LIGHTING SYSTEM FOR STUDYING PLANT GROWTH

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ABSTRACT. The cultivation of plants on artificial light has gained special popularity in recent years. On one hand, it is economically advantageous for places with low sunshine - in the winter months or in places above the 50th parallel. Even in the conditions of our country, in the winter it is economically advantageous to grow some plants on artificial light. On the other hand, it is also relevant to the growing of plants in space - for longer stays outside the Earth where, besides providing oxygen, cosmonauts will need vegetation as a food and an environmental factor.
It is well known that plant photosynthesis has maximum effectiveness in irradiation with blue and red light. In order to investigate which part of the spectrum of visible light has the greatest impact on the growth and development of plants, the Scientific and Research Laboratory (SRL) "Lighting Equipment" at the University of Mining and Geology "St. Ivan Rilski" a specialised lighting system was created. It is an improved version and a functional extension of the lighting system from 2015. It consists of 7 cabins with dimensions 600x600x1250mm, illuminated by LED modules, each radiating in a narrow range of the visible spectrum. The cabin sizes are suitable for plant growing and full life cycle research, which includes biomass in addition to qualitative indicators such as colour, smell, taste, etc. With the help of the newly created lighting system, the influence of light of different wavelengths on the effectiveness of photosynthesis can be investigated. Research will allow plants to grow under artificial light with minimal energy consumption.

Keywords: LED, photosynthesis, photosynthetic active radiation (PAR), growth of plants, light spectrum

ОСВЕТИТЕЛНА УРЕДБА ЗА ИЗСЛЕДВАНЕ РАСТЕЖА И РАЗВИТИЕТО НА РАСТЕНИЯ

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РЕЗЮМЕ. Отглеждането на растения на изкуствена светлина в последните години доби особена популярност. От една страна това е икономически изгодно за места със слабо слънчево греене – през зимните месеци или на места над 50–ия паралел. Дори в условията на нашата страна, през зимата е икономически изгодно да се отглеждат някои растения на изкуствено осветление. От друга страна, интерес представлява също и отглеждането на растения в Космоса - при по-продължително пребиваване извън Земята, където освен за снабдяването с кислород, на космонавтите ще бъде нужна растителността като храна и средообразуващ фактор.
Известно е, че фотосинтезата при растенията има максимална ефективност при облъчване със синя и червена светлина. За да се изследва коя част от спектъра на видимата светлина влияе най-силно върху растежа и развитието на растенията, в НИЛ "Осветителна техника" към Минно-геоложки университет "Св. Иван Рилски" беше създадена специализирана осветителна уредба. Тя е подобрен вариант и функционално продължение на осветителната уредба от 2015 г. Съставена е от 7 кабини с размери 600x600x1250мм, осветявани от светодиодни модули, всеки излъчващ в тясна област от видимия спектър. Размерите на кабините са подходящи за отглеждане на растения и изследването на пълния им жизнен цикъл, което включва освен получената биомаса, така и качествени показатели като цвят, мирис, вкусови качества и др. С помощта на новосъздадената осветителна уредба може да се изследва влиянието на светлина с различна дължина на вълната върху ефективността на фотосинтезата. Изследванията ще позволят да се отглеждат растения при изкуствена светлина с минимален разход на енергия.

Ключови думи: LED, photosynthesis, photosynthetic active radiation (PAR), growth of plants, light spectrum

Introduction

In recent years cultivation of artificial light plants has gained special popularity. On one hand, it is economically advantageous for places with low sunshine - in the winter months or in places above the 50th parallel. Even in the conditions of our country, in the winter months it is economically advantageous to grow some vegetables in artificial lighting. Plant growing in space is also of interest - for longer stays outside the Earth where, besides supplying oxygen and carbon dioxide, cosmonauts will need vegetation as a food and a place to rest.

To achieve photosynthesis, a critical level of illumination is required. Photosynthesis in plants has maximum efficacy in irradiation with blue and red light. (For comparison, the human eye has a maximum sensitivity in the yellow-green range, about 555 nanometres.) (Fig. 1).

Blue and red rays affect photosynthesis directly and indirectly. Blue beams (70 kcal / mole) have about 1.5 times more energy than red (40 kcal / mole). According to quantum theory, once a photon replaces only one electron of the pigment molecule, the blue loses more unproductive energy. It was observed that in normal illumination with the same energy of blue and red light, photosynthesis is more effective with red rays. This can be explained by the fact that, with the same energy, more red quanta will fall on the leaves and therefore more pigment molecules will be excited.

