

# High-power LEDs for plant cultivation

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# Outline

❑ Horticulture + LED = efficient production of safe food



❑ Illumination facility

❑ Growth experiments



❑ Conclusions

## Photosynthesis

light absorption by chlorophyll *a* 660 nm  
chlorophyll *b* 640 nm

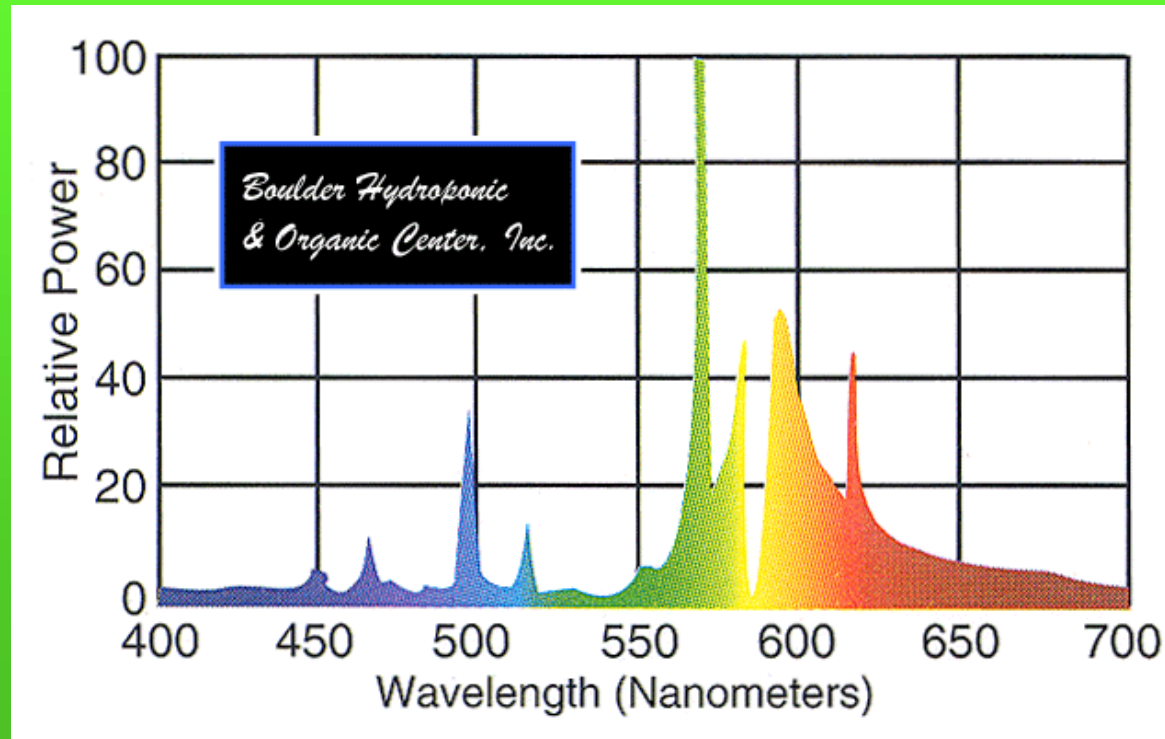
## Phototropy

light absorption at 455 nm

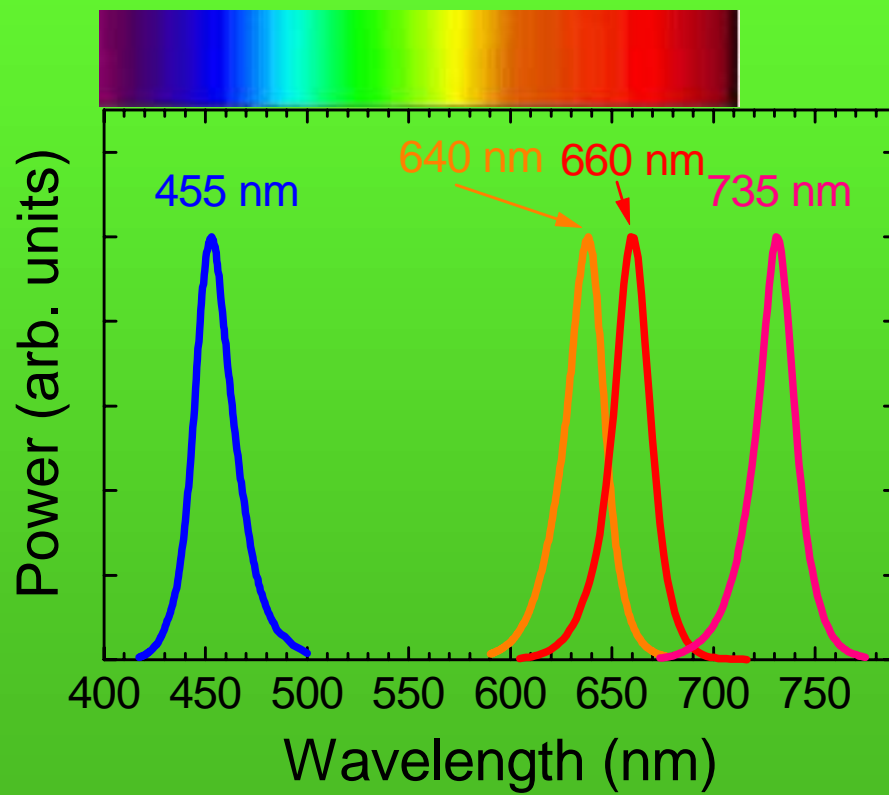
## Photomorphology

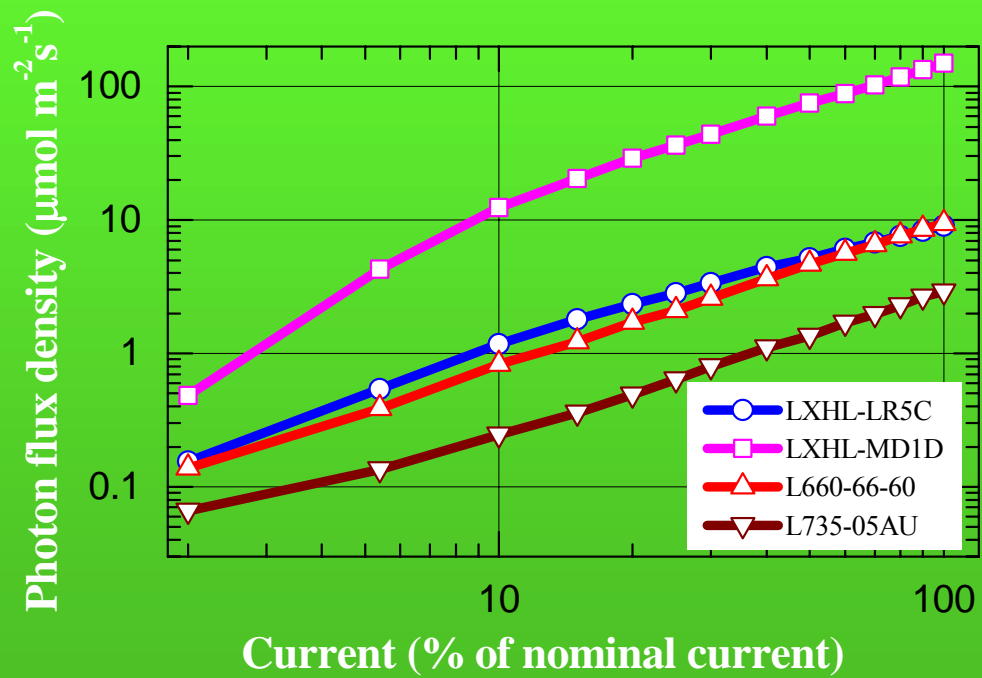
light absorption at 735 nm

# High pressure sodium lamp



[www.bhocenter.com/ag\\_light/](http://www.bhocenter.com/ag_light/),







Shares in total price and in typical total photon flux for four LED groups used in the illuminator designed.

<b>Nominal wavelength, nm</b>	<b>735</b>	<b>660</b>	<b>640</b>	<b>455</b>
<b>Type</b>	<b>L735-05-AU</b>	<b>L660-66-60</b>	<b>LXHL-MD1D</b>	<b>LXHL-LR3C</b>
<b>Materials system</b>	<b>AlGaAs</b>	<b>AlGaAs</b>	<b>AlGaInP</b>	<b>AlInGaN</b>
<b>Share in total price, %</b>	<b>3</b>	<b>32</b>	<b>60</b>	<b>5</b>
<b>Share in typical photon flux, %</b>	<b>2</b>	<b>7</b>	<b>85</b>	<b>6</b>

Shares in total price and in typical total photon flux for four LED groups used in the illuminator designed.

