhouses.

O5

LED SPECTRUM OPTIMISATION USING STEADY-STATE FLUORESCENCE GAINS

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[2]Heliospectra AB, Sweden

The use of light emitting diodes (LEDs) in greenhouses entails the possibility to control the light in a better way, since both spectrum and light intensity can be adjusted. We aim at developing a method to automatically find the optimal spectrum in terms of energy consumption and plant growth. Previous work shows that chlorophyll fluorescence (ChlF) at 740 nm strongly correlates with the photosynthetic rate (carbon dioxide uptake rate) and that the net efficiency of a LED group therefore is coupled to the fluorescence gain w.r.t energy consumption, i.e. the slope of a curve depicting steady-state ChlF versus applied power to the LED group.

In the present work we compare the fluorescence gains for six different LED types (wavelength peaks from 400 to 660 nm) and six different species: tomato, cucumber, basil, lettuce (two species) and dill. We also compare two different kinds of experiments: steady-state experiments, waiting for the fluorescence to reach a steady state at a few incident light intensities, and ramp experiments, where the light intensity is increased slowly. The ramp experiment gives essentially the same information as the steady-state experiment, but was found to slightly overestimate the gains of the blue LEDs. Being aware of this, it should be possible to initially use the faster (ramp) method in order to find the right light composition, possibly using steady-state experiments for a few LED colours to fine tune the lamp. The relative order of the fluorescence gains among the tested LED groups is similar, but not identical, for all species tested. LED660 has the highest fluorescence gain w.r.t. incident photon flux density, and LED400 and/or LED530 have the lowest. However, the important quantity is in fact the fluorescence gain w.r.t. applied electrical power. If the individual electrical efficiencies of the LEDs change the most efficient power split on the different LEDs might change.

O6

USING ULTRAVIOLET-C (UV-C) IRRADIATION ON GREENHOUSE ORNAMENTAL PLANTS FOR GROWTH REGULATION

M.P. Bridgen[1]
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Plants use sunlight for photosynthesis and are exposed to the ultraviolet (UV) radiation that is present in sunlight. UV radiation is divided into 3 classes: UV-A, UV-B, and UV-C. The Ultraviolet-C (UV-C) region of the UV spectrum includes wavelengths below 280 nm; these highly energetic wavelengths are absorbed by ozone and are not present in the sunlight at the earth's surface. Under normal growing conditions, effects of UC-C light are not seen on plants. This research examined the effects of the application of ultraviolet-C irradiation (UV-C) on greenhouse

ornamental plants and demonstrated very promising uses of UV-C as a treatment to increase branching and reduce height of plants, and in some situations, affect the speed of flowering. Several conclusions have been made from this research that are consistent with multiple plant species. First, the amount of UV-C light that a greenhouse plant receives is critical to its response. The proper weekly dosage, for as little at 15 minutes a week, will control a plant's growth response. In addition, too high a dosage of UV-C irradiation will burn plants and too low will have no effect. Second, proper applications of UV-C light decreases final plant height. Several plant species have responded to applications of UV-C light by growing shorter than the control plants that receive normal greenhouse lighting. Third, UV-C light increases branching of greenhouse plants. At appropriate dosage rates, UV-C light increases branching on some species and increases the number of flowers that are produced. This avoids the need to pinch plants and to apply plant growth regulators. Fourth, the application of UV-C light can affect flowering time. The application of UV-C irradiation can either delay flowering or cause earlier flowering depending on plant species and dosage rate. In some cases, the increased branching is accompanied by delayed flowering.

O7

EFFECT OF UV LIGHT ON PHYTOCHEMICAL ACCUMULATION AND EXPRESSION OF ANTHOCYANIN BIOSYNTHESIS GENES IN RED LEAF LETTUCE

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Light manipulation is a key environmental control method to increase functional phytochemical concentrations and antioxidant capacity in leaves of leafy vegetables. Here, we evaluated the effect of UV light on the accumulation of functional phytochemicals in the leaves of red leaf lettuce. We developed a novel lighting system, consisting of UV LEDs as a UV light source and red LEDs as a photosynthetic light source. Red leaf lettuce grown under white light was used as the plant material. Three peak wavelengths (310, 325, and 340 nm) of UV lights at 0.5 Wm^{-2} for 16 h were added to the white light for 3 d prior to harvest. Anthocyanin concentration and ORAC value of the leaves were measured every 8 h. mRNA gene expression of chalcone synthase (CHS) and the flavonoid 3-O-glucosyltransferase (UFGT) were also analyzed every 8 h. Anthocyanin concentration was significantly higher at 310 nm compared with 325 and 340 nm. Total ORAC values of the UV treatments were higher than in the control. *CHS* was highest at 310 nm, followed by 325 nm. *UFGT* increased with time, similarly to the anthocyanin concentration. These results indicated that UV-B light stimulated the biosynthesis of anthocyanin and other antioxidant polyphenols. From this research, we concluded that addition of UV light 1 to 3 d prior to harvest is effective for the production of functional phytochemical rich lettuce.

O8

LED IT BE: A ROAD TO 50% ENERGY SAVING BY THE SMART USE OF LEDS IN GREENHOUSE HORTICULTURE

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LEDs provide exciting new possibilities to modulate spectrum and direction of light, to control instantaneously light intensity, and to decouple lighting from heating. In 2015 a 5-years research programme called 'LED it be' started. In this programme five Dutch universities and nine private companies (Philips, LTO Glaskracht, Nunhems, Bejo, Rijkzwaan, Plantenkwekerij Van der Lugt, Westlandse Planten Kwekerij, Hortimax, B-Mex) cooperate. The aim is to fundamentally understand the responses of plant processes to many of the different features of light and translate this knowledge in management practices; thereby saving 50% energy in greenhouse tomato production. In the Netherlands a modern tomato grower with HPS lighting uses typically 3100 MJ/m^2 fossil energy per year, of which 80% consists of electricity for lighting (2480 MJ/m^2). The remaining 20% (620 MJ/m^2) is mainly for heating and humidity control. Furthermore, 530 MJ/m^2 of the lighting energy also contributes to fulfilling the energy demand for heating and humidity control. The energy demand for heating will be reduced by applying Next Generation Cultivation ("The New Way of Growing"). The main bottlenecks for energy saving are the energy use for lighting and to a lesser extent for control of air humidity. To realize an overall energy reduction of 50%, a reduction of 60% in use of electricity for lighting is required. Compared to HPS lighting 30% reduction can be realised by a better conversion from electricity to light. Improved light absorption by adapted canopy architecture and positioning of LEDs can save 15% energy. Ten percent will be realised by improved photosynthesis and 5% by improved assimilate partitioning. Furthermore, lighting will be used to enhance disease resistance of the crop and decrease transpiration at moments that transpiration leads to energy costs. The generated knowledge will be accumulated in a model based management support system. This presentation will outline the concept of how to realise 50% energy saving and it will briefly explain the set-up of the research programme as a whole, including some first experimental results.

O9

REDUCING THE CARBON FOOTPRINT OF GREENHOUSE GROWN CROPS: RE-DESIGNING LED-BASED PRODUCTION SYSTEMS

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To fulfill the market demand for year-round high-quality production, the use of assimilation light has increased over the last decades by 10% per year and continues to expand. The electrical consumption involved largely contributes to the high CO_2 emission of greenhouse horticulture. Following the Kyoto protocol, the emission of greenhouse gases should be reduced. Light-emitting diodes (LEDs) can contribute to the reduction in carbon footprint by their high efficiency in converting electricity into light. Due to their low heat emission, LEDs can be positioned within the canopy, which allows the design of new, low-carbon production systems. Inter-canopy LED lighting is already commercially used on a small scale. This paper describes the steps taken to further optimize LED-based production systems. Since it is impossible to test all possible strategies of using LED lighting, a 3D functional-structural plant model was used to do scenario calculations to determine the light interception of the canopy and crop photosynthesis at different positions and orientations of the LEDs. Orienting inter-lighting LEDs 30° downwards positively affected the light interception by the crop, provided that there was sufficient leaf area below the LEDs to prevent light loss to the floor. Replacing the conventional high-pressure sodium (HPS) lamps by LED lamps (efficiency 2.3 µmol/J) reduced the carbon footprint of a tomato crop by approximately 15%, due to a combination of the higher efficiency of LEDs and an increased use of thermal energy to maintain plant temperatures. These calculations were validated in a greenhouse trial, where the production and energy consumption of a HPS+LED hybrid system was compared to those of a LED top-lighting and LED inter-lighting combination. Plant development and production levels were comparable, whereas the electrical consumption in the LED+LED system was 37% lower than under HPS+LED

lighting. Approximately half of the reduction in electricity was used for additional heat input to maintain plant development rate, which agreed well with the carbon footprint calculations. Work in the near future will focus on plant architecture and LEDs with altered light emission patterns, aiming to design new LED-based production systems, which combine a high production level with a low-carbon footprint.

O10

EVALUATION OF DIFFUSING PROPERTIES OF GREENHOUSE COVERING MATERIALS

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Modern greenhouse covering and screen materials are able to transform direct sunlight into diffuse light. After entering the greenhouse the sunlight is scattered and penetrates the crop where it is absorbed and used for photosynthesis. Diffuse light has been shown to increase light interception of crops, increase crop photosynthesis and results in higher yields. Many different types of diffuse covering materials are available, and growers select materials based on crop, outside climate where the greenhouse is located and market situation. Earlier measurement methods to evaluate diffuse covering materials have been proposed (Hemming et al, 2008) and are mainly based on the measurement and evaluation of the hemispherical light transmittance, the average amount of light coming into the greenhouse (Nijskens, et al., 1985; Papadakis et al, 2000) and the Haze (e.g. ASTM-D1003-07), the average amount of scattered light reaching the crop. A more detailed evaluation of the angular and spectral light transmittance of materials is needed (Hemming et al., 2014), including the spatial distribution of scattered light, or the way light is scattered by a material. In this paper we propose a new method of measuring the spatial distribution of scattered light by a bi-directional transmittance distribution function (BTDF) measurement. By comparing the BTDF values of a diffuse covering or screen material with the BTDF values of a Lambertian diffuser, we calculate one simple value for material characterisation, the F-scatter. F-scatter is a more representative value for the scattering properties of a material than Haze. The detailed material scatter properties can be used for further raytracing analysis of materials in greenhouses with a specific roof construction, at a specific location for any moment of the year. It can also be used for 3D functional crop models in the future.

O11

GENOTYPE AND LIGHTING ENVIRONMENT IMPACT PETAL TISSUE PIGMENTATION IN *TAGETES TENUIFOLIA*

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The carotenoid molecular structure allows for absorption of short-wave radiation resulting in pigment coloration from yellow to red. In chloroplasts, carotenoids function in a number of essential processes in photosynthesis; whereas in chromoplasts they are used to attract insect pollinators and seed dispersing herbivores. Carotenoids in petal tissues of ornamental specialty crops contribute to aesthetic value. However, carotenoids are extracted from petals of *Tagetes* species and used as carotenoid sources. Recently, edible flower *Tagetes* have been promoted as a salad garnish which can contribute valuable anti-oxidant carotenoids to the human diet. The objectives of these studies were to characterize the profiles and concentrations of petal tissue carotenoids among different *T. tenuifolia* genotypes and to determine the potential to increase carotenoid concentrations through simple LED lighting techniques. ‘Lemon Gem’, ‘Tangerine Gem’, and ‘Red Gem’ edible marigolds were grown in nutrient solution culture in a greenhouse

environment at the University of Tennessee. Flowers were harvested after 60 days and measured for carotenoids. 'Red Gem' petals had the highest concentrations of α-carotene, β-carotene, lutein, zeaxanthin, antheraxanthin, violaxanthin, and neoxanthin, followed by 'Tangerine Gem' then 'Lemon Gem'. 'Lemon Gem' and 'Tangerine Gem' were grown in controlled environments at a total light intensity of 250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ during a 12 hour photoperiod. Light quality treatments were established as: 1) fluorescent/incandescent light; 2) 10% blue (447 $\pm$ 5 nm) / 90% red (627 $\pm$ 5 nm) LED light; 3) 20% blue / 80% red LED light; and 4) 40% blue / 60% red light-emitting diode (LED) light as sole source lighting. Petal carotenoid pigments in both genotypes were much higher under LED light, and were highest under 20% blue light. Both genetics and environmental conditions can be managed to maximize nutritionally important carotenoids in the petal tissues of *T. tenuifolia*.

O12

IMPROVEMENT OF VINBLASTINE PRODUCTION BY CONTROLLING LIGHT CONDITIONS IN *CATHARANTHUS ROSEUS*

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Vinblastine, a compound in *Catharanthus roseus*, is a source of some anti-cancer drugs. In the Japanese climate, its concentration is low in leaves of plants grown in the field. Consequently, the supply of vinblastine is dependent on imports. The aim of this study was to develop a cultivation method for efficient vinblastine production in an environmentally controlled room. Vindoline and catharanthine are precursors of vinblastine used as materials for vinblastine semi-synthesis. First, the lighting conditions that increase the concentration of vindoline and catharanthine in leaves were investigated. Plants were cultivated under red (660 nm), blue (450 nm) and a mixture of red and blue LEDs, and white light from fluorescent lamps. Plants grown under red light had the highest vindoline and catharanthine yields per plant. Vinblastine was not detected in plants from any of the treatments. A previous report showed that vinblastine concentration increased rapidly after irradiation of a shoot culture of *C. roseus* with short-wavelength light (450 or 370 nm). Therefore, we measured vinblastine content in the leaves of plants grown under blue light alone and red supplemented with ultraviolet A (UVA, 370 nm) light. The plants were harvested 0, 1, 3, 5, and 7 days after treatments. Vinblastine content in the leaves increased to a maximum at five days after irradiation of red light supplemented with UVA, and declined as the day progressed. Thus, we proposed that the method of irradiating plants with a high concentration of vindoline and catharanthine with UVA for five days could be more efficient than continuous UVA irradiation during cultivation for vinblastine production.

O13

LETTUCE GROWTH AND QUALITY OPTIMIZATION IN A PLANT FACTORY

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Since the early 2000s, plant factory (or vertical farm) technology has been introduced for growing vegetables and soft fruits. With a well-controlled environment, new health benefits, food safety, optimized nutrients and increased shelf-life can be offered to consumers. With the progress of light emitting diode (LED) lighting efficiency and the knowledge of light-plant interaction, a better quality

control can now be achieved together with improved energy efficiency. Growth strategies combining crop quality attributes (e.g. color, nutrients, shelf life) with efficient growth are key for economic viability of plant factories. Most research so far has been addressing quality and growth efficiency separately. Several strategies exist from literature to improve quality attributes, but so far not in terms of optimization of the total growth efficiency including space and energy use. We are aiming to achieve a high growth efficiency (in g/mol) and at the same time fulfill the requirements on crop quality; for example: high yield, good color (high anthocyanin index or chlorophyll index) and texture (firmness), high flavonoids content or controlled nitrate levels. An optimization routine has been used with high technical engineering and plant physiology approach in a state of the art plant factory research center at Philips Research Laboratories. LED lighting with a large variety of spectral composition (from UV to far-red) and dynamic control has been used with a total radiation level dimmable per color up to 600 $\mu mol \cdot m^{-2} \cdot s^{-1}$. In this presentation we will illustrate our optimization approach (growth recipe) with specific experimental results on three different red lettuce varieties with results showing the evolution of the anthocyanin accumulation, spacing optimization and yield during growth.

O14

DAILY LIGHT INTEGRAL AND LIGHT QUALITY FROM SOLE-SOURCE LIGHT-EMITTING DIODES IMPACTS NUTRIENT UPTAKE AND ANTHOCYANIN CONTENT OF BRASSICA MICROGREENS

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Microgreens are a relatively new specialty crop that consist of vegetables and herbs harvested at a very young stage of growth. One alternative to greenhouse microgreen production is multi-layer vertical production using sole-source (SS) light-emitting diode (LED) lighting. However, the specific effects of SS LED lighting conditions on microgreen nutritional content are unknown. Therefore, the objectives of this study were to: 1) evaluate the nutrient uptake of three *Brassica* microgreens, and 2) quantify the total anthocyanin levels of purple kohlrabi (*Brassica oleracea* var. *gongylodes*) microgreens using SS LEDs of varying light qualities and intensities. Purple kohlrabi, mustard (*Brassica juncea* 'Garnet Giant'), and mizuna (*Brassica rapa* var. *japonica*) were grown in hydroponic tray systems placed on multilayer shelves in a walk-in growth chamber. A daily light integral (DLI) of 6, 12, or 18 $mol \cdot m^{-2} \cdot d^{-1}$ was achieved from SS LED arrays with light ratios (%) of red:green:blue 74:18:8 (R_{74}:G_{18}:B_8), red:blue 87:13 (R_{87}:B_{13}), or red:far-red:blue 84:7:9 (R_{84}:FR_7:B_9) with a total photon flux from 400 to 800 nm of 105, 210, or 315 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for 16-h, respectively. For kohlrabi, total anthocyanins significantly increased with increasing DLIs. Additionally, under a DLI of 18 $mol \cdot m^{-2} \cdot d^{-1}$ and light ratios of R_{87}:B_{13} and R_{84}:FR_7:B_9, kohlrabi produced significantly higher total anthocyanins when compared to those under R_{74}:G_{18}:B_8. In contrast, nutrient uptake generally decreased as the DLI increased for all three species. Additionally, mizuna under the R_{74}:G_{18}:B_8 light ratio accumulated significantly higher levels of nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg) compared to R_{84}:FR_7:B_9 under a DLI of 18 $mol \cdot m^{-2} \cdot d^{-1}$. Similarly, mustard produced under the R_{74}:G_{18}:B_8 light ratio accumulated significantly higher levels of K, Ca, and zinc (Zn) compared to the R_{84}:FR_7:B_9 under a DLI of 18 $mol \cdot m^{-2} \cdot d^{-1}$. The results from this study may help microgreens producers using SS LEDs in selecting light qualities and intensities to achieve preferred nutritional content and pigmentation of *Brassica* microgreens.

O15

ILLUMINATING TOMATO FRUIT ENHANCES FRUIT VITAMIN C CONTENT

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L-ascorbate (AsA; vitamin C) is an anti- and pro-oxidant phytochemical essential for the proper functioning of the human body. Field grown tomato fruit (*Solanum lycopersicum*) contain substantial amounts of AsA. When grown in the greenhouse, tomato fruit typically have low levels of AsA. Light is the major regulatory abiotic factor for AsA in plants. The introduction of light emitting diodes (LED) in horticulture provides the opportunity for improving quality of plant products. AsA levels of tomato fruit increase with additional light applied to the plant. In this work we examine the effects of irradiance on AsA levels of tomato fruit when light is applied to the fruit. Detached tomato fruit were treated with different irradiance levels provided by LEDs in a climate controlled environment. Tomato fruit treated with 263 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of white light for 13 days contained 32% more AsA than fruit kept at lower irradiances or in darkness. The light induced biosynthesis of AsA and the role of soluble carbohydrates in AsA regulation is discussed.

O16

COMPARISON OF HPS LIGHTING AND HYBRID LIGHTING WITH TOP HPS AND INTRA-CANOPY LED LIGHTING FOR HIGH-WIRE MINI-CUCUMBER PRODUCTION

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High-pressure sodium lamps (HPS) are the conventional lighting technology used to increase photosynthetically active radiation in greenhouse crop production. Because of its high operating temperature, HPS can only be used as top lighting placed well above crop canopy, which has resulted in uneven vertical light distribution in tall crops such as high-wire mini-cucumbers. LEDs have low surface temperature and can be used as inter-lighting within canopy to improve vertical light distribution and increase whole light use efficiency. Therefore, a trial was conducted at a commercial greenhouse from Oct. 2014 to Jan. 2015 to evaluate the hybrid lighting systems with top HPS and intra-canopy LED, in comparison to the top HPS only, for year-round high-wire mini-cucumber production. Three lighting treatments consisting of i) Top HPS lighting (177 $\mu mol \cdot m^{-2} \cdot s^{-1}$) only, ii) Top HPS (177 $\mu mol \cdot m^{-2} \cdot s^{-1}$) plus one row of LED inter-lighting (49 $\mu mol \cdot m^{-2} \cdot s^{-1}$), and iii) Top HPS lighting (177 $\mu mol \cdot m^{-2} \cdot s^{-1}$) plus two rows of LEDs inter-lighting (99 $\mu mol \cdot m^{-2} \cdot s^{-1}$) were evaluated; each was applied to 550 m^2 of growing area. Leaf chlorophyll index of the 10^{th} and 15^{th} leaf was improved by the addition of one row and two rows of inter-lighting LEDs. The visual fruit quality of mini-cucumbers was also improved with the LED inter-lighting. Fruit yield was increased by 22.3% and 30.8% by the addition of one or two rows of inter-lighting LEDs over no inter-lighting, respectively. Combining the electricity and capital costs, the production cost for each kg of mini-cucumbers would be $1.30 for top HPS lighting only, $1.45 for top HPS plus one row of inter-lighting LEDs and $1.72 for top HPS plus two rows of inter-lighting LEDs, based on the current prices of electricity and LED and HPS light fixtures in Ontario, Canada, the largest greenhouse vegetable production area in North America. The high production cost of hybrid lighting systems is due to the high cost of inter-lighting LED fixtures. It is anticipated that with potential price reduction in LED light fixtures, the production cost with the hybrid lighting system will decrease significantly in the near future.

O17

RESPONSE OF GREENHOUSE MINI-CUCUMBER TO DIFFERENT VERTICAL SPECTRA OF LED LIGHTING UNDER OVERHEAD HIGH PRESSURE SODIUM AND PLASMA LIGHTING

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Different light spectra trigger different plant growth processes. Therefore, the optimum light spectrum for various plant growth processes such as leaf and fruit growth may be different. Greenhouse mini-cucumber (*Cucumis sativus* L.) is a tall crop, with most leaf growth occurring in the top and middle canopy while fruit growth occurs in the middle and bottom canopy. Therefore, optimized vertical light spectral distribution profiles could be developed for improving both vegetative and fruit growth. In this study, we investigated the effects of different vertical spectra of light-emitting diodes (LED) lighting under high-pressure sodium (HPS) and plasma overhead lighting on plant growth and fruit yield of mini-cucumber. The study was conducted from Oct. 2014 to Apr. 2015 in a large greenhouse divided into 4 sections (50 m^2 growing area in each section). Two sections were installed with plasma overhead light and the other two sections with HPS light, with both of them providing the same amount of overhead light (165 $\mu mol \cdot m^{-2} \cdot s^{-1}$). Four vertical LED regimes (the top far red with bottom blue; the top blue with bottom far red; the top far red with bottom red; the top red with bottom far red) were applied to 4 plots inside each of the 4 sections. The blue or red LED each provided 10 $\mu mol \cdot m^{-2} \cdot s^{-1}$, while the far red LED provided 8 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of light. The vertical LED treatments resulted in more than a 10% difference in fruit yield despite the small amount of light, indicating that the vertical light distribution had a large influence on plant growth. Top blue LED reduced leaf size and plant height in the early growth period which reduced total fruit yield for the plants grown under plasma light but not under HPS. Far red LED placed at the top of the canopy increased fruit yield, in comparison to bottom canopy placement, for plants grown under plasma light. This study has demonstrated that vertical light spectral distribution can have a large influence on plant growth and development, and optimized light distribution should and can be developed for year-round greenhouse vegetable production with supplemental lighting.

O18

THE ADDED VALUE OF LED ASSIMILATION LIGHT IN COMBINATION WITH HIGH PRESSURE SODIUM LAMPS IN PROTECTED TOMATO CROPS IN BELGIUM

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The total area of protected tomato crops in Belgium comprises 450 hectares. In 2014 only 11 hectares were lighted crops. One year later, this number increased with 400% towards 55 hectares. 53 Hectares are equipped with high pressure sodium lamps (HPS), while the remaining two hectares combine these lamps with light emitting diode (LED) assimilation light strains in between the crop. High pressure sodium lamps are not energy efficient. A lot of energy is wasted as warmth in comparison to LED light. In order to explore the full potential of LED light in protected tomato crops in combination with high pressure sodium lamps, a trial was set up at Research Centre Hoogstraten, Belgium in October 2014. High pressure sodium lamps (SON-T, Philips) of 169 $\mu mol \cdot m^{-2} \cdot s^{-1}$ were installed in a tomato greenhouse compartment of 500 m^2. In four plant rows (total: 100 m^2) a combination with LED assimilation light (two interlight modules of 55 $\mu mol \cdot m^{-2} \cdot s^{-1}$) was made. These two LED's were hung horizontally on top of each other at a distance of 70 cm. The height relative to the plant was adjustable according to the cropping stage. Two tomato cultivars were planted on

the 22 Oct. 2014, each at two different plant distances (3.33 stems m^{-2} and 4.17 stems m^{-2}). A comparison in crop parameters and production was made for each cultivar at both plant distances grown under high pressure sodium lamps with or without additional LED assimilation light. Results are very promising for both cultivars with increased yields of 20% with HPS and LED light. For practice, more research is needed to optimize plant distances, light strategies and light intensities to make the technology more profitable and durable.

