New lighting strategy for indoor leafy greens by segmenting the photoperiod and replacing the dark period by their light compensation point

L. Boucher, T. T. An Nguyen, J. Eaves, A. Brégard, S. Pepin, M. Dorais*

*laurent.boucher.1@ulaval.ca

Introduction

New plant production techniques like vertical farming are needed for the 21st century agriculture to reinvent itself[1]. Leafy greens and especially lettuce, due to its economic value, short growth cycle, size and low maintenance is the main crop production of vertical farming. The main limiting factor of indoor farming is the high initial investment cost related to the lamps (artificial light) as well as their running costs[2]. Thus, development of more efficient lighting strategies is indispensable to improve the profitability of vertical farms[3]. Exposing leafy vegetables alternatively to a short photoperiod having high PPFD followed by a same photoperiod having low PPFD, corresponding to the LCP, might be more profitable than using a longer photoperiod of moderate PPFD, for a same DLI.

Table 1. SPAD values, Fv/Fm ratio, performance index of PSII (PI_{abs}), maximum net photosynthetic rate (A_{max}), rate of leaf dark respiration (R_d), apparent quantum yield (ϕ), light compensation point (Γ; LCP) and light saturation point (LSP) of four leafy greens (BG: lettuce cv Bergam's Green; A: arugula; SG: lettuce cv Salanova Green Butter; SR: lettuce cv Salanova Red) exposed to three light treatments (*n*= 2 to 15).

	Chlorophyll content (SPAD unit)	Fv/Fm	PI	A_{max} ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	R_d ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)	ϕ ($\mu mol\ CO_2\ \mu mol\ photon^{-1}$)	LCP ($\mu mol\ photon\ m^{-2}\ s^{-1}$)	LSP ($\mu mol\ photon\ m^{-2}\ s^{-1}$)
Species								
Bergam's Green (BG)	34.0	0.842	3.07	12.0 b	-1.10 bc	0.084	13.73 ab	1247
Arugula (A)	52.6	0.831	8.73	19.2 a	-1.25 c	0.089	17.02 a	920
Salanova Green (SG)	42.1	0.823	3.19	11.0 b	-0.832 ab	0.084	10.65 bc	813
Salanova Red (SR)	42.5	0.830	3.45	11.8 b	-0.678 a	0.086	8.94 c	900
Lighting treatments								
5L/1N	42.8	0.828	3.75	13.4	-1.06	0.083	15.12	1095
5L/1LCP	42.0	0.833	8.10	13.5	-0.805	0.083	11.33	1030
6L/6LCP	43.6	0.834	1.97	13.5	-1.03	0.091	11.31	785
Species x Treatments								
BG x 5L/1N	32.6 g[x]	0.841 ab	2.13 e	11.9	-1.06	0.085 b	14.53	1360
BG x 5L/1LCP	36.2 eg	0.838 abc	5.56 bc	12.7	-1.05	0.089 ab	12.76	1360
BG x 6L/6LCP	33.2 g	0.846 a	1.51 e	11.3	-1.20	0.079 b	13.91	1020
A x 5L/1N	53.5 a	0.827 cde	7.50 b	20.8	-1.45	0.083 b	21.62	1140
A x 5L/1LCP	45.9 bc	0.845 ab	15.8 a	18.2	-0.871	0.074 b	15.71	940
A x 6L/6LCP	58.2 a	0.821 def	2.92 cde	18.7	-1.42	0.111 a	13.74	680
SG x 5L/1N	41.9 bcde	0.817 f	2.24 e	10.3	-0.943	0.081 b	13.16	920
SG x 5L/1LCP	44.5 bcd	0.820 ef	5.72 bc	10.6	-0.798	0.090 ab	8.80	820
SG x 6L/6LCP	39.9 cef	0.834 bc	1.60 de	12.0	-0.756	0.079 b	10.01	700
SR x 5L/1N	43.3 bcd	0.825 de	3.12 d	10.8	-0.795	0.083 b	11.16	960
SR x 5L/1LCP	41.2 df	0.830 cd	5.36 bc	12.6	-0.505	0.080 b	8.07	1000
SR x 6L/6LCP	43.0 bd	0.836 bc	1.87 de	11.9	-0.734	0.096 ab	7.59	740
P values								
Species (S)	<0.001	<0.001	<0.001	<0.001	0.033	0.693	0.002	-
Treatments (T)	0.841	0.153	0.001	0.999	0.680	0.535	0.139	-
S × T	<0.001	0.001	<0.001	0.857	0.838	0.017	0.758	-