Nominal wavelength, nm	735	660	640	455
Type	L735-05-AU	L660-66-60	LXHL-MD1D	LXHL-LR3C
Materials system	AlGaAs	AlGaAs	AlGaInP	AlInGaN
Share in total price, %	3	32	60	5
Share in typical photon flux, %	2	7	85	6

**High-power LED emission at 652 nm demonstrated:**

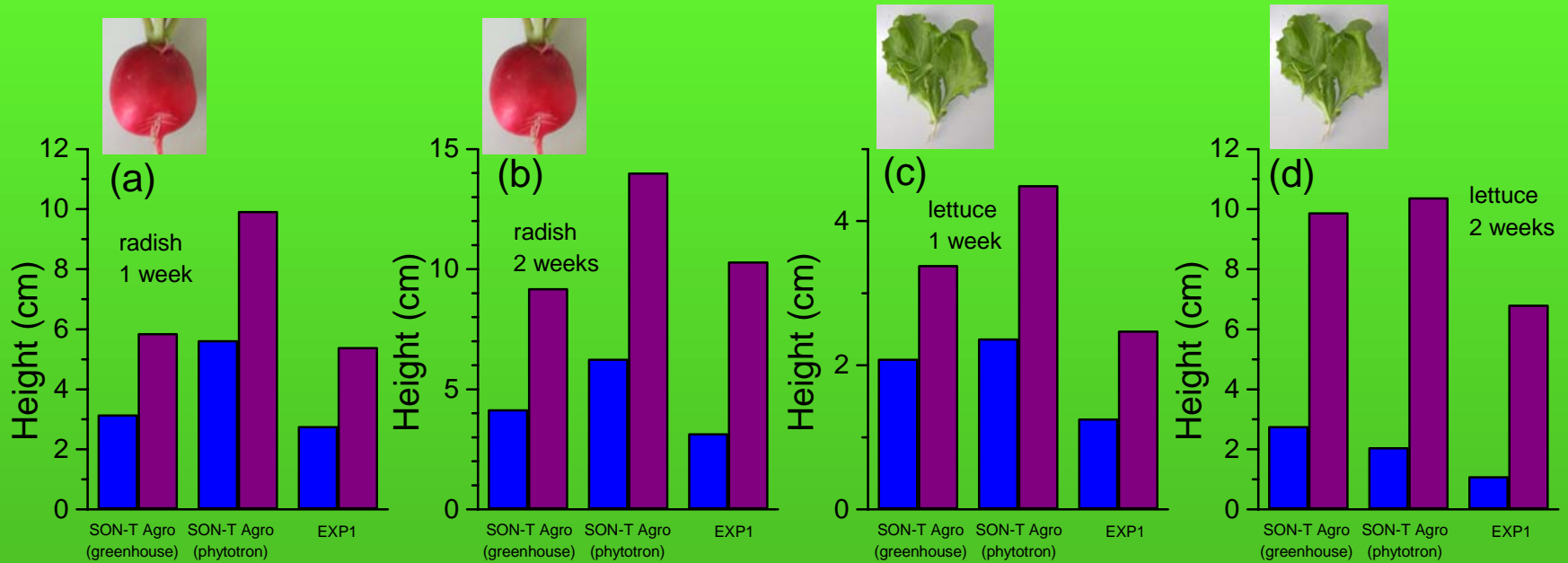
M. R. Krames et al. "High-power truncated-inverted-pyramid  $(\text{Al}_x\text{Ga}_{1-x})_{0.5}\text{In}_{0.5}\text{P}/\text{GaP}$  light-emitting diodes exhibiting >50% external quantum efficiency," *Appl. Phys. Lett.* **75**, 2365 (1999).

**Photon flux densities, in  $\mu\text{mol m}^{-2} \text{s}^{-1}$  and % of the total day or night flux density, produced by LEDs with peak emission wavelengths, indicated, in four different plant growth experiments, numbered as EXP1 to EXP4.**

	455 nm		640 nm		660 nm		735 nm	
	day	night	day	night	day	night	day	night
<b>EXP1</b>	<b>9</b> (6.4%)	0	<b>120</b> (85%)	0	<b>9.4</b> (6.6%)	0	<b>2.9</b> (2%)	0
<b>EXP2</b>	<b>9</b> (6.5%)	0	<b>120</b> (86.7%)	0	<b>9.4</b> (6.8%)	0	0	<b>2.9</b> (100%)
<b>EXP3</b>	<b>9</b> (8.8%)	0	<b>80</b> (79%)	0	<b>9.4</b> (9.3%)	0	2.9 (2.9%)	0
<b>EXP4</b>	<b>9</b> (6.5%)	0	<b>120</b> (86.7%)	0	<b>9.4</b> (6.8%)	0	0	<b>2.9*</b> (100%)

