LUXEON SunPlus Series Lime LEDs Produce High Yield and Nutrition in Leafy Greens

Lime, Green and Purple LEDs from Lumileds have shown to produce high red lettuce yields while raising the concentrations of essential nutrients that contribute to human health.

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LEDs are rapidly becoming the light source of choice for indoor horticultural applications due to the ability to customize the light spectra to meet the growth and nutritional needs of the plant of interest—something that legacy horticulture light sources cannot do. In addition, LEDs have superior lifetimes, greater energy efficiency versus fluorescent tubes used in vertical farms and plant factories, require low to no maintenance and emit less heat to the growing environment.

Salad crops are consumed for their nutritive and health benefits rather than for caloric requirements. If grown properly, they can be an excellent source of nutrients including antioxidants, which help control the level of damaging free radicals in the body. In this study, the concentrations of chlorophyll as well as two important bioactive antioxidants—the anthocyanins and the carotenoids—were monitored and quantified. Carotenoids are a family of yellow and orange pigments including beta-carotene (the precursor of vitamin A) and zeaxanthin and lutein, which are yellow pigments that protect the retina against high energy radiation (eg. UV and blue light).[1] Anthocyanins are red, blue and purple pigments and their dietary uptake is positively correlated with human health such as in the treatment of vision disorders, protection against neurological disorders, reduction in incidence of cardiovascular disease, increase in cognitive ability and enhancement of antioxidant protection.[2] Previous studies using commercially available LEDs indicated that many leafy greens grown under phosphor converted (PC) LEDs had large, thin and pale leaves with consistently lower levels of chlorophyll and anthocyanins[3].

The present plant growth study was conducted to evaluate the performance of new commercially available PC LEDs designed for horticulture from Lumileds (LUXEON SunPlus Series) in comparison to Valoya and custom built direct emission RGB LEDs. The goal was to determine whether recently introduced phosphor converted (PC) LEDs could improve the yield of red lettuce while producing high levels of key nutrients including anthocyanins and carotenoids. The relationship or compromise between yield (above ground biomass) and nutritional quality of red lettuce Rouxai was examined.

Lighting Configuration and Methods

Spectral photon distributions were selected to deliver photosynthetic photon flux densities (PPFDs) at the crop level with identical output in red (600-700 nm), blue (400-500 nm) and green (500-600 nm) wavelength ranges (spectral ratios) between fixtures. Two fixtures were installed in each environmentally controlled growth chamber (Adaptis 1000, Conviron) with PPFDs between 217-242 μmol/m^{2}s by setting light programs and/or adjusting distance to the crop (Figure 1). The spectral photon distributions in the center of the chambers and in a grid spanning the growth area were measured to examine the uniformity (Figure 2). The spectral ratios were designed to be identical across the photosynthetic active radiation (PAR); 20% blue (400-500 nm), 20% green (500-600 nm) and 60% red (600-700 nm). There was, however, a difference in PPFD in the far red region (700-800 nm). It was absent from the RGB direct emission spectra but ranged from 19 μmol in the Valoya PC to 25 μmol in the LUXEON SunPlus Lime + Purple fixture, 28 μmol in the LUXEON SunPlus Green + Purple fixture and 32 μmol in the LUXEON SunPlus Purple fixture. The light analyses indicated that spectral and PPFD uniformities were poorer on average from side to side of the chambers and significantly better from front to rear. A larger installation of light bars would improve these uniformity discrepancies. The photoperiods were 16 hours/day for 14 days, the day/night temperatures were 23°C/18°C and the relative humidity was between 50% and 70%. The plants were fertilized with a modified Hoagland's solution. Three independent replicates were performed and statistical differences between light trials were determined (KruskalWallis ANOVA, SigmaPlot v11). Samples from growth areas with the greatest light uniformity were harvested for measurements. Anthocyanin concentrations were quantified spectrophotometrically according to the method in Pocock.[3] The carotenoid and chlorophyll concentrations were quantified according to the method in Lichtenthaler.[4]

