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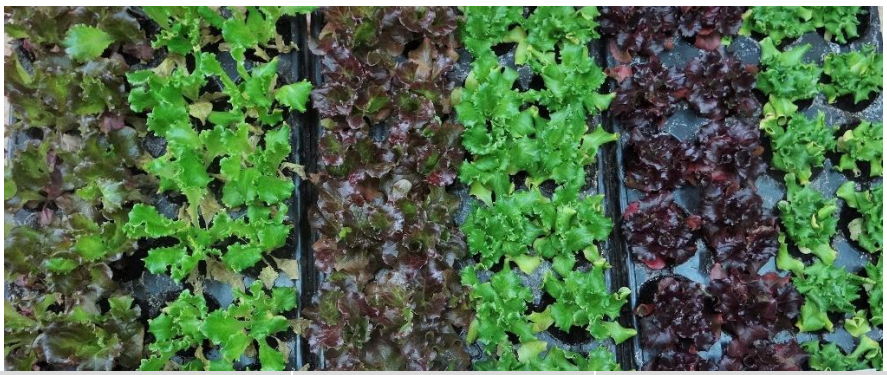
Lettuces are green vegetables, intensively cultivated in winter/spring season, when natural illumination in greenhouse is low. Seeking for optimal productivity, supplemental lighting is used, what also helps to control nitrate contents, which is usually accumulated in lettuces cultivated in intense horticultural systems.

HLFC series lighting for 'baby leaf' lettuces

Baby leaf lettuces are very popular due to their small leaves, decorative forms and colors. Their leaves are used for food not cut, thus the higher contents of nutritionally important bioactive compounds. However, higher quality requirements are applied for this type of lettuces. Specific varieties of "baby leaf" lettuces are more sensitive for environment, more pronounced senescence processes reveal.

The experiments, performed with HLFC series LED lighting show, that this LED lighting affects compact morphology of lettuces, leaf curling and coloration (Fig. 1).

Fig. 1. Green leaf 'Letony' and red leaf 'Redlo' baby leaf lettuces cultivated in closed growth chambers under HLFC series LED or high pressure sodium (HPS) lighting, when photosynthetic photon flux density is 150 and 250 µmol m^{-2} s^{-1}.



HPS 150	LED 150	LED 250

Table 1. Biometric parameters of baby leaf lettuces, raised under HPS and HLFC series LED lighting in growth chambers, when photosynthetic photon flux density was 150 or 250 µmol m^{-2} s^{-1}.

Biometric parameters	HPS 150	LED 150	LED 250
Green leaf 'Lettony'			
Plant height, cm	8,8±0,5	**6,6**±0,7[b]	**5,0**±0,5[b]
Leaf number, pcs.	4,2±0,1	**5,3**±0,3[a]	**5,6**±0,9[a]
Leaf area, cm^2	32±6	**42**±8	32±9
Green weight, g	0,9±0,1	**1,3**±0,1	**1,4**±0,2
Dry weight, g	0,08±0,01	0,10±0,02	**0,18**±0,03[a]

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Red leaf 'Redlo'			
Plant height, cm	9,1±0,6	**7,9**±0,5[b]	**5,7**±0,5[b]
Leaf number, pcs.	4,4±0,14	**5,3**±0,2[a]	**5,8**±0,5[a]
Leaf area, cm^2	52±8	**62**±16	47±9
Green weight, g	1,0±0,1	**1,3**±0,3	**1,4**±0,2
Dry weight, g	0,08±0,01	0,08±0,02	**0,15**±0,03[a]