At a high level of brightness, however, blue rays have the advantage because they activate protein synthesis and this has a stimulating effect on the carboxylating enzymes, while the red rays - enhance the formation of carbohydrates. The addition of blue light (about 20%) to the red, significantly enhances photosynthesis and can be used in greenhouse production.

The efficiency of conversion of light energy into chemical energy in plants is estimated to be between 3 and 6%. The actual effectiveness of photosynthesis varies greatly with changes in the light spectrum, intensity of light, temperature and carbon dioxide concentration. This part of the solar radiation spectrum (400-700 nm) is called photosynthetic active radiation (PAR) (Fig. 1). In the process of photosynthesis, practically only 1-3% of PHARE is used. Typically, PAR is expressed in μmol photons m-2s-1.

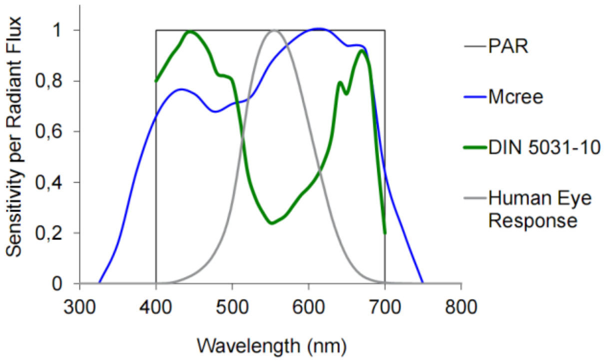

Fig. 1. Different methods of weighting the light spectrum

McCree measured three physiological parameters, including the quantum yield of photosynthesis, action, and absorptance. Physiologically, it describes the maximum photosynthetic efficiency with which light can be converted into chemical energy at low light (Fig. 1).

It is also possible to calculate the effective spectrum of photosynthesis, as its values are taken from DIN 5031-10 (Fig. 1).

The superior plants (Embryophyta) photosynthesise through leaves and stems that are rich in photosynthetic structures – chloroplasts. (Although they do not participate directly in photosynthesis, the roots are also involved.)

Photosynthesis (air feeding) is performed in the tilacloid membranes of the chloroplasts. (Fig. 2).

The chloroplasts perform: absorption of light from chlorophyll; transformation of light energy into chemical; fixing and reducing CO2; photolysis of the water.

The main role in photosynthesis plays the plant pigments, which act as primary acceptors of the light quanta and carry out the further transformation of the chemical energy.

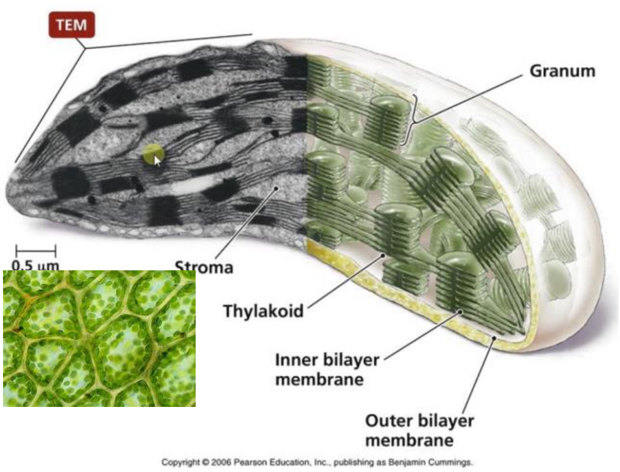

Fig. 2. Structure of the chloroplast

Plant pigments are divided into 4 types: chlorophylls, carotenoids, phycobiliens, and anthocyanins.

The main property of chlorophyll is to selectively absorb the light rays - a maximum absorption in the red area at a wavelength of 668 nm; fluorescein - dissolved in organic solvents emit red light (Krumov, A.).

Chlorophyll a and b is mainly responsible for the photosynthesis and for the definition of the area for PAR. Carotenoid are further photosynthetic pigments also known as antenna pigments like carotenoids-carotene, zeaxanthin, lycopene and lutein etc. (Fig. 3).