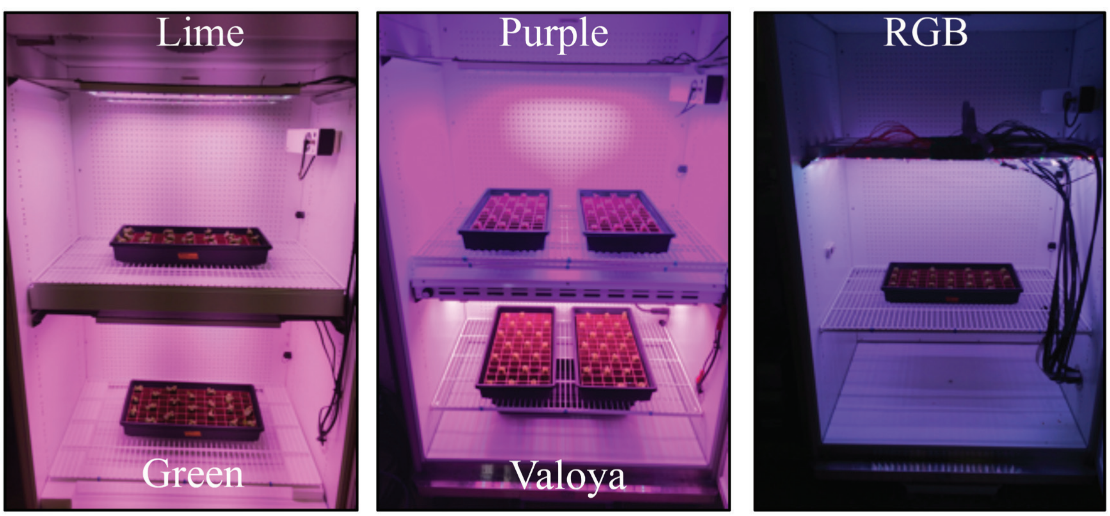


Figure 1. Rouxai red lettuce is grown for 14 days under LUXEON SunPlus Lime + Purple, LUXEON SunPlus Green + Purple and LUXEON SunPlus Purple, Valoya, and RGB fixtures in Adaptis chambers.