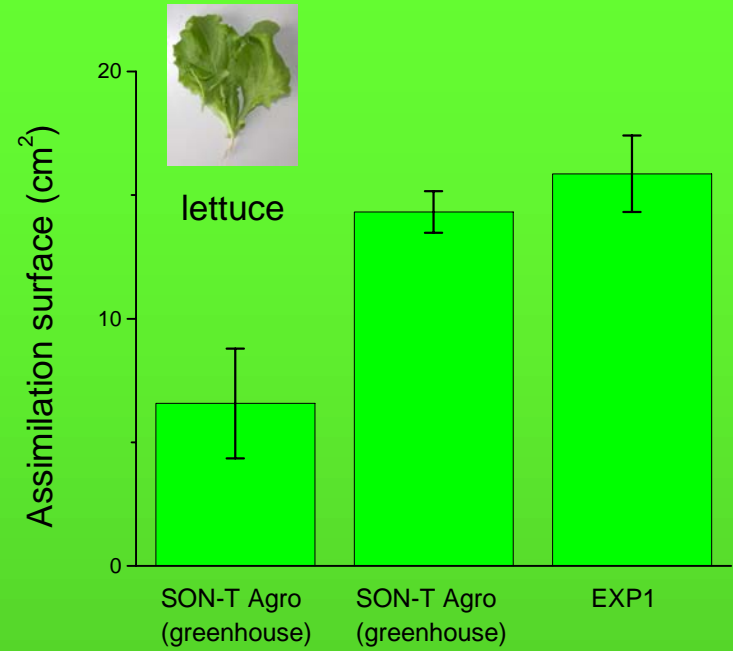
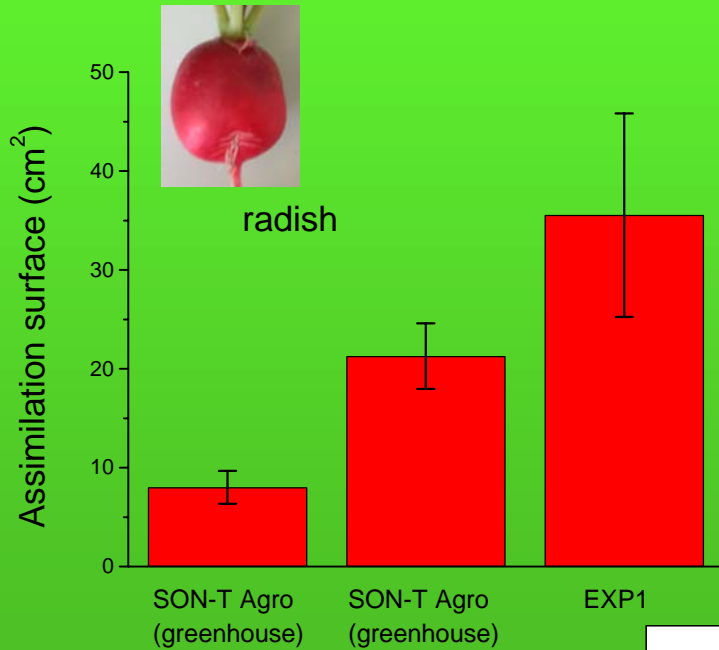
\* Illumination by 735 nm LEDs was on only for 1 hour between 2-3 AM in EXP4

**Height of radish** until apex (blue columns) and of the whole plant (violet column) of radish (a, b) and lettuce (c, d) measured after one week in the stage of cotyledons formation (a, c) and after two weeks, when leaves are formed (b, d)