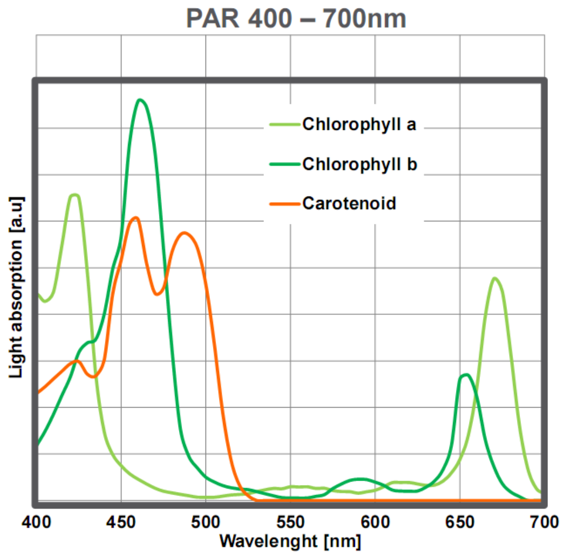

Fig. 3. Spectral sensitivity in photosynthesis (portions of the light spectrum used by the main pigments)

For some time, leading light source manufacturers have been working hard to create effective photosynthesis lamps by producing high-pressure sodium, metal halide, luminescent sodium lamps, and so on.

In recent years, due to the rapid development of LED technology, specialised photoinitiator luminaires are already available from many companies. Examples of emission spectra of such light sources are shown in Figure 4.

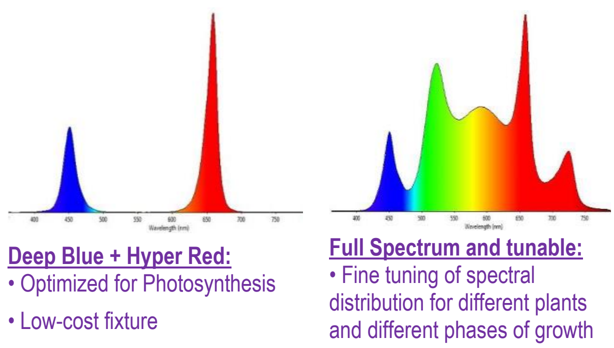

Fig. 4. Variations of radiation spectra of specialised photosynthesis luminaires

The advantage of horticultural lighting of LEDs is that a single-color LED emits light in a narrow spectral band, resulting in a saturated colour. There is also the possibility to reproduce several spectra with single-colour LEDs.

Realization

In order to investigate which part of the spectrum has the greatest influence on the photosynthesis at SRL "Lighting Engineering" at the University of Mining and Geology "St. Ivan Rilski" (UMG), a specialised lighting system was set up in 2015. It consists of 18 LEDs, each of which emits in a narrow area of the spectrum and has an intensity of photosynthetic radiation of 300-500 μmol / m3 (Table 5 and Fig. 6) and Table 1 (Velinova, 2015).

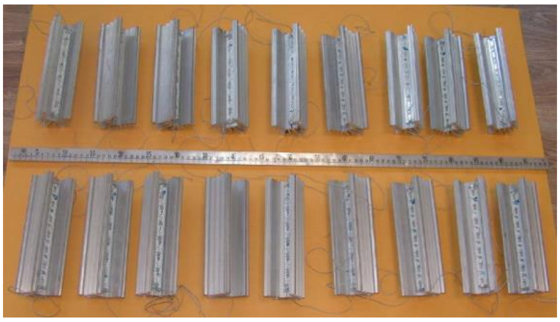

Fig. 5. 18 luminaires, each of which radiates in a narrow area of the visible spectrum

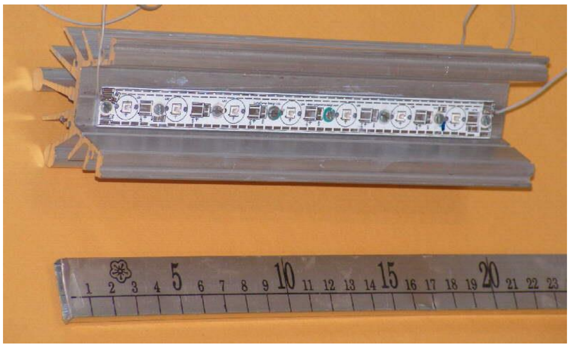

Fig. 6. One of the LED luminaries

The purpose of this system is to investigate the influence of particular parts of the light spectrum on the quantitative and qualitative characteristics of photosynthesis in different plant species, while tracking their growth and development.

Table 1.