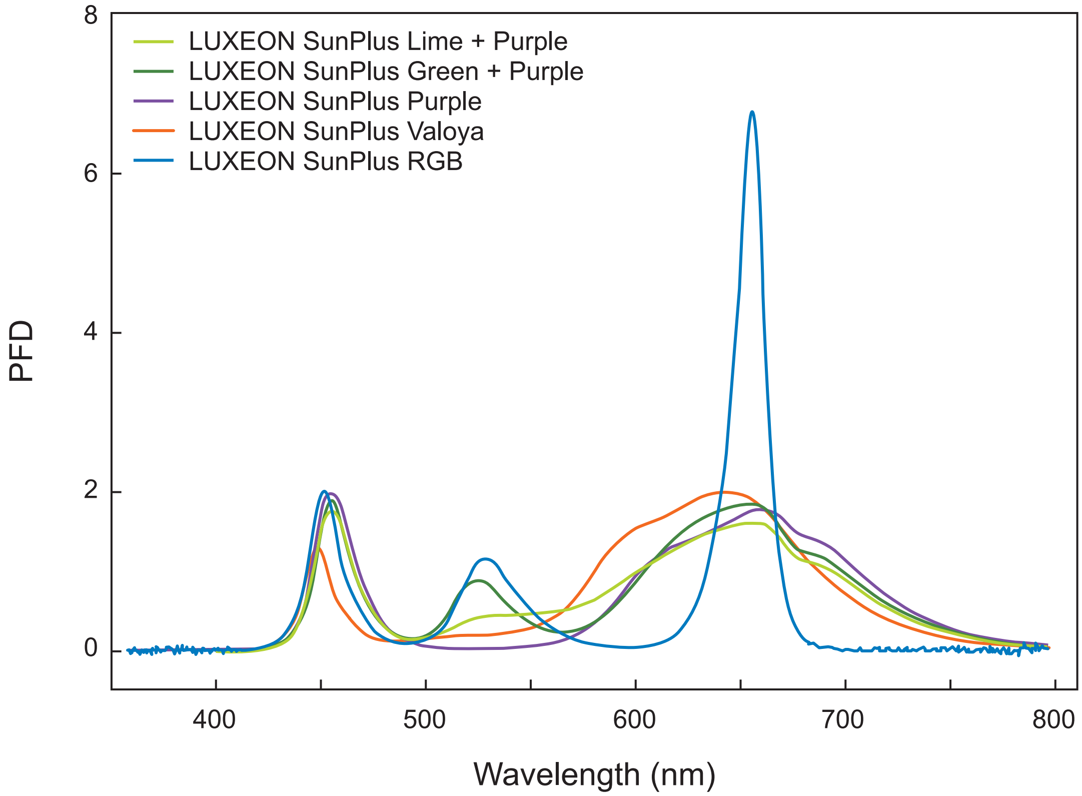


Figure 2. Spectral photon distribution measured as photon flux density (PFD) for each light source. To enable uniform comparison, SPD was measured at the center of each chamber at the crop level.

Yield, Plant Health and Antioxidants

Yield, as determined by fresh weight (g), anthocyanin, carotenoid and chlorophyll concentrations and photochemistry in red lettuce cultivar Rouxai grown under the different light treatments were examined. Yields were significantly higher in seedlings grown under LUXEON SunPlus Series Lime + Purple and Green + Purple LEDs and Valoya, followed by LUXEON SunPlus Series Purple only and then RGB (Figure 3). The lack of far red (700-800 nm) output of the last two could account for the low fresh weight of lettuce grown compared to LUXEON SunPlus Lime + Purple and Green + Purple and the Valoya fixtures. It is well accepted that far red induces cell elongation and leaf size. Significantly higher anthocyanin concentrations were observed in Rouxai grown under LUXEON SunPlus Lime + Purple, Green + Purple and RBG spectra compared to Valoya (Figure 4). Carotenoid concentrations were not affected by the light treatments and, though not significant, the chlorophyll concentrations were consistently higher under the LUXEON SunPlus Series and the RGB LEDs compared to Valoya (Figures 5 & 6). Plant health can be measured through the technique of chlorophyll fluorescence using a pulse amplitude modulated chlorophyll fluorometer (PAM 2500, Walz, DE)[5]. Plant health (FV/FM), the efficiencies of light conversion in the plant (Y(II)) and photoprotection (NPQ) were in healthy ranges indicating that there was no stress on the processes of photosynthesis (Figure 7) in these studies. The plants were well acclimated to all light sources.

a. LUXEON SunPlus Lime + Purple

Position		PFD	% PAR	PFD	% PAR	PFD	% PAR
Back	UVA	0		0		0	
	B	29	19%	39	20%	31	19%
	G	32	21%	42	21%	33	21%
	R	94	60%	116	59%	97	60%
	PAR	155		196		161	
	FR	16		21		16	
	R/FR	5.9		5.6		5.9	
Center	UVA	0		0		0	
	B	35	19%	47	21%	35	19%
	G	37	21%	50	22%	38	21%
	R	107	60%	131	58%	109	60%
	PAR	179		227		182	
	FR	18		25		19	
	R/FR	5.8		5.2		5.8	
Front	UVA	0		0		0	
	B	35	20%	46	20%	34	19%
	G	38	21%	49	21%	37	21%
	R	107	59%	138	59%	106	60%
	PAR	180		233		177	
	FR	19		24		18	
	R/FR	5.7		5.8		5.8	

25 in/635 cm deep

37 in/949 cm wide

b. LUXEON SunPlus Green + Purple

Position		PFD	% PAR	PFD	% PAR	PFD	% PAR
Back	UVA	0		0		0	
	B	30	19%	39	20%	32	19%
	G	33	21%	41	21%	35	21%
	R	97	61%	117	59%	101	60%
	PAR	160		197		168	
	FR	17		23		18	
	R/FR	5.7		5.2		5.5	
Center	UVA	0		0		0	
	B	34	18.9%	49	20%	39	21%
	G	37	20.4%	49	20%	40	22%
	R	110	60.7%	146	60%	106	57%
	PAR	181		244		185	
	FR	20		28		23	
	R/FR	5.6		5.2		4.5	
Front	UVA	0		0		0	
	B	32	20%	45	22%	40	21%
	G	34	21%	45	22%	40	22%
	R	93	59%	113	56%	107	57%
	PAR	159		204		187	
	FR	18		28		24	
	R/FR	5.1		4.0		4.5	