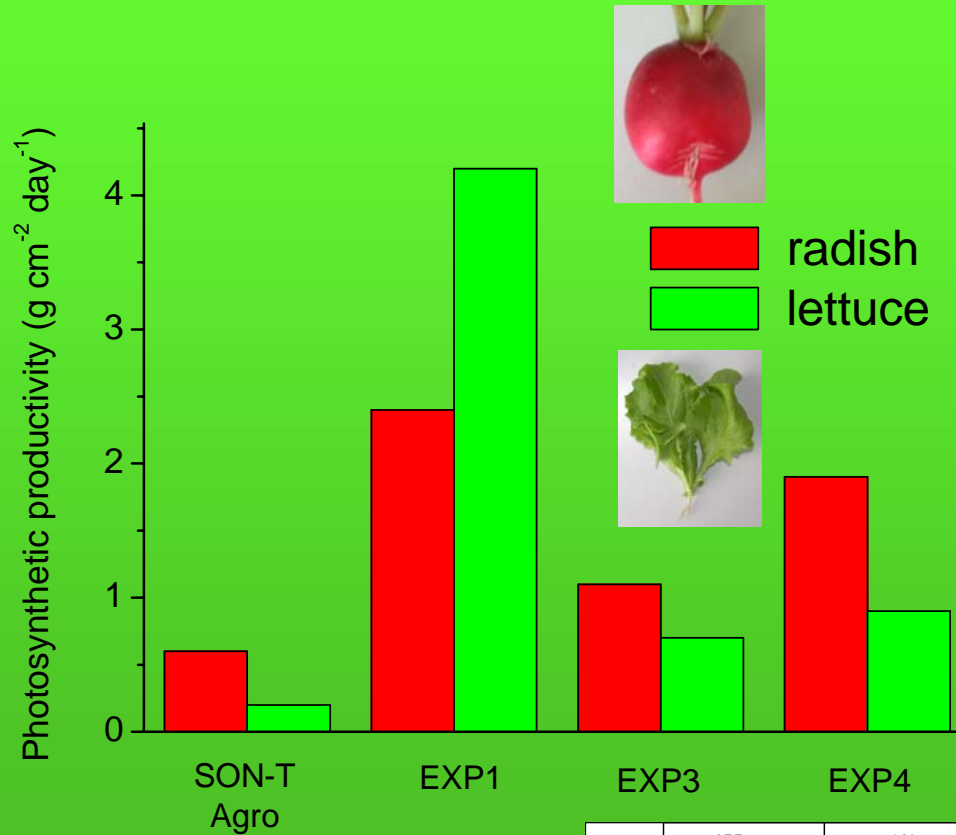
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# Assimilation surface



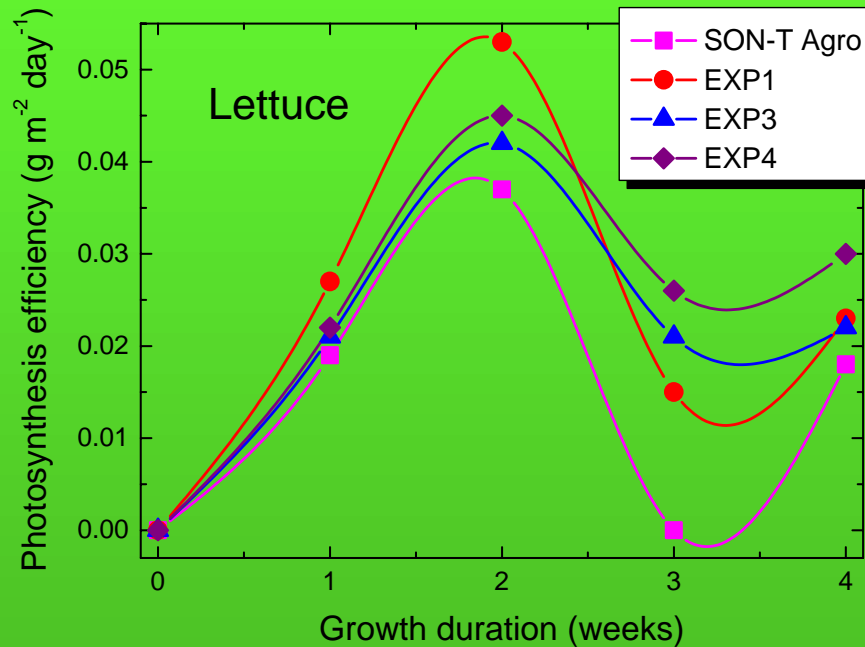
	455 nm		640 nm		660 nm		735 nm	
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<b>EXP3</b>	9 (8.8%)	0	80 (79%)	0	9.4 (9.3%)	0	2.9 (2.9%)	0
<b>EXP4</b>	9 (6.5%)	0	120 (86.7%)	0	9.4 (6.8%)	0	0	2.9* (100%)