LED №:	LED type	Length on wave λ / nm
1.	INDIGO BLUE	402 +/-3
2.	INDIGO BLUE	407 +/-3
3.	DEEP BLUE	422 +/-2
4.	DEEP BLUE	427 +/-2
5.	ROYAL BLUE	452 +/-2
6.	ROYAL BLUE	457 +/-2
7.	BLUE 1	462 +/-2
8.	BLUE 2	472 +/-2
9.	CYAN 1	497 +/-2
10.	CYAN 2	502 +/-2
11.	GREEN 1	522 +/-2
12.	GREEN 2	527 +/-2
13.	AMBER	592 +/-2
14.	RED 1	616 +/-3
15.	RED 2	625 +/-5
16.	TRUE RED 1	652 +/-2
17.	TRUE RED 2	663 +/-2
18.	DEEP RED	730 +/-10

The following species were selected as test subjects: salad (Lactuca sativa), cloves (Dianthus caryophyllus), French marigold (Tagetes patula), and tomato (Solanum lycopersicum). The following morphological indicators were examined: plant height; foliage development; number of developed leaves; stem length; length and width of the leaves; length and development of the root system.

The results of these studies are published in (Velinova, 2017a; 2017b; 2018).

Fig. 7. Test facility - mounted luminaires and plants

In the above-mentioned LED lighting system, the volume of the chambers and the size of the plants examined is limited to the dimensions of about 30x30x40 cm (Fig. 7). That is why, in 2019, another specialised lighting system was set up at the SRL "Lighting equipment" at the UMG. It is an improved version and a functional continuation of the lighting system from 2015. It consists of 7 cabins with dimensions 60x60x125 cm, illuminated by LED modules, each emitting in a narrow area of the visible spectrum. (Fig. 8 - 9 and Table 2).

Fig. 8. Specialised lighting system 2 in 2019 - cabins with illuminators and studied plants

The luminaires are made of aluminium, donated by BSM. In the first five chambers 3 luminaires with a light emitting module are housed (Figure 10, Table 2). In each module 40 LEDs are mounted GA type CS8PM1.23, GB + CS8PM1.13, GH CSSPM1.24, GT CS8PM1.13, GY CS8PM1.23. The drivers are part of a donation by OSRAM. The total power of the luminaires for each cab is about 160W.

A specialised LED light for photosynthesis is installed in chamber № 6.

In chamber № 7 is installed a LED luminaire emitting a neutral white light - 4337 K, which will be used as a cabin with control measurement samples (Fig. 9, 11 and 12; Table 2).

Table 2.

Camera №	Luminaire	Length on wave λ / nm	PAR/ mmol	Power/ W
1.	BLUE	467 +/-3	298	150
2.	GREEN	523 +/-3	219	150
3.	AMBER	601 +/-2	77	150
4.	RED	626 +/-2	237	150
5.	DEEP RED	658 +/-2	333	150
6.	BLUE / RED	447 / 650	333	160
7.	WHITE	4337 K	188	180