25 in/635 cm deep

37 in/949 cm wide

c. LUXEON SunPlus Purple

Position		PFD	% PAR	PFD	% PAR	PFD	% PAR
Back	UVA	0		0		0	
	B	31	22%	49	23%	35	22%
	G	10	8%	16	8%	12	7%
	R	98	70%	147	69%	111	70%
	PAR	139		212		158	
	FR	18		28		20	
	R/FR	5.5		5.2		5.6	
Center	UVA	0		0		0	
	B	36	23%	54	25%	41	23%
	G	12	8%	19	9%	14	8%
	R	110	70%	145	67%	122	69%
	PAR	158		217		176	
	FR	20		32		23	
	R/FR	5.4		4.5		5.2	
Front	UVA	0		0		0	
	B	37	23%	51	25%	39	23%
	G	12	8%	18	9%	13	8%
	R	109	69%	132	66%	113	69%
	PAR	158		202		164	
	FR	21		32		22	
	R/FR	5.1		4.2		5.0	

25 in/635 cm deep

37 in/949 cm wide

d. Valova PC

Position		PFD	% PAR	PFD	% PAR	PFD	% PAR
Back	UVA	0		0		0	
	B	25	12%	28	12%	25	12%
	G	45	21%	50	21%	44	21%
	R	141	67%	159	67%	141	67%
	PAR	211		236		210	
	FR	15		16		15	
	R/FR	9.3		9.7		9.7	
Center	UVA	0		0		0	
	B	29	12%	31	13%	27	12%
	G	49	21%	52	22%	47	21%
	R	151	66%	159	65%	148	66%
	PAR	229		242		223	
	FR	17		19		16	
	R/FR	8.9		8.5		9.0	
Front	UVA	0		0		0	
	B	22	12%	25	12%	22	12%
	G	39	21%	43	21%	39	21%
	R	127	68%	139	67%	128	68%
	PAR	188		207		190	
	FR	13		15		13	
	R/FR	9.6		9.2		9.6	

25 in/635 cm deep

37 in/949 cm wide

e. RGB

Position		PFD	% PAR	PFD	% PAR	PFD	% PAR
Back	UVA	0		0		0	
	B	37	20%	41	20%	37	19%
	G	36	19%	40	19%	37	19%
	R	111	60%	125	61%	116	61%
	PAR	184		206		190	
	FR	0		0		0	
	R/FR	NA		NA		NA	
Center	UVA	0		0		0	
	B	41	20%	46	20%	42	20%
	G	39	19%	44	19%	41	19%
	R	123	60%	140	61%	129	61%
	PAR	203		230		211	
	FR	0		0		0	
	R/FR	NA		NA		NA	
Front	UVA	0		0		0	
	B	41	20%	44	20%	38	20%
	G	38	19%	41	19%	36	19%
	R	122	61%	132	61%	116	61%
	PAR	201		217		190	
	FR	0		0		0	
	R/FR	NA		NA		NA	

25 in/635 cm deep

Figure 3. The highest yield (fresh weight) of 14 day old red lettuce was produced using LUXEON SunPlus Lime + Purple, Valoya and LUXEON SunPlus Green + Purple fixtures.