# Net photosynthetic productivity



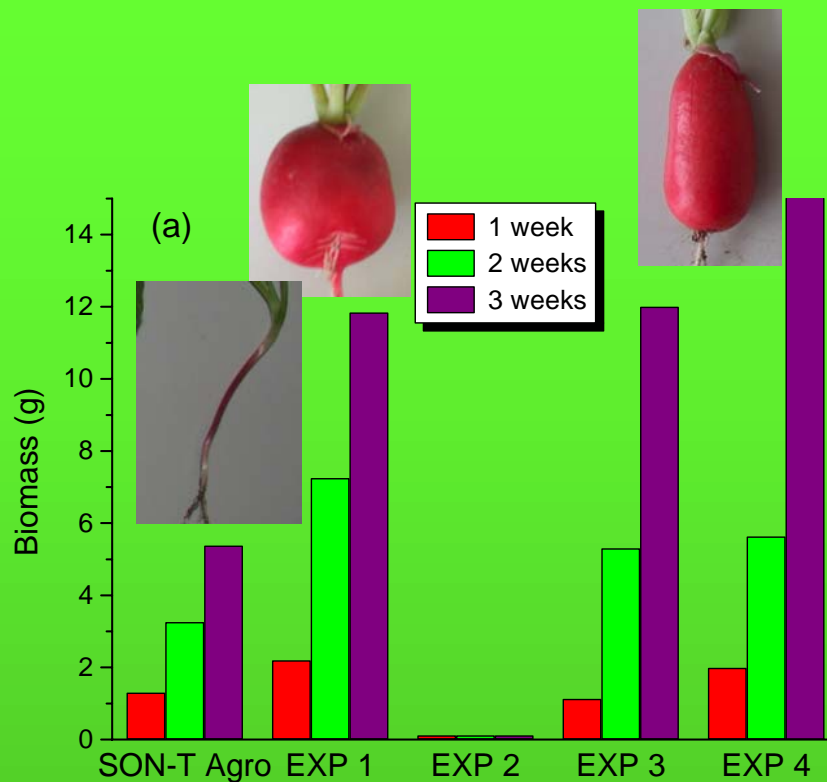
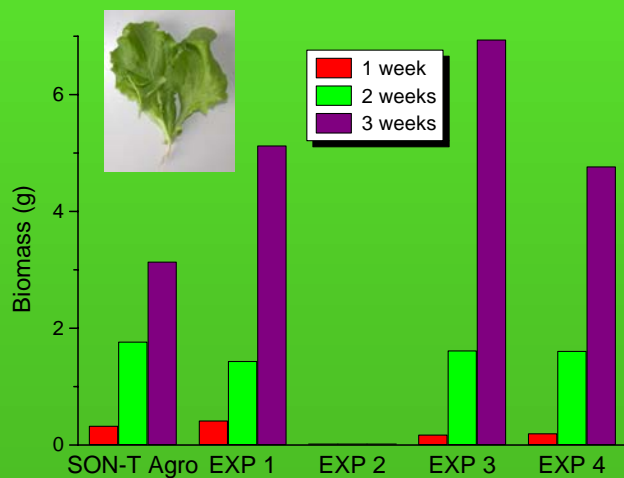
	455 nm		640 nm		660 nm		735 nm	
	day	night	day	night	day	night	day	night
<b>EXP1</b>	<b>9</b> (6.4%)	0	<b>120</b> (85%)	0	<b>9.4</b> (6.6%)	0	<b>2.9</b> (2%)	0
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<b>EXP4</b>	<b>9</b> (6.5%)	0	<b>120</b> (86.7%)	0	<b>9.4</b> (6.8%)	0	0	<b>2.9*</b> (100%)

# Dynamics of photosynthetic productivity in growth experiments under illumination with different spectrum



	455 nm		640 nm		660 nm		735 nm	
	day	night	day	night	day	night	day	night
<b>EXP1</b>	<b>9</b> (6.4%)	0	<b>120</b> (85%)	0	<b>9.4</b> (6.6%)	0	<b>2.9</b> (2%)	0
<b>EXP2</b>	<b>9</b> (6.5%)	0	<b>120</b> (86.7%)	0	<b>9.4</b> (6.8%)	0	0	<b>2.9</b> (100%)
<b>EXP3</b>	<b>9</b> (8.8%)	0	<b>80</b> (79%)	0	<b>9.4</b> (9.3%)	0	2.9 (2.9%)	0
<b>EXP4</b>	<b>9</b> (6.5%)	0	<b>120</b> (86.7%)	0	<b>9.4</b> (6.8%)	0	0	<b>2.9*</b> (100%)

# Green mass production



	455 nm		640 nm		660 nm		735 nm	
	day	night	day	night	day	night	day	night
<b>EXP1</b>	<b>9</b> (6.4%)	0	<b>120</b> (85%)	0	<b>9.4</b> (6.6%)	0	<b>2.9</b> (2%)	0
<b>EXP2</b>	<b>9</b> (6.5%)	0	<b>120</b> (86.7%)	0	<b>9.4</b> (6.8%)	0	0	<b>2.9</b> (100%)
<b>EXP3</b>	<b>9</b> (8.8%)	0	<b>80</b> (79%)	0	<b>9.4</b> (9.3%)	0	2.9 (2.9%)	0
<b>EXP4</b>	<b>9</b> (6.5%)	0	<b>120</b> (86.7%)	0	<b>9.4</b> (6.8%)	0	0	<b>2.9*</b> (100%)