O19

FAR-RED LEDS IMPROVE FRUIT PRODUCTION IN GREENHOUSE TOMATO GROWN UNDER HIGH-PRESSURE SODIUM LIGHTING

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A study was conducted from Nov. 2014 to Apr. 2015 in a greenhouse (192 m^2 growing area) to investigate the effects of far-red LED light on plant growth, fruit yield and quality of greenhouse tomato (*Solanum lycopersicum*). Twin-head (stem) transplants of tomato cv. Foronti grafted on rootstock cv. Stallone were planted into six twin-rows at 2.8 stems m^{-2} in the greenhouse in late Nov. The two outside twin-rows were used as the guard row while the four middle twin-rows were divided into 16 experimental plots (24 stems per plot). Four far-red LED treatments which provided 0 (control), 8, 16, and 24 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of far-red photon flux were applied to the 16 plots in a Latin-square design with 4 replications. Overhead high-pressure sodium (HPS) lamps provided 165 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of PAR to all the plots in the greenhouse. The application of far red light and overhead HPS supplement light was started in early Dec. with a consistent photoperiod of 16 h (1:00 to 17:00 HRS). Both lighting systems were automatically shut-off when outside global solar radiation was >300 $W \cdot m^{-2}$. All 3 far-red light treatments increased the stem length in the early but not in the late stage of the greenhouse trial. Fruit yield in the first month of fruit harvest was increased by all three far-red treatments. However, the increase diminished in the second and third month of fruit harvest. The fruit harvested from the plants exposed to far-red light also had higher carotenoid content. Therefore, this study showed some beneficial effects of low dose of far red light in early stage of fruit production of greenhouse tomatoes grown under HPS lighting.

O20

STRONGLY INCREASED STOMATAL CONDUCTANCE IN TOMATO DOES NOT SPEED UP PHOTOSYNTHETIC INDUCTION IN AMBIENT NOR ELEVATED CO_2 CONCENTRATION

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Irradiance-dependent opening and closure of stomata is comparably slow. Therefore, stomatal conductance (g_s) often limits photosynthesis in fluctuating irradiance, particularly after large stepwise increases in irradiance in leaves adapted to low irradiance or darkness. This limitation to photosynthesis may reduce crop productivity in natural environments and greenhouses, where irradiance incident on a leaf can fluctuate rapidly. To test whether this limitation applies to typical greenhouse crops such as tomato (*Solanum lycopersicum* L.), photosynthetic gas exchange of *flacca*, a mutant with very high g_s (2-4 times wildtype level) was compared with its wildtype (WT), cv. Rheinlands Ruhm. The steady-state response to leaf internal CO_2 concentration (C_i) was similar between genotypes, indicating similar properties of the leaf photosynthetic apparatus. Surprisingly, when exposing dark-adapted leaves in ambient CO_2 concentration (400 ppm) to a stepwise increase

in irradiance, photosynthetic induction was not faster in *flacca* than in WT, despite *flacca* having 3.5 times higher g_s in darkness (0.26 ± 0.03 mol·m^{-2}·s^{-1} in WT; 0.90 ± 0.01 m^{-2}·s^{-1} in *flacca*). The same was true for leaves in 800 ppm, despite dark-adapted g_s being 4.6 times higher in *flacca*. During photosynthetic induction of leaves in 200 ppm CO_2 concentration, however, photosynthesis in *flacca* had a significantly higher induction state 60 seconds after illumination (19% in WT; 35% in *flacca*; P=0.04), and took less time to reach 90% of full photosynthetic induction (19.5 minutes in WT; 8.5 minutes in *flacca*; P=0.04). Hence, the rate of photosynthetic induction was only increased in reduced CO_2 concentration in *flacca*, but not in ambient nor elevated CO_2, indicating that wildtype g_s did not pose a limitation to photosynthetic induction in ambient nor elevated CO_2 concentration.

O21

TEMPERATURE AND IRRADIANCE AFFECTS PHOTOPERIODIC FLOWER INDUCTION

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Manipulation of plant growth and development utilizing night interruption lighting on photoperiodic plants is well characterized. However, application of night interruption lighting to induce flowering of long-day plants or inhibit flowering of short-day plants using treatments characterized in the lab can often not result in expected responses when applied commercially in greenhouses or in the field. Field observations suggested the efficacy of night interruption lighting in modifying growth was related to the irradiance during the day, the irradiance of the night interruption itself, the duration of the night interruption, and the temperature at which the night interruption occurs. We conducted a series of experiments on photoperiodic spring annual species (grown for flowering) to explore the impact of the before mentioned factors on the efficacy of night interruption lighting in manipulating growth of each species. Data were collected on time to flower, leaf number below the first flower, and other noteworthy attributes such as branch number, flower number etc. when appropriate. Recommended 'alternative' night interruption lighting treatments will be suggested when the growing environment differs from a typical lab environment.

O22

INVESTIGATING RECIPROCITY OF INTENSITY AND DURATION OF PHOTOPERIODIC LIGHTING TO REGULATE FLOWERING OF LONG-DAY PLANTS

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When the natural photoperiod is short, commercial growers typically create long days (LDs) to stimulate flowering of LD crops using fixed lamps that deliver 1 to 2 µmol·m^{-2}·s^{-1}. As an alternative to fixed lamps, growers have experimented with "boom lighting", which is a form of intermittent (cyclic) lighting in which lamps are attached to irrigation booms and the booms operate during the night. We simulated boom lighting in a research greenhouse to determine whether there was a reciprocal relationship between irradiance and lighting duration and whether regulation of flowering simply required delivering a specific quantity of photons. Two LD crops were grown under a 9-h photoperiod and night-interruption (NI) lighting was delivered by high-pressure sodium (HPS) or incandescent lamps that operated continuously or cyclically (e.g., 2 min every 15 min) for 4 h. Cyclic and 4-h continuous NI lighting treatments delivered an NI light integral (NIL_{int}) of 3,600 or 14,400 µmol·m^{-2}, which included the warm-up time of the HPS lamps. In the qualitative LD plant *Campanula carpatica*, HPS lamps that operated cyclically for 2 min every 15 or 30 min for 4 h and an NIL_{int} of 14,400 µmol·m^{-2} promoted flowering similarly to HPS lamps that operated continuously

for 4 h with the same NIL_{int}. However, a 2.4- or 24-min single continuous NI treatment did not promote complete flowering even with an NIL_{int} of 14,400 μmol·m^{-2}. In contrast, an NI for at least 2.4 min delivered continuously and with an NIL_{int} of 14,400 μmol·m^{-2} promoted flowering of the quantitative LD plant *Petunia ×hybrida*. The cyclic lighting treatment with the longest interval (2 min every 45 min) and an NIL_{int} of 3,600 μmol·m^{-2} also promoted flowering of *Petunia* similar to the 4-h continuous NI at the same NIL_{int}. We conclude that the law of reciprocity held true for *Petunia* under both NIL_{int} studied, but did not for *Campanula*.

O23

GROWTH CONTROL OF ORNAMENTAL AND BEDDING PLANTS BY MANIPULATION OF PHOTOPERIOD AND LIGHT QUALITY

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Altering the light regime is a sound and non-polluting way of controlling the growth of greenhouse-grown pot and bedding plants, and a promising way of eliminating the use of chemical plant growth regulators (PGRs), which are now becoming less available and more questioned by consumers. Modern greenhouses often have blackout screens, originally installed for flower regulation purposes but which can also be used for growth regulation. Modern light emitting diode (LED) light sources can be designed to provide narrow-band light (NBL), which can affect growth and elongation of plants if given in addition to natural sunlight, or as daylight extension (end-of-day or pre-day treatments). Two different approaches were used: short photoperiods in combination with pre-day and end-of-day NBL treatments, and short photoperiods combined with simultaneous addition of NBL and natural light. The plants used were *Calibrachoa*, *Pelargonium*, *Euphorbia,* and *Chrysanthemum*. A light regime with 620 nm light given before the period of natural light and 525 nm light given at the end of the natural light effectively controlled elongation in both *Calibrachoa* and *Pelargonium*. Supplementation of natural sunlight with a small portion of 660 nm light significantly reduced plant height in *Euphorbia*, but not in *Chrysanthemum*. It was concluded that management of photoperiod and light quality is very promising for replacing PGRs within greenhouse production of ornamental and bedding plants.

O24

REGULATING FLOWER AND TUBER FORMATION IN POTATO WITH LIGHT SPECTRUM AND DAY LENGTH

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Solanum tuberosum (potato) can reproduce through tubers and through seeds. Recent developments have enabled hybrid breeding and propagation from seeds in this crop. This makes potato flowering a new focus of research interest. Tuberization and presumably flowering, followed by seed set, are strongly regulated by environmental cues. A well-studied environmental regulator of tuber formation is day length. Photoreceptors are involved in this photoperiodic control of tuberization, suggesting light spectrum may be an important factor for tuberization. However, it is not known how photoreceptors control potato flowering. Here, we aim to elucidate the influence of light spectrum and photoperiod on tuber and flower formation, by growing three potato genotypes in climate chambers with light-emitting diode (LED) lighting and additional far-red and blue LEDs under long and short days. Far-red light accelerated tuber formation up to eleven days

and blue light slightly delayed it up to four days. An effect of light spectrum on flowering was not found. Long photoperiods delayed tuber formation compared to short-day conditions in two of the three tested genotypes. Aside from one genotype which only flowered in long-days, no effect of photoperiod on flowering was found.

O25

THE WONDERS OF YELLOW NETTING

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Photoselective netting is an innovative technology, by which chromatic elements are incorporated into netting materials in order to gain specific physiological and horticultural benefits, in addition to the initial protective purpose of each type of net (shade-, anti-hail- wind-, insect-proof, etc.). Field studies of plant responses to the photoselective filtration of solar radiation by these nets had provided vast amounts of productive horticultural knowledge, which is already being applied by growers, worldwide. Yet, the particular physiological mechanisms behind the apparent responses could not always be revealed, since these studies were carried under the ever changing environments of light, microclimate and agricultural practices. Physiological understanding can, however, be deduced by analyzing the similarity and variability in the responses of different crop species/cultivars grown in different environments to particular photoselective nettings, and by linking the field results with the molecular knowledge gained under fully controlled conditions. We had previously reported that while Blue shade nets slow down vegetative growth and induce dwarfing in ornamental foliage and cut-flower crops, Red and Yellow nets that reduce the relative content of blue light, are stimulating vegetative vigor. Between the latter two nets, the Yellow repeatedly exceeded the Red net in its stimulating effects. Studies in table grapes revealed that both the Red and Yellow nets delayed fruit maturation, and again the effect of the Yellow exceeded the Red net. The Yellow net additionally surpassed the Red net in its berry enlarging effect. In sweet peppers both Red and Yellow shade nets increased productivity. However, the Yellow, but not the Red net additionally reduced pre- and post-harvest fungal decay of the fruit. The latter effect coincided with elevated anti-oxidant accumulation under the Yellow net. This paper discusses crop responses to Yellow netting, and infers a possible connection with the recently proposed green photoreceptor, awaiting its discovery.

O26

PROTECTIVE RAIN SHIELDS ALTER LEAF MICROCLIMATE AND PHOTOSYNTHESIS IN ORGANIC APPLE PRODUCTION

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Plastic rain shields reduce the leaf and fruit wetness and protect apple trees against major leaf diseases and hail damage. Shielding the trees may reduce incoming radiation, especially in the ultraviolet (UV) region of the light spectrum, and affect the microclimate and photosynthesis. In July of 2014 and June of 2015, we measured the leaf microclimate and photosynthetic performance using chlorophyll fluorescence and gas exchange in the apple cultivar ‘Santana’ grown in three treatments. In one treatment the trees were exposed to natural light and sprayed (control), and in two treatments the trees were unsprayed and shielded with a plastic film not permeable to UV-light (UV-) or a plastic film permeable to UV-light (UV+). The light transmittance was reduced in the shielded treatments, protecting the leaves from high solar irradiance during noon on sunny days,

and avoiding afternoon depression of photosynthesis. Due to this, the leaf photosynthetic rates were often higher in the protected trees in comparison to the control trees at similar high light intensities, whereas there were no differences between treatments on cloudy days. The effect of the UV+ film on photosynthesis did not differ from the UV- film, except there was a tendency for higher values accompanied with increased light transmittance of the UV+ film. We conclude that a microclimate with more diffused light maintained the photosynthetic yield, despite a lower light level under the rain shields.

O27

ORNAMENTALS IN NEW LIGHT - THE STORY OF THE INVISIBLES

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Artificial assimilation lighting is a common practice in greenhouse horticulture in the circumpolar region to compensate for natural low light conditions. Light emitting diodes (LEDs) have been suggested as an alternative to energy intensive high pressure sodium lamps (HPS). Most studies focus on plant responses to LEDs, few examined the interactions between light sources and aerial pathogens, but none considered the impact on the microbial matrix beyond. LED light differs from conventional lighting with regard to spectral output, light distribution as well as heat emission, thus altering the microclimate within the crop stand. We used a concept-based approach to study how the leaf associated (*phyllosphere*) microbiota is affected by three light sources, namely two types of LED light (red (660 nm) + blue (460 nm) LED, 80:20, RB-LED; white LED, W-LED) and HPS. Ornamental sunflower (*Helianthus annuus* cv. Teddy Bear) was used as model plant. Plant performance and biomass, leaf temperature, photobiological parameters as well as the leaf associated microbiome (both fungal and bacterial microbiome) were analyzed. The microbial analysis considered also the leaf position. Preliminary results indicate, that the fungal and bacterial microbiome use different strategies to respond to light sources for artificial assimilation lighting, which may impact on plant resilience to biotic stress.

O28

THE EFFECTS OF UV RADIATION ON ARTHROPODS: A REVIEW OF RECENT PUBLICATIONS (2010 – 2015)

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Insects and mites use optical cues for finding host plants and for orientation during flight. These arthropods often use UV radiation as the cue for taking-off and for orientation. Growing crop plants without UV often leads to low pest infestation, slow dispersal of pests and low incidences of insect borne diseases. Therefore, covering crops with plastics or screens containing UV-blocking additives provides protection from pests and diseases compared to standard cladding materials. The attraction of insects to host plants and to monitoring traps is enhanced by moderate UV reflection. In contrast, high UV reflection (over 25%) acts as a deterrent for most arthropods. Direct exposure of arthropods to UV often elicits stress responses and it is damaging or lethal to some life stages. Therefore, direct exposure of arthropods to UV often induces an avoidance behavior and this is why they often reside on the abaxial side of leaves or inside plant apices as a means to avoid solar UV.

Solar UV often elicits stress response in host plants, which indirectly may reduce infestation by certain arthropod pests. Jasmonate signaling plays a central role in the mechanisms by which solar UV increases resistance to insect herbivores in the field. Thus, UV radiation affects agroecosystems by complex interactions between several trophic levels. A summary of recent publications is presented and discussed.

O29

CYATHIA DEVELOPMENT AND BRACT DEVELOPMENT OF POINSETTIA HAVE DIFFERENT CRITICAL NIGHT LENGTHS

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Poinsettia (*Euphorbia pulcherrima*) flower development consists of cyathia development, which includes the reproductive floral parts, and bract coloration, which occurs when the green leaves subtending the cyathia turn red. These developmental processes occur as the natural night length becomes progressively longer. We have recently observed that poinsettias collected from a native habitat in western Mexico develop bracts at the same time as cyathia development and anthesis occur, while modern, domesticated poinsettia cultivars develop significantly more bracts prior to anthesis, i.e., the time of anthesis for wild and domesticated poinsettias is similar while domesticated poinsettias develop bract color several weeks earlier than the wild-type. This suggests that bract and cyathia development are unique processes that have been independently altered through decades of human selection. Both developmental processes are short-day responses, thus it was hypothesized that the critical night length for cyathia and bract development are not the same. To test this hypothesis, an experiment was conducted on two sibling poinsettia cultivars (Advent and Tikal) in which plants were grown in one of 12 different night lengths ranging from 10:30 to 12:20 HR:MIN at 10 min. increments. Time to first color, visible bud, and anthesis were recorded, and bract color was given a qualitative rating from 0 (green) to 4 (fully red). Cyathia development of Tikal began at a night length of 11:00 HR:MIN, while bract development did not begin until the night length was 11:30 HR:MIN. Night lengths from 11:00 to 11:30 HR:MIN resulted in plants that produced cyathia without red bracts. Results for the Advent were similar except that Advent flowers under shorter night lengths compared to Tikal, so the critical night lengths for cyathia and bract development were 10:30 and 11:00 HR:MIN, respectively. This study suggests that poinsettia breeding programs have been inadvertently screening seedlings for shorter critical night lengths for bract coloration in order to have a showier plant at the time of anthesis, which is typically when poinsettias are considered to be ready for market.

O30

TIMING OF BLUE AND RED LIGHT EXPOSURE AND CPPU APPLICATION DURING THE RAISING OF SEEDLINGS CAN CONTROL FLOWERING TIMING OF PETUNIA

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As previously shown, blue (B) light promotes shoot elongation and flowering in petunia, whereas red (R) light inhibits these responses. Here we aimed to test whether the plant growth regulator CPPU and temporal B light irradiation could induce floral bud initiation while still keeping the dwarfed plant shape observed under R light. In this respect, we evaluated effects of irradiation timing of B and R light, and CPPU application during raising of seedlings on subsequent growth and floral induction in petunia (*Petunia* x *hybrida* ‘Baccarat blue’ and ‘Merlin blue Moon’). Petunia plants were grown under white fluorescent light (WFL) until seven true leaves had developed. They were then exposed to WFL, R and B light from LEDs in growth cabinets with a 14 h photoperiod for 4 weeks. In one experiment, 0, 1 or 10 ppm CPPU was applied to plants during R treatment for 4 weeks before being moved into a greenhouse. The treatment with 10 ppm CPPU induced flowering 4 to 7 days earlier compared to the exposure to R only with keeping the dwarfed plant shape. In another experiment, plants were exposed to R and B for different periods; plants were either continuously grown under R LED or exposed to B LED during the last 1, 2 or 3 weeks during raising of the seedlings. After these treatments, plants were moved into a greenhouse. Longer duration of exposure to B LED induced earlier flowering. After 3 weeks exposure to B LED, 'Baccarat blue' and 'Merlin blue' flowered earlier as compared to continuous exposure to R LED, but there was no difference in plant height among treatments. In conclusion, R light and CPPU treatment during raising of seedlings, could be used to control plant morphology and timing of flowering in petunia.

O31

INVESTIGATING THE MERIT OF INCLUDING FAR-RED RADIATION IN THE PRODUCTION OF ORNAMENTAL SEEDLINGS GROWN UNDER SOLE-SOURCE LIGHTING

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A combination of red (R; 600 to 700 nm) and blue (B; 400 to 500 nm) light-emitting diodes (LEDs) is commonly used in sole-source lighting of plants grown in highly controlled environments. R and far-red radiation (FR; 700 to 800 nm) regulate photomorphogenesis, including stem elongation and leaf expansion, and to some extent, photosynthesis. However, little research has been published on how FR LEDs can be used to improve plant growth and quality attributes during seedling production. We grew seedlings of snapdragon (*Antirrhinum majus*) at 20 °C under six sole-source LED treatments with an 18-h photoperiod. All treatments included 32 $\mu mol \cdot m^{-2} \cdot s^{-1}$ of B radiation (peak=451 nm) and different intensities (subscript in $\mu mol \cdot m^{-2} \cdot s^{-1}$) from R (peak=660 nm) and FR (peak=729 nm) LEDs: R_{128}, R_{128}+FR_{16}, R_{128}+FR_{32}, R_{128}+FR_{64}, R_{96}+FR_{32}, and R_{64}+FR_{64}. Plant height and total leaf area linearly increased as the R:FR or the estimated phytochrome photoequilibrium of each treatment decreased. Shoot dry weight was similar under the same total photon flux (400 to 800 nm) even when R radiation was partially substituted with FR (considered minimally photosynthetic) and linearly increased when R was constant and FR increased. Photosynthetic efficiency (PE), which is calculated as shoot dry weight per unit leaf area, was correlated positively with the calculated yield photon flux of each +FR treatment. In addition, PE linearly decreased as the amount of R was increasingly substituted with FR radiation. We conclude that supplementation of FR to R and B radiation can increase PE and subsequent dry mass accumulation without excessive leaf and stem expansion.

O32

LIGHT QUALITY AND ADVENTITIOUS ROOTING: A MINI-REVIEW

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Efficient adventitious rooting is a key process in the vegetative propagation of horticultural and woody species. A well-rooted cutting is essential for optimal growth and high quality plants. The use of spectral light quality to influence adventitious rooting has been studied for many years, but

got a lot more attention since LEDs came on the market for horticultural practices. Contrasting results of the effect of light quality on adventitious rooting are reviewed in this paper. Even though more fundamental research is needed to easily determine which light quality can be used for a specific species, the use of LEDs for adventitious rooting is promising. For in vitro plantlets implementation can be done easily, for in vivo cuttings, the use of LEDs seems also promising in a multi-layered system. The controlled environment will lead to a year-round high quality rooted cutting production.

O33

RESPONSES OF TWO ANTHURIUM CULTIVARS TO HIGH DAILY INTEGRALS OF DIFFUSE LIGHT

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Heavy shading is commonly applied during production of pot-plants in order to avoid damage caused by high light intensities. However, shading also carries a production penalty as light is the driving force for photosynthesis. Diffuse glass has been developed to scatter the incident light in greenhouses. This study aims at investigating the effect of diffuse glass cover and high daily light integral [DLI, $mol \cdot m^{-2} \cdot d^{-1}$ photosynthetic active radiation (PAR)] under diffuse glass cover on the growth of pot-plants. Experiments were carried out with two *Anthurium andreanum* cultivars (Royal Champion and Pink Champion) in a conventional modern glasshouse compartment covered by clear glass with DLI limited to 7.5 $mol \cdot m^{-2} \cdot d^{-1}$, and another two glasshouse compartments covered by diffuse glass with DLI limited to 7.5 and 10 $mol \cdot m^{-2} \cdot d^{-1}$, respectively. Diffuse glass cover resulted in a less variable of temporal photosynthetic photon flux density (PPFD) distribution compared with the clear glass cover. Under similar DLI conditions (DLI limited to 7.5 $mol \cdot m^{-2} \cdot d^{-1}$), diffuse glass cover stimulated dry mass production per unit intercepted PPFD (RUE) in 'Royal Champion' by 8 %; whilst this stimulating effect did not occur in 'Pink Champion'. This discrepancy resulted from the distinct properties of stomatal conductance which showed different dynamic response to transient light condition in these two cultivars. Under diffuse glass cover, high DLI stimulated biomass production in both cultivars, consequently, more flowers, leaves and stems. Furthermore, high DLI resulted in more compact plants without light damage in leaves or flowers in both cultivars. We conclude that 1) the stimulating effect of diffuse light on RUE depends on the dynamic response of stomatal conductance to incident PPFD; 2) less shading under diffuse glass cover not only stimulates plant growth but also improves plant ornamental quality (i.e. compactness).

O34

EFFECTS OF CONTINUOUS LED LIGHTING ON REDUCING NITRATE CONTENT AND ENHANCING EDIBLE QUALITY OF LETTUCE DURING PRE-HARVEST STAGE

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Lettuce easily accumulates higher nitrate content during production, especially in hydroponic system, and higher nitrate content poses a threat to human health. Light condition (light quality, intensity and duration) significantly affects nitrate content in plants. Lighting-emitting diodes (LEDs) have showed the great potential for plant growth and development with the higher luminous efficiency and positive impact compared with other artificial light. The effects of combination of red (R)/ blue (B) or/and green (G), and white (W) LED lights on the plant growth, plant physiological

changes, including chlorophyll fluorescence, nitrate contents and phytochemical concentration before harvest were investigated. The results showed that Pre-harvest continuous light exposure can effectively reduce nitrate accumulation and increase phytochemical concentrations in lettuce plants, and the reduction in nitrate content is dependent on the spectral composition and light intensity of the applied light sources and continuous light duration. Lettuce plants grown under the continuous combined red, green and blue LED light (RGB) with a PPFD at 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (RGB-200) and RB-200 treatments exhibited a remarkable decrease of nitrate contents at 24 h compared to other LED light treatments. Moreover, continuous LED light at 24 h significantly enhanced the DPPH free-radical scavenging activity and increase phenolic compound concentrations. In this study, we suggest that a period of continuous LED light (RGB-200 or RB-200) exposure is needed in order to decrease nitrate concentrations and enhance lettuce quality. The period of 24 h continuous LED light exposure appears to be the best, and this period should not exceed 48 h.