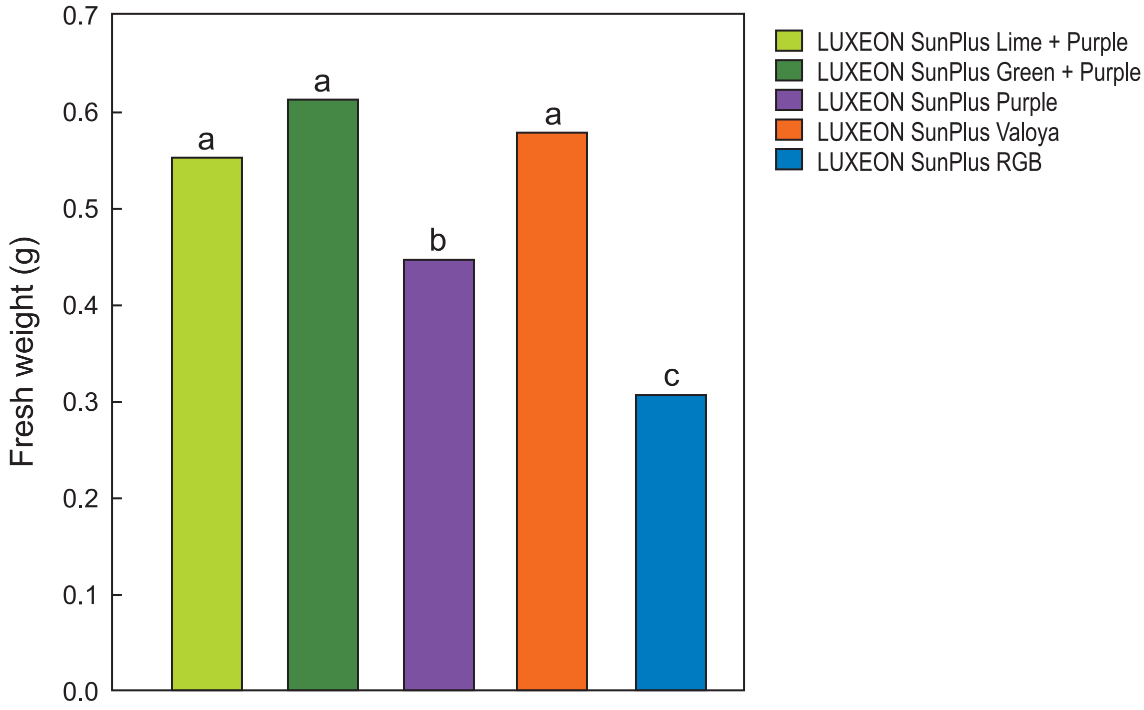


Figure 4. Anthocyanin concentration was highest for LUXEON SunPlus Lime + Purple and Green + Purple LEDs.

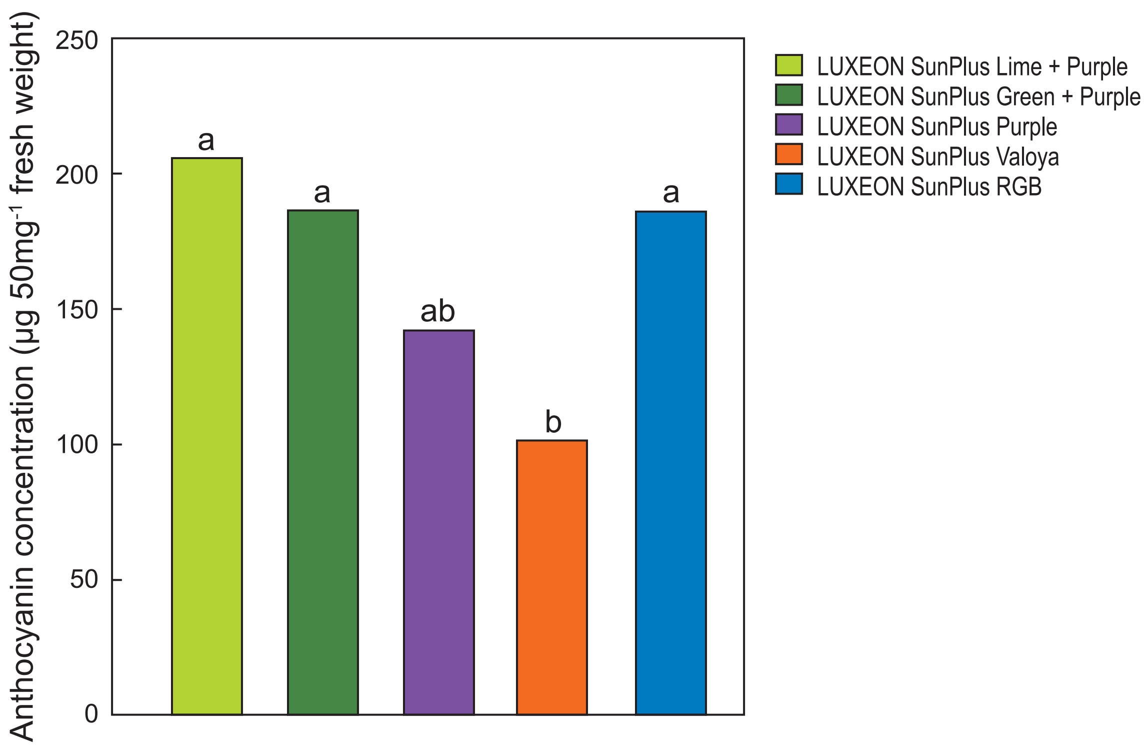


Figure 5. All LED light treatments boosted carotenoid concentration.

