Examination of thyme leaves grown under different spectra

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Abstract—Nowadays, artificial light is often used in horticulture. The proper light composition may significantly impact plant properties, which is important from the consumer's point of view. An examination of thyme leaves grown under different spectra was performed based on experimental cultivation of thyme. Transmissive spectra, colorimetric properties, dry mass yield, and biometrical properties (shape of leaves) were determined. Attention to the issues of energy efficacy of light sources was also paid.

Nowadays, artificial lighting is commonly based on LEDs because of their increasing luminous efficacy of 200 lm/W [1] or even more [2]. However, luminous efficacy is not the main parameter describing the light sources used in horticulture, where lighting efficacy is defined as PPF photosynthetic photon flux [3,4] in the PAR range (photosynthesis active radiation, 380–780 nm) [5]. In contrast, illumination of plant cultivation is described by PPFD (photosynthetic photon flux density) [6, 7].

Test cultivation of thyme (Thymus vulgaris) [8] was carried out for the experiments. The plants were grown in a set of 7 cm × 7 cm plastic pots. Eight seeds were sown in each pot. After germination, only five plants were left in each pot. Examined leaves were harvested after 4 weeks. All plants were divided into six separate climate chambers and grown in the same environmental conditions. The temperature was set to 24±1ºC [3, 4, 9] during the day and 20±1ºC by night, the humidity was 70±10% [10], and a photoperiod of 16h day and 8h night was applied [10]. For plant illumination, dedicated lamps with six different light spectra were prepared. These spectra are a mixture of white, blue, ultraviolet, red, and far-red LEDs, with different wavelengths and proportions between individual spectral components. The last lamp, Lamp 6 utilizes a spectrum of commercially available lamp dedicated for growing plants. All lamps have light intensity (PPFD) adjusted to the same value. The reported values of PPFD for Thyme vary widely, from 38 µmol m^{-2} s^{-1} [9] up to 200 µmol m^{-2} s^{-1} [10]. Finally, all lamps were adjusted to 150 µmol/s measured at the cultivation surface level. The spectra of all the lamps are presented in Fig. 1.

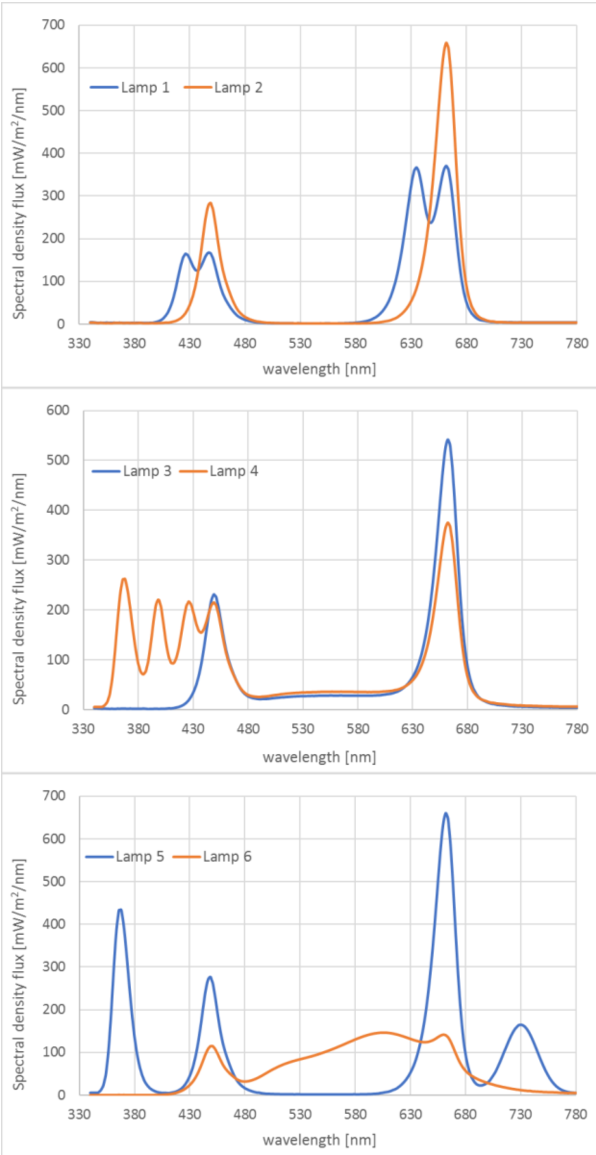

Fig. 1. Individual spectra of the lamps applied in the experiment.