O35

GROWTH AND MORPHOLOGY OF VEGETABLE SEEDLINGS UNDER DIFFERENT BLUE AND RED PHOTON FLUX RATIOS USING LIGHT-EMITTING DIODES AS SOLE-SOURCE LIGHTING

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Vertical-farming (VF) can be more energy-efficient with light-emitting diodes (LEDs) with higher efficiencies than fluorescent lamps (FL). Plant responses to blue (B) and red (R) light are species-specific. The objective was to evaluate B:R photon flux (PF) ratios for the production of vegetable seedlings. Cucumber (cv. Cumlaude) and tomato (cv. Komeett) were grown under 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPF, 18-h photoperiod, and 25 ˚C temperature. B (455-nm peak) and R (661-nm peak) LEDs were used as the sole source lighting and the percentage B PF was varied at 0%, 10%, 30%, 50%, 75%, and 100%. For cucumber, hypocotyl length decreased with increasing B up to 75B. Plants in 0B, 10B, and 100B showed 156%, 65%, and 297%, respectively greater hypocotyl length than under FL. Dry mass and leaf area decreased with increasing B from 10B to 75B. Plants under FL had 34% and 73% greater dry mass than in 75B and 0B, respectively and 48%, 30%, 55% and 68% greater leaf area than in 0B, 30B, 50B and 75B, respectively. For tomato, hypocotyl length also decreased with increasing B up to 75B. Plants in 0B, 10B, 30B, 50B, and 100B showed 113%, 82%, 32%, 29% and 90%, respectively, greater hypocotyl length than under FL. Dry mass and leaf area increased with increasing B up to 30–50B, and then decreased from 50B to 100B. Plants in 30B and 50B had 66% and 59%, respectively greater dry mass than plants in FL. Tomatoes under FL had 71% and 62% greater leaf area than in 0B and 100B, respectively. For cucumber seedlings, the optimal percent was 10B, which, however, produced taller seedlings with less dry mass than those under FL. For tomato, the optimal percent was 30B-50B, which produced seedlings with comparable morphology and growth as those under FL.

O36

END-OF-DAY FAR-RED LIGHTING COMBINED WITH BLUE-RICH LIGHT ENVIRONMENT TO MITIGATE INTUMESCENCE INJURY OF TWO INTERSPECIFIC TOMATO ROOTSTOCKS

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Effects of end-of-day far-red (EOD-FR, 700-800 nm) light and high blue photon flux ratio during the photoperiod on intumescence injury were examined for ‘Beaufort’ and ‘Maxifort’ tomato rootstock

seedlings (*Solanum lycopersicum* × *Solanum habrochaites*) grown with 13 mol·m^{-2}·d^{-1} daily light integral (199 µmol·m^{-2}·s^{-1} photosynthetic photon flux, 18 hours photoperiod). The EOD-FR light treatment (1.1 mmol·m^{-2}·d^{-1} provided by 6.0 µmol·m^{-2}·s^{-1} FR photon flux for 3 minutes at EOD) significantly reduced intumescence injury. For example, by the EOD-FR light treatment, the incidences of leaf abscission were reduced from 88% to 8% for 'Beaufort' and from 79% to 25% for 'Maxifort'. However, EOD-FR light caused undesirable stem extension (41% greater than that without EOD-FR light). By combining relatively high B (blue, 400-500 nm) to R (red, 600-700 nm) photon flux ratio (50%B-50%R) during the photoperiod with EOD-FR light, intumescence injury was further decreased without causing undesirable stem extension. For example, the incidences of leaf abscission were reduced from 88% to 0% for 'Beaufort' and from 79% to 0% for 'Maxifort', compared to those under 10%B-90%R without EOD-FR light. Also, the percentages of leaves that exhibited intumescences were reduced from 68% to 30% for 'Beaufort' and from 55% to 19% for 'Maxifort'. Our study demonstrated that blue-rich light quality combined with a small dose of EOD-FR lighting could be applied to mitigate the problematic intumescence injury of tomato seedlings grown under LEDs.

O37

LIGHT QUALITY: GROWTH AND NUTRITIONAL VALUE OF MICROGREENS UNDER INDOOR AND GREENHOUSE CONDITIONS

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The objective of our studies was to determine the growth and nutritional value of microgreens cultivated under light-emitting diode (LEDs) lamps of various spectral compositions. We have performed several experiments in growth chambers and in a greenhouse. A system of high-power solid-state lighting modules with the main set of 447-, 638-, 665- and 731 nm LEDs with the possibility to use supplemental 366-, 390-, 402-, 520-, 595-, 622 nm LEDs was used in indoors experiments. High-pressure sodium (HPS) lamps supplemented by 390- and 638 nm LEDs were used for experiments in a greenhouse. Microgreens of 6 species (mustard, red pak choi, tatsoi, basil, beet and parsley) were grown up to harvest time (about 7-10 d). The experiments indoors revealed that supplemental 520- and 622 nm lighting was more efficient for nitrate reduction, while the antioxidative system indices were enhanced by 595 nm diodes. Positive effect of UV-A radiation for antioxidant compounds was determined, but such effect on growth parameters was insignificant. Supplemental 366- and 390 nm UV-A radiation have been more favourable for antioxidant accumulation. Short-term (3-days before harvesting) lighting with high PPFD level of red (638 nm) LEDs increased the amounts of the secondary metabolites of microgreens under both cultivation conditions. Studies showed that various LEDs illumination could be a good tool for investigating the impact of specific wavelengths on nutritional value compounds in microgreens.

O38

INFLUENCE OF LIGHT QUALITY ON THE GROWTH AND SECONDARY METABOLITES CONTENT OF *CATHARANTHUS ROSEUS* IN A MODULAR AGRICULTURAL PRODUCTION SYSTEM

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Catharanthus roseus (L.) G. Don known formerly as *Vinca rosea*, is a main source of vinca alkaloids, and produces about 130 of these compounds, including vinblastine and vincristine, two drugs used to treat cancer. Cultivation of this plant in a closed-type plant production system under different light-emitting diodes (LEDs) is advantageous over traditional field cultivation due to the feasibility of producing improved amounts of pharmaceutically important anti-cancerous and anti-hypertensive secondary metabolites present in it. Using combined red, blue, and white (RBW=8:1:1), white (W), and ultraviolet (UV) LEDs, we investigated the effects of light qualities on the growth and phytochemical content of *C. roseus* in a modular agricultural production system. Photosynthetic photon flux, photoperiod (Light/Dark), temperature and relative humidity were 200±10 $\mu mol \cdot m^{-2} \cdot s^{-1}$, 16/8, 30±2°C, and 60±10%, respectively in all treatments. Flowers and shoots of *C. roseus* were successively extracted with methanol and then screened for their antioxidant potential. They were also evaluated for their anticancer activity on cultured A249human lung adenocarcinoma cell lines. Total phenolic and flavonoid content were assessed by spectrophotometric methods. After 120 days of light quality treatment, growth and phytochemical concentration of *C. roseus* plants were significantly affected by light quality treatments. Plant growth parameters such as leaf length, number of leaves and flowers, chlorophyll value, length of the longest root, and shoot fresh weight were significantly greater in the RBW treatment. Variations in flavonoid and phenols content were observed. A total of 30 compounds of high medicinal value were identified by GC-MS analysis and the peak area percentage was different when compared among different light quality treatments. The study results provide an efficient and cost effective production method for the propagation of the commercially important medicinal plant *C. roseus* and will be useful for producing raw materials for enhanced alkaloids production.

O39

LIGHT-EMITTING DIODE TECHNOLOGY STATUS AND DIRECTIONS: OPPORTUNITIES FOR HORTICULTURAL LIGHTING

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Light-emitting diode (LED) technology has advanced rapidly over the last decade, primarily driven by display and general illumination applications (“solid-state lighting (SSL) for humans”). These advancements have made LED lighting technically and economically advantageous not only for these applications, but also, as an indirect benefit, for adjacent applications such as horticultural lighting (“SSL for plants”). Moreover, LED technology has much room for continued improvement. In the near-term, these improvements will continue to be driven by SSL for humans (with indirect benefit to SSL for plants), the most important of which can be anticipated to be: expanded chromaticity range and control; higher efficiency at higher current densities; improvements in reliability; intelligent control of chromaticity and intensity; and decreased cost of light. In the long-term, additional improvements may be driven directly by SSL for plants, the most important of which can be anticipated to be: even further expanded chromaticity range and control; and control over the light intensity distribution in space and time. One can even anticipate that plants and artificial lighting (as well as other aspects of a plant’s environment) will ultimately *co-evolve*, with plants evolving to thrive in artificial lighting environments, and artificial lighting environments evolving to best serve plants.

O40

IMPROVING LIGHT DISTRIBUTION OF LIGHT-EMITTING DIODES IN PLANT FACTORY BY ZOOM LENS FOR ELECTRICITY SAVING

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Artificial light in the plant factory is not efficiently utilized. During the exponential growth phase, the crop canopy is small and consequently a large fraction of the cultivation area is not covered by leaf area, thus the incident light in these areas cannot be utilized for photosynthesis. To solve this problem, we designed a system of which zoom lens were applied just below the light-emitting diodes (LED), thus the incident light can be focused on the plant canopy. In this study, the performances of the zoom lighting LED system (Z-LED) were evaluated by comparison with the conventional LED lighting system (C-LED). Butterhead lettuce (*Lactuca sativa* var. capitata) was grown in both lighting systems, the growth and photosynthesis parameters, as well as energy saving of the Z-LED were evaluated. The photosynthetic photon flux density (PPFD) at the canopy level was kept at 70 $\mu mol \cdot m^{-2} \cdot s^{-1}$ during the first 10 days after transplanting, thereafter onwards the PPFD was maintained at 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The leaf area under Z-LED increased by 31.3% compared with N-LED's. Lettuce grown with Z-LED significantly decreased energy consumption by 52.1% compared with the N-LED treatment. The energy-conversion efficiency is 17.9 MJ/mg and 11.4 MJ/mg dry biomass in Z-LED and C-LED, respectively. We concluded that Z-LED lighting system significantly improves energy use efficiency without negative influence on plant growth.

O41

EVALUATING OPERATING CHARACTERISTICS OF LIGHT SOURCES FOR HORTICULTURAL APPLICATIONS

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In this paper we report on several operating characteristics for a select group of light sources used for horticultural applications. These characteristics include: photon flux (including photosynthetically active radiation or PAR), power consumption, efficiency, and light distribution. We evaluated two (power adjustable) high-pressure sodium lamps (HPS: mogul base and double-ended lamps), three light emitting diode (LED) lamps (two arrays and one standard bulb), a compact fluorescent lamp, and an incandescent lamp. The tested high-pressure sodium lamps recorded the highest PAR efficiency (1.6 µmol/J) when operated at their highest power consumption settings. But these lamps also exhibited the most rapid decline in intensity during our light distribution tests.

O42

COMPARISON OF ENERGY CONSUMPTION: GREENHOUSES AND PLANT FACTORIES

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Annual energy consumption and carbon footprints are compared in simulation for two controlled environments: plant factory and traditional greenhouse. Energy consumed for heating, ventilating, and air conditioning (HVAC) as well as supplemental lighting are included in the models. In the greenhouse case, supplemental lighting is controlled to a consistent daily light integral (DLI) of Photosynthetically Active Radiation (PAR) using Light and Shade System Implementation (LASSI). In the plant factory model, lighting power is sized according to photoperiod and DLI requirements.

Building HVAC loads and system responses are computed using the ASHRAE heat balance method with a one hour time-step. Both environments are simulated in four different climates using Typical Meteorological Year (TMY) data sets. In each simulation, energy consumption and carbon footprints are shown to be significantly higher in the plant factory environment compared to the greenhouse.

O43

GROWTH CHAMBERS ON THE INTERNATIONAL SPACE STATION FOR LARGE PLANTS

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The International Space Station (ISS) now has platforms for conducting research on horticultural plant species under LED lighting, and those capabilities continue to expand. The 'Veggie' vegetable production system was deployed to the ISS as an applied research platform for food production in space. Veggie is capable of growing a wide array of horticultural crops. It was designed for low power usage, low launch mass and stowage volume, and minimal crew time requirements. The Veggie flight hardware consists of a light cap containing red (630 nm), blue, (455 nm) and green (530 nm) LEDs. Interfacing with the light cap is an extendable bellows/baseplate for enclosing the plant canopy. A second large plant growth chamber, the Advanced Plant Habitat (APH), is will fly to the ISS in 2017. APH will be a fully controllable environment for high-quality plant physiological research. APH will control light (quality, level, and timing), temperature, CO_2, relative humidity, and irrigation, while scrubbing any cabin or plant-derived ethylene and other volatile organic compounds. Additional capabilities include sensing of leaf temperature and root zone moisture, root zone temperature, and oxygen concentration. The light cap will have red (630 nm), blue (450 nm), green (525 nm), far red (730 nm) and broad spectrum white LEDs (4100K). There will be several internal cameras (visible and IR) to monitor and record plant growth and operations. Veggie and APH are available for research proposals.

O44

LEDS AS SUPPLEMENTAL LIGHTING FOR GREENHOUSE CUT FLOWER PRODUCTION AT NORTHERN LATITUDES

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Greenhouse trials were conducted to determine whether LEDs could be used to replace HPS for greenhouse cut flower production in Ontario, Canada (and surrounding regions). Additional trials investigated the optimum supplemental light levels for using LEDs for greenhouse cut flower production. These trials were conducted over the past three years, during the supplemental lighting season (ie. November to March) using cut gerbera and cut snapdragons as surrogate commodities. All trials used four concurrent replications per treatment. The first year compared LED to HPS for growing three cut gerbera cultivars. The plants received about 5.5 $mol{\cdot}m^{-2}{\cdot}day^{-1}$ with supplemental lighting providing about 2.2 $mol{\cdot}day^{-1}$ (11hr photoperiod). Flower quality metrics and numbers of marketable flowers were equal or better with LEDs than HPS. The second year investigated four levels of LED lighting (55, 95, 135 and 175 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$, 14hr photoperiod) for snapdragon production. The highest supplemental level shortened production time by 13 days and marketable yield was greatest in the two highest levels. The third year replicated the second year's trial, using cut gerbera (results not yet known). This talk will present the combined results from these three trials.

O45

REGULATION OF AXILLARY BUDBREAK IN A CUT-ROSE CROP

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When flower-bearing shoots in cut-rose (*Rosa hybrida*) are harvested (removed), a varying number of repressed axillary buds on the shoot remainder start to grow into new shoots (budbreak). Besides removing within-shoot correlative inhibition, it is hypothesized that shoot removal leads to 1) increased light intensity lower in the crop canopy; 2) changes in the light spectrum (particularly red:far-red ratio); and 3) changed source:sink ratio (i.e., the ratio between supply and demand of assimilates). As a fourth hypothesis it is proposed that the degree of budbreak on a shoot remainder is also influenced by the correlative inhibition exerted by other shoots on the plant. It is the goal of this work to determine which of these four hypotheses is most important for budbreak in a cut-rose crop. Seven experiments were conducted, involving leaf removal, removal of mature shoots, varying the number of young shoots, shading of the crop, and application of direct light on the buds. Furthermore, light intensity and red:far-red ratio at the level of the buds were independently varied, whereas intensity and red:far-red ratio of incident light on the crop were not changed. It was concluded that after removal of the flower-bearing shoot, among the factors tested, light intensity on the buds was the most important and consistent factor explaining budbreak on the shoot remainder. Source:sink ratio gave inconsistent results: some treatments resulting in lower source:sink ratio decreased budbreak whereas other treatments did not. The more competing shoots on the plant the more correlative inhibition the less budbreak.

O46

LIGHT QUALITY IMPACTS ON GROWTH, FLOWERING, MINERAL UPTAKE AND PETAL PIGMENTATION OF MARIGOLD

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Light quality has a significant impact on growth and development and time to flower in many plant species. Recently, the percentages of blue and red in narrow-band wavelengths of light from light-emitting diodes (LEDs) have been shown to impact mineral uptake, pigment development, and the rate of growth and development of several plant species. The objective of this research was to evaluate the effects of light quality on shoot growth, flower development, mineral uptake, and pigment content of marigold (*Tagetes patula* “Safari Orange”). Plants were grown in 10 cm square pots in a greenhouse ebb and flood system with a complete nutrient solution. Plants received average day temperatures of 25 °C and night temperatures of 16 °C. The following light treatments were utilized in this study: 1) natural sunlight; 2) High pressure sodium (HPS) lighting at 100 μmols·m^{-2}·sec^{-1} intensity above natural sunlight intensity; 3) LED lighting with blue and red wavelengths at 50% each and intensity at 100 μmols m^{-2} sec^{-1} above natural sunlight intensity; and 4) LED lighting with blue at 25% and red at 75% and intensity at 100 μmols·m^{-2}·sec^{-1} above natural sunlight intensity. Total shoot growth was twice as high in all supplemental light treatments compared to the natural sunlight treatment. Shoot growth was greater in the 25% blue/75% red LED treatment than in the HPS light treatment. The 50% blue/50% red LED treatment was not significantly different from the HPS light treatment. Plants in the 25% blue/ 75% red LED treatment had 15% more blooms than plants in the 50% blue/50% red LED treatment or the HPS light

treatment. All supplemental light treatments produced plants with significantly more blooms than plants in the natural sunlight treatment. Plants in the LED light treatments had greater petal pigment content than plants in the natural sunlight treatment.

O47

ADVANCING THE STRAWBERRY SEASON IN BELGIAN GLASSHOUSES WITH SUPPLEMENTAL ASSIMILATION LIGHTING

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Over the years, the strawberry season in Belgium developed to an almost year-round production from mid-March until early January. This became possible by combination of cultivation systems and the cold storage of plants. With assimilation light, the season could even be more extended. To test the possibilities of advancing the strawberry season by lighting in combination with an increased temperature in the glasshouse, trials under high pressure sodium (HPS) lamps were started in 2006 and continued till 2010 with different varieties. A lighted and unlighted glasshouse, both 250m², were compared under 130 $\mu mol \cdot s^{-1} \cdot m^{-2}$ supplemental lighting. From 2012 to 2014 trials with LED were done with December plantings of strawberry cultivar 'Clery'. With LED assimilation light, different light intensities (35 and 70 $\mu mol \cdot s^{-1} \cdot m^{-2}$) were compared in combination with light strategies, and different LED systems were compared with two spectra. This study shows an increase in petiole length and leaf area under assimilation lighting. The assimilation light caused an earlier yield, but the advancement was reduced when less artificial light was given. The total yield decreased with lower light intensities or reduced operation hours. Next to that, an increase in total yield could be obtained, but was negatively correlated with earliness. The regulation of temperature and lighting strategy seems to be important for plant balance between earliness and total yield. The strawberry season is advanced with assimilation light until beginning of February. The final gap can be filled by plantings in October to produce strawberries in January – February, to obtain a year-round strawberry production in Belgium.

O48

USING DIFFERENT RATIOS OF RED AND BLUE LEDS TO IMPROVE THE GROWTH OF STRAWBERRY PLANTS

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Red and blue light emitting diodes (LEDs) are known to be effective for enhancing plant growth. The aim of this study was to evaluate the growth of strawberry plants under different red:blue light ratios from LEDs compared with high pressure sodium lamps (HPS). In this study, three ratios of red (661 nm) to blue (449 nm) LED light (5:1, 10:1 and 19:1) were applied and HPS was used as a control. Strawberry plants cultured under different ratios of red to blue LEDs showed higher plant height, leaf, runner, inflorescence and crown number, fresh mass, and dry mass accumulation than that of plants cultured under HPS. The significantly higher fresh and dry mass accumulation were observed for strawberry plants cultured under 10:1 and 19:1 ratio of red to blue LEDs than HPS. The treatment 19:1 ratio of red to blue LED was significantly higher in inflorescences number and crown number than the other treatments. These results indicate that inflorescence production of strawberry plants is promoted by a higher level of red to blue light.

Abstracts for Poster Presentations

P1

THE EFFECT OF DIURNAL LIGHT INTENSITY DISTRIBUTION ON PLANT PRODUCTIVITY IN A CONTROLLED ENVIRONMENT

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Leafy crops, basil 'Aroma 2' and lettuce 'Galiano', were grown under six LED light regimes of the same spectral composition, photoperiod, and daily light integral (DLI), but different distribution of light intensities during the day. In natural environments, plants experience rapid changes of light conditions. Variation in light intensity influences vital plant functions, such as photosynthetic activity, carbohydrate metabolism, leaf expansion etc., and has an effect on productivity. Intelligent LED technology enables a high level of control over the amount of light provided to plants as supplemental or sole source lighting. Diurnal variation of light intensities can be based on plant responses and/or economic factors such as energy price. It is well known that plant biomass depends on the total amount of light provided to plants, but the effects of different strategies of providing light remains speculative. Here we present a comparison of biomass accumulation and growth performance of plants cultivated under constant, fluctuating (changing within minutes), sinusoid, and increasing at the beginning or the end of photoperiod light regimes. Results show that plant growth is best when light intensity is constant or imitates the natural distribution. Fluctuations or large changes in light intensity may decrease plant productivity. However, the differences were not large enough to compromise the visual quality of the crops.

P2

DIURNAL FLUCTUATIONS OF NUTRITIONAL COMPOUNDS OF THREE LEAFY VEGETABLES UNDER ARTIFICIAL CONDITION

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The effects of harvesting time at an artificial light type plant factory on the diurnal fluctuations in the nutritional compounds (ascorbic acid, β-carotene, calcium and iron) of three types of leafy vegetables was investigated to examine the possibility of the indication of the nutritional compounds for leafy vegetables. Chingen-sai (*Brassica rapa* L. var. *chinensis*), Komatsuna (*Brassica rapa* L. var. *peruviridis*), and rocket (*Eruca vesicaria* L.) were cultivated in a hydroponic culture system under identical conditions (white fluorescent lamp; lighting period: 12 h; photosynthetic photon flux: 220 $\mu mol \cdot m^{-2} \cdot s^{-1}$; air temperature: 24/20°C; relative humidity: 40–60%; CO_2 concentration: 1,000 $\mu mol \cdot mol^{-1}$). Sets of 6-8 plants for each crop were collected every 6 hours from the start of light period at 34 days after seeding (28 days for Chingen-sai) for 18 hours (until the middle of dark period) to analyze the four nutritional compounds. It was revealed that the diurnal fluctuations were small for nutritional compounds, since the coefficient of variance for the nutritional compounds was below 10% in all crops. The results showed that the concentrations of four nutritive components in the three leafy vegetables would not differ among the sampling time, demonstrating that a difference in harvesting time would have little impact on the concentrations of these nutritive components. Thus, the indication of nutritional compounds for leafy vegetables cultivated in plant factories was considered possible.

P3

EFFECTS OF PULSED LIGHTING BASED LIGHT-EMITTING DIODES ON THE GROWTH AND PHOTOSYNTHESIS OF LETTUCE LEAVES

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The effects of pulsed irradiation based-LEDs (light-emitting diodes, red and blue wavelengths, 660:455 nm = 4:1) on the growth and photosynthetic light utilization efficiency of lettuce (*Lactuca sativa*) leaves were studied. Plants were hydroponically grown in an incubator at 22 ℃ for one month after seeding under different pulse-cycled irradiations, compared with continuous light at PPFD of 200 μmol photons m^{-2} s^{-1} with 16-h light/8-h dark photoperiod. The tested pulse-cycled irradiations were of 0.5, 1, 1.3, 2.5, 5, 50, 500 Hz, and 1, 1.3, 2, 4, 10, 20 kHz frequencies, at 50 % duty ratio (illuminated duration/cycle). The photosynthetic rate (Pn) was maintained relatively constant over the range of measurements at pulsed light at PPFD of 80 μmol m^{-2} s^{-1}. At PPFD of 200 μmol m^{-2} s^{-1}, Pn gradually decreased by lowering frequency below 2.5 Hz of pulsed light. When Pn of plants grown under pulsed light was measured at the same irradiance, it was slightly higher at the measurement under pulsed light than that at the measurement under continuous light. Chlorophyll fluorescence parameters (Fv/Fm, Fv'/Fm', qP), which were measured under dark or light conditions, showed no significant difference between plants grown under pulsed light and those grown under continuous light except at the lowest frequency (0.2 Hz). The similar quantum yield (ØPSII) and electron transport rate (ETR) of Photosystem II were obtained in wide range of frequency of pulsed light, which might be an effective illumination strategy for cultivating leaf lettuce by using artificial lamps. Flashing irradiation did not significantly change chlorophyll content. Results suggested the effectiveness of pulsed light at 50% duty ratio on the growth of leaf vegetables that were richly cultivated in a closed type plant factory with the possibility of saving electricity by using intermittent illumination system with LEDs.

P4

THE ROLE OF CONDENSATION IN GREENHOUSES ON LIGHT TRANSMISSION

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Model calculations and the few data that are available show that over 100 l water condense yearly on each square meter of a greenhouse cover at northern latitudes. It is known that the presence of condensate in the form of droplets reduces light transmission. This effect is suppressed to some extent by adding (anti-drop) additives/coatings forming a water film on greenhouse covering or screen materials. Also special surface structures (e.g. special diffuse glasses) are able to avoid light losses. Furthermore, model calculations and few practical data show that during winter month from October to March under Dutch greenhouse conditions the inside of the greenhouse covering is wet during most daytime hours due to condensation. There is therefore a need to assess the effect of wet surfaces of greenhouse coverings and screens on the loss of light. Preliminary experiments have shown that light losses of 4-5% due to droplets are no exception (Stanghellini et al., 2011). The optical properties of wet materials can be characterised under laboratory conditions as well as under greenhouse conditions. In this paper measurements of wet materials under laboratory conditions will be shown. We will analyse the effect of surface structure and surface treatment of glasses on light transmission and scattering properties. Next to that we will present data of dry and wet glasses measured in a greenhouse experiment. Different materials have been mounted in a duplicate next to each other during several months in a greenhouse. Condensation occurred, half of the materials were wet, the other half has been dried, light intensity under the materials has

been measured continuously. We will show the effect of different surface structures and surface treatments of glasses on light transmission. We will compare data under laboratory conditions with greenhouse conditions. Raytracing and greenhouse climate modelling data will translate the obtained material properties to year-round figures of light transmission for different materials. Challenges for future material development will be pointed out.