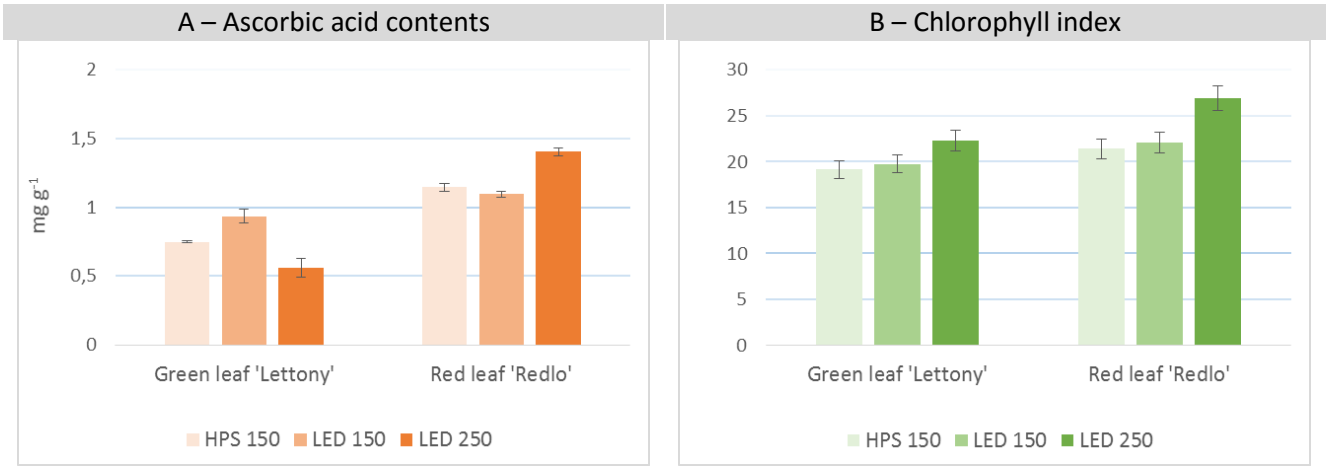
a – significantly higher, b – significantly lower than HPS 150; when p≤0,05.

Blue light deficiency in high pressure sodium lamps determines, that lettuces, cultivated under them possess long, but delicate leaves (table 1). Suitably balanced lighting spectra of HLFC series LED lamps, enriched with certain blue light wavelengths, results in smaller plant height, but higher leaf area and productivity (table 1, LED 150). However, for "baby leaf" lettuce plants, sensible for environment, the lower, 150 µmol $m^{-2}s^{-1}$ LED flux is enough, because increasing it, leaf area is reduced and rapid senescence occur.

Very important is light effect on pigment content in lettuce leaves: HLFC LED light and bigger its flux resulted in significantly higher anthocyan level in lettuce leaves and brighter red coloration of leaves (Fig. 1). Chlorophyll index in lettuce, cultivated under LED and HOS lamps, did not differ, however higher flux of LED light resulted in higher chlorophyll index in leaves (Fig. 2 B)

Worth to mention, that green leaf lettuces are more sensitive for light and 250 µmol $m^{-2}s^{-1}$ LED light flux acted as photostress. When red leaf lettuces, naturally containing higher contents of antioxidant compounds (anthocyan, ascorbic acid, phenolic compounds), tolerated high intensity of lighting, which even stimulates the accumulation of ascorbic acid in their leaves (Fig. 2 A).

Fig. 2. Biochemical parameters of "baby leaf" lettuces, raised under HPS and HLFC series LED lamps. Photosynthetic photon flux density - 150 or 250 µmol m^{-2} s^{-1}. Results are presented in green weight.



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HLFC series lighting for lettuce transplants in greenhouse

Intense horticultural systems usually seek to minimize cultivation costs by eliminating supplemental lighting, or minimizing it, depending on the season. However, suitable flux of proper supplemental lighting determines total productivity, quality of yield. It is of special importance cultivating lettuce transplants, even if in further cultivation steps no lighting would be used.