Several parameters of illuminating light and Thyme leaves were determined during the examination. The dry mass yield was determined with a BTS 110 moisture

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analyzer (Axis, Poland). Light intensity, spectrum, and irradiance were measured and recorded using a portable spectrometer GL Optic Spectis 1.0 (Puszczykowo, Poland) with dedicated software. Finally, colorimetric properties were measured using a dedicated setup consisting of a reference light source and a high-end spectrometer Konica Minolta CS-2000 (Konica Minolta Sensing Europe B.V., Nieuwegein, the Netherlands) [11].

After harvesting (28 days after sowing), measurements of dry mass yield were carried out. The obtained results were subsequently averaged for all the examined lamps and presented in Table 1.

Table 1. Average dry mass of thyme leaves harvested on day 28.

Averaged dry mass of Thyme leaves [mg]						
Lamp	1	2	3	4	5	6
Thyme	33	38	30	40	52	26

The highest dry mass, significantly higher than for the other lamps, was obtained for lamp 5. This lamp utilizes blue (B) and red (R) light, with ratio R:B = 2.5:1, additionally supported by UV and far red (FR) radiation. A medium amount of dry mass was obtained for Lamps 2 and 4, while the least amount of dry mass was achieved for the remaining lamps (Lamp 1, Lamp 3, and Lamp 6).
During cultivation and harvesting, attention was also paid to the shape and color of leaves. A view of the collected samples of leaves of Thyme grown under each of the six different spectra (lamps) is shown in Fig. 2.

Fig. 2. View of the collected samples of Thyme leaves, arranged in order from left to right for the following lamps: Lamp 1, Lamp 2, Lamp 3, Lamp 4, Lamp 5, Lamp 6.

Although visual inspection of leaves may also lead to interesting conclusions, objective measurements were performed. Thus, color measurements were carried out. First, two different leaves were measured at 15 points each for each lamp. Next, colorimetric coordinates *x* and *y* (CIE 1931 Yxy color space) were calculated. Finally, the obtained coordinates for each lamp were averaged and presented in a colorimetric diagram.

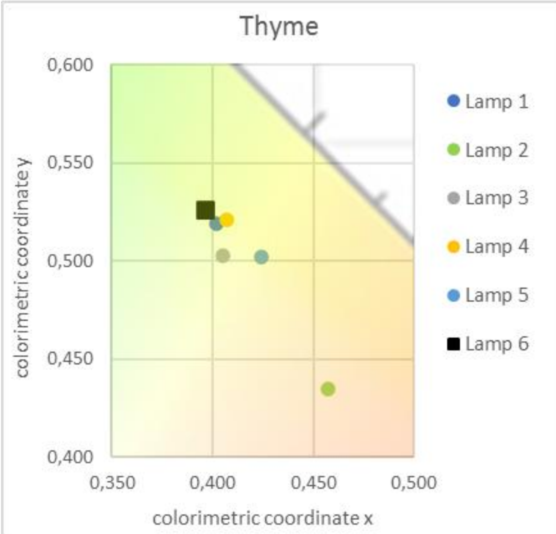

Fig. 3. Determined averaged colorimetric coordinates of Thyme leaves grown under various lamps.

The measurement results confirm the visual observations. In particular, the color of the leaves under Lamp 2 (strong red) stands out, which may indicate the presence of certain substances in them (e.g., an increased amount of anthocyanins).
Biometrical properties (leaf shape) were also examined. The length (vertical) and width (horizontal) of leaves were measured, and then an aspect ratio of leaves (elongation coefficient) was calculated. The obtained values are shown in Table 2.

Table 2. Biometrical properties of leaves of Thyme grown under different spectra.

Lamp	Leaf width W [mm]	Leaf length L [mm]	Leaf aspect ratio W/L
1	7.7	14.3	0.53
2	7.6	13.4	0.57
3	6.1	13.2	0.46
4	8.9	11.4	0.78
5	6.6	12.8	0.52
6	9.7	13.5	0.72

As can be noticed, the shape of Thyme leaves varies depending on the light spectrum. Significant differences occur for Lamps 4 and 6 (aspect ratio greater than 0.7), while for the remaining lamps these values are smaller (aspect ratio of about 0.5). Considering the results obtained from color measurements, biometrical measurements, and subjective assessment, the most attractive appearance from the consumer's point of view is characterized by plants under Lamp 2.
In the performed experimental cultivation, all lamps were adjusted for comparative study to keep the same PPFD, independently of their spectrum. However, PPFD (or

PPF) is not an ideal parameter corresponding to plants' needs for lighting. PPF applies to the entire range from 400 to 700 nm PAR range), not considering the absorption band of chlorophyll. Additionally, it relates only to the number of photons but not to photon energy (e.g., 2.75eV of 450 nm, and 1.88eV of 660 nm). Finally, some wavelengths that have a significant impact on plant development, e.g., UV or far-red (FR), are placed outside the PAR range and not included in PPF determination. Thus, in some publications, other quantities are used, such as biologically active radiation between 300–800 nm [12] or photon flux density (PFD) defined for different wavelength ranges [13].