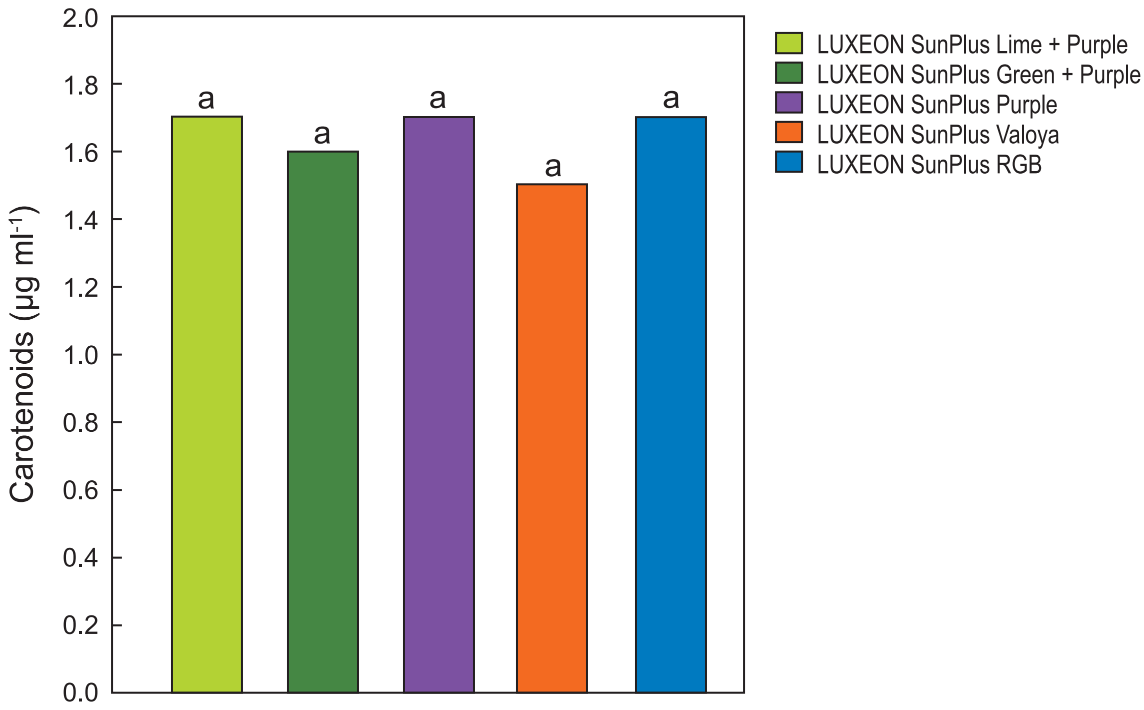


Figure 6. Chlorophyll concentration was highest for RGB and LUXEON SunPlus Series grown lettuce.