Experiments, performed at industrial greenhouses of LRCAF Institute of Horticulture, show, that red and green leaf lettuce transplants, cultivated under HLFC series LED lighting, were less elongated, but accumulated the same biomass as the ones, cultivated under high pressure sodium (HPS) lamps (Fig. 2). Red and green leaf lettuce roots differentially responded to applied lighting: green leaf lettuces formed 56% higher root green biomass and two times higher root dry mass, as compared to lettuce transplants, cultivated under HPS lamps under the same intensity. Red leaf lettuce formed slightly lower green root biomass, however dry root mass was the same. This shows that LED lighting resulted in higher flux of materials to roots, thus, independently from the accumulated biomass, roots were stronger.

Compact lettuce transplant morphology resulted in their better rooting and starting growth after transplanting in greenhouse or field. More positive results were not obtained, when photosynthetic flux density of LED lighting was increased to 250 µmol $m^{-2}s^{-1}$.

Table 2. Biometric parameters of lettuce transplants, raised under HPS or HLFC series lighting in greenhouse. Photosynthetic photon flux density was 150 or 250 µmol m^{-2} s^{-1}.

Biometric parameters	HPS 150	LED 150	LED 250
Green leaf lettuce 'Lollo Bionda' transplants			
Plant height, cm	9,4±1,2	**5,9**±0,5[b]	**6,4**±0,4[b]
Leaf number, pcs.	5,1±0,2	5,3±0,3	5,3±0,1
Leaf area, cm^2	123±18	91±25	100±25
Aboveground green weight, g	3,8±0,4	3,8±1,1	**2,5**±0,3[b]
Root green weight, g	0,8±0,1	1,2±0,2[a]	1,2±0,1[a]
Root dry weight, g	0,04±0,02	0,08±0,01[a]	0,08±0,01[a]
Red leaf lettuce 'Lollo Rosa' transplants			
Plant height, cm	11,6±1,2	**8,7**±0,6[b]	**7,9**±0,9[b]
Leaf number, pcs.	5,3±0,3	5,4±0,3	5,7±0,6
Leaf area, cm^2	176±30	**127**±11[b]	**122**±23[b]
Aboveground green weight, g	3,3±0,1	3,0±0,7	3,4±0,3
Root green weight, g	0,9±0,3	0,7±0,1	0,7±0,0
Root dry weight, g	0,04±0,14	0,04±0,00	0,05±0,01

a – significantly higher, b – significantly lower than HPS 150; when p≤0,05.

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After transplanting in greenhouse (Fig.3), no significantly different effect on lettuce productivity, cultivated under HPS or HLFC series LED lighting was observed (table 3)., however, optimal photosynthetic flux of LED lighting – 150 µmol $m^{-2}s^{-1}$ – resulted in higher chlorophyll index, ascorbic acid contents and lower nitrate concentration in lettuce leaves (Fig. 4). Higher light flux of 250 µmol $m^{-2}s^{-1}$ during the whole cultivation cycle, was redundant and possibly evoked more rapid senescence processes.

Fig. 3. Different lettuce varieties, cultivated under HLFC series LED or high pressure sodium (HPS) lighting, when photosynthetic photon flux density 150 or 250 µmol m^{-2} s^{-1}