# Dependence of rhizocarp shape on illumination spectrum



HPS lamp



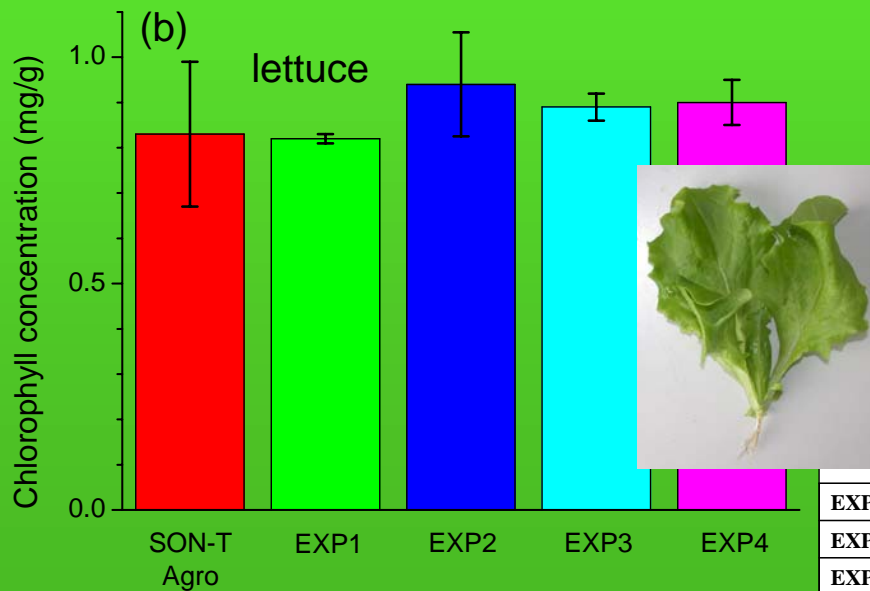
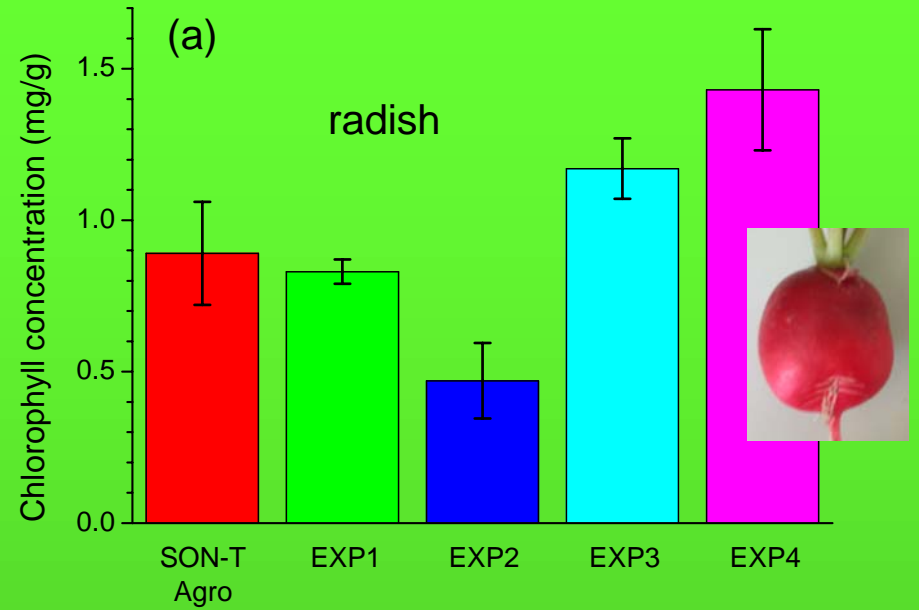
EXP1



EXP4

	455 nm		640 nm		660 nm		735 nm	
	day	night	day	night	day	night	day	night
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EXP4	9 (6.5%)	0	120 (86.7%)	0	9.4 (6.8%)	0	0	2.9* (100%)