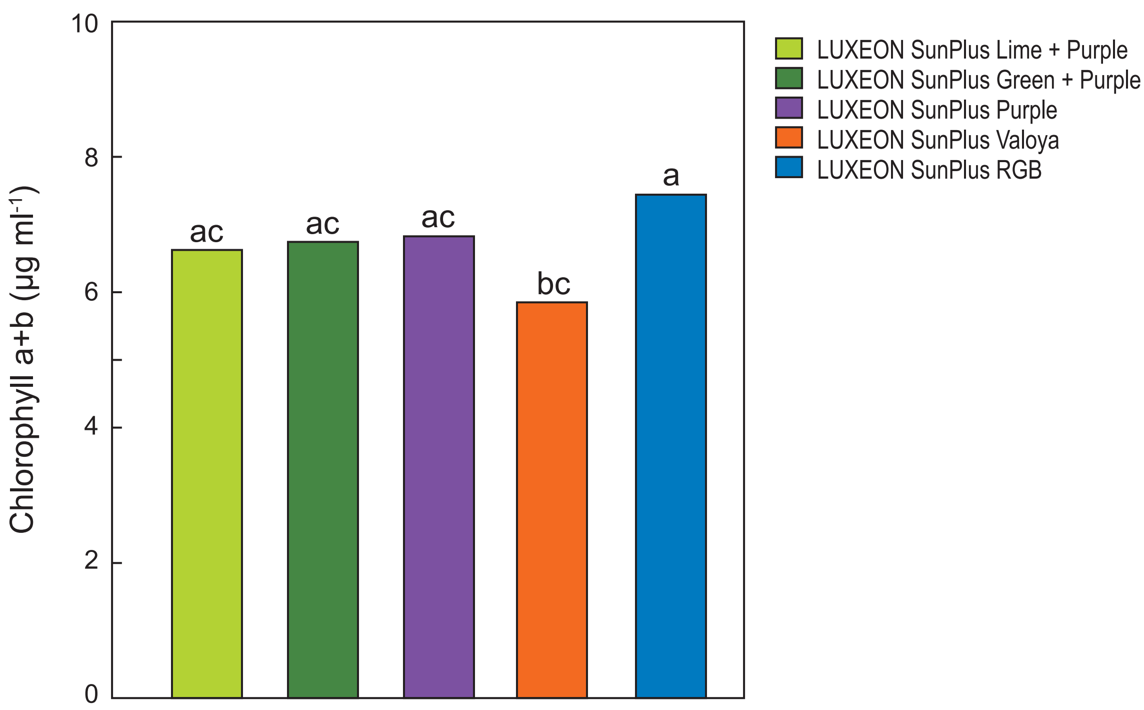
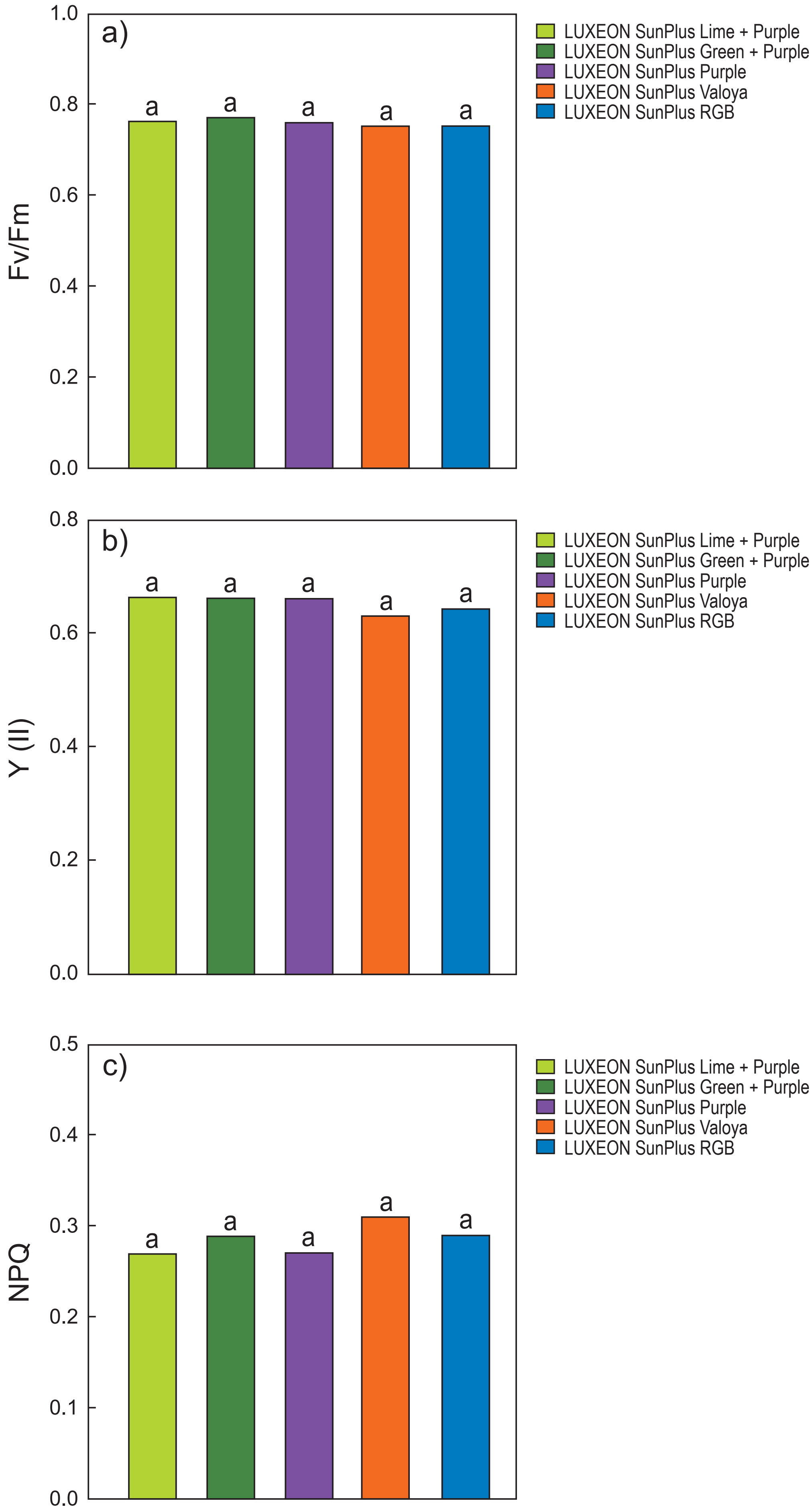