P5

AMBIENT UV MANIPULATION IN GREENHOUSES: PLANT RESPONSES AND INSECT PEST MANAGEMENT IN CUCUMBER (*CUCUMIS SATIVUS*)

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Effects of different polyethylene covers with different light transmission properties on growth and productivity of two commercial cultivars of cucumber (*Cucumis sativus* L.) namely Safa62 and Aseel were studied under protected cropping systems. Cladding treatments included plastic covers of UV transparent (UVT), UV opaque (UVO), standard clear as well as the Egyptian local clear film. Results showed that, for the two studied cultivars, plants grown under the presence of UVB&A radiation (UVT cover) resulted in significant decrease in their vegetative characters (leaf area, plant height, and leaf dry weight) when compared with plants grown under either the absence of UVB&A radiation (UVO cover) or standard cover. Plants grown under UVO cover showed a significant increase in their vegetative characters when compared with plants grown under others films. No significant differences were found between UVT and UVO covers in total fruit yield per plant even with the pronounced differences in their vegetative responses to both films. However, both films exhibited a higher yield in comparison with standard and local films especially with cultivar Aseel. Significant differences were found between examined covers on aphid’s infestation. Plants grown under UVO cover had a minimum infestation throughout the experiments in the two seasons for both cultivars. Interestingly, UV radiation reduced aphid population but with lower influence than UV-blocking film.

P6

EFFECTS OF PRE- AND POSTHARVEST LIGHTING ON QUALITY AND SHELF LIFE OF FRESH-CUT LETTUCE

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The effects of pre- and postharvest lighting on quality and shelf life of fresh-cut lettuce was investigated. Lettuce was grown under different light intensities (120 and 250 µmol m^{-2} s^{-1} PAR from fluorescent tubes) and quality at harvest and subsequent postharvest performance of intact leaves and fresh-cut product was monitored. Cultivation under high light prolonged the shelf life (dark storage) of both intact leaves and fresh-cut product (butterhead and iceberg lettuce). The improved shelf life was reflected in improved chlorophyll fluorescence values. Postharvest lighting of the fresh-cut product, at low intensities (7 and 30 µmol m^{-2} s^{-1} PAR from fluorescent tubes) considerably prolonged the shelf life of fresh-cut product (butterhead lettuce) compared to storage in darkness. This was reflected in higher overall visual quality values and delayed cut-edge browning. The applied

light levels caused a 8 to 10 times increase in carbohydrate levels (sugars and starch) whereas carbohydrates decreased when the fresh-cut product was stored in the dark. Storage in light caused an increase in dark respiration leading to increasingly negative photosynthetic values. The prolonged shelf life of low light-treated samples is presumably related to the higher levels of sugar, counteracting starvation processes. Currently it is not clear which processes are responsible for the sugar accumulation in lit samples. We hypothesize that, under low light conditions, sugars may be produced through the processing of chloroplast degradation products in the glyoxysome, subsequent production of malate and oxaloacetate and production of glucose through reversal of the glycolysis pathway (gluconeogenesis).

P7

INFLUENCE OF SHADING SCREENS ON MICROCLIMATE, GROWTH AND YIELD OF CUCUMBER

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Photoselective screens and thermal reflector one promote better solar radiation quality and attenuate the extreme climatic conditions allowing greater efficiency in the vegetables production in protected crops. The cucumber is traditionally cultivated under field conditions in tropical areas. Recently there have been investments in screenhouses and greenhouses in order to improve the fruit quality. This research evaluated the effect of blue, red and thermal reflector screens on the vegetative development and productivity of cucumber (cv. Safira) in Goiânia, Goiás, Brazil (16º35'47"S, 49º16'47 "W, 730 m). The cucumber were cultivated under four conditions: three 16x12x2.20 m^3 40% shading screenhouses and field plots as control. The shading screens caused significant changes in relative humidity, the global solar radiation (SR) and photosynthetically active radiation (PAR). The red photoselective screens and the thermal reflector promoted greater attenuation of SR and PAR, increased production of total fresh fruit weight and obtained better PAR use efficiency compared to the open-air conditions. Red screen promoted higher yield compared to the blue one. The thermal reflector screen promoted higher fruit production and better PAR use efficiency compared to the blue and red screens. Among the colored screens, the red one proved to be more economically viable for the production of cucumber under the tropical conditions evaluated.

P8

EFFECTS OF LIGHT INTENSITY AND AIR TEMPERATURE ON LUTEIN AND BETA-CAROTENE CONTENT OF SPINACH

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Lutein and beta-carotene are major carotenoid pigments in Spinach (*Spinacia oleracea*) leaves, which are effective in protecting against lifestyle diseases owing to their antioxidant activity. Lutein is also effective in preventing ocular disorders such as age-related macular degeneration. Since humans do not synthesize lutein in the body, dietary intake of lutein is considered important. In this study, we evaluated the effects of light intensity and air temperature on lutein and beta-carotene content and the ratio of lutein to beta-carotene (L/B ratio) in 4 different spinach cultivars. The cultivars were grown at a photosynthetic photon flux density (PPFD) of 250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ under white fluorescent light for 30 days, and then cultivated under different light and temperature conditions for 7 days in growth chambers. Light intensity was set at 150, 250, and 350 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in a 12-h light period. Air temperature (day/night) was set at 10/5, 15/10, 20/15 and 25/20 ºC.

Beta-carotene content in dry matter significantly increased as light intensity increased, in the 4 cultivars. Lutein content was relatively high at 250 and 350 μmol·m^{-2}·s^{-1}. The L/B ratio of the cultivar 'Active' significantly changed, and it was the highest at 150 μmol·m^{-2}·s^{-1}. Lutein content in dry matter significantly increased as air temperature increased, however, beta-carotene content did not differ among the different temperature treatments. The L/B ratio in 'Active' was the highest at 25/20 °C. Based on our results, we suggest that lutein-rich spinach can be produced at a PPFD of 150 μmol·m^{-2}·s^{-1} and 25/20 °C. We also suggest that carotenoid pigment content is widely affected not only by light intensity but also by temperature, and that L/B ratio can be changed by changing environmental conditions, although both the pigments are biosynthesized from the same precursor, “lycopene”.

P9

EFFECTS OF SUPPLEMENTAL LIGHTING ON THE GROWTH AND MEDICINAL INGREDIENT CONCENTRATIONS OF JAPANESE HONEYSUCKLE (*LONICERA JAPONICA*)

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Japanese honeysuckle (*Lonicera japonica* Thunb.) is an evergreen vine-type plant that grows wild in Japan and East Asia. The buds and leaves of this plant are used as a crude drug and are known as Kinginka and Nindou, respectively, in Japan. The concentrations of the medicinal compounds (chlorogenic acid and luteolin) of Kinginka are known to vary across wild plants. Chlorogenic acid is known to have antiviral, anticancer, anti-inflammatory, and antioxidant activities (Wang et al. 2009). However, the optimal environmental conditions for growing Japanese honeysuckle are not yet known. Sustainable production and persistent supply of Kinginka to Japanese markets requires that these plants are grown in the greenhouse throughout a year. In this study, we cultivated Japanese honeysuckle plants in a greenhouse with supplemental lighting provided using high-pressure sodium lamps and measured not only the growth rate and flower bud number but also the main medicinal ingredient concentrations. The photosynthetic rate under different light intensities was measured, and the average photosynthetic photon flux density was adjusted to 225 mmol·m^{-2}·s^{-1} for supplemental lighting. During the experiment, the daily light integral by the supplemental lighting was maintained at 10 mol·m^{-2}·d^{-1}. The total dry weight and total leaf area of plants subjected to 55 days of supplemental lighting were significantly higher than those in the control (no supplemental lighting) plants. Although the number of flower buds was significantly higher in the treated than in the control plants, there were no differences in the concentrations of chlorogenic acid and luteolin between the two groups. In conclusion, supplemental lighting is a useful method for the winter cultivation of Japanese honeysuckle without causing any decrease in the yield (number and fresh weight) of flower buds and the main medicinal ingredients.

P10

EFFECTS OF RED, BLUE, AND WHITE LED IRRADIATION ON ROOT AND SHOOT DEVELOPMENT OF CALIBRACHOA CUTTINGS IN COMPARISON TO HIGH PRESSURE SODIUM LAMPS

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Both light intensity and spectral quality are known to affect plant growth and development. However, studies dealing with the effect of these light parameters on root and shoot development of ornamental cuttings are limited. The aim of this investigation was to test the effects of light intensity and spectral quality on the root and shoot development of *Calibrachoa* 'MiniFamous Neo Royal Blue' cuttings. Five spectral treatments at two irradiation levels (40 and 80 $\mu mol \cdot m^{-2} \cdot s^{-1}$) were used: red (660 nm), blue (440 nm), white (400-700 nm) as well as a mixture of all these spectra and a high pressure sodium lamp (HPS) as control. Experiments were conducted in climate controlled growth chambers to exclude natural sunlight. For each treatment, shoot and root length was determined and their respective dry weight measured. In addition, leaf area was determined. *Calibrachoa* propagated under blue LEDs had greater shoot elongation and leaf area compared to other lighting treatments. The total root length of the blue and mix LED treatments were similar, while the highest results achieved under the white LED treatment at 80 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Root dry weight was the highest under HPS lamps and mix LED treatments. The HPS treatment had a higher dry weight and a higher root length than all treatments. The results support both spectral quality and intensity influence shoot and root development of *Calibrachoa* cuttings. However, the best cutting quality in terms of visual appearance was obtained in treatments with white LEDs and a mixture of all available wavelengths. In further studies an optimized light recipe could be developed for production in multilayer systems.

P11

EFFECTS OF HIGH-PRESSURE SODIUM TOP LIGHTING, LED INTER-LIGHTING AND THEIR INTERACTION WITH CALCIUM SUPPLY IN NUTRIENT SOLUTION IN GREENHOUSE SWEET PEPPER PRODUCTION

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High-pressure sodium lamp (HPS) is the conventional lighting source used to provide assimilation light in greenhouse crop production. Because of its high operating temperature, HPS can only be used as top lighting placed well above crop canopy, which results in uneven vertical light distribution in tall crop canopy, such as greenhouse sweet peppers. LEDs have low surface temperature and can be used as inter-lighting within canopy to improve vertical light distribution and increase whole plant light use efficiency. Also, several studies have shown Ca requirement of plants increases with strong light. Therefore, the effects of top HPS lighting, LED inter-lighting, hybrid lighting system with top HPS plus LED inter-lighting, and their interaction with Ca supply in nutrient solution were investigated in a greenhouse sweet pepper trial from Oct. 2013 to Jun. 2014 in this study. Each of the four lighting treatments (no lighting – control, 80µmol m^{-2} s^{-1} top HPS only, 80µmol m^{-2} s^{-1} LED inter-lighting only, and 80µmol m^{-2} s^{-1} top HPS plus 40µmol m^{-2} s^{-1} LED inter-lighting) were applied to 2 plots, each with 18 twin-head plants, from early Nov. to late Apr. Three Ca treatments (140, 190 and 240µg L^{-1}) were applied with each lighting treatment. Fruit yield linearly increased with increasing supplemental light intensity regardless of top HPS lighting or LED inter-lighting during the winter months – from Dec. to Feb. However, the top HPS lighting reduced top leaf size and increased fruit disorders in late growth stage while the LED inter-lighting didn't. High supply of Ca significantly reduced the fruit disorders. Therefore, for year-round production with lighting, high supply of Ca is needed, especially with top HPS lighting.

P12

USING MOVABLE LIGHT-EMITTING DIODES FOR ELECTRICITY SAVINGS IN A PLANT FACTORY GROWING LETTUCE

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As an attractive alternative to traditional light sources, light-emitting diode (LED) have been widely used in plant growth applications, however, the irradiation under LEDs shows an exponentially decline distribution and the advantage of long lifetime was not fully utilized. In this study, the effects of light-emitting diode (LED) panels with different illumination schedules and mounted above lettuce (*Lactuca sativa* var. capitata) seedlings on lettuce growth and photosynthesis were examined, and the performance of the vertical and horizontal movable system on energy savings was evaluated. The illumination schedules used were fixed LED (F-LED: four LED panels illuminated the area below) and movable LED (M-LED: two LED panels moved left and right once per day to illuminate the same area as F-LED) at distances of 10 and 30 cm above the seedlings. The plant yields were uniform in all LED treatments. The highest light utilization efficiencies and lowest electricity consumption were found for the treatments with irradiation from a shorter distance above the seedlings. The true leaf numbers and ascorbic acid concentrations were the highest in the M-LED and F-LED treatments at a distance above the seedlings of 10 cm, while the leaf lengths and sucrose concentrations in these groups were significantly lower than those in the 30 cm treatment. These results indicate that illumination with M-LED can halve the initial light source input while maintaining yield and that sustained illumination from a shorter distance above the seedlings is the main factor in electricity savings.

P13

EFFECTS OF LIGHT QUALITY ON GROWTH AND COLOR OF RED-LEAF LETTUCE

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The effects of light quality on growth, quality and color of red-leaf lettuce in hydroponic were studied under 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ red (660nm) and blue (470nm) LED light, there were four light treatments (R:B=1:1, R:B=2:1, R:B=4:1, R:B=8:1). The fresh and dry weight of plant and shoot were significantly affected by light quality, the fresh and dry weight of plant and shoot of red-leaf lettuce in treatments with more red light (R:B=8:1, 4:1) were higher that in treatments less red light (R:B=2:1, 1:1). The color of red-leaf lettuce was significantly affected by light quality. With increasing red light, the color of red-leaf lettuce got green gradually, the more red color was found in red-leaf lettuce under R:B=1:1 treatment, and the highest contents of chlorophyll a, chlorophyll a+b and anthocyanin were found under R:B=1:1 treatment. Thus more red light was beneficial to growth, while more blue light was beneficial to anthocyanin contents and red color in red-leaf lettuce.

P14

INTERACTIVE EFFECTS OF ILLUMINATION TIME AND NUTRIENT SOLUTION ON GROWTH AND QUALITY OF LETTUCE

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The effects of illumination time interacted with nutrient solution concentration on yield and quality of hydroponic lettuce were studied under 350 μmol·m^{-2}·s^{-1} red and blue LED light, there were three illumination time (15h, 12h, 18h) and three nutrient solution concentration (1/4, 1/2, 3/4 Hoagland nutrient solution). The fresh and dry weight of plant and shoot were significantly affected by illumination time, while not significantly by nutrient solution concentration. Under 18h illumination with 1/4 nutrient solution, the fresh and dry weight of plant and shoot were the highest. The contents of chlorophyll, carotenoid, and the ratio of chlorophyll a/b were significantly affected by illumination time and nutrient solution concentration. The contents of chlorophyll and carotenoid were the highest under 15h illumination with 1/4 nutrient solution, while the highest ratio of chlorophyll a/b was found under 15h illumination with 1/2 nutrient solution. The contents of soluble protein, vitamin C, soluble sugar and free amino acid in lettuce were significantly affected by illumination time, and the contents of soluble protein, vitamin C, soluble sugar, nitrate and free amino acid were significantly influenced by nutrient solution concentration. Under 15h illumination with 1/4 nutrient solution, the contents of soluble protein and Vc increased, while nitrate content reduced in lettuce, under 15h illumination with 1/2 nutrient solution. There was significant interactions of illumination time and nutrient solution concentration on the growth and quality of lettuce in hydroponic.

P15

RESPONSES OF LEAF PHOTOSYNTHETIC CAPACITY OF LETTUCE ON DIFFERENT LIGHT QUALITY

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Light emitting diodes (LEDs) are often applied in plant factory as light source, therefore the light quality can be easily manipulated. This study aims to investigate the responses of leaf photosynthetic capacity on different light quality. Six treatments with red/blue light ratios of 1, 4, 8, 12, monochromatic red and blue light, respectively, were set up in this experiment. The peak wavelength of red light was 657nm and blue light was 450nm. Lettuce (*Lactuca sativa L.*) was used as experimental plant. During the experiment, photosynthetic photon flux density (PPFD) at the canopy level was maintained at 200 μmol m^{2}·s^{-1}. Day/night temperature was kept at 24/20 °C, diel relative humidity and CO_2 concentration were 60% and 400 μmol mol^{-1}, respectively. Yamasaki lettuce nutrient solution (pH≈5.8; EC≈1.5mS cm^{-1}) was applied. Results showed that: 1) Maximum leaf photosynthetic capacity (A_{max}) of lettuce was increased with decreasing red/blue light ratio, except under monochromatic blue light treatment; 2) A_{max} per unit nitrogen per leaf area (PNUE) increased with increasing proportion of blue light up to 50%; 3) stomatal conductance increased with decreasing red/blue light ratio. We conclude that blue light plays a pivotal role for improving leaf photosynthetic capacity, A_{max} is quantitatively increasing with the proportion of blue light except under monochromatic blue light condition.

P16

CAN SUPPLEMENTAL LIGHT QUALITY INFLUENCE THE NUTRITIONAL QUALITY OF GREENHOUSE-GROWN TOMATOES?

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Greenhouse tomatoes tend to have a reputation of inferior nutritional and sensory quality compared to their field-grown counterparts. It has been long known that light is a critical mediator of secondary metabolism in plants; signaling the production of nutritionally important

phytochemicals and regulating the emission of volatile organic compounds that can alter a consumer's perception of flavor. By leveraging photobiological principles, we are using supplemental light from high-pressure sodium (HPS) lamps (38% Red, 13% Blue) as well as light-emitting diodes (LEDs), including research-grade fixtures (93% Red, 7% Blue) as well as a hybrid LED-HPS system, to determine effects of supplemental light spectral distribution on greenhouse tomato fruit quality attributes. We hypothesized that enriching the amount of blue light that tomatoes receive would positively impact the amount of carotenoids and phenolic compounds that accumulate in tomato fruits through cryptochrome and/or phototropin-dependent signaling pathways. We also hypothesized that unsupplemented controls would be nutritionally inferior to their supplementally lit counterparts. To test these hypotheses, tomato fruits were subjected to a battery of physicochemical measurements. Total soluble solids, citric/ascorbic acid content, pH, and electrical conductivity were found to be statistically similar among all treatments. Additionally, phenolic compounds were quantified using the Folin-Ciocalteu method in concert with a more targeted approach using HPLC-ESI(-)-MS, which revealed that total phenolics and specific flavonols (e.g. quercetin-3-O-rutinoside) were largely unaffected by supplemental light. Lycopene and β-carotene remained consistent across treatments. Our data indicate that supplemental light in a greenhouse setting had little effect on the phytochemical parameters that influence the nutritional quality of tomato fruits.

P17

INFLUENCE OF LIGHT INTENSITY ON CO_2 NET ASSIMILATION OF SEVERAL ORNAMENTAL SPECIES SUITABLE FOR INDOOR MODULAR WALL SYSTEMS

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Living green fences and walls are new and well appreciated systems for indoor landscaping, used mainly for ornamental purpose and to produce an environmental-friendly sensation. Their aesthetic value is strictly influenced by technological system and overall by number and morpho-physiology of selected cultivars. Many foliage varieties, interesting for growth rate, canopy habitus and the colour and structure of leaves and flowers have to be (re)valued for their adaptability to vertical growing, hydroponic systems and especially low light intensity. Lack of adequate natural light intensity is the most common factor limiting the ornamental performances and diffusion of vertical gardens and is the reason for artificial indoor lighting systems use. The purpose of this work is to compare the response of net photosynthesis to light intensity in leaves of 20 indoor foliage varieties for their better location in wall and a right project of artificial lighting systems. The CO_2 assimilation was measured by an infrared gas analyzer LI-6400XT, on completely expanded leaves of plant grown in the same environmental controlled conditions, at increasing PPF from 0 to 2000 µmol m^{-2} s^{-1}, for 3 times. The light compensation and saturation points, photosynthetic capacity and respiration rate of species/cvs of *Aglaonema*, *Asplenium*, *Begonia*, *Calathea*, *Codiaeum*, *Cordyline*, *Dieffenbachia*, *Ficus*, *Hoya*, *Peperomia*, *Philodendron*, *Syngonium*, *Spathiphyllum*, *Streptocarpus* and *Tradescantia* are statistically compared and used for species ordering. The PPF-response curves of species shoved a typical trend to saturation and only *Asplenium*, *Syngonium*, *Streptocarpus* and *Fittonia* suffered photoinhibition when the PPF went beyond 1000, 1200, 1400 and 1600 µmol m^{-2} s^{-1}, respectively. Excluding *Ficus lanceolata*, all cvs have a compensation point lower than 15 µmol m^{-2} s^{-1} and a photosynthetic capacity under 7 µmol m^{-2} s`¹.

P18

DOES NIGHTTIME UV-B EFFICACY AGAINST POWDERY MILDEW DEPEND ON DAY LENGTH IN CUCUMBER?

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Previous experiments with broad spectrum ultraviolet (UV) sources indicated that UV applied with red light or UV applied during dark is most effective against cucumber powdery mildew caused by *Podosphaera xanthii*. However, the effect of daily growth light on efficacy of nighttime UV-B against powdery mildew has not been studied. Growth chamber experiments were conducted to examine the effect of day length, irradiance level, and daily light integral on sensitivity of cucumber plants and *Podosphaera xanthii* to nighttime UV-B. Non-inoculated and inoculated cucumber plants cv. Odeon were exposed to daily growth light with irradiances of either 75 or 150 µmol/m^{2}s with day lengths of either 8 or 16 h provided with high-pressure mercury lamps. All four combinations of growth light treatments were combined with or without UV-B (1.6 ± 0.1 W/m^2 for 3 min) applied during the night. Daily growth light significantly influenced nighttime UV-B efficacy against powdery mildew; primarily via day length. UV-B efficacy was reduced when day length was 16 h compared with 8 h. Inoculated plants exposed to 8 h of day length with nighttime UV-B showed no disease symptoms, while the severity was between 4-8% in plants exposed to nighttime UV-B with a 16-h day length. Relative chlorophyll content was significantly higher in plants grown under long days than short days, independent of irradiance level, daily light integral and UV treatment. However, above ground plant dry weight increased significantly with increased daily light integral. This knowledge will be useful to optimize nighttime UV-B efficacy against powdery mildew management in practice.

P19

HOW IS THE STATUS: SPECTRAL EFFECTS OF LEDS ON PHYSIOLOGY AND METABOLITES

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Light-emitting diode (LED) technology as supplementary light has shown great advancement in protected cultivation. One of the greatest challenges for the LED as alternative light source for greenhouses and closed environments is the diversity of the way experiments are conducted that often makes results difficult to compare. We need to get an overview of the impacts of light spectra on plant physiology and on secondary metabolism in relation to greenhouse production. As targeted use of LEDs can shape plants increase the amount of protective metabolites to enhance food quality and taste and potentially trigger the defense mechanisms of the plants the potential for intelligent use of LED. The outcome shows a direct transfer of knowledge obtained in controlled environments to greenhouses is difficult, as the natural light will reduce the effects of specific spectra and the species or even cultivar differences are important. To use high efficiency LED units in greenhouses might be both energy saving and beneficial to plants, but the design of light unit for closed environment might need to be developed in terms of dynamic light level and spectral composition to secure plants with desired quality with respect to growth, post harvest performance and specific metabolites.

P20

GROWING DWARF SUNFLOWERS USING LIGHT EMITTING DIODES

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Panels of light emitting diodes (LEDs) designed for plant growth often provide spectral peaks centered on blue (450 nm) and red (630 to 660 nm) wavelengths. Although red and blue irradiance effectively drive photosynthesis, morphological development and flowering may be altered under the more limited spectra than natural light. The dwarf sunflower 'Sunny Smile' was seeded and placed into light quality treatments of red LEDs (peak emission at 630 and 665 nm), blue LEDs (peak at 455 nm), red/blue LEDs (80:20, peak at 665 and 455 nm), or white LEDs (3700 K). In addition, T5 fluorescent (4100 K) and natural greenhouse light supplemented with high-pressure sodium (HPS) irradiance were evaluated. The study was completed in a greenhouse covered with an acrylic material (DEGLAS®) and conducted from February 16 to April 27. The growing areas of LEDs and fluorescent were separated and shielded from natural and greenhouse light using an opaque blackout material. Plants were grown at a constant 21 ± 2°C (70°F) with a 16-hour photoperiod at a photosynthetic photon flux of approximately 150 $\mu mol \cdot m^{-2}s^{-1}$. Most LED grown plants flowered in 62 ± 3 days from seeding. Sunflowers in treatments with fluorescent, red or white LEDs were 15.5 ± 2.2 cm tall at flowering. Under red/blue LEDs, plant height was significantly shorter (12.4 ± 0.8 cm) and under blue LEDs significantly taller (19.8 ± 0.3 cm). The shorter red/blue grown plants had stem calipers of 12.1 ± 1.2 mm while the taller blue grown plants averaged 8.2 ± 0.8 mm. In contrast, the stem caliper in red, white or fluorescent treatments averaged 10.9 ± 1.2 mm. All growing environments supported the development of quality sunflowers, although the compact growth under red/blue LEDs may be preferred in some markets of flowering potted plants.