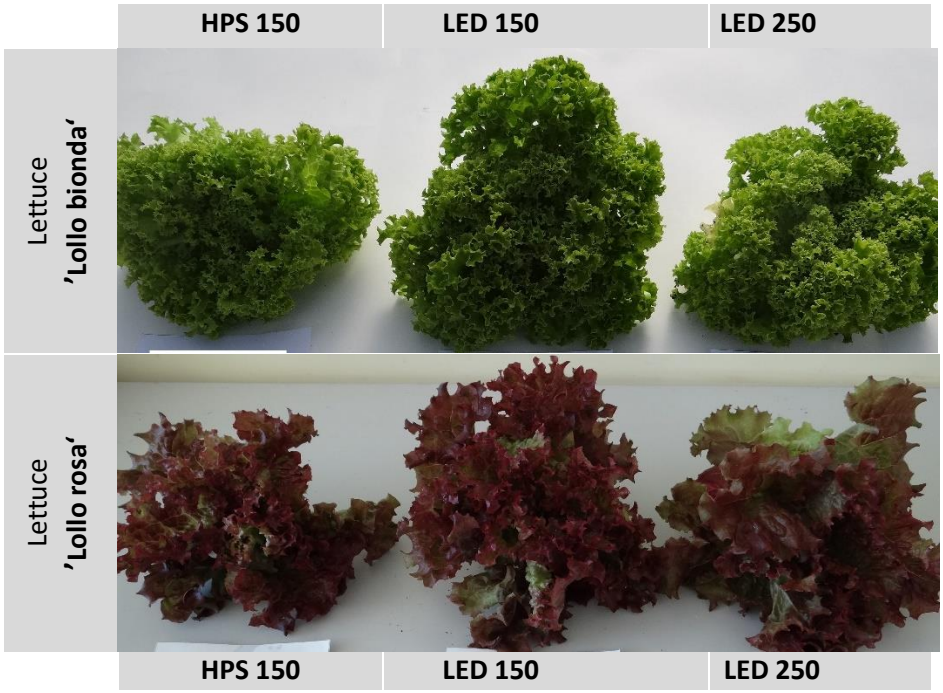

Table 3. Aboveground green mass of lettuces, cultivated under HPS or HFLC series LED lights in greenhouse. Photosynthetic photon flux – 150 or 250 µmol m^{-2} s^{-1}.

Biometric parameters	HPS 150	LED 150	LED 250
Green leaf lettuce 'Lollo Bionda'			
Aboveground green weight, g	85,1±11,6	75,3±12,6	82,2±17,2
Red leaf lettuce 'Lollo Rosa'			
Aboveground green weight, g	90,3±11,2	79,4±15,6	88,6±14,1

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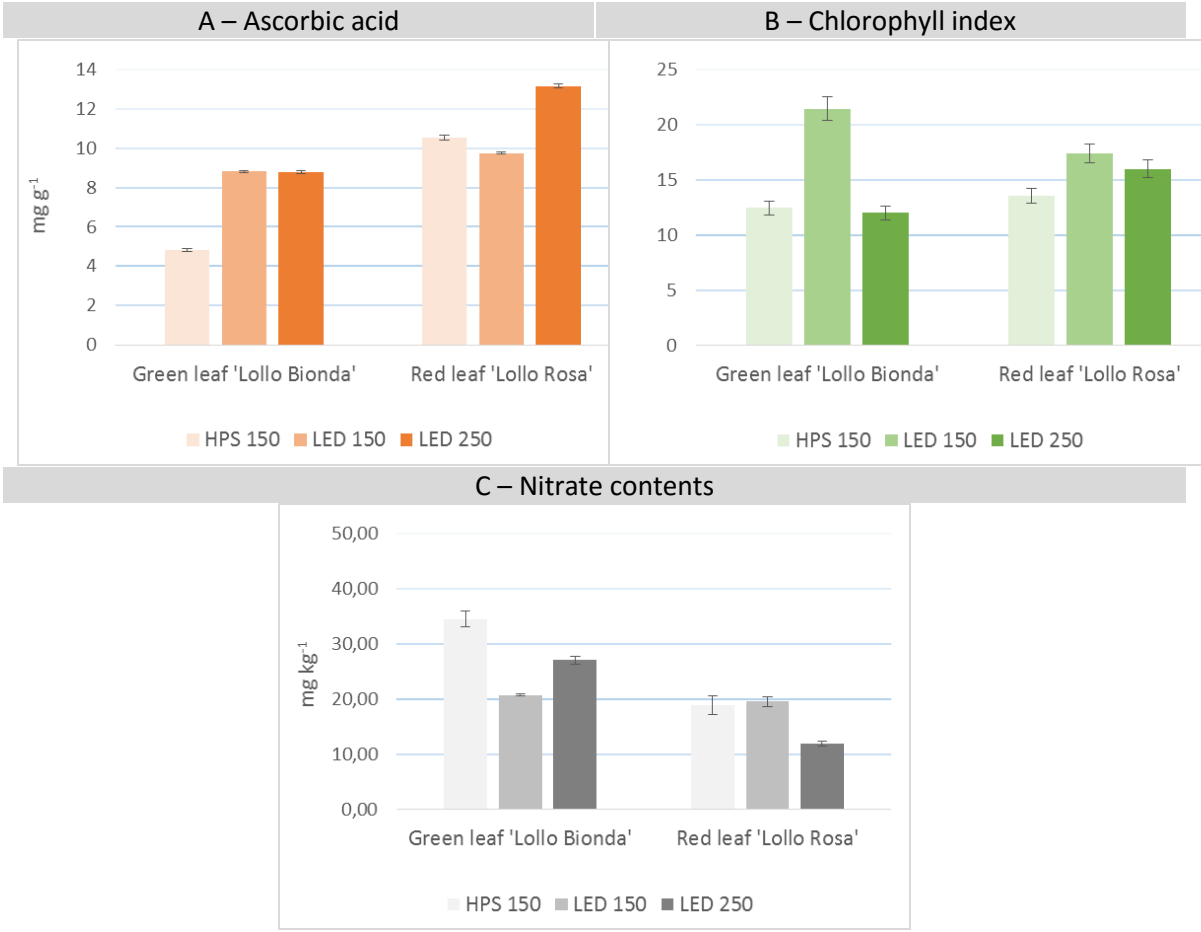
Fig 4. Biochemical parameters of lettuces, cultivated under HPS or HFLC series LED lights in greenhouse. Photosynthetic photon flux – 150 or 250 µmol m^{-2} s^{-1}.