Figure 7. Photochemistry results indicated good plant health (Fv/Fm); efficient photochemistry Y(II); and the induction of photo-protective mechanisms (NPQ) using all light sources.


1.0
a)
0.8
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Fv/Fm
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LUXEON SunPlus Lime + Purple
LUXEON SunPlus Green + Purple
LUXEON SunPlus Purple
LUXEON SunPlus Valoya
LUXEON SunPlus RGB
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LUXEON SunPlus Lime + Purple
LUXEON SunPlus Green + Purple
LUXEON SunPlus Purple
LUXEON SunPlus Valoya
LUXEON SunPlus RGB
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LUXEON SunPlus Lime + Purple
LUXEON SunPlus Green + Purple
LUXEON SunPlus Purple
LUXEON SunPlus Valoya
LUXEON SunPlus RGB

Conclusions

Leafy greens are desirable crops for daily eating due to their nutritive value. This study showed that red lettuce Rouxai grown under specific LED spectra can have significantly higher yields as well as greater concentrations of anthocyanins and carotenoids.

The LUXEON SunPlus Lime + Purple LEDs performed best in terms of yield (fresh weight) and antioxidant levels. The spectrum of this light source includes output in the far red range (700-800 nm) that can boost lettuce yields. The Valoya PC LEDs produced greens of comparable yield but statistically lower levels of antioxidants, indicating that the spectral photon distribution of phosphor down conversion can have different effects on crop quality. In summary, these data suggest that growth and nutrition are optimized using PC LEDs with strong royal blue, green, deep red and far red components found in the combination of LUXEON SunPlus Lime + Purple LEDs.

The spectra that performed best for both yield (fresh weight) and nutrient concentrations were the LUXEON SunPlus Series Lime + Purple and Green + Purple LEDs. To effectively grow Rouxai red lettuce and similar crops in indoor environments, the use of LUXEON SunPlus Series Lime + Purple and Green + Purple LEDs demonstrated significant advantages.

References

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About Lumileds

Companies developing automotive, mobile, IoT and illumination lighting applications need a partner who can collaborate with them to push the boundaries of light. With over 100 years of inventions and industry firsts, Lumileds is a global lighting solutions company that helps customers around the world deliver differentiated solutions to gain and maintain a competitive edge. As the inventor of Xenon technology, a pioneer in halogen lighting and the leader in high performance LEDs, Lumileds builds innovation, quality and reliability into its technology, products and every customer engagement. Together with its customers, Lumileds is making the world safer, better and more beautiful—with light.

To learn more about our lighting solutions, visit lumileds.com.