P21

AN ALGORITHM FOR DETERMINING THE SUNLIGHT DISTRIBUTION INSIDE PHOTOVOLTAIC GREENHOUSES

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The photovoltaic (PV) greenhouse is a structure producing energy and crops on the same land unit, in which part of the sunlight is shaded by a PV array integrated on the roof. Depending on the amount of solar light available, the most suitable crops can be chosen. A novel algorithm is introduced for evaluating the amount of solar radiation and its spatial distribution inside PV greenhouses. Based on the geographic coordinates of the location, the algorithm calculates both the direct and scatter radiation on an arbitrarily observation point (OP) situated inside the PV greenhouse. The algorithm determines whether the sunrays reach the OP or the PV module, exemplified as a polygon with four edges. This calculation is carried out as a function of the altitude and azimuth angle of both the sunrays and the edges of the PV module. When the sunrays cast inside the PV polygon area, the direct radiation is shaded, thus only the scatter fraction reaches the OP. The calculation can be reiterated simultaneously for all the modules of the PV array, in order to evaluate the cumulated global radiation incident on a chosen OP throughout the year. By repeating this process for numerous OP, the global radiation can be calculated for each desired zone of the greenhouse area, also considering factors such as the greenhouse orientation, the cover material transmissivity and the percentage of the roof covered by the PV array. The calculated results were validated using the measured data of a real PV greenhouse in Sardinia (Italy). The algorithm allows

the creation of maps of light distribution which can be used to compare the existing typologies of PV greenhouse, with the attempt of identifying the more sustainable structures for crop cultivation.

P22

ROOTING OF SINGLE-NODE *PENNISETUM SETACEUM* 'RUBRUM' CULM CUTTINGS IS INFLUENCED BY PHOTOSYNTHETIC DAILY LIGHT INTEGRAL AND ROOTING MEDIUM TEMPERATURE

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Crown divisions and tissue culture plantlets are popular methods for propagating purple fountain grass (*Pennisetum setaceum* (Forsk.) Chiov. 'Rubrum'). Alternatively, culm cuttings are an economically attractive propagation method for quick liner production. Our objective was to quantify the impact of photosynthetic daily light integral (DLI) and rooting medium temperature during propagation on root and shoot development of single-node purple fountain grass culm cuttings. Cuttings were harvested, dipped in a rooting hormone containing 1000 $mg·L^{-1}$ indole-3-butyric acid (IBA) + 500 $mg·L^{-1}$ 1-napthaleneacetic acid (NAA) and placed in a glass-glazed greenhouse with 23 °C air and benches with root-zone medium temperature set points of 23, 25, 27, or 29 °C. Daily light integrals of 4.2, 8.4, 11.6, and 16.4 $mol·m^{-2}·d^{-1}$ were achieved with the use of two different fixed-woven shade cloths (≈30% or 54%) or no shade with 16 h of supplemental light from high-pressure sodium (HPS) lamps for 28 days. Cuttings were harvested at 7, 14, 21, or 28 d after initiation of treatments. In general, as DLI and rooting medium temperature increased, root dry mass increased. For example, as rooting medium temperatures increased from 23 to 27 °C under a DLI of 11.6 $mol·m^{-2}·d^{-1}$, root dry mass of cuttings increased by 24%, respectively. Root dry mass increased by 380% when cuttings were propagated at rooting medium temperature of 27 °C under increasing DLIs of 4.2 to 16.4 $mol·m^{-2}·d^{-1}$. Our results indicate that quick liner production of single-node purple fountain grass cuttings occurs when propagated on medium temperatures of 25 to 27 °C and DLIs of ≈12 to 16 $mol·m^{-2}·d^{-1}$.

P23

EFFICIENCY OF PLASTIC COVER TYPES ON ESSENTIAL OIL COMPOSITION AND VEGETATIVE GROWTH OF DILL (*ANETHUM GRAVEOLENS*)

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One of the most interesting developments in commercial protected cropping in recent years is the introduction of spectral plastic filter films in the horticultural industry. These plastic films can be used to clad tunnels used in current growing systems they selectively absorb or transmit specific wavelengths and particularly, in the UV region. Thus, they allow studies of effects of the spectral quality and quantity on growth, morphology and yield of many plant species. Here different plastic types (UVO- blocker and Stander) have been used to study the growth of dill (*Anethum graveolens L.*) under a low tunnel compared to outside a low tunnel. The results indicated that, the UVO-blocker significantly increased plant height, fresh weight % and dry weight% of shoot and root. Dill oil percentage significantly increased under the Stander plastic (0.068%) compared to plants outside (0.046%). Our studies showed that dill leaves contain 37 various essential oils consists of Eugenol, Trans-caryophyllene, Mefranal, Beta-santalene, Pentadecane, Apiole, Eudesmol, Haxadecanol, Methyl undecanoate, Limonene, n-Octane, α- Phellandren, Sabinene bicycle, D-

Carvone and Cyclo hexasiloxane and other oils. The percentages of essential oil and main components of dill oil were affected by the spectral properties of the plastic.

P24

RESPONSE OF GREENHOUSE TOMATO TO LONG PHOTOPERIOD OF LED INTERLIGHTING AT DIFFERENT TOP HPS PHOTOPERIODS AND TEMPERATURE INTEGRATION REGIMES

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Long photoperiods (>16 h) of lighting cause photo-injury and limit the yield increase by lighting in greenhouse tomatoes. The information is mostly from researches using top light such as HPS (high pressure sodium) lighting. There has been no report on response of tomatoes to long photoperiod of LED interlighting. Furthermore, we found in a recent study that dynamic temperature integration (TI) with temperature drop can promote translocation of photo-assimilates from leaf to fruit and thus has the potential to improve the response to long photoperiods. Therefore, this study was conducted from Oct. 2014 to Mar. 2015 with the aim 1) to examine response of tomatoes to long photoperiods of LED interlighting, and 2) to determine if the response can be improved by dynamic TI. Two top HPS photoperiods (16h and 19h, at 80 µmol m^{-2} s^{-1}) and two TI strategies (Control TI – no temperature drop and Dynamic TI - with temperature drop to 13.5 °C at the end of photoperiod) were applied in 8 greenhouse compartments (2 replications). Four LED treatments (0, 16h, 19h, and 22h, at 80 µmol m^{-2} s^{-1}) were applied inside each compartment. At Control TI, fruit yield increased with longer photoperiod of LED interlighting (up to 22h) when 16h of top HPS lighting was used whereas it was not increased by LED interlighting longer than 16h at 19h of top HPS lighting. Therefore, long photoperiod of top HPS lighting limited the response to long photoperiods of LED interlighting. Dynamic TI reduced leaf chlorosis and improved fruit yield response to both long photoperiods of top HPS lighting and LED interlighting. Fruit yield was increased further by 19h of LED interlighting at 19h of top HPS lighting when Dynamic TI was used. Dynamic TI also showed good potentials for saving heating energy.

P25

EFFECTS OF LIGHT QUALITY ON THE GROWTH AND ESSENTIAL OIL PRODUCTION IN MEXICAN MINT

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Mexican mint (*Plectranthus amboinicus* (Lour.) Spreng.) is a tender perennial plant in the family Lamiaceae, and used as an ornamental pot-plant in Japan. The leaves are fleshy and aromatic. This study aimed to examine the effects of light quality on the growth, leaf morphology, and essential oil production in Mexican mint. The plants propagated by cutting were transferred under respective monochromatic or combined (white) light conditions. Three monochromatic lights were irradiated with blue, green, or red LEDs which have the peak wavelength of 470, 525, or 660 nm respectively. A combined light was simultaneously irradiated by white, blue, green, and red LEDs (the PPFD ratio was 3:1:1:1). The light treatment conditions were 24±2 °C, 16-hr photoperiod at 100 µmol·m^{-2}·s^{-1} PPFD. Plants were cultivated under the respective light quality conditions for 70 days. The elongation of the main and lateral shoots was significantly reduced under blue and combined lights. The growth of lateral shoots was significantly reduced under the blue light. However, the thickness and fresh weight of leaves increased under the blue light. The constitution of volatile flavors was changed by the difference of light quality. It seemed to be more active by the sesquiterpenoid biosynthesis pathway under the blue light.

P26

EFFECT OF INTRACANOPY LIGHTING AND/OR ROOT-ZONE TEMPERATURE ON HIGH-WIRE TOMATO PRODUCTION UNDER SUPRA-OPTIMAL AIR TEMPERATURE

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The effects of providing intracanopy lighting to mutually shaded leaves using light-emitting diodes (ICL-LED; 93% red and 7% blue) and/or root-zone temperature were evaluated as strategies for stimulating high-wire greenhouse tomato (*Solanum lycopersicum* 'Felicity') production during summer conditions in a mid-northern climate (lat. 40° N). Plants were grown in a glass-glazed greenhouse with ambient day temperatures at or above 30 °C. Four treatments were evaluated in the study: 1) ICL-LED, which provided an average daily light integral (DLI) at mid-canopy height of 4 $mol \cdot m^{-2} \cdot d^{-1}$; 2) Root-zone cooling (RZC) at 18±2 °C; 3) ICL-LED + RZC; and 4) control for which no treatment was applied. ICL-LED was used as a potential stimulator of gas exchange and, thus, was expected to promote evaporative cooling within the canopy. RZC was used as an approach to reduce thermal stress in supraoptimal air-temperature conditions. Weekly plant-growth measurements, productivity, and leaf gas-exchange responses [stomatal conductance (*gs*), transpiration (*E*), and CO_2 assimilation (*A*)] were measured for plants in each treatment. No significant differences were observed for any physiological or harvest parameters evaluated. However, ICL-LED + RZC increased leaf length relative to control. Results suggest that neither ICL-LED (in the spectral composition used in our experiment) nor RZC are viable strategies to promote growth or productivity for greenhouse-tomato production during summer conditions in a northern climate.

P27

THE SPECTRAL DISTRIBUTION OF PHOTOPERIODIC LIGHTING REGULATES FLOWERING: A SUMMARY OF RECENT RESEARCH

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Lighting at the end of a short day (day extension) or in the middle of a long night (night interruption) can regulate flowering of long-day plants (LDPs) and short-day plants (SDPs). The spectral effects of low- (1–4 $\mu mol \cdot m^{-2} \cdot s^{-1}$) and moderate- (up to 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$) intensity lighting on flowering have been investigated on various floriculture crops grown in controlled-environment greenhouses to determine the functionality of single or multiple wavebands using light-emitting diodes (LEDs). For low-intensity lighting, a moderate radio of red (R, 600–700 nm) to far-red (FR, 700–800 nm) radiation promoted flowering of LDPs, whereas only R radiation was needed to inhibit flowering of SDPs. Consistently, a coordinated grower trial revealed the comparable effectiveness of R+FR LEDs and conventional incandescent or high-pressure sodium lamps. The addition of FR radiation to R+white radiation was critical for rapid flowering of some LDPs [e.g., snapdragon (*Antirrhinum majus*)], but not others, and its importance was more predominant under a low photosynthetic daily light integral. The interaction of R and FR radiation did not differ between day-extension and night-interruption lighting. Low-intensity blue (B, 400–500 nm) radiation, when alone or added to R and/or FR radiation, did not affect flowering; however, moderate-intensity B radiation was effective by itself. Irrespective of the B-to-R radiation ratio, white or R LEDs similarly regulated flowering of LDPs and SDPs. Collectively, these results have advanced our understanding of photoperiodic control of flowering and will ultimately facilitate the improvement of lighting products and applications to regulate flowering of commercial photoperiodic crops.

P28

INCREASE IN CHLOROGENIC ACID CONCENTRATION IN LETTUCE BY OVERNIGHT SUPPLEMENTAL LIGHTING AND CO_2 ENRICHMENT

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Chlorogenic acid (CGA) has been attracting attention as an antioxidant that affects human health. As we previously reported, overnight supplemental lighting (OSL) with light-emitting diodes (LEDs) can promote the growth of some leafy vegetables. However, when we investigated some functional materials in lettuce 'Greenwave' grown under OSL, a drastic increase in CGA concentration was observed. In Experiment 1, plants were exposed to low and high intensities (10 and 50 μmol m^{-2} s^{-1}, respectively) of OSL using blue, green, red, and far-red LEDs in growth chambers equipped with white fluorescent lamps as the main light source. In the growth chamber, we set the photoperiod such that the day/night time was 10 h/14 h. OSL was used for irradiation for 14 h during the night. OSL with blue and red LEDs increased the CGA concentration compared with that obtained using no supplemental lighting; however, other light qualities of OSL could not demonstrate any change in the CGA concentration. In particular, five times higher CGA concentration (60 mg 100 gFW^{-1}) was observed in lettuce grown under OSL using red LEDs with high intensity than those grown under no supplemental lighting. In Experiment 2, lettuce plants were grown under OSL (17:00–7:00 HR) with red LEDs in a greenhouse throughout the year. Unlike the results of experiment 1, the CGA concentration in lettuce was unstable, and OSL could not maintain a high CGA concentration, particularly during summer. However, during winter, OSL increased the CGA concentration in lettuce. Furthermore, CO_2 enrichment under OSL increased the CGA concentration up to 50 mg 100 gFW^{-1} on day 14 of treatment in the greenhouse. Therefore, it was concluded that OSL and CO_2 enrichment can promote CGA accumulation in lettuce; however, the increased CGA concentration under OSL could depend on other environmental factors.

P29

IN VITRO ORGANOGENESIS OF *ANOECTOCHILUS FORMOSANAUS* UNDER DIFFERENT SOURCES OF LIGHTS

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Light has a profound effect on plant growth and development. Light-emitting diodes (LEDs) represent a fundamentally different technology from the gaseous discharge-type lamps currently used in horticulture, and LEDs have a number of advantages when compared to traditional forms of lighting. For horticultural researchers and crop producers to benefit from LED use, a variety of preliminary findings should be considered. *Anoectochilus formosanaus* (Orchidaceae) is an important medicinal herb that flowers only once in a year. The whole plant of *A. formosanaus*, fresh or dried, is boiled in water and taken orally as medicine. The objective of this study was to develop new procedures of rapid production of *A. formosanaus* from the shoot tip of the plants by using different sources of lights. Shoot tips of *A. formosanaus* were cultured with modified Murashige and Skoog medium and all cultures were maintained under five different sources of lights (white fluorescent tube, blue LED, red LED, green LED, and Red field emission lamp or Red FEL) with a 16 h photoperiod for 6 weeks Our experimental results indicate that green LED promotes the maximum number of branches, leaves and roots without the use of any plant growth regulator.

Fresh weight (158.5 mg) and maximum formation rate of branches (92%) and roots (56%) were observed under green LED compared with the other four sources of light. Reports from this study suggest an easy, fast and reliable *in vitro* regeneration system for the organogenesis of *A. formosanaus*.

P30

PLANT FACTORY: HYDROPONIC LETTUCE GROWTH UNDER LIGHT LED CONDITIONS - RED, FAR-RED AND BLUE LIGHT IRRADIATION

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In the study one variety of leaf lettuce (*Lactuca sativa* L. cv Jocanda) was used to examine the effect of different LED and fluorescent light (control). Plants were cultivated in a climatic chamber (walk-in chamber) with a hydroponic system and under the following light conditions arranged in six shelves, respectively: 1- three rows of LED (BLUE and RED) complemented with fluorescent (F) 10% - 191 $\mu mol \cdot m^{-2} \cdot s^{-1}$; 2 - two rows of LED (BLUE and RED) complemented with fluorescent (F) 25% - 136 $\mu mol \cdot m^{-2} \cdot s^{-1}$; 3 - three rows of LED (BLUE, RED and Far RED) complemented with fluorescent (F) 10 % - 160 $\mu mol \cdot m^{-2} \cdot s^{-1}$; 4 - two rows of LED (BLUE, RED and Far Red) complemented with fluorescent (F) 25% - 114 $\mu mol \cdot m^{-2} \cdot s^{-1}$; 5 - two rows of LED (BLUE, RED and WARM WHITE) complemented with fluorescent (F) - 183 $\mu mol \cdot m^{-2} \cdot s^{-1}$; 6 - four rows of fluorescent (F) lamps - 75 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The spectral energy distribution was analysed in each shelve. The optimal quantum efficiency (Fv/Fm), the effective quantum yield of PSII (Y), and the photosynthetic rate (µmolCO2.m-2.s-1) of leaves lettuce have been evaluated for each one of the light conditions mentioned above. After one, two and three weeks the plants were collected and measured their fresh weight (FW).

P31

DIFFERENT RATIOS OF RED AND BLUE LED LIGHT EFFECTS ON CORIANDER PRODUCTIVITY AND ANTIOXIDANT PROPERTIES

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Light emitting diodes (LEDs) can be selected to target the wavelengths absorbed by plants, enabling the users to customize the wavelengths of light required for maximum production. The purpose of this study was to evaluate the growth and antioxidant accumulation in coriander plants cultured under various ratios of red to blue LEDs. Four light treatments including: red LEDs (100%) and three ratios of red (661 nm) to blue (449 nm) LEDs light (5:1, 10:1 and 19:1) at 120 $\mu mol\ m^{-2}\ s^{-1}$, were applied for this study. Coriander plants were cultured under different ratios of red to blue LEDs and were found to have an increase in the leaf and shoot number and fresh and dry mass than those plants cultured under 100% red LEDs. The highest fresh and dry mass accumulation were observed in plants cultured under the 10:1 ratio of red to blue LEDs but were not significantly different from the 19:1 ratio of red to blue LEDs. The coriander plants cultured under 100% red LEDs showed a significant decrease in antioxidant properties. This research will allow for improved selection of red to blue ratios of LEDs lighting for antioxidant rich leafy vegetables or spice production.

P32

SHORT TERM LED LIGHTING EFFECT ON ISOPRENOID COMPOUNDS IN *PERILLA FRUTESCENS* LEAVES

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In this study we present the short-term LED lighting effect on isoprenoid compounds in Perilla frutescens leaves seeking to reveal the reaction of plant antioxidant system to the changing light environment and to raise plants with increased antioxidant and nutritional value. Red and green leaf perilla plants were cultivated in phytotron (21/17°C) under high pressure sodium (HPS; 18h, 300µmol $m^{-2}s^{-1}$)) illumination for 30 days from sowing and were transferred to experimental light emitting diode (LED) based lighting (18h) for the last 3 days of experiment (short-term exposure). Experimental lighting spectra consisted of sole red 660nm LED light (300µmol $m^{-2}s^{-1}$) or the combination of red with 50µmol $m^{-2}s^{-1}$ of blue 455, yellow 595, green 520nm or 15µmol $m^{-2}s^{-1}$ of UV-A 385nm light (total PPFD of 300µmol $m^{-2}s^{-1}$ maintained). Short term effect of different LED spectra resulted in differential effects in red and green leaf plants. The change in phytochemical compounds was more expressed in young leaves, as compared to mature ones. In green perillas, significantly higher contents of α-carotene, violaxanthin and neoxanthin were observed under the exposure of red and green or UV-A light combination. In red leaf perilla, red, green and UV light combination resulted in increased ursolic and oleanolic acid contents. α-tocopherol contents were determined 1,9-2,0 times higher in young red and green perilla leaves, when exposed to red and green 520 nm light for 3 days.

P33

EFFECTS OF PLASMA VS. HIGH PRESSURE SODIUM LAMPS ON PLANT GROWTH, FRUIT YIELD AND QUALITY IN GREENHOUSE CUCUMBER PRODUCTION

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High pressure sodium (HPS) lamps have traditionally been the main light source for supplemental lighting in greenhouse crop production because of high reliability and efficiency in producing photosynthetically active radiation (PAR). The light spectrum of HPS has reduced blue light in comparison to sunlight. Therefore, plant growth and development could be benefited from an alternative light source with a spectrum similar to sunlight and containing more blue light, such as the recently developed plasma lambs. Some growth chamber studies reveal that plant growth and development was indeed better under plasma light in comparison to HPS, when plasma light was used as the sole overhead light source. Plant responses to plasma in greenhouse conditions could be different because the plant is also exposed to natural solar radiation. Therefore, this study investigated the impacts of plasma light on greenhouse-grown mini cucumber (*Cucumis sativus* L. 'Picowell') growth, fruit yield and quality, in comparison to HPS light over two winter seasons (Oct. 2012 to Mar. 2013 and Oct. 2014 to Apr. 2015) in a 200 m^2 greenhouse. The greenhouse was divided into 4 sections (50 m^2 in each section); two sections were fitted with plasma light while the other two sections had HPS (2 replications). Both lighting types provided the same amount of PAR (165 µmol m^{-2} s^{-1}). For both seasons, the total fruit yield was not affected by lamp type. However, in the first season (Oct. 2012 to Mar. 2013), the cumulative marketable fruit yield under plasma was significantly greater than that under HPS light. Due to the different impacts of light type on marketable fruit yield during the two winter season, future research should focus on the effect of solar radiation on choosing the proper light source in year-round greenhouse vegetable production with supplemental light.

P34

A NEW QUANTUM SENSOR FOR MEASURING PHOTOSYNTHETICALLY ACTIVE RADIATION

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A quantum sensor measures photosynthetically active radiation (PAR, in µmol of photons m^{-2} s^{-1}) in the 400 nm to 700 nm waveband. Plants utilize this radiation to drive photosynthesis, though individual plant responses to incident radiation may vary within this range. The new quantum sensor (model LI-190R, LI-COR Biosciences, Lincoln, NE), with an optical filter and silicon photodiode detector housed in a cosine-corrected head, is designed to provide a better response to incident radiation across the 400-700 nm range. The new design is expected to significantly improve spectral response due to uniformity across the PAR waveband, but particularly in the wavebands from 520 nm to 600 nm and 665 nm to 680 nm, and sharp cutoffs in the regions below and above the PAR waveband. Special care was taken to make sure that PAR sensor would not substantially respond to incident radiation above the 700 nm threshold because this can lead to errors when performing measurements in environments with a large proportion of near-infrared radiation, such as canopy understory. The physical housing of the sensor is designed to be weather-resistant, to effectively shed precipitation, provide protection at high temperature and high humidity conditions, and has a cosine-corrected response to 82° zenith angle. The latter is particularly important when measuring incident radiation at low elevation angles, diffuse light, or low light conditions. This presentation describes the principles of the new design, and shows the spectral and stability results from field experiments and laboratory tests.

P35

EFFECTS OF PLASMA VS. HIGH PRESSURE SODIUM LAMPS ON PLANT GROWTH, MICROCLIMATE, FRUIT YIELD AND QUALITY IN GREENHOUSE TOMATO PRODUCTION

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High pressure sodium (HPS) lamps have traditionally been the main light source for supplementing light in greenhouse crop production because of its high reliability and efficiency in producing photosynthetically active radiation (PAR). The light spectrum of HPS is short of blue light in comparison to sunlight. Therefore, plant growth and development could be benefited from an alternative light source with a spectrum similar to sunlight and containing more blue light, such as the recently developed plasma lighting system (plasma). Some growth chamber studies have shown that plant growth and development was indeed better under plasma in comparison to HPS, when they were used as the sole light source. The response of plants to plasma in greenhouses could be different because the plants are also exposed to natural solar radiation. Therefore, this study was initiated in 2012 to investigate the effects of plasma on plant growth, fruit yield and quality in greenhouse tomato production, in comparison to HPS. The study was conducted in a large greenhouse (200 m^2) over two winter seasons (Oct. 2012 to Apr. 2013 and Oct. 2013 to Apr. 2014). The greenhouse was divided into 4 sections (50 m^2 in each section); two sections were installed with plasma while other 2 sections with HPS (2 replications), which provided the same amount of PAR (165 µmol m^{-2} s^{-1}). The seasonal-total marketable fruit yield of plants grown under plasma light was the same as that under HPS in both years; fruit size (weight per fruit) was reduced while fruit number increased by plasma. Plasma improved fruit grades – increased the percentage of #1 fruit and reduced percentages of #2 and Commercial fruit, in comparison to HPS. The light sources also

affected plant microclimate and the dynamic of fruit production over the season; leaf temperature was higher under HPS during the winter months (Nov. to Feb.) and fruit production was better under HPS in early growth period while it was better under plasma light in late growth period. The information is valuable for growers to choose proper light source in greenhouse vegetable production.