Conclusions

- Cultivating lettuces under high pressure sodium and HLFC series LED light at the same intensity level, it was determined, that the spectra of HLFC series lamps results in more compact lettuce morphology (in all maturity stages) with no negative effect on total plant productivity,
- HLFC series LED light spectra enhanced assimilate transport to roots, thus in lettuce roots relatively higher amount of dry matter was accumulated. Lighting effect on root green biomass formation is specific for lettuce varieties.
- HLFC series LED light spectra promotes accumulation of chlorophyll pigments, ascorbic acid and evokes more intense nitrate reduction, thus increasing nutritional value of lettuce.
- There is no use to increase LED light intensity form 150 to 250 µmol m^{-2} s^{-1}, as higher lighting flux does not increase lettuce growth and productivity, but

induces natural physiological senescence processes, what is of high importance cultivating special “baby leaf” varieties.

- Seeking for optimal effect, solid state lighting spectra and intensity should be properly selected according lettuce type, variety.

Methods

The objective of studies – “baby leaf” type green leaf lettuces ‘Lettony’ and red leaf ‘Redlo’ and regular maturity green leaf ‘Lollo Bionda’ and red leaf ‘Lollo Rosa’ lettuces, cultivated in industrial greenhouse of LRCAF Institute of Horticulture, covered by double plastic cover. Lettuces raised in neutralized peat substrate PG mix. Day/night temperature ~21/17±2°C.

Supplemental lighting (in the background of natural lighting) was provided by HLFC series LED lamps, photosynthetic photon flux density of 150 or 250 µmol m^{-2} s^{-1}. High pressure sodium lamps (HPS; Son-T Agro, Philips) were used for reference at photosynthetic photon flux density of 150 µmol m^{-2} s^{-1}. 16 h photoperiod was maintained.

10 occasionally selected plants, suitable to represent the treatment were used for biometric analysis. For biochemical analysis, the conjugated biological sample from representative plants was prepared. Ascorbic acid contents were determined by spectrophotometric method. Nitrate contents – by potentiometric method, using nitrate selective electrode. Chlorophyll index – using Dualex meter (Force-A). Results are presented as the average ±standard deviation.

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