[x]means of the same column with different letters are significantly different at P ≤ 0.05 (protected Fisher's LSD)

Materiel and methods

Three lighting treatments were compared for 4 leafy greens (arugula, *Eruca sativa* Mill.; lettuce, *Lactuca sativa* L. cvs Salanova Green and Red Butter, and Bergam's Green) grown in growth chambers under LED having a Blue: Red ratio of 0.13.

Two experiments were performed by using two lighting treatments: 5L/1N (5h at PPFD of 180 µmol m^{-2} s^{-1} and one hour of dark; total of 20h of lighting per day, control) and 6L/6LCP (6h at PPFD of 280 µmol m^{-2} s^{-1} and 6h of LCP at 20 µmol m^{-2} s^{-1}; total of 12h of lighting per day + 12h at LCP) for a similar DLI of 12.96 mol m^{-2} per day.

A third experiment using the same DLI was performed to compare 5L/1N (20h lighting + 4h dark per day) and 5L/1LCP (20h lighting + 4h LCP per day) treatments.

Results and discussion

For arugula, the use of 5L/1LCP reduced the SPAD value by 18% and a slight increase was observed for Fv/Fm (+2.5%) compared with the other light treatments (Table 1). For all studied species, the Fv/Fm ratio were within the 0.80-0.84 values generally observed for C3 plants[4], showing the absence of stress under short night (1N) or continuous lighting (LCP). The apparent quantum yield (ϕ) of arugula increased by 41% under 6L/6LPC compared with 5L/1N and 5L/1LCP. For all species or cultivars, PI was higher under 5L/1LCP and the light saturation point (LSP) was lower (-26%) under the 6L/6LCP treatment, showing a low light adaptation compared with 5L/1N and 5L/1LCP.

SR showed a lower shoot fresh weight (SFW) under 6L/6LCP (-37%) compared with 5L/1LCP. However, 5L/1LCP decreased the shoot dry biomass of BG (-28%) compared to 5L/1N and 6L/6LCP, while its leaf area increased (+43%). The leaf area of SG also increased (+54%) under 5L/1LCP compared with 6L/6LCP, without any effect on the plant biomass. For arugula, 5L/1LCP reduced by 29% the shoot dry biomass compared with 5L/1N. Based on fresh biomass, the photon yield of SR exposed to 6L/6LCP was 44% lower compared with the two other treatments. However, on a dry weight basis, 6L/6LCP increased the photon yield of BG by 29% compared with 5L/1LCP, while 5L/1LCP decreased the photon yield of arugula compared with 5L/1N.

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Table 2. Growth parameters, Shoot Fresh Weight (SFW), Root Fresh Weight (RFW), Shoot Dry Weight (SDW), Root Dry Weight (RDW), Shoot Root Ratio, Leaf Area (LA), Leaf Area Index (LAI), Specific Leaf Weight (SLW) and Pphoton Yield (PY) performance of four leafy greens after 31 days of cultivation exposed to three light treatments (*n*=5 to 9)