P36

EFFECT OF LED INTERLIGHTING COMBINED WITH OVERHEAD HPS LIGHT ON FRUIT YIELD AND QUALITY OF YEAR-ROUND SWEET PEPPER IN COMMERCIAL GREENHOUSE

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Inter-lighting, applying supplemental light within crop canopy, has been shown to improve plant vertical light distribution and light use efficiency, with high-pressure sodium (HPS) lamps. However, it is not feasible on vegetables cultivated with the popular twin-row system (narrow row) used in major greenhouse vegetable production area in northern regions because of its high bulb temperature. Light-emitting diodes (LEDs) has low operating temperature and thus is potentially a good fit for inter-lighting. In this study, therefore, the effects of LED inter-lighting on sweet pepper growth, fruit yield and quality, and light and energy use efficiency were investigated in the commercial greenhouse. To optimize the production system with LED inter-lighting, different levels of top HPS lighting were also evaluated in the two experiments. Experiment one evaluated single row of LED inter-lighting module per twin-row (56.8 µmol m^{-2} s^{-1}) without or with top HPS (78 µmol m^{-2} s^{-1}). Experiment two evaluated the same LED inter-lighting module without or with the top HPS lamps at greater light intensity (155 µmol m^{-2} s^{-1}). LED inter-lighting improved plant growth, fruit yield and quality compared to the top HPS treatment. Moreover, LED inter-lighting significantly increased fruit dry matter content and the content of health promoting compounds in fruits, including total phenolic content, total carotenoid content and antioxidant activities (ferric reducing antioxidant power assay and 2, 2-diphenyl-1-picrylhydrazyl assay), compared with the HPS treatments. As a result of LED inter-lighting more light reached the crop canopy with a higher efficiency of electricity to light conversion and the plants grown with LED inter-lighting and top HPS achieved higher yield and quality than that with the top HPS only in both experiments.

P37

DAY/NIGHT TEMPERATURE REGIME AFFECTS PHOTOSYNTHETIC RESPONSES TO IRRADIANCE AND CARBON DIOXIDE, AND MINERAL, VITAMIN AND FIBER CONTENT OF SEVERAL VEGETABLE CROPS

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Cucumber, kale, mizuna, arugula, spinach, and red mustard plants were germinated and grown in a common greenhouse environment (22C day/18C night temperature under ambient daylight conditions. After cotyledons unfolded, plants were moved to five growth chambers maintained at 10, 15, 20, 25 and 30C (leaf temperature). Plants where moved among those chambers daily at 0800 and 1600HR to provide 25 day/night temperature regimes. After 2-6 weeks (species dependent; at least 3 leaves had unfolded) irradiance and carbon dioxide (CO_2) photosynthetic response curves were collected from a fully expanded leaf (varied with species) on plants grown

under each day/night temperature regime. Irradiance and/or carbon dioxide levels (other factors held constant) when photosynthesis saturated, as well as, the maximum photosynthetic rate achieved were documented. Temperature response curves were also collected on plants grown at constant 10, 15, 20, 25 and 30C (irradiance and CO_2 levels held constant). How day/night temperature regime affected the ability of a plant to utilize light and CO_2 for photosynthesis will be discussed. Data on leaf fresh and dry weight, leaf mineral content (P, K, Ca, Mg, Fe, Mn, Zn, Cu, Mo, B), and leaf vitamin C and fiber content from plants grown under each day/night temperature regime will also be presented.

P38

DAILY LIGHT INTEGRAL AND PLANT DENSITY AFFECT GROWTH OF GREEN AND PURPLE SWEET BASIL

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Specific recommendations for spacing basil plants grown hydroponically under high and low daily light integrals (DLIs) are lacking. Our objective was to quantify the effect of plant density and DLI on productivity of green and purple sweet basil (*Ocimum basilicum* L.). In one experiment, seeds of green sweet basil were sown into phenolic foam propagation cells, grown in a growth chamber for two weeks, and then transplanted into deep-flow technique (DFT) hydroponic systems. Plants were spaced 10-, 15-, 20-, 25-, or 30-cm apart with mean DLIs of 5.0–6.3 (low) or 14.2–15.2 (high) $mol{\cdot}m^{-2}{\cdot}d^{-1}$ and grown for three weeks. Fresh mass per m^2 increased with increasing plant density, though the magnitude of change differed between DLIs. Under a high DLI, decreasing spacing from 30 to 10 cm between plants increased fresh mass by 940 $g{\cdot}m^{-2}$, though fresh mass per plant slightly decreased. A similar trend occurred under a low DLI, where increasing density increased fresh mass by 542 $g{\cdot}m^{-2}$. Though trends are similar in low and high DLI conditions, yield per m^2 varied between the two different DLIs. For example, when basil was spaced on 10-cm centers, fresh mass was 498 g greater under high DLI compared to low DLI conditions. In second experiment, purple sweet basil was planted 10-cm or 15-cm apart with one or two plants per propagation cell and harvested after four weeks in the greenhouse. Yield (per m^2) increased with increasing plant densities. For example, by increasing the plants per cell from one to two, fresh mass per cell increased from 54.8 to 210.3 $g{\cdot}m^{-2}$, respectively, under a low DLI and 160.6 to 223.9 $g{\cdot}m^{-2}$, respectively, under a high DLI. In summary, increasing the DLI and modifying planting density with spacing and/or double-seeding can increase yield of green and purple sweet basil in hydroponic production.

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EFFECTS OF LED PLANT EXPOSURE ON GUSTATORY AND HEALTH PROMOTING COMPOUNDS OF GREENHOUSE TOMATO

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There has been over the last decade an increasing demand for healthy and tasty foods produced locally and available throughout the year. However under northern latitudes, supplemental lighting is required during the October-March period to produce vegetables on a year-round basis. The recent advent of LED (light emitting diode) technology offers great opportunities for increasing yield

and fruit quality as it has been shown that supplementary lighting of specific wavelengths may enhance the concentration of health components such as vitamin C and phenolic compounds in fruits and vegetables. We thus hypothesized that (*i*) exposure of tomato fruit to LED lighting of specific wavelength spectra within the plant canopy could enhance the nutritive and gustatory attributes of tomatoes compared to above-canopy lighting; and (*ii*) UV-B light pulses will increase the nutritive compounds and phytonutrients in tomatoes without causing any damage to the plant. A randomized complete block (*n*=4) experiment was conducted in a conventional 150 m^2 greenhouse located in Quebec City. Tomato plants (cv. 'Trust') were cultivated in coco coir and grown under natural light. Four horizontal and four vertical intracanopy LED lighting treatments were compared with the control treatment (natural light conditions): 1) Blue (460 nm)–Red (660 nm); 2) Blue (460 nm)–Red (660 nm)–Far Red (740 nm); 3) Blue–Red–Far Red–Far Red, *i.e.* with 740 nm diodes turned on an additional 2 hours during the night; and 4) UV-B pulses (20 kJ m^{-2} d^{-1}). All LED lighting treatments had a daily light integral of ~11 mol m^{-2} d^{-1}. The light environment and plant microclimate were characterized for each treatment. The following growth parameters were measured on two plants per experimental unit: leaf area, fresh and dry plant biomass (stem, leaf, fruit), carbohydrate partitioning, number of days after anthesis to reach maturity, fruit number and size, Chl*a* fluorescence parameters and leaf chlorophyll content. Soluble solids, titratable acidity, pH, EC, vitamin C, carotenoids, phenolic compounds and aromas were measured for each experimental unit on clusters 2 to 5 by using a refractometer (Brix), pH/EC meter, titrator, HPLC-UV, UPLC-MS/MS and GC-MS-SPME. After ~2 months of treatment, LEDs and UV-B lighting had no significant effect on photosynthetic capacity (as determined by the F_v/F_m ratio) compared with control plants. Differences were observed for growth parameters such as weekly apex growth, stem diameter and leaf length. In general, the vertical UV-B treatment reduced plant growth by ~15% compared with controls, while the horizontal B–R–FR treatment increased some of the growth parameters (+8.5%). Analysis of health and gustatory compounds are in process and will be discussed in relation to microclimate conditions and growth parameters.

P40

EFFECTS OF END-OF-DAY IRRADIATION ON THE GROWTH AND NICOTINE ACCUMULATION IN TOBACCO

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In this study we investigated the effects of "end-of-day (EOD)" light irradiation using LEDs on the nicotine accumulation in tobacco of *Nicotiana tabacum* 'Samsun'. Tobacco was cultivated under white fluorescent lamps with 150 µmol m^{-2} s^{-1} for a 16-h photoperiod for 35 days. EOD light treatments were started 14 days after seeding. EOD irradiation using red LEDs (EOD-R, peak wavelength: 660 nm) or far-red LEDs (EOD-FR, peak wavelength: 730 nm) was applied for only five minutes after the end of light period by white fluorescent lamps each day. The light intensities of EOD-R and EOD-FR were 20±5 µmol m^{-2} s^{-1}, and 18±5 µmol m^{-2} s^{-1}, respectively. We examined the growth and nicotine contents in the leaves, stems, and roots of tobacco after 21-day-cultivation with EOD light treatments. The petiole length under EOD-FR was longer than that of the EOD-R treatment. There was no difference in dry weights of the whole plant under the conditions between EOD-R and EOD-FR. The nicotine content in leaves under EOD-R was higher than that of EOD-FR treatment. Conversely, the nicotine content in roots under EOD-FR was higher than that of EOD-R treatment. On the other hand, the nicotine content in whole plant was not changed between EOD-R and EOD-FR. However, the significant difference in the total nicotine content per plant was not showed between EOD-R and EOD-FR. Those results suggested that a possibility that phytochrome reaction regulated the nicotine transportation from roots to leaves. Therefore, we should have

further examination that the gene expressions of nicotine biosynthesis and transportation are regulated by phytochrome reaction. This study shows a possibility that contributes to development a new method of secondary metabolite production in tobacco using light environment control.

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EFFECT OF LIGHT SPECTRA ON SELECTED MICROORGANISMS ASSOCIATED TO THE PHYLLOSPHERE OF ORNAMENTAL PLANTS

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In greenhouse production, alternative methods for heating and artificial lightning have been suggested to reduce the use of energy and light emitting diodes (LED) have been suggested as promising technology to replace high pressure sodium (HPS). Change of source for assimilation lighting may alterate abiotic and biotic as well as plant dependent preconditions and thus affects the leaf associated (*phyllosphere*) microbiota. We studied the utilization of sole nutrient sources in the presence of different LED sources (red: 664 nm; blue/red: 454 nm / 664 nm, white: 444 nm; 556 nm) as well as under dark conditions (control) by three selected bacteria with high biocontrol capacity, two commercial biocontrol agents (*Trichoderma harzianum*, *Streptomyces griseoviridis)* and plant pathogen *Botrytis cinerea*. The selected bacteria had been isolated from the phyllosphere of greenhouse grown *Euphorbia pulcherima, Begonia x hiemalis*, *Impatiens* L. and *Kalanchoë blossfeldiana* screened with respect to enzyme activities (protease and chitinase) and production of biosurfactants. Omnilog technology was used for monitoring of the bacterial and fungal isolates. Utilization patterns were analyzed with respect to utilization of single sources and maximum extinction as well as length of lag and exponential phase. Preliminary results indicate that two gram negative selected bacteria had the highest utilization after 48hr in sulfur (s) or phosphorus (p) source, while lowest utilization was noticed in carbon (C) source under red light. In contrast, gram positive selected bacteria showed the highest utilization when exposed to red light in C source, while the lowest was recorded in (P) or (S) sources. More results will be presented in detail in the paper.

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THE CONNECTION BETWEEN NITRATE REDUCTION AND PHOTOSYNTHETIC PLANT PERFORMANCE UNDER RED LIGHT TREATMENT

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The objective was to evaluate the effect of supplemental red (638 nm) light on nitrate reduction, photosynthesis intensity and related metabolites in corn salad (*Valerianella locusta*, 'Vit'), tatsoi (*Brassica narinosa*, 'Rozetto F1') and amaranth (*Amaranthus*, 'Red Army'). Plants grew in a polycarbonate greenhouse (23/17°C) under natural illumination supplemented with high-pressure sodium lamps (HPS; 150 μmol $m^{-2}s^{-1}$, 16h). Effect of short-term (1-7 days) red light-emitting diodes (LEDs) pre-harvest lighting was investigated. Plant were irradiated with 300 μmol $m^{-2}s^{-1}$ photosynthetic photon flux density (PPFD), 16h photoperiod red light. Reference plants grew under HPS lighting at the same PPFD. The results revealed that red light stimulates reduction of nitrates and nitrites and this effect depends on plant genotype. Content of nitrates was lower under red LEDs than under HPS in tatsoi and amaranth, but it increased in corn salad. The amount of nitrites was equal or greater under red LEDs compared to HPS. Photosynthesis intensity and chlorophyll/flavonoid indexes increased with increasing duration of red light in corn salad. Whereas these indexes decreased, except for flavonoid index, in tatsoi. Photosynthesis intensity and chlorophyll index increased until the third day of red LED treatment and then the decrease was observed in amaranth. However, flavonoid index increased during red light. In conclusion, photosynthesis system adapted to high PPFD level of red light and after more than 3 days treatment reduced nitrate amount recovered in corn salad and amaranth. Therefore, for nitrate reduction, it is appropriate to irradiate plants with high intensity red light for 3 days, because after 5 days of treatment, nitrate content no longer decreased and photosynthesis was suppressed. In comparison to other plants, corn salad adapted to changed lighting conditions, because its photosynthesis was not suppressed. Thus content of nitrates/nitrites and nitrate reduction depends on photosynthesis processes. Hereby LED characteristics, high intensity, and particular wavelength, allows manipulating secondary products.

P43

PRODUCTIVITY AND PHOTOSYNTHETIC CHARACTERISTICS OF HEAT-RESISTANT AND HEAT-SENSITIVE RECOMBINANT INBRED LINES (RILS) OF LACTUCA SATIVA IN RESPONSE TO DIFFERENT DURATIONS OF LED LIGHTING

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Many studies have shown that longer photoperiods result in increased rates of plant growth. This study investigated the impact of different photoperiods of red- and blue-LED lighting on the growth, as well as, photosynthetic characteristics of heat-resistant (HR) and heat-sensitive (HS) RILs of *Lactuca sativa* grown in a vertical farming system. Lettuce plants were grown under three different photoperiods (12, 16 and 18 h) of red- (85%) and blue- (15%) LED lighting, at a mean photosynthetic photon flux density (PPFD) of 300 µmol m^{-2} s^{-1}. 27 days after transplanting, both HR- and HS-RIL plants had significantly higher shoot and root fresh (FW) and dry (DW) weights, leaf number and total leaf area (TLA) when subjected to extended photoperiods of 16 and 18 h than the normal 12 h photoperiod. Highest growth parameters were observed for the longest photoperiod of 18 h. However, photosynthetic properties were not greatly enhanced under the extended photoperiods of 16 and 18 h - only chlorophyll (Chl) a/b ratio was increased. Light saturated photosynthetic CO_2 assimilation (A_{sat}) and stomatal conductance ($g_{s\ sat}$) among plants exposed to different durations of LED lighting showed no significant difference among the various photoperiods. Though longer photoperiods resulted in increased total carbon assimilation, this would have been due to the plants having a larger TLA. The decrease in soluble and insoluble sugar concentrations in lettuce leaves, under longer photoperiods, was most probably due to the dilution of carbohydrates as a result of increased leaf number and total leaf area. Thus, the results suggest a lack of feedback inhibition of photosynthetic end products in the leaves of lettuce plants, despite its exposure to longer photoperiods.

P44

INITIAL STUDIES ON INCREASING GARLIC BULB SIZE THROUGH NIGHT-BREAK TREATMENT IN THE PHILIPPINES

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Garlic received unique attention in the Philippines when its price surged by 100% in 2014. The insufficiency of a local supply makes the Philippines dependent on imported low-priced garlic. One significant limitation to garlic yield is bulb size, which is highly affected by day length. Since garlic is grown after rice during the dry season, day length is not optimal under this condition. To examine the effect of night-break on garlic yield-limiting factors—leaf count, plant height, bulb size and weight, and cloves per bulb—three locally produced ('Ilocos white', 'Tan bolter', and 'Mindoro white') and one imported ('Taiwan') garlic cultivars were tested in top-producing garlic provinces (Ilocos Norte 18.1° N, 120.7° E; Mindoro Occidental 13.0° N, 120.9° E; and Nueva Ecija 15.5° N, 121.0° E). At 30 days after planting (DAP), 20 plants per cultivar in three replicates were exposed to night-break for 30 d using a red fluorescent tube with wavelength of 660±30 nm and photosynthetic photon flux density (PPFD) of ~5 µmol m^{-2} s^{-1} at the top of the plant from 1900 to 2300 HR. Similar sets of garlic cultivars were grown under natural sunlight as control. In the period between 30 and 60 DAP, increases in leaf count and plant height were more apparent in plants exposed to a night-break than in the control. A high stem elongation rate was similar for 'Ilocos white' and 'Mindoro white' under both treatments, whereas the relative elongation rate of 'Taiwan' exposed to red light was higher than that of the control. Bulb size for all garlic cultivars across locations improved after 60 and 100 d, but the highest percentage of increases (55.0%, 52.2%, and 46.6% for 'Ilocos white', 'Mindoro white' and 'Taiwan', respectively) were in response to a night-break. 'Taiwan's' long maturity period of >120 d explains its slow increase in bulb size. At harvest, bulb weights did not show significant differences (p-value=0.536) between treatments but the number of cloves per bulb had significantly increased (p-value=0.030) in night-break treatment. The increase in bulb weight may be attributed to the increase in number of large cloves as enhanced by a night-break.

P45

EFFECTS OF THE IRRADIATION PATTERNS OF RED AND BLUE LED LIGHTS ON PLANT GROWTH

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Plant factories with artificial light have been attracting attention as a new vegetable production system. However, the high production cost of vegetables grown in plant factories is a problem. The cost of electricity for light irradiation is a major factor in production costs. The ultimate goal of this project is to develop a new lighting strategy, which reduces the electricity cost associated with light irradiation. The specific objective of this study was to evaluate the effect of irradiation patterns of red and blue lights on the growth of leafy vegetables. Red (660nm) and blue (430nm) light emitting diodes (LEDs) were used as a light source for the growth of leafy vegetables. The photosynthetic photon flux density (PPFD) of red and blue LEDs was set to 160 and 80 µmol m^{-2} s^{-1}, respectively, by adjusting the electrical current supplied to each of the LEDs. The photoperiod was set to 12 h each for red and blue light. Four experimental conditions were prepared. Red LED was turned on at 06:00 and off at 18:00 in all conditions. On the contrary, the irradiation timing of the blue LED was shifted by 4 h, such that (1) R/B: 0600–1800/0600–1800 h, (2) R/B: 0600–1800/1000–2200 h, (3) R/B: 0600–1800/1400-0200 h, and (4) R/B: 0600–1800/1800–0600 h. Leafy lettuce (*Lactuca sativa* 'Greenwave') was grown under the four light conditions for 3 weeks after transplant. The weights of aerial parts of leafy lettuce at harvest under the four light conditions were (1) 48.3 g, (2) 54.8 g, (3) 68.0 g, and (4) 78.6 g. The aerial part of leafy lettuce increased as the timing of irradiation with red and blue LEDs was shifted. The aerial part of leafy lettuce increased as the timing of irradiation with red and blue LEDs was shifted.

P46

REFLECTED SUNLIGHT WEED CONTROL CAPABILITIES OF WATERMELON (*CITRULLUS LANATUS*) IN AMARANTH CROPPING SYSTEM

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In-situ live mulch crops such as watermelon could suppress weed population and provide better quality vegetables through incident radiation control in cropping systems. This study therefore seeks to find alternative weed control techniques apart from herbicidal control using watermelon live mulch to impede incident radiation in amaranth cropping systems. Grain amaranth cultivar NH84/493 was planted 2011 and 2012 cropping seasons at 0.50m x 0.50m in three sowing spacing of watermelon: 1.5 x 0.45m; 1.5 x 0.68m; 1.5 x 1.35m**.** There was a control plot without cropping and a check plot with amaranth cropping while the weed population in each was monitored. The experiment was a randomized complete block design with five replications. Results revealed that mean light transmittance of 0.25 % PPFD (photo synthetic photon flux density) was optimum for weed control and yields in amaranth and watermelon cropping systems in the humid tropics. This corresponded to amaranth and melon planted at 1.5 x 0.68 m compared to other treatments. Reflected sunlight, total weed biomass and density were significantly (p=0.05) and consistently lower in the watermelon treatments relative to the bare soil treatment (control) in the order: 1.5 x 0.45m<1.5 x 0.68m<1.5 x 1.35m<Check<Control**.** It was obvious that changes in yields, weed biomass and density proofed to explain reflected light weed suppression capabilities of watermelon as live mulch in amaranth intercropping system in the humid tropics.

P47

COMPARATIVE STUDY OF LETTUCE AND RADISH GROWN UNDER RED AND BLUE LEDS AND WHITE FLUORESCENT LAMPS

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Growing vegetable crops in space will be an essential part of sustaining astronauts during long-range missions. To drive photosynthesis, red and blue light-emitting diodes (LEDs) have attracted attention because of their efficiency, longevity, small size, and safety. In efforts to optimize crop yield, there have also been recent interests in analyzing the subtle effects of additional wavelengths on plant growth. For instance, since plants often look purplish gray under red and blue LEDs, the addition of green light allows easy recognition of disease and the assessment of plant health status. However, it is important to know if wavelengths outside the traditional red and blue wavebands have a direct effect on enhancing or hindering the mechanisms involved in plant growth. In this work, a comparative study was performed on two short cycle crops of red romaine lettuce cv. Outredgeous and radish cv. Cherry Bomb, which were grown under two light treatments. The first treatment being red (630 nm) and blue (450 nm) LEDs alone, while the second treatment consisted of daylight tri-phosphor fluorescent lamps (CCT~5000°K) at equal photosynthetic photon flux. To evaluate the treatment effects, we measured fresh and dry biomass production, and compared plant morphology, leaf chlorophyll content, and analyzed ATP production within plant/root tissues. For lettuce, the results indicated larger and more elongated leaves, and higher biomass accumulation under the fluorescent lamp treatment. However, the radish crops showed larger leaves under the red and blue LEDs, but no significant difference in biomass between either of the two treatments. The ATP analysis, which is a general measure of metabolic activity, revealed no difference between treatments for either crops, but instead was influenced more by plant age.

Ultimately, this study showed the effects of broad spectrum lighting and narrow spectrum LEDs on plant growth and ATP production to be species-dependent.

P48

GROWTH AND MORPHOLOGY OF GREENHOUSE BELL-PEPPER TRANSPLANTS GROWN UNDER SUPPLEMENTAL LEDS AND HPS LIGHTING

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Greenhouse bell pepper transplants develop undesirable leaf curling if supplemented with high-pressure sodium (HPS) lamps. Light emitting diodes (LEDs) are a promising supplemental lighting technology since the spectrum can be customized for specific plant applications. An experiment was conducted to evaluate bell pepper (*Capsicum annuum*) morphological and growth rate responses when grown under LEDs and HPS supplemental lighting. Four cultivars (Orangela, Viper, Fascinato, and PP0710) were grown in a greenhouse under low daily solar-light integral of 5.2 ± 0.8 mol m^{-2} d^{-1} for 56 days. The supplemental lighting treatments provided 55 µmol m^{-2} s^{-1} PPF for 18 hours (2 AM – 8 PM). The treatment consisted of a red-LED (peak wavelength 633 nm), a blue-LED (peak wavelength 443 nm), and a 600W HPS. The growth of pepper transplants was variety dependent, 'Orangela' and 'Viper' did not show any differences in shoot dry mass between the three treatments; the shoot dry mass of 'Fascinato' was 19 % greater in the HPS treatment compared to the LED treatments; and the shoot dry mass of 'PP0710' in the HPS treatment was 17 % and 30 % greater than the red and blue LED treatments, respectively. There was no difference in leaf net photosynthetic rate (Pn) under white-light between treatments. In order to evaluate leaf curling under the different treatments, the midrib vein was cut from a mature leaf to compare the extent of leaf curling geometrically, using the ratio of sagitta (midpoint height of the arc) and the half-chord-length (length between the two end points of the arc). Results showed that the HPS and red-LED treatments had 57 % greater leaf curling index than the blue-LED treatment, regardless of cultivar. From these results it is evident that blue-LED supplemental lighting can be an alternative to conventional HPS supplemental lighting to prevent leaf curling on pepper transplants.

P49

EFFECT OF LED BLUE LIGHT ON ETHYLENE PRODUCTION OF *PENICILLIUM DIGITATUM* AND ITS CAPABILITY TO INFECT CITRUS FRUITS

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The fungus *Penicillium digitatum* (Pers.:Fr.) Sacc. is the main postharvest pathogen of citrus fruit grown under Mediterranean climate conditions. The hormone ethylene is produced by higher plants and by a wide variety of micro-organisms. Ethylene production increases in citrus fruit after *P. digitatum* infection. This fungus is able to produce ethylene but the role of the fungal ethylene in pathogenicity is not well understood. Our previous work showed the potential of blue light (BL) generated by light emitting diodes (LEDs) in controlling *P. digitatum* growth. The effect of BL on ethylene biosynthesis by *P. digitatum* is unknown, whereas ethylene production in BL-irradiated plants depends on light fluence. To get an insight into the effect of BL on *P. digitatum* ethylene production and deepen the understanding of the pathogenesis mechanisms of this fungus, we compared the effect of different BL regimes on ethylene production of *P. digitatum* and its capability to infect citrus fruits. BL applied at a quantum flux of 150 µmol m^{-2} s^{-2} reduced fungal ethylene production. Petri plates inoculated with the same concentration of conidia were held

under darkness (control) or light for 9 days, or were treated with light for 3 days and then shifted to darkness for 6 days (noncontinuous light). Ethylene production in cultures exposed to continuous or noncontinuous light showed little differences and was lower than in control samples. However, when considering the number of survival spores, the highest ethylene production was found in samples held continuously under light and little differences were found between control samples and samples exposed to noncontinuous light. Results also showed that the cultures treated with noncontinuous light had the lowest capability to infect citrus fruit. The potential involvement of BL-induced changes in the *P. digitatum* ethylene production and/or in its capability to infect citrus fruit will be discussed.