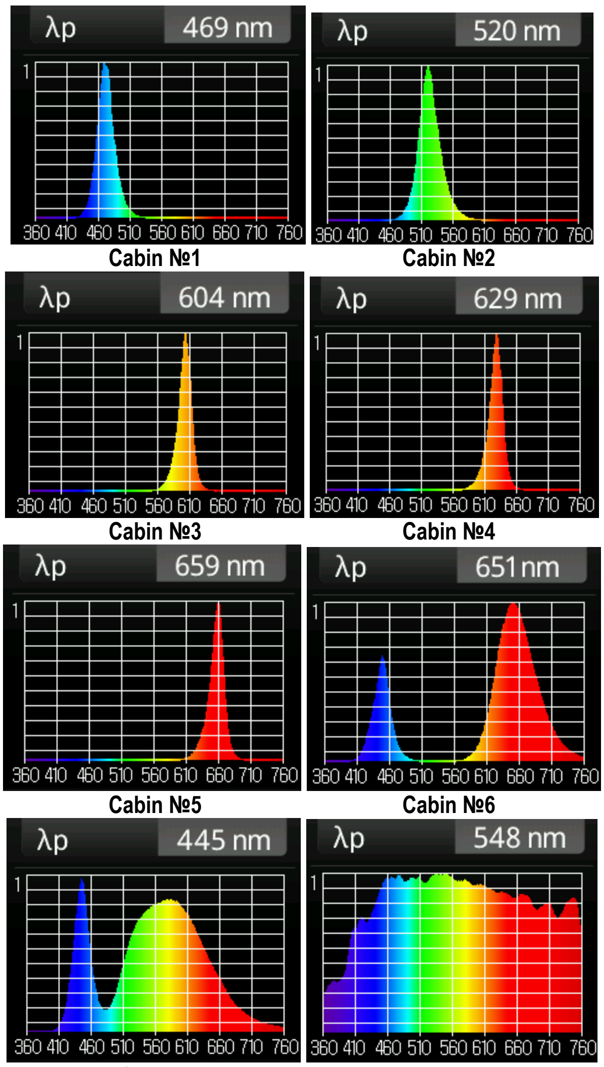

Fig. 9. Radiation spectra of each of the cameras and a spectrum of daylight (as a control)

Cabin sizes are suitable for plant growing and their full life cycle research, which includes biomass in addition to qualitative indicators like colour, smell, taste, etc.

With the help of the newly-created lighting system, the effects of light of different wavelengths on the effectiveness of photosynthesis as well as the growth and development of plants can be studied. Research will allow plants to grow under artificial light with minimal energy consumption.

Fig. 10. Cabins № 1 to 5. Lights, each of them emitting in a narrow range of the spectrum

Fig. 11. Cabin No 6 - Specialised luminaire designed for photosynthesis

Fig. 12. Cabin No 7 - Illumination light emitting neutral white light - 4337 K (control)

So far, some preliminary experiments have been made in the newly created chambers to study the impact of the light spectrum. As an experimental species the tomatoes (Solanum lycopersicum) - interdimensional strain "Milliana" are chosen and the strawberries (Fragaria sp.) - self-pollinating variety are used. (Fig. 13).

The nourishment of the plants is hydroponic using food solutions according to recipes recommended by Prof. Hristo Simidchiev (Simidchiev, Kanazirska, 2017). Other important parameters influencing their growth and development are temperature, humidity, CO2, etc., which are maintained at constant rate.

Growth assessment is done by measuring certain parameters (plant height, stem thickness, number of leaves, leaf size, number of cobs or runners, number of flowers, number of worms, number of fruits ripened, quality evaluation of fruits, etc.); visually - by assessing the total plant habit and assessing their health status.

Additionally, the chlorophyll content of plant leaf samples (in relative units) was measured using the Chlorophyll Content Meter CCM-200.

Initial results of the first samples in these chambers can be seen in Fig. 13 and 14.

Fig. 13. Cabin No 7 - Test plants on 06.06.19 (control)

Fig. 14. Cabin No 7 - Test plants on 12.07.19 (control)

It is envisaged to carry out experiments with the following types of plants: salads (Lactuca) and other leafy vegetables, spices and essential oil plants, wheat and others. Poaceae, Fabaceae, Orchidaceae, other members of the Solanaceae family, some suitable representatives of tree-shrub species. (Kalinkov, Pavlov, 1993).

The pursuit of plant selection is to use those that have a strong light response as a factor; to be suitable both as indicators and for growing in the conditions of existing cabins, if possible self-pollinating (or at least one-domed) and last but not least, suitable for consumption.

It is planned to carry out similar experiments with representatives of unicellular algae together with the Department of Engineering Geoecology, and for this purpose special containers will be made which will be illuminated with the same types of diodes mentioned above.

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References

Aleksandrov, N. 2012. *Fundamental theory of colors*. East-West, 255 p.

Angelov, V. 2018. Irradiator for growing plants without sunlight. – *VII Balkan conference on lighting - Balkanlight 2018, 04-06 june, Sofia*, 161–164.

Blankenship, R. 2014. *Molecular mechanisms of photosynthesis.* Wiley Blackwell, Washington University in St. Louis, Missouri, USA, 314 p.

Bula, R. J., D. Tennessen et al. 1994. Light emitting diodes as a plant lightning source. – *International Lightning in Controlled Environments Workshop, NASA-CP-95-3309*, 225–267.

DIN 5031-10, Deutsche norm, 2000. 03, 16-18.

Goltsev, V., M. Kaladzhi, M. Kuzmanova, S. Allahverdiev. 2014. Chlorophyll fluorescence in studies of the physiological state of plants. – *Izhevsk Moscow, Institute for Computer Studies*, 197 p.

Howell, C. H. 2009. *Flora mirabilis – how plants have shaped world knowledge, health, wealth, and beauty*. – National Geographic Society, Washington, D.C., 175 p.