The spectrophotometer software allows for measurement and calculation of PPFD and spectral irradiance (in radiometric and PAR ranges). The obtained values are placed in Table 3 and presented in Fig. 4.

Table 3. Measured PPFD and irradiance values.

Lamp	PPFD [μmol/m²s]	Radiometric [W/m²]	PAR [W/m²]
1	148.8	30.8	25.6
2	148.7	30.6	26.3
3	148.5	30.9	24.7
4	149.8	42.8	26.9
5	148.8	54.0	27.2
6	148.1	31.8	20.6

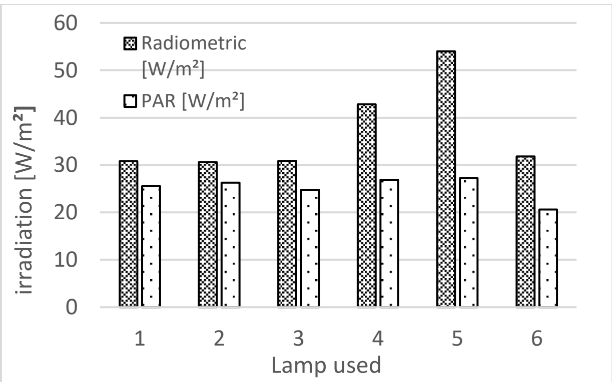

Fig. 4. Graphical presentation of measured irradiation.

Analyzing the irradiance values for individual lamps, it can be seen that the highest irradiance value (especially for the radiometric range) is correlated with the highest dry mass yield (Lamp 5). This is mainly because this lamp's energy is also delivered in the UV and FR range, not covered by the 400–700 nm range (in which PPFD and PAR are determined). An interesting observation was made for illumination resulting in the medium dry mass yield. For Lamp 4, a correlation between radiometric irradiation and mass yield is observed, however for Lamp 2 such a relationship is not noticed. This leads to the conclusion that both the spectrum and the total delivered energy (also outside the PAR range) are important.

Additionally, it can be taken into account that an increasing amount of total (radiometric) irradiation is related to increased power consumption, which became more and more important due to significant increasing of energy prices. However, it will require additional study, as the power to radiation efficiency of individual LEDs should be analyzed.

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References

[1] D.L. DiLaura, K.W. Houser, R.G. Mistrick, G.R. Steffy, *The lighting handbook* (Illuminating Engineering Society 2011).

[2] CREE Inc, *Cree® 2835 LEDs Product family datasheet*, https://cree-led.com/media/documents/data-sheet-JSeries-2835-3v.pdf (accessed 19/02/2023).

[3] M. Gilewski, Phot. Lett. Poland **11**, 115 (2019).

[4] J. Yan, H. Liu, W. Zhao, Y. Su, Proc. SPIE **12319** (2022).

[5] B. Purabi, V. Kumari V.R. Nath, P.K. Chakraborty, A. Gaber, W.F. Alsanie, B.M. Raafat, A. Hossain, Agronomy **12**, 1125 (2022).

[6] T. Hegemann, J. Balasus, Q. Trinh, A. Herzog, T. Khanh, Light Res. Technol. **54**, 429 (2022).

[7] R.J. Ritchie, Photosynthetica **48**, 596 (2010).

[8] D. Kulpa, A. Wesolowska, P. Jadczak, Notulae Botanicae Horti Agrobotanici Cluj-Napoca **46**, 525 (2018).

[9] V.R. Affonso, H.R. Bizzo, C.L.S. Lage, A. Sato, J. Agric. Food Chem. **57**, 6392 (2009).

[10] W. Letchamo, J. Hortic. Sci. **71** (1996).

[11] M. Feldzensztajn,, P. Wierzba, A. Mazikowski, Sensors **21**, 4122 (2021).

[12] H. Spalholz, P. Perkins-Veazie, R. Hernández, Sci. Hortic. **264**, 109195 (2020).

[13] J.M. Tabbert, H. Schulz, A. Krähmer, Plants **10**, 960 (2021).