P50

BLUE LIGHT-INDUCED CHANGES IN SCOPARONE AS RELATED TO ETHYLENE AND REDUCED CITRUS POSTHARVEST DISEASE

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The antimicrobial properties of light is a research area of increasing interest due in part to the development of resistance to actual control methods. Previous reports have shown the potential of LED Blue light (BL) for reducing postharvest decay caused by *Penicillium digitatum* (Pers.:Fr.) Sacc., the major pathogen of citrus fruit after harvesting. The mechanisms by which BL may increase resistance against this fungus in citrus fruits are little understood. Phenypropanoids and the plant hormone ethylene are important players in resistance of citrus fruit against *P. digitatum*. It is known that ethylene production in BL-irradiated plants may depend on light fluence and that the hormone stimulates phenylpropanoid biosynthesis in citrus fruit. Therefore, we hypothesized that BL may induce changes in ethylene and phenolic compounds related to the BL-elicited resistance in this crop. To test this hypothesis, we examined the effect of exposing sweet oranges for different periods to BL at quantum fluxes ranging between 60 and 600 µmol m-2 s-1 on ethylene production, phenolic composition and induced resistance against *P. digitatum* in oranges. Ethylene production increased with BL intensity. Applying the highest quantum flux markedly increased endogenous ethylene by 1 hr although extending the treatment for 3 hr reduced the hormone production respect to control fruits (darkness). This treatment did not elicited resistance; whereas disease incidence was reduced by applying the light for 18 h. Little changes were induced by BL in flavonoids under the experimental conditions of the study. The most relevant change in phenypropanoids was the increase in the coumarin scoparone, which markedly increased 3 days after finishing the 600 µmol m-2 s-1 light treatment. Nevertheless induction of scoparone was not a critical factor in the BL-elicited response. The connection between changes induced by BL in ethylene production and in phenylpropanoids in citrus fruit will be also discussed.

P51

VEGETATIVE GROWTH OF YOUNG *PHALAENOPSIS* 'BLANC ROUGE' AND *DORITAENOPSIS* 'MANTEFON' PLANTS UNDER DIFFERENT ARTIFICIAL LIGHT SOURCES

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This study was conducted to determine the effects of artificial light sources on vegetative growth of young *Phalaenopsis* 'Blanc Rouge' and *Doritaenopsis* 'Mantefon' plants. One-month-old young clones were cultivated under either fluorescent lamp, cool-white LED, or warm-white LED at 80 and 160 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Photo-treatments were maintained for 15 weeks in a closed plant production

system. The mean leaf span was 9.7 and 11.9 cm in *Phalaenopsis* 'Blanc Rouge' and *Doritaenopsis* 'Mantefon', respectively, at the start of photo-treatments. The longest leaf span and length and width of the uppermost mature leaf were observed in plants treated with warm-white LED light. Plants grown under fluorescent lamp showed longer leaf length, width, and span than plants grown under cool-white LED light. Leaf span increased with higher light intensity in both cultivars. Maximum photochemical efficiency of PSII was higher under cool-white treatments. Relative chlorophyll content decreased under relatively high light intensity in both cultivars. These results indicate that relatively high intensity light can promote vegetative growth and warm-white LED is better light source than cool-white LED or fluorescent lamp for the vegetative growth of young *Phalaenopsis* plants. Thus, this result can be useful in using the supplementary lighting in a greenhouse or artificial lighting in a closed plant production system to effectively promote the vegetative growth of *Phalaenopsis* plants.

P52

MAINTAINING DIFFERENT ELECTRON TRANSPORT RATES IN LETTUCE: EFFECTS ON QUANTUM YIELD AND NON-PHOTOCHEMICAL QUENCHING

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Chlorophyll fluorescence measurements can be used to determine the quantum yield of photosystem II (ϕ_{PSII}), as well as non-photochemical quenching (NPQ). The electron transport rate (ETR) through photosystem II can then be determined based in the photosynthetic photon flux density (PPFD) and ϕ_{PSII}. Using a biofeedback-based control system, the PPFD can then be adjusted automatically to maintain the ETR close to a target ETR. We used the biofeedback control system to maintain the ETR of lettuce 'Green Towers' at 25 to 150 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for 16 h. The ϕ_{PSII} decreased gradually, and non-linearly as the target ETR increased, while NPQ increased with increasing target ETRs. The gradual decrease in ETR with increasing PPFD indicates that light is used less efficiently by the crop as PPFD increases. The ability to monitor and control the efficiency and rate of the light reactions of photosynthesis will allow growers to adjust PPFD automatically and in real-time, based on the crop's ability to use the light. We expect that controlling PPFD based on the plant's physiology will allow growers to better weigh the benefits of providing additional PPFD versus the additional energy costs associated with providing that light.

P53

ACCUMULATION OF PHENYLPROPANOIDS AND THE GROWTH OF *AGASTACHE RUGOSA* USING DIFFERENT TYPES OF LEDS

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Agastache rugosa Kuntze is a perennial herb of the mint family (Lamiaceae) that is widely found in East and Southeast Asian countries. The extracts from *A. rugosa* have shown antifungal activity in *in vitro* experiments; they also have significant antiatherogenic and anti-inflammatory properties. We investigated optimum light conditions using different LEDs to enhance the growth of *A. rugosa* and its antioxidant compounds, especially phenylpropanoids, such as rosmarinic acid, tilianin, and acacetin, using a hydroponic culture system for a period of four weeks after transplantation. *A. rugosa* seeds were sown in a rockwool seedling plate and placed in an environment consisting of 22±2°C and 60–75% humidity under 180±5 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux density (PPFD) for six weeks in a controlled growth room. Twenty-five seedlings for one light treatment were

transplanted in a closed-type plant production system that was maintained at a temperature of 22°C and 18±1°C (day and night) and at 50–70% relative humidity. *A. rugosa* was subjected to the following light system conditions (treatments): fluorescent light (FL) as the control, W10 (white 100%), R10 (100% red, 645 nm), R3B1 (75% red, 25% blue, 456 nm), R5B1 (82% red, 18% blue), R2B1G1 (50% red, 25% blue, 25$ green, 525 nm), and W2B1G1 (50% white, 25% blue, 25% green) with PPFD= 230±10 $\mu mol \cdot m^{-2} \cdot s^{-1}$ to understand the light efficiency for plant growth and the accumulation of phenylpropanoids. The extracts from *A. rugosa* were analyzed using high performance liquid chromatography. The fresh shoot and dry weights of *A. rugosa* grown using the W2B1G1, R2B1G1, W10, and FL light system treatments were greater than those grown using the R10, R3B1, and R5B1 treatments. The fresh root and dry weights increased in the W2B1G1 and R2G1B1 treatments for the four-week growth period after transplanting. The amounts of rosmarinic acid and tilianin, the main antioxidant compounds from *A. rugosa*, were the highest in the R2B1G1 treatment, followed by the R10, W10, and W2B1G1 treatments. However, the acacetin content was higher in the FL treatment than in the other treatments and the amount of acacetin-malonyl hexoside of the *A. rugosa* grown with the R2B2G1 light system was greater than the amount in the other treatments. The total antioxidant content of the fresh shoot *A. rugosa,* including flowers, stems, and leaves grown under the R2B1G1 and W2B1G1 light systems, was significantly greater than the total antioxidant content observed from the other treatments. The present results demonstrated that full visible spectrum (white color), or the addition of green light, would be an optimum light source in which to enhance phenylpropanoid accumulation and growth for an *A. rugosa* hydroponic culture system.

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DOES SUPPLEMENTAL LIGHTING MAKE SENSE FOR MY CROP? – EMPIRICAL EVALUATIONS

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An empirical approach to conduct crop-specific cost and return analyses is presented in order to assist greenhouse growers to make better decisions regarding investing in appropriate supplemental lighting (SL) technologies. Electricity cost of lighting was estimated to obtain the target daily light integral (photosynthetically active radiation, PAR) considering factors including lamp photon efficiencies ($\mu mol\ J^{-1}$). Possible heating fuel cost offsets by SL were also considered in the analyses. Crop specific efficacy of lighting was expressed as dollar return (gross profit) per mole of PAR, estimated from crop productivity ($g\ mol^{-1}$ PAR), wholesale prices, and gross margin. The crop productivity was obtained from linear regression of cumulative yield ($kg\ m^{-2}$) of selected crops (lettuce, tomato, and strawberry) versus cumulative PAR ($mol\ m^{-2}$) obtained in previous studies in Arizona and New York, in which we assumed that crop-specific productivity ($g\ mol^{-1}$) was the same under natural light and under SL. In these example analyses, the highest productivity (14 $g\ mol^{-1}$) was found for cluster-type tomatoes. Lettuce productivity varied largely (2.8-6.9 $g\ mol^{-1}$). The least productive crop was strawberry (1.5-2.1 $g\ mol^{-1}$). For strawberry, even at a high wholesale price of \$10 kg^{-1} and a relatively low electricity price (\$0.09 kWh^{-1}), SL was not profitable for most cases according to our analysis. Lettuce and tomato efficacy ranged between \$0.011-\$0.041 mol^{-1} and \$0.010-\$0.018 mol^{-1} respectively, depending on the growing conditions and cultivar. For lettuce and tomato, profitability from supplemental lighting was dependent on the lamp photon efficiency, electricity price, lamp photon utilization factor and heating fuel cost offset. The approach presented here is easily adoptable by growers who have access to their historical yield data and daily light integrals and the growing conditions (such as environmental set points and utility rates).

P55

EFFECT OF CO_2 ENRICHMENT ON PHOTOSYNTHESIS AND GROWTH CHARACTERISTICS OF QUEEN BEER 'MANTEFON'

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Photosynthetic and growth characteristics of *Doritaenopsis* Queen Beer 'Mantefon' were investigated when the plants were exposed to different CO_2 concentrations during their vegetative growth stage. The 9-month-old 'Mantefon' was exposed to 450 (control), 800, and 1600 μmol·mol^{-1} CO_2 during nighttime (00:00 to 06:00 HR). All plants were placed in growth chambers with 160 μmol·m^{-2}·s^{-1} photosynthetic photon flux for 12 hours from high-pressure sodium lamps and day/night temperature of 29/29°C. Plants performed typical crassulacean acid metabolism photosynthesis, which absorbed CO_2 during the night. Net CO_2 uptake between 00:00 to 02:00 HR was the highest (5.30 - 5.57 μmol·m^{-2}·s^{-1} CO_2) compared to that at 12:00 HR (0.032 μmol·m^{-2}·s^{-1} CO_2) in plants grown with 1600 μmol·m^{-2}·s^{-1} CO_2 at 12 weeks after treatments. During the night, the highest transpiration rate and stomatal conductance were obtained in plants grown under 1600 μmol·m^{-2}·s^{-1} CO_2 among the plants grown under different CO_2 concentrations. At 20 weeks after CO_2 enrichment, the number of total leaves and the length of new second leaf increased in the plants grown with 1600 μmol·mol^{-1} CO_2 compared to those in the plants grown with control and 800 μmol·mol^{-1} CO_2. A new third leaf was produced only in the plants grown with 1600 μmol·mol^{-1} CO_2. The time to leaf initiation decreased in plants grown with 1600 μmol·mol^{-1} CO_2compared to the control plants. These results suggest that 1600 μmol·mol^{-1} CO_2 increased net CO_2 uptake, transpiration rate, and stomatal conductance in *Doritaenopsis* Queen Beer 'Mantefon' during the vegetative growth stage, resulting in promoting the leaf growth.

P56

GROWTH OF ICE PLANT AS AFFECTED BY LIGHT QUALITY AND LIGHT INTENSITY IN CLOSED-TYPE PLANT PRODUCTION SYSTEM

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This study was conducted to examine the growth of ice plant (*Mesembryanthemum crystallinum* L.) as affected by different light quality and light intensity treatments in the closed-type plant production system. Seeds were sown in 128-cell plug tray (54 x 28 x 5 cm) using rockwool on Sep. 3, 2015, and then transferred in a growth chamber for 7 days for further germination at 20°C and 60% relative humidity. When the seedlings developed 6 true leaves, they were transplanted in a closed-type plant production system using deep floating technique (DFT) system and grown at setpoints of 25±1°C, 60±10% relative humidity with 14/10 hours (light/dark) photoperiod at 40 days after sowing. The light source was provided by fluorescent lamps (FL), a mixture of red and white LEDs at a 7:3 ratio (RW LEDs), or red, blue, and white LEDs at a 8:1:1 ratio (RBW LEDs) combined with 3 light intensities (120, 150, and 180 μmol·m^{-2}·s^{-1} PPFD). Plants were fed with a nutrient solution (initial pH 6.0 and EC 8.5 dS·m^{-1}) contained in a tank. The value of leaf length and width was the highest under the FL with 150 μmol·m^{-2}·s^{-1} PPFD. In RW and RBW LEDs treatment, leaf length was longest in 180 μmol·m^{-2}·s^{-1} PPFD. The number of leaves tended to be greatest at 180 μmol·m^{-2}·s^{-1} PPFD in each light source treatment. Root length was the highest under the RBW LEDs with 180 μmol·m^{-2}·s^{-1} PPFD. Chlorophyll value was the highest in 150 μmol·m^{-2}·s^{-1} PPFD treatment under the FL and RW LEDs, whereas in RBW LEDs, it was the highest in 180 μmol·m^{-2}·s^{-1} PPFD. The results obtained suggest that ice plant grew the best under the fluorescent lamp with 150 μmol·m^{-2}·s^{-1} PPFD. Later, phytochemicals and antioxidant capacity should be also considered.

P57

GROWTH AND PHYTOCHEMICAL CONTENTS OF ICE PLANT AS AFFECTED BY LIGHT SOURCES AND NACL CONCENTRATION IN A CLOSED-TYPE PLANT PRODUCTION SYSTEM

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A study was conducted to examine the effect of light sources and NaCl concentration levels on the growth and phytochemical contents of ice plant (*Mesembryanthemum crystallinum* L.) in a closed-type plant production system. Seeds, sown in 128-cell plug tray (54 cm x 28 cm x 5 cm) using rockwool on Sep. 3, 2015, were germinated at 20℃ and 60% relative humidity in a growth chamber for 3 days and seedlings were grown for 19 days in the venlo-type greenhouse. Seedlings were transplanted into NFT (nutrient film technique) system with a recycling nutrient solution in a closed-type plant production system. Three light sources were used FL (fluorescent lamps), combined red (R) and white (W) LED (RW; R:W=7:3), and combined RW and blue (B) LED (RBW; R:B:W=8:1:1) at 150 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD with an 14/10 hours (light/dark) photoperiod. NaCl concentration was supplied at three levels (1.0, 2.0, or 3.0 mM) in all treatments. As a result, leaf area, fresh weights of shoot and root, and root dry weight were the greatest in the FL treatment at 2.0 mM. In the case of LED treatments, leaf area, fresh and dry weights of shoots and roots were the greatest in the 1 mM. Chlorophyll fluorescence was significantly highest in FL treatment regardless of NaCl concentration level. Salinity and electrical conductivity of ice plant increased with increasing NaCl concentration level. Total phenol content, DPPH (1,1-Diphenyl-2-picrylhydrazyl) radical scavenging activity, and reducing power were greatest in the FL treatment at 3.0 mM. Total flavonoid content was the highest in the FL treatment at 1.0 mM. Total antioxidant activity decreased with increasing NaCl concentration level regardless of light source. Hence, the results indicate that growth of ice plant was best achieved by FL treatment at 2.0 mM. The phytochemical contents were the greatest in the FL treatment except for 2.0 mM.

P58

EFFECT OF DIFFERENT PROPORTION OF LIGHT INTENSITY ON GLUCOSINOLATES AND CAROTENIODS IN KALE (*BRASSICA OLERACEA ACEPHALA*)

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Light energy plays a crucial role in plant growth by modulating the intensity of plant pigment and other phytochemicals. Vegetables belonging to the *Brassica* family are rich in phytochemicals namely anthocyanins, carotenoids, and glucosinolates (GSLs) and are used for the treatment of various chronic diseases. The concentration of individual phytochemicals is affected by the intensity of the light. Therefore, the present study aimed to investigate the effect of different light intensities and photoperiods on the accumulation of GSLs and carotenoids in kale. HPLC analysis guided to identify 15 GSLs (9 aliphatic, 4 indolyl, 1 aromatic and 1 unknown) and four carotenoids (lutein, zeaxanthin, α and β carotene) in kale leaves. Results indicate that the highest total GSLs (2.62 μmol/g DW) contents were observed under 160 $\mu mol\ m^{-2}\ s^{-1}$ of red and white (RW) light and a 12 h/12 h (day/night). Carotenoids were highest (1,177.28 mg/kg DW) under 160 $\mu mol\ m^{-2}\ s^{-1}$ fluorescence light and a 14 h photoperiod. Among the GSLs, above 60% of total GSLs were documented by the aliphatic GSLs namely progoitrin, sinigrin and gluconapin, whereas the neoglucobrassicin contents were comparatively higher in indolyl GSLs in all the treatment. Total

carotenoid contents were ranged from 514.3 to 1,177.3 mg/kg DW in all the treatment. Remarkably, the content of lutein (ranged from 131 to 688.02 mg/kg DW) and β carotene (83.92 to 427.24 mg/kg DW) were dominant in all the cultivation conditions. Overall, the influence of light intensity on glucobrassicin in kale should be studied extensively because GSL is the precursor of indole-3-carbinol, a potent anticancer isothiocyanate.

P59

INDOOR CULTIVATION OF TOMATO TRANSPLANTS UNDER VARIOUS INTENSITIES OF RED AND BLUE LED LIGHT

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Light quantity is one of the light parameters that influences plant growth. The majority of research concerning irradiance level was conducted in greenhouse conditions, where the amount of natural light plays an important role. However, limited research is available on the impact of irradiance in an indoor environment, especially using light-emitting diodes (LEDs) illumination. The objective of our studies was to evaluate the growth and photosynthesis parameters of tomato 'Celsus F_1' transplants under various intensities from LED lighting. Experiment was performed in the phytotron complex of Institute of Horticulture, LCAFS. A system of high-power, solid-state lighting modules delivered the spectra, consisting of 92% red [638 nm (red) + 665 nm (red) + 731 nm (far red)] and 8% blue (447 nm) light (blue). The generated photosynthetic photon flux density (PPFD) of each module was about 100, 200, 300, 400, 500 µmol m^{-2} s^{-1}. Our investigations revealed that from 200 to 500 µmol m^{-2} s^{-1}, leaf number and area, shoot and root fresh/dry weight, and hypocotyl diameter gradually increased. Low 100 µmol m^{-2} s^{-1} PPFD caused hypocotyl elongation and suppressed development of tomato transplants. Such irradiance level had the highest positive impact on the content of photosynthetic pigments in leaves of tomato hybrid transplants. Meanwhile, a greater photosynthetic rate (Pn) was determined under 300 and 400 µmol m^{-2} s^{-1} LED illumination. Lower PPFD from 100 to 300 µmol m^{-2} s^{-1} promoted stomatal conductance (gs) of tomato 'Celsus F_1' transplants leaves. Irradiance level of 400 and 500 µmol m^{-2} s^{-1} PPFD resulted in higher intercellular CO_2 concentration (Ci) and transpiration rate (Tn). In summary, irradiance level of 300–400 µmol m^{-2} s^{-1} PPFD was the most suitable for growth of the appropriate quality of tomato transplants under indoor conditions.

P60

INTER-LIGHTING LED TRIAL IN GREENHOUSE TOMATO PRODUCTION IN ALBERTA, CANADA

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Greenhouse growers have used inter-lighting technology to increase supplemental lighting efficiency for growing greenhouse winter crops. Light-emitting diodes (LED) can produce more efficiency specific light, especially in the red and blue ranges, and also produce lower temperature during lighting, is a more suitable lighting source for greenhouse inter-lighting system. We have a new research greenhouse complex in Alberta, Canada, and have installed roof high-pressure sodium (HPS) lamps for each greenhouse bay to produce winter vegetables. In order to evaluate inter-lighting LED on greenhouse crop growth and production, we installed inter-lighting LED lamps at a red to blue ratio of 4:1 for half of the greenhouse areas in 2014. One commercial greenhouse beef tomato 'Torero' and one commercial greenhouse grape tomato 'Florantino' have been used in a 2014-2015 crop trial. We used planting density at 2.7 plants/m^2 for beef tomatoes and 2.6 plants/m^2 for grape tomatoes, and used 'Maxiford' as rootstock for both type of tomatoes. All of the growing strategies were kept the same for both controls (without inter-panting LED) and treatments (with inter-planting LED). We collected data from transplanting day, October 7, 2014 until June 10, 2015. Inter-lighting LED increased fruit production for both beef tomatoes and grape tomatoes during the winter lighting period until early April. No yield difference has been found between control and treatment in the non-lighting period from early April. Inter-lighting LED has not shown having effects on crop weekly growing and stem thickness. Further trails are being conducting.

P61

EMERSON'S ENHANCEMENT EFFECT REVISITED: INCREASING PHOTOSYNTHETIC RATE AND QUANTUM YIELD OF PHOTOSYSTEM II WITH FAR-RED LEDS

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Light emitting diodes (LEDs) are increasingly used for supplemental lighting to increase photosynthesis or as sole-source lighting for production of high value crops. In addition to their high efficiency, the availability of LEDs with narrow spectral output, ranging from UV to far-red, also enables precise control over the spectral composition of the light. A combination of narrow spectrum red and blue lights is commonly used for grow lights in controlled environments. Red and blue light are absorbed most efficiently by plants and are considered to be most effective in driving photosynthesis, based on McCree's action spectrum of photosynthesis. However, light of different wavelengths may have synergistic effects on photosynthesis: photosynthetic efficiency is low when light with only wavelengths < 680 nm is provided and this efficiency can be increased greatly by providing far-red light (> 680 nm) (*i.e.*, Emerson's enhancement effect). We found that adding far-red light (peak at 735 nm) to red and blue LED light enhanced photosynthetic rate of lettuce (*Lactuca sativa*) 'Green Towers' disproportionally, relative to the increase in photosynthetic photon flux density or yield photon flux (which weighs photons in the 360 to 760 nm range based on their efficacy for photosynthesis). The quantum yield of photosystem II also increased when far-red light was added. As light of wavelengths > 680 nm largely excites photosystem I, but not photosystem II, far-red light stimulates the oxidation of the intermediate electron transporters between PSII and PSI in the electron transport chain. The oxidization of the plastoquinone pool, the electron acceptor immediately downstream of PSII, can help to re-open photosystem II more quickly. This in turn explains the observed increase the quantum yield of photosystem II. The addition of far-red light may help to balance the excitation energy received by the two photosystems and ensure that they operate at matching rates, enhancing the photosynthetic rate and quantum yield of photosystem II.

P62

SEVEN DIMENSIONS OF LIGHT IN REGULATING PLANT GROWTH

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Light is one of the most important factors for plant growth and development, regulating plants' photosynthesis, morphogenesis, metabolism, gene expression, and other physiological responses. The characteristics of light in influencing plant growth are generally attributed to three dimensions, i.e., the intensity, quality, and duration of light. The real situation could, however, be more complicated and may not be fully realized and revealed in the natural environment. As plants are moved into artificially controlled environment agriculture, more dimensions of light must be considered. Based on our observations and experiments, a model of seven dimensions of light in

regulating plant growth is proposed, which includes intensity, quality, pattern, uniformity, direction, polarization, and coherence. Preliminary experiments have also been conducted to demonstrate these characteristics. Light intensity, which is quantified as μmol photons $m^{-2}\,s^{-1}$, is a measure of the photosynthetic photon flux density (PPFD) in the range of photosynthetically active radiation (PAR). Light quality refers to the composition and distribution of the illumination's spectrum. The pattern of illumination, much more complicated than the duration of illumination, is defined as the possible combinations of illumination modes. The uniformity of illumination includes that of light intensity and quality. Direction of light will cause phototropic response of plants. Polarization is the property of light with all light waves oscillating in the same transverse direction and the influence of the polarized light on plants is still unknown. Coherence of light can be intuitively viewed as the length a light wave can extend. It is a unique property of the laser that the ordinary light generally does not have. Comparison of the effects of coherent and non-coherent lights on plants has not yet been conducted.