Ilieva, I., Y. Naydenov. 2012. Influence of green/blue light ratio on leaf chicory physiology in rgb light. – *Eighth Scientific Conference With International Participation – Space, Ecology, Safety, 4-6, 12, Sofia, Bulgaria*, 239–243.

Ilieva, I., Y. Naydenov. 2011. Morphometric characteristics and photosynthetic activity of leaf chicory in RGB LED lighting. – *Seven Scientific Conference with International Participation, SES, Sofia, Bulgaria, 29.11-01.12*, 119–124.

Ilieva, V. 2013. Impact with optical radiation on plant and microbiological sites. – In: *Impact and study with electromagnetic fields in agriculture,* under No. 82/93 in the Central Technological Library, Sofia, 39–180.

Ilieva, V., S. Velinova. 2017. Photosynthetic active radiation - Theoretical prerequisites, basic systems and measuring units for it's measurement. *XVI National Conference with International Participation Bullight / Bulgaria Light 2017 and BalkanlightJunior 2017, 25–27 may, Sozopol*, 62–64.

Ilieva, V., S. Velinova. 2017. On some specific aspects of photosynthesis and photosynthetic active radiation. – *International Scientific Conference Uniteh 2017, 17-18 November, Gabrovo*, *1*, 154–159.

Ilieva, V., S. Velinova. 2018. LED-technology in greenhouse horticulture. *VII Balkan conference on lighting - Balkanlight 2018, 04-06 june, Sofia*, 157–160.

Ilieva, M. 2017. LED Development trends – functions, management, applications. – *Bullight 2017 – Balkan Light Junior 2017, 27.05.2017, Sozopol*, 130–135.

Ilieva, M., V. Ilieva. 2014. LED Irradiation systems for plant growing. – *XV National Conference with International Participation Bullight / Bulgaria LIGHT 2014, 10–13 June, Sozopol*, 184–187.

ISBN 978-954-765-064-0, 167-184

Kalinkov, V., D. Pavlov. 1993. *Botany*. Martilen Publishing House, Sofia, 37–43; 428–429.

Krumov, A., N. Nikolova, V. Vassilev. Biocamera for the study of fluorescence in plants.

Kudryumov, N., K. Malishevski. 2008. *The Smart Greenhouse.* Ed. Allivgo, Sofia, 173 p.

Lalayants, I., I. S. Milovanova. 1989. Green, green grass. *Quantum, 7*, Nauka, Moscow, 6–9.

Massa, G. D., J. Emmerich. 2006. Plant-growth lighting for space life support: a review. – *Gravitational and Space Biology 19 (2)*, 8, 19–29.

Mitchell, C., A. Jan Both. 2012. LEDs: The Future of Greenhouse Lighting! – *Chronica horticulturae, 52*, 1, 6–12.

OSRAM Horticultural Lighting with LEDs Presentation. – Seminar Bulgarian National Committee on Illumination (BNCI) 2019-04-09.

Pavlov, D. 2006. *Phytocenology*. ED. House LTU, Sofia, 250 p.

Poryazov, I., V. Petkova, N. Tommekova. 2013. *Vegetable production.* Publishing House "DIMI 99", Sofia.

Rittershausen, B. and W. 2002. *Orchids a practical handbook*. Hermes House.

Rossi, M., D. Casciani. 2018. Lighting design research for horticultural vegetables growing: A case study. – *VII Balkan Conference on Lighting - Balkanlight 2018, 04-06 june, Sofia,* 145–149.

Simidchiev, H., V. Kanazirska. 2017. *For hydroponics from A to Z*. Kota publ., 496 p.

Velinova, S. 2015. LED Lighting system for the study of the photosynthesis. – *Annual of Mining and Geological University "St. Ivan Rilski", 58*, 3, 105–109.

Velinova, S. 2017. Possibilities for using of mining galleries for growing plants on artificial lighting. – *International Scientific Conference UNITECH 2017, November 17-18, Gabrovo*, *1*, 148–153.

Velinova, S. 2018. Growing plants on artificial lighting. – *VII Balkan Conference on Lighting - Balkanlight 2018, 04-06 June, Sofia,* 150-156.

Velinova, S., V. Ilieva. 2017. Influence of the spectrum of light on plant growth. – *XVI National Conference with International Participation Bullight / Bulgaria Light 2017 and BalkanlightJunior 2017, 25 - 27 May, Sozopol*, 55–61.