# Concentration of chlorophylls *a* + *b*



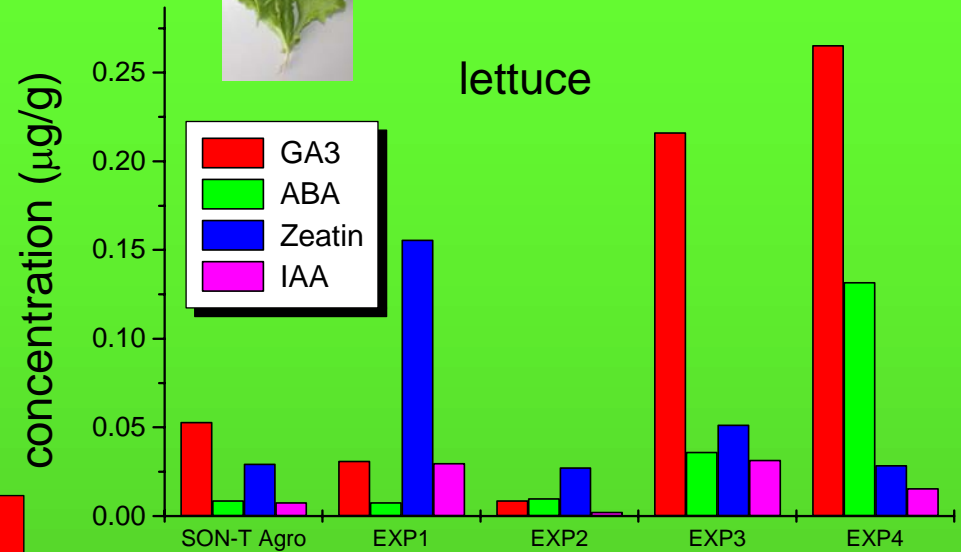
	455 nm		640 nm		660 nm		735 nm	
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EXP4	9 (6.5%)	0	120 (86.7%)	0	9.4 (6.8%)	0	0	2.9* (100%)

# Concentration of phytohormones

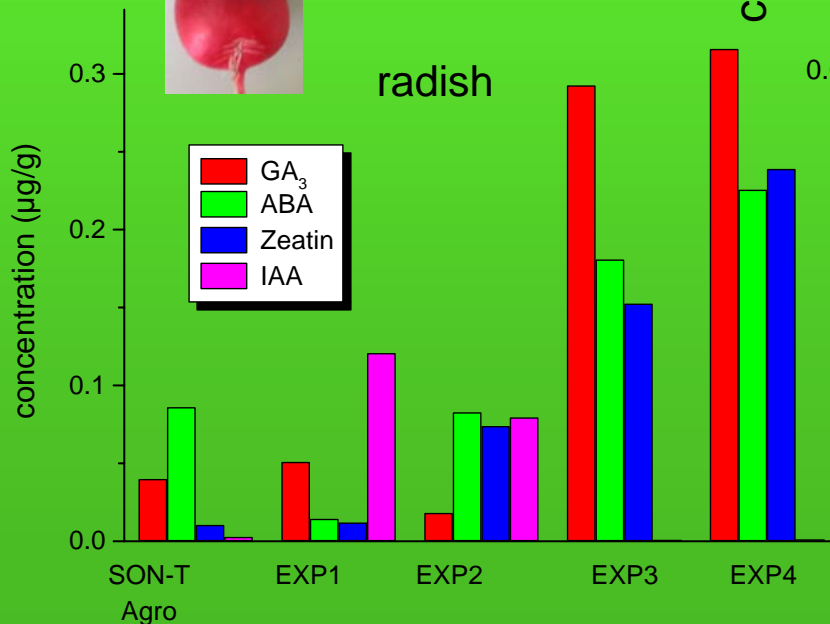
gibberelic acid (GA<sub>3</sub>),  
 abscisic acid (ABA),  
 zeatin,  
 indole-3-acetic acid (IAA)



lettuce



radish



	455 nm		640 nm		660 nm		735 nm	
	day	night	day	night	day	night	day	night
EXP1	9 (6.4%)	0	120 (85%)	0	9.4 (6.6%)	0	2.9 (2%)	0
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EXP3	9 (8.8%)	0	80 (79%)	0	9.4 (9.3%)	0	2.9 (2.9%)	0
EXP4	9 (6.5%)	0	120 (86.7%)	0	9.4 (6.8%)	0	0	2.9* (100%)

# CONCLUSIONS

- The LED-based illumination with a proper proportion of light components enhances photosynthetic productivity and ensures better plant morphology in comparison with illumination using high pressure sodium lamps.
- The implementation of LED-based illumination on industrial scale for greenhouse plant cultivation requires lowering of LED prices, what might be achieved by producing LEDs specifically for horticulture applications.
- High-power AlInGaP-based red LEDs emitting at wavelengths as close as possible to 660 nm as well as further development of LEDs emitting in the vicinity of 640 nm are of major interest for horticulture applications.