P63

GROWTH AND DEVELOPMENT OF LIGULARIA FISCHERI AS AFFECTED BY LIGHT SOURCE, PHOTOPERIOD, AND LIGHT INTENSITY

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The effect of light source, photoperiod, and light intensity on the growth and development of *Ligularia fischeri* grown in a closed walk-in growth chamber was examined. The plant was grown under either 100 or 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD provided by either cool white fluorescent lamps (F, the control), a 2:1 mixture of red and white (RW) light emitting diodes (LEDs), or a 8:1:1 mixture of red, blue and white (RBW) LEDs. A photoperiod with either 8/16 or 16/8 hours (light/dark) was provided. Fresh and dry weights of the shoot and the root were the greatest under 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD provided by the F for a 16/8 hours photoperiod. The incidence of leaf tip burn decreased in the RW and RBW treatments as compared to the F treatment. Thickness of the palisade parenchyma and that of the spongy parenchyma were greater under 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD provided by either F or RBW for a 16/8 hours photoperiod than the other treatments. Stomatal density and size were the greatest under 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD provided by the RBW for a 16/8 hours photoperiod. Moreover, total phenol content, total flavonoid content, total antioxidant activity, and reducing power were the greatest under 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD provided by the RBW for a 16/8 hours photoperiod. These results suggest that the combination of the RBW which provided the widest spectrum of PAR, the highest light intensity, and the longest photoperiod provided the most the suitable environmental condition for vegetative growth and secondary metabolite content of *Ligularia fischeri* among the tested light conditions.

P64

THE IMPACT OF CULTURAL PARAMETERS ON GROWTH OF *NICOTIANA BENTHAMIANA*

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Nicotiana benthamiana, a wild relative of tobacco, is increasingly used as a model plant for the transient expression of foreign proteins. The project aims to determine the impact of basic cultural parameters on *Nicotiana benthamiana* in relation with plant growth. A major objective of this research project was to optimize cultural conditions to ensure high biomass and minimize seasonal variations. Experiments were conducted in four glasshouses, at Laval University, Quebec, Canada.

The greenhouse compartments were equipped with HPS supplemental lighting. Two compartments were maintained at high temperatures (32°C/28°C) and two others at lower temperatures (28°C/24°C). Each compartment was divided in two sections to compare the effects of 16 h and 24 h photoperiods. Each photoperiod treatment supplied either a high (160 μmol m^{-2} s^{-1}) or a low (80 μmol m^{-2} s^{-1}) PPFD. The following growth parameters were measured 14 days after transplanting and before use for transient expression: leaf area, fresh biomass and dry weight. The leaves were divided in 6 groups based on leaf age and position (main or secondary stems). In brief, our data highlighted the importance of the light regime on growth of *Nicotiana benthamiana*. The lengthening of photoperiod as well as the increase of PPFD resulted in significant increases in fresh biomass.

P65

BLUE LED LIGHT AFFECTS STRESS METABOLITES IN CHRYSANTHEMUM CULTIVARS

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Cutting propagation of mum chrysanthemum (*Chrysanthemum x morifolium*) is important in Belgium. Due to the high energy costs for chrysanthemum rooting, ways to reduce this production factor were investigated. One potential way might be to root and acclimate cuttings in multilayer systems using artificial LED light. Light quality will, however, impact plant characteristics as phenotypic plasticity is widely recognized as a potential adaptive trait under a wide array of environmental conditions. Therefore we studied selected morphological and physiological parameters of 11 *Chrysanthemum x morifolium* cultivars under blue (460 nm), red (660 nm), blue + red (1:1) and white (400-700 nm) LED. Plant morphology is cultivar dependent, but was also affected by the light spectrum. On average, leaf surface and plant height was reduced under red light, while leaf thickness was not affected. Looking at stress levels under different light qualities, the production of reactive oxygen species (ROS) and proline was monitored. The production of ROS is an early event of plant defense responses to different stresses and was enhanced under blue light as average hydrogen peroxide levels were highest. Excessive ROS formation can induce oxidative stress, leading to cell damage. Proline has a multifunctional role in plant stress tolerance; it is among others a component of the non-enzymatic antioxidative defense system which neutralizes ROS species. Again, blue light clearly enhanced the overall levels of proline, which was confirmed in two consecutive experiments. Both the reaction of light quality to ROS and proline was highly cultivar dependent. Nevertheless, for four cultivars, a significant correlation between ROS and proline levels was noted. But the results show also that there are cultivar exceptions on the global findings for the investigated parameters.

P66

EFFECTS OF VARYING DAILY LIGHT INTEGRAL (DLI) AND CARBON DIOXIDE CONCENTRATION ON THE GROWTH AND NUTRITIONAL CHARACTERISTICS OF THREE MICROGREEN SPECIES OF THE BRASSICACEAE FAMILY

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Microgreens are a young, tender and edible crop harvested shortly after emergence of the first true leaf. To date, insufficient published data exists on the influence of cultivation practices on plant yield, morphology and nutritional composition of microgreens. CO_2 enrichment is often used in greenhouse production to reduce the need for supplemental lighting, but little information is

available on the response of microgreens to both light and CO_2. Our overall objective was to evaluate the effects of varying daily light integral (DLI) and CO_2 enrichment on the growth and nutritional characteristics of microgreens. Three species, mizuna (*Brassica rapa*), arugula (*Eruca sativa*) and mustard 'Garnet Giant' (*Brassica juncea*) were grown under a combination of four DLI (3, 6, 9, and 12 $mol{\cdot}m^{-2}{\cdot}d^{-1}$) and four CO_2 (400, 600, 800 & 1000 ppm) treatments in controlled environment chambers. Treatment combinations were assessed for their effects on plant height, fresh weight (FW), dry weight, total flavonoids and phenolics. DLI targets were determined through shading trials conducted in a glass greenhouse in Ithaca, New York, USA. Four treatments of varying layers of black shade cloth were used to achieve DLIs that varied from an average of 0.6 to 10.0 $mol{\cdot}m^{-2}{\cdot}d^{-1}$. FW and height were recorded and analyzed using linear and quadratic regression. For all species, greatest FW was achieved at 10.0 $mol{\cdot}m^{-2}{\cdot}d^{-1}$. For mizuna, arugula, and mustard 'Garnet Giant', FW increased from 1378 to 2350, 919 to 1396, and 1382 to 2129 $g{\cdot}m^{-2}$ respectively as DLI increased from 0.6 to 10.0 $mol{\cdot}m^{-2}{\cdot}d^{-1}$. As might be expected with a crop harvested at such an early stage, our preliminary results indicate, substantial plant FW is achieved through very low DLI's, which can be attributed to the seed/seedling gaining water weight. Controlled environment chamber experiments are ongoing to determine plant response to both DLI and CO_2 enrichment.

P67

CULTIVAR-SPECIFIC DIFFERENCES OF GROWTH AND HEAD FORMATION IN ICEBERG LETTUCE UNDER SELECTED LIGHT INTENSITIES AND LED LIGHT QUALITIES

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Present research was aimed to elucidate the optimum cultivar and light intensity condition for the production of iceberg lettuce in closed-type plant factory system. Five commercial iceberg lettuce cultivars ('Adam', 'Early Impulse', 'Sensation', 'Arirang', and 'Manchu') were grown on DFT beds in closed-type plant factory system under three different fluorescent light intensity conditions (150, 200, and 250 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$) and twelve light quality combinations using red, blue, green, and white light emitting diodes LEDs) for 60 days. Key growth parameters including head formation rate and tip burn incidence were measured. The air temperature was initially maintained at 22/18°C (day/night) until 30 days after transplanting and then the temperature was subsequently converted to 18/14°C to accelerate the head formation until harvest (60 days after transplanting). Day length and relative humidity were maintained to 12 hours and 60 ± 10%, respectively. All the cultivars exhibited statistically higher growth rates under 200 or 250 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ compared to 150 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$, showing cultivar-specific light response differences in growth pattern. The cultivar 'Early Impulse' showed highest total leaf biomass than the other cultivars, while the head formation was only observed in two cultivars of 'Sensation' and 'Adam'. Light intensity dependent head formation rate changes were also observed; 'Sensation' showed normal head formation under the medium light intensity of 200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$, while 'Adam' showed visible head formation only in high light intensity of 250 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$. The head formation rate of 'Sensation' was accelerated under 250 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$, exhibiting maximum head fresh weight of 283 g. Among the tested cultivars, 'Sensation' was evaluated as the potentially applicable cultivar in terms of the stable head formation under closed-type plant factory system. The critical day and night air temperature and optimum monochromatic light quality condition for stable head formation of iceberg lettuce were also discussed. This study confirmed that head formation of iceberg lettuce could be normally induced under critical ranges of light intensity and light quality condition using early head-forming cultivars.

P68
SMART LED-BASED LIGHTING DEVICE FOR PLANT RESEARCH

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The smart light emitting diode (LED) based lighting solution for diverse plant research environments (growth chambers, phytotrons, laboratories and greenhouses) is described. Requirements and amenities for the lighting unit, arising from years of experimentation in the field of plant photophysiology, were transferred for designers and engineers to construct ergonomic device with controllable light parameters. The HLRD-series lighting units consists of numerous single LED lamps fitted on the panel. This construction allows to use any producer's LEDs; to compose various light spectra (red, blue, green, orange, yellow, UV-A) and to update the spectra with new wavelengths easily during operation. Light parameter control includes possibilities to control lighting photoperiod, spectra, intensity of each spectral component and blinking frequency via user-friendly software in mobile devices or computer. Optional electric engine for raising or lowering the lighting panel allows to adapt the distance from lighting unit to different plants and maintain the same lighting intensity at the top of the plant during its growth. The lighting unit was designed for versatility, ergonomics, flexibility and functionality, as well as precise control of lighting parameters to realize the researcher's ideas.

P69
EFFECT OF CO_2 CONCENTRATION, LIGHT INTENSITY, AND RED/FAR-RED RATIO ON GROWTH OF *ARABIDOPSIS THALIANA*

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The growth and development of *Arabidopsis thaliana* plants were examined in both ambient and elevated CO_2 concentrations under three light intensities and three R/FR ratios, respectively. Increased CO_2concentrations stimulated shoot biomass accumulation and promoted bolting in the plants. Increased CO_2 concentrations did not impact the flowering time of *Arabidopsis thaliana* plants. Higher light intensity promoted plant biomass accumulation and growth, and also promoted an earlier transition to the reproductive growth stage. Changes in R/FR impacted the morphology and flower timing of the *Arabidopsis thaliana* plants, with lower R/FR corresponding to longer plants and earlier flowering. Increased CO_2 concentrations could to some degree limit the extent to which low R/FR treatment promoted earlier flowering time.

P70
LED-IT-BE 50%: SPECTRUM EFFECT OF LED LIGHTING ON TOMATO (*SOLANUM LYCOPERSICUM*) FRUIT SET

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Dutch horticulture sector is seeking a breakthrough in reducing the energy cost in lighting, and the development of light-emitting diodes (LEDs) opens up new possibilities for researchers and growers

to better tailor their light sources with increased energy efficiency. In a recently granted STW programme LED-it-BE-50%, we will tackle these challenges from different approaches. One of them is to investigate how assimilate partitioning is affected by the spectrum of LED lighting. In this approach we focus on tomato (*Solanum lycopersicum* cv. Cappricia), one of the most important horticultural products. In the first experiment we grow the plants under different supplementary light regimes in a glasshouse. These treatments include high pressure sodium (HPS) lamps, red/blue LEDs, red/blue with far-red LEDs, and red/blue LEDs with UV-B. Plant materials were germinated in a commercial nursery and moved under the treatment conditions 4 weeks after sowing. We investigated the effect of lighting on fruit set, which is a key component determining yield of tomato. Furthermore, we also evaluated agronomic and photosynthetic parameters as affected by lighting. Currently the experiment is on-going and the results will be presented at the symposium. These results will allow us to view the spectrum effect of LEDs on the control of assimilate partitioning in tomato and provide directions for further study of this topic.

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ENGINEERING MODELING AND ANALYSIS OF SUSTAINABLE INDOOR CROP PRODUCTION SYSTEMS IN SEMI-ARID CLIMATE I: ENERGY AND RESOURCE USE FOR INDEPENDENT PRODUCTION SYSTEMS MUSHROOM AND LETTUCE

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Indoor crop production in a semi-arid climate is expected to be costly especially for mushrooms, due to the optimal mushroom growing environments (critical CO_2 concentration, >90% relative humidity, and 18°C air temperature) largely different from outside climate. One strategy to reduce energy and/or resource consumption may be integration with an indoor lettuce production facility with sole-source lighting. As the first step, the steady-state energy and mass balance models were developed to estimate resource requirements for both indoor mushroom and lettuce production systems over five selected seasons. The ventilation rate of a mushroom production system (volume: 105 m^3) to maintain a CO_2 concentration below the critical concentration was estimated as 13.87 $m^3\ m^{-2}\ h^{-1}$, under which fogging and cooling are needed to achieve the required relative humidity and air temperature. The average water use by fogging was 2.16 kg $m^{-2}\ d^{-1}$ and average electrical energy use was 1.03 kWh $m^{-2}\ d^{-1}$. For a lettuce production system (volume: 240 m^3) with limited ventilation, the largest resource use was electricity (lighting and cooling). Relative humidity in the lettuce production system was affected by thermal energy input from the electrical lighting. At a target PPF of 250 µmol $m^{-2}\ s^{-1}$ over the lettuce canopy (24 h d^{-1} photoperiod) and lamp photon efficiency of 2.2 mmol J^{-1}, the average electrical energy use and resulting relative humidity were 2.16 kWh $m^{-2}\ d^{-1}$ and 71.1%, respectively. Since the system was considered to be airtight, CO_2 needs to be enriched (40.3 mmol $m^{-2}\ d^{-1}$). Similarly, water condensed from air conditioning provided most of the water needed for irrigation and the supplemental water use of 0.03 kg $m^{-2}\ d^{-1}$ in average. As a result of this analysis, integration of the two systems has the potential to reduce overall energy and resource use needed for the systems.

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ENGINEERING MODELING AND ANALYSIS OF SUSTAINABLE INDOOR CROP PRODUCTION SYSTEMS IN SEMI-ARID CLIMATE II: INTEGRATION OF MUSHROOM AND LETTUCE PRODUCTION SYSTEMS

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To improve mushroom production sustainability under semi-arid climate, possible integration of an indoor mushroom production system and an indoor lettuce production system was evaluated. Using steady-state energy and mass balance models developed for individual systems, we evaluated exhaust air properties of both production systems as a potential valuable resource for the complementary production system to enhance the resource use efficiency under typical semi-arid conditions in spring, summer, fall, winter, and monsoon. The size of lettuce production system (240 m^3) to integrate was determined so that the CO_2 absorbed by the lettuce plants was solely provided by the exhaust CO_2 (500 mmol mol^{-1}) from the mushroom production system (105 m^3), eliminating the need of CO_2 enrichment (39.70 mol d^{-1}). The average electrical energy use of the lettuce production system increased by 0.50-0.53% (or 1.06-1.14 kWh d^{-1}) as a result of integrating with the mushroom production system. In contrast, changes in the mushroom system electrical energy use from the integration was seasonally dependent: decrease by 99.67% (or 57.08 kWh d^{-1}) in spring, 66.23% (or 1.44 kWh d^{-1}) in summer, and 99.97% (or 75.04 kWh d^{-1}) in winter and increase by 892.12% (or 0.71 kWh d^{-1}) in fall and 164.78% (or 0.50 kWh d^{-1}) in monsoon. Finally, there was year-round water resource savings for both systems. When integrated, water use for fogging in the mushroom system to maintain the relative humidity at 90% was reduced by 74.79% (or 42.44 kg d^{-1}). In contrast, by integration water recycled from air-conditioning condensed water in the lettuce system produced more water for irrigation than needed to compensate for evapotranspiration. From this analysis, integrating mushroom and lettuce production systems will increase overall sustainability for mushroom and lettuce production in a semi-arid climate.

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GROWTH AND BIOACTIVE COMPOUNDS OF LETTUCE UNDER CHANGING LIGHT QUALITY CREATED BY RED AND BLUE LIGHT-EMITTING DIODES DURING CULTIVATION

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The objective of this study was to determine the effects of light quality variation using light-emitting diodes (LEDs) at different growth stages on the growth and bioactive compounds of red leaf lettuce (*Lactuca sativa* L. ‘Sunmang’). Eighteen-day-old lettuce seedlings were transferred to a plant factory with normal growing conditions. Five lighting sources, red (R; 655 nm), blue (B; 456 nm), R9B1, R8B2, and R6B4 (based on chip number) were used for twelve LED treatments, which consisted of a control (continuous irradiation of each light source for 4 weeks), mono-type treatments (changing red LEDs to blue LEDs at 1, 2, or 3 weeks after the onset of LED treatment) and combined-type treatments (changing R9B1 to R8B2 or R6B4 at 1 or 2 weeks after the onset of LED treatment). Growth characteristics, photosynthetic rate, and bioactive parameters such as total phenolic concentration, antioxidant capacity, and individual phenolic compounds were measured weekly after the onset of LED treatment. As a result, the growth and photosynthetic rate of lettuce increased as red LEDs increased. In contrast, the chlorophyll content and bioactive compounds decreased with an increase in red LEDs. Although the amount of blue LEDs induced the concentration of bioactive compounds in lettuce leaves, the content per lettuce plant was more directly affected by red LEDs suggesting that biomass and bioactive compound accumulation is important for phytochemical production. In addition, our results suggested that growth and antioxidant phenolic compounds were more sensitive to light quality variation within monochromatic LEDs than RB combined LEDs. In conclusion, the adjustment of light quality at a specific growth stage should be considered for crop yield and quality in closed plant production systems.

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GROWTH AND THE ANTIOXIDANT PHENOLIC CONTENT OF DROPWORT GROWN UNDER MONOCHROMATIC AND VARIOUS COMBINED RATIOS OF RED TO BLUE LIGHT-EMITTING DIODES

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This study aimed to determine the effect of monochromatic and combined ratios of red to blue light-emitting diodes (LEDs) on the growth and antioxidant phenolic content of dropwort (*Oenanthe stolonifera*). Propagules of dropwort (average fresh weight 0.8 ± 0.04 g) were transplanted on rock wool and grown under normal growing condition (air temp. 22 °C, RH 60 %, CO_2 1000 ppm, PPFD 170 μmol/m^2/s, light period 12 h). Monochromatic LEDs such as red (R; 654 nm), blue (B; 456 nm), and green (G; 518 nm) LEDs, as well as various combinations of R and B LEDs (R:B = 9:1, 8:2, 7:3, 6:4) and fluorescent lamps as a control were used to irradiate dropwort plants for 6 weeks. As a result, shoot fresh weight (51%) and plant height (96%) when exposed to R LED treatment was significantly higher than those in B LEDs, after 6 weeks of treatment. Photosynthetic rate at 5 weeks of treatment supported these growth results. In case of the combined R and B LEDs, shoot fresh weight and dry weight of RB 8:2 were the highest. Antioxidant capacity, total phenolics and flavonoids concentration of dropwort leaves was two times higher than dropwort stems under all the light sources at 6 weeks of treatment. The B LEDs among monochromatic lights was the most effective in increasing the concentration of total phenolics, flavonoids, and antioxidant capacity, and opposite effect was found with G LEDs. For example, the concentration of total phenolics (51 %) and flavonoids (57%) of dropwort leaves in B LEDs was significantly higher than that in G LEDs. Therefore, B LEDs effectively enhanced the antioxidant phenolics content of dropwort and RB 8:2 was confirmed as the most appropriate light source considering both growth and bioactive compounds of dropwort in this study.

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PHYTOCHEMICALS OF CREPIDIASTRUM DENTICULATUM UNDER CONTINUOUS OR SHORT-TERM IRRADIATION OF FAR-RED LEDS IN A PLANT FACTORY

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The ratios of red to far-red light are important for flowering and plant morphology. The aim of this study was to analyze the phytochemical content of *Crepidiastrum denticulatum*, a valuable medicinal plant, grown under continuous and short-term irradiation of far-red LEDs combined with red and blue LEDs. Three-week-old *C. denticulatum* seedlings were transplanted to a hydroponic system in a plant factory equipped with red (R), blue (B), and far-red (FR) LEDs. After setting the ratio of R to B LEDs at 8:2 (130 μmol·m^{-2}·s^{-1} PPFD) as the control, the ratio of R to FR was adjusted to 0.7, 1.2, 4.1, and 8.6. After the light period, *C. denticulatum* were exposed to 4 different R/FR ratios for 30 min in short-term FR treatments. Total phenolic and individual phenolic acid contents of *C. denticulatum* were analyzed at 3 and 6 wk. The total phenolic concentration (per unit dry weight) of continuous 0.7 and 1.2 R/FR treatments was lower than that of the control. However, the continuous irradiation of R/FR 0.7 and 1.2 significantly improved the fresh weight of shoots compared with the control. Consequently, total phenolic content (per plant) of R/FR 0.7 or 1.2 was higher than the other treatments and the control. The results were similar to this for caffeic acid, chlorogenic acid, and chicoric acid contents. Short-term treatments of R/FR did not have any significant effects on the phytochemical content compared with the control. These results

suggested that the continuous irradiation of FR LEDs with specific ratios of R/FR improved the phytochemical content of *C. denticulatum* in a closed plant factory.

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COMPARISONS OF PHOTOSYNTHETIC AND GROWTH CHARACTERISTICS BETWEEN PLASMA LIGHTING SYSTEMS AND HIGH PRESSURE SODIUM LAMP IN HORTICULTURAL CROPS

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The high-pressure sodium (HPS) lamp is generally used as a supplemental lighting source in greenhouses but has insufficient blue light. Plasma lighting system (PLS) with high electric power can be a substitute for HPS because PLS has more blue and red light than HPS. To compare the photosynthetic characteristics between PLS and HPS, paprika (*Capsicum annuum*), cucumber (*Cucumis sativus*), and rose (*Rosa hybrida*) plants were grown under 0.7 kW HPS, 0.7 kW and 1.0 kW sulfur PLSs (SPLS), 1.0 kW indium monobromide (InBr) PLS (IPLS) in growth chambers. Photosynthetic characteristics were measured using a portable photosynthesis system. When lamps were equipped at the same height, photosynthetic rate under three PLSs was higher than HPS and stomatal conductance was highest under 1.0 kW SPLS followed by 0.7 kW SPLS and 1.0 kW IPLS, and that under HPS was lowest. Growth characteristics such as plant height, dry weight, and leaf number were greater under SPLSs. When the lamps were equipped at the same PPFD, photosynthetic rate under SPLSs was higher than under HPS and IPLS. Effects of supplemental lighting using these lamps on crop yield and quality were also investigated in greenhouses.

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THE EFFECT OF LIGHT SPECTRAL QUALITY ON GROWTH CHARACTERISTICS AND CRYOPRESERVATION SUCCESS OF POTATO (*SOLANUM TUBEROSUM*) SHOOT TIPS IN VITRO

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Cryopreservation – the storage of viable plant material on ultra-low temperature (under -150 C) - has become the most powerful tool for long-term storage of plant genetic resources. Cryopreservation is especially suitable for economically important food crops like potato, which can be stored only vegetatively. Recently, the importance of non-cryogenic factors affecting cryopreservation results has been emphasized. Light is among one of the most important factors affecting plant development and physiology. Therefore, we studied the effect of different light spectral qualities on the growth and morphology of in vitro cultivated potato as well as the effect on cryopreservation success of potato shoot tips grown in different light conditions either before or after cryopreservation. The light qualities studied both pre- and post-cryopreservation were: cool-white fluorescent light (CW), warm-white light (HQI), blue LEDs (B), red LEDs (R), red with 10% of blue (RB), RBF – red with 10% of blue including 20 % of far-red LEDs and white LEDs. The results show that both pre- and post-cryopreservation light spectra significantly affect growth characteristics as well as cryopreservation success of all cultivars tested. Therefore, the modification of light spectral quality may be a promising tool for increasing the survival and regeneration into new plants after cryopreservation. The present study emphasizes the importance of non-cryogenic factors, especially the light spectral quality on cryopreservation success of plant germplasm.

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EFFECTS OF BIO-PM LAMP TREATMENTS ON WHITEFLY ADULTS IN GREENHOUSE

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Whitefly is an important pest to vegetable crops in greenhouses, which is killed by chemical pesticide or prevented by plastic net and yellow sticky traps, the cost of such treatment is high and labour-intensive. Bio-PM lamp is an insect-removing apparatus equipped with a multi-spectrum filter, such kind of pesticide instrument based on principle of lamp flickering harming the insect nervous system. According to the kinds of insects which are parasitic on various crops such as flowers, vegetables, and fruits planted in a facility planting garden, based on certain periods, the instrument can alternatively irradiate light rays with multiple wavelengths such as a near infrared (540-584 nm) suitable for inducing insects, a near ultraviolet waveband (350-400 nm) suitable for killing the induced insects, and all green wavebands (410-500 nm) capable of promoting the generation of chlorophyll and photosynthesis, thereby not only killing the various insects which are parasitic on crops, but also promoting the growth of corresponding crops. The experiment with Bio PM was done in tri-arch plastic greenhouse in October, the vegetables for treatments is cucumber and eggplant. Bio PM was located on the two sides of greenhouse. Five plants were chosen to be whitefly calculated in southern, middle and northern part of greenhouse. The results showed that after treatment for 10 days, the whitefly adults decreased significantly, whereas whitefly adults on control cucumber leaves increased dramatically, the control effects can be reached to 75 to 87%. We suggest the crop insect removing apparatus can be used in greenhouses to prevent whitefly and other pests with low cost (only electric cost) and is safe to vegetable quality.

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