	SFW	RFW	SDW	RDW	Shoot/ Root (FW)	Shoot/ Root (DW)	LA (cm^2 $plant^{-1}$)	LAI	SLW (mg DW cm^{-2})	PY (FW) (g FW mol^{-1})	PY (DW) (g DW mol^{-1})
	(g $plant^{-1}$)										
Species											
Bergam's Green (BG)	153	13.2 a	9.89	0.94 b	9.77 c	8.53 b	2010	4.50	3.82	8.67	0.560
Arugula (A)	65	9.11 b	7.66	1.11 a	7.46 d	5.96 c	720	1.71	7.4.3	3.55	0.435
Salanova Green (SG)	105	8.91 b	4.58	0.590 c	12.2 b	7.82 b	2030	4.44	2.1.9	6.06	0.264
Salanova Red (SR)	95	7.95 b	4.69	0.523 d	14.0 a	9.76 a	2156	5.19	2.2.2	5.25	0.270
Lighting treatments											
5L/1N	107	9.93	7.33	0.869	9.76	7.45	1535	3.69	4.1.6	5.91	0.413
5L/1LCP	109	9.65	5.70	0.714	11.9	8.59	1924	4.65	3.6.7	6.58	0.345
6L/6LCP	97	9.57	7.08	0.806	10.7	7.72	1502	3.63	3.3.9	5.16	0.389
Species x Treatments											
BG x 5L/1N	156 a[x]	13.0	10.6 a	0.988	9.00	7.99	1688 b	4.09 bd	4.24	8.70 ab	0.592 ab
BG x 5L/1LCP	138 ab	13.4	7.87 bc	0.892	10.5	9.06	2332 a	5.64 ab	3.40	8.32 a	0.474 bcd
BG x 6L/6LCP	164 a	11.7	11.2 a	1.05	9.88	7.85	1562 b	3.78 abce	4.17	9.00 ab	0.613 a
A x 5L/1N	69 ef	9.74	8.99 b	1.24	6.14	5.53	615 c	1.43 f	7.52	3.67 ef	0.505 c
A x 5L/1LCP	71 cdef	8.48	6.03 cd	0.980	8.77	6.39	826 c	2.00 ef	7.34	4.28 def	0.368 de
A x 6L/6LCP	56 f	-[y]	7.96 bc	-	-	-	-	-	-	2.70 f	0.431 cd
SG x 5L/1N	102 bc	9.04	4.61 de	0.647	10.9	7.11	1832 ab	4.44 ac	2.37	5.78 cde	0.263 g
SG x 5L/1LCP	115 b	8.78	4.47 e	0.533	13.5	8.54	2228 a	5.39 abc	2.01	6.94 bc	0.269 fg
SG x 6L/6LCP	99 bc	7.46	4.67 de	0.559	11.5	7.58	1442 b	3.49 cde	2.61	5.46 cde	0.260 fg
SR x 5L/1N	101 bcd	7.91	5.09 de	0.595	13.0	9.17	2005 a	4.79 ac	2.5	5.48 cde	0.289 ef
SR x 5L/1LCP	113 b	7.99	4.45 de	0.452	14.9	10.4	2308 a	5.58 ab	1.93	6.79 dbc	0.268 fg
SR x 6L/6LCP	71 de	-	4.52 de	-	-	-	-	-	-	3.49 f	0.253 fg
P values											
Species (S)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Treatments (T)	0.760	0.647	0.122	0.383	0.308	0.425	0.236	0.293	0.447	0.489	0.076
S × T	<0.001	0.493	0.009	0.322	0.777	0.927	0.042	0.001	0.082	<0.001	0.011

[x]means of the same column with different letters are significantly different at P ≤ 0.05 (protected Fisher's LSD)

[y]not available

Conclusions

- A higher DLI, for A, SG and SR, with relatively low PPFD and long photoperiod (5L/1LCP) may increase fresh shoot biomass more than a higher PPFD and shorter photoperiod (6L/6LCP)
- 5L/1LCP may reduce the lettuce SLW, while a positive effect may be observed for arugula.
- 5L/1LCP reduced the shoot dry weight of arugula and BG compared with 5L/1N, although no effect was observed for SG and SR.
- For a same DLI of 12.96 mol m^{-2} day^{-1}, leafy greens exposed alternatively to a short photoperiod having high PPFD followed by an equivalent (6L/6LCP) or shorter photoperiod of low PPFD (5L/1LCP), corresponding to their LCP, did not have a better light use efficiency and productivity than plants grown under moderate PPFD with a short dark period (5L/1N).

Literature cited

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