RESEARCH OF GROWTH AND DEVELOPMENT OF PLANTS UNDER ARTIFICIAL LIGHT

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ABSTRACT. Growing plants with artificial light recently becomes quite relevant. Two specialized lighting systems were created in the Research Laboratory "Lighting Technology" at the University of Mining and Geology "St. Ivan Rilski" in order to study which part of the spectrum of visible light has the strongest influence on the growth and development of plants. The first one was set up in 2015 and the second one - in 2019. Cabins dimensions of the second system are suitable for growing plants to their full life cycle - not only measurement of quantitative indicators and the obtained biomass, but also qualitative indicators such as color, odor, taste and others. The influence of light with different wavelengths on photosynthesis efficiency was studied with the help of the newly created lighting system. This report presents some pilot experiments for the selection of plant species that would be suitable as indicators for research in their cultivation under artificial light. Some guidelines are also mentioned in determining the methods for evaluation of obtained results. More detailed examination in the recent experiments, showed in this paper, concernes cultivation of tomato plants (Solanum lycopersicum) with the application of newly created lighting system. Research will allow plants to be grown with artificial light with minimal energy consumption.

Keywords: LED, photosynthesis, photosynthetic active radiation (PAR), growing plants in artificial light, light spectrum

ИЗСЛЕДВАНЕ НА РАСТЕЖА И РАЗВИТИЕТО НА РАСТЕНИЯ ПРИ ОТГЛЕЖДАНЕТО ИМ НА ИЗКУСТВЕНА СВЕТЛИНА

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РЕЗЮМЕ. Отглеждането на растения при изкуствена светлина в последно време придоби особена актуалност. За да се изследва коя част от спектъра на видимата светлина влияе най-силно върху растежа и развитието на растенията, веднъж през 2015 и втори път през 2019 г. в НИЛ "Осветителна техника" към Минно-геоложки университет "Св. Иван Рилски" бяха създадени две специализирани осветителни уредби. Размерите на кабините на втората уредба са подходящи за отглеждане на растения и изследването на пълния им жизнен цикъл, което включва освен измерването на количествени показатели и получената биомаса, така и качествени показатели като цвят, мирис, вкусови качества и др. С помощта на новосъздадената осветителна уредба е изследвано влиянието на светлина с различна дължина на вълната върху ефективността на фотосинтезата. Този доклад представя някои пилотни експерименти за избор на растителни видове, които биха били подходящи като индикатори за изследвания при отглеждането им на изкуствена светлина. Споменати са също и някои насоки при определяне на методите за оценка на получените резултати. В доклада по-подробно са разгледани последно проведените експерименти с отглеждане на доматени растения (Solanum lycopersicum) в новосъздадената осветителна уредба. Изследванията ще позволят да се отглеждат растения при изкуствена светлина с минимален разход на енергия.

Ключови думи: LED, фотосинтеза, фотосинтетичнактивна радиация (ФАР), отглеждане на растения на изкуствена светлина, спектър на светлината

Introduction

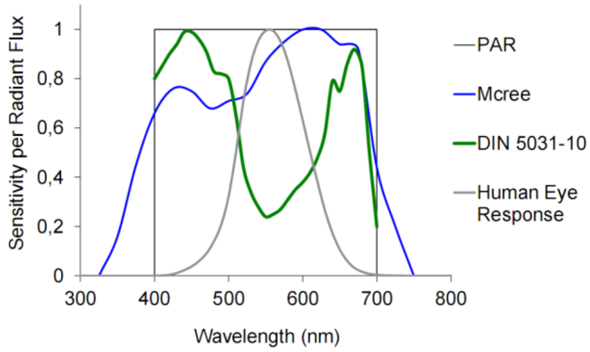
Cultivation of artificial light plants in recent years has gained special popularity. On one hand, it is economically advantageous for places with low sunshine during winter time or northern from 50th parallel. Even in the conditions of our country, in the winter months it is economically advantageous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

Critical level of illumination is required for photosynthesis. Photosynthesis in plants has maximum effect in irradiation with blue and red light. (For comparison, the human eye has a maximum sensitivity in the yellow-green range, about 555 nanometers.) (Figure 1).

Blue and red rays affect photosynthesis directly and indirectly. Blue rays (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 is losing 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) (Figure 1). In the process of photosynthesis, practically only 1-3% of PAR is used. Typically, PAR is expressed in µmol photons m-2s-1.



Фиг. 1. Different methods of weighting the light spectrum

McCree measured three physiological parameters: 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 based on DIN 5031-10 (Fig. 1).

Due to the rapid development of technologies in the field of LED technology, specialized luminaires for photosynthesis are already available from many companies. Examples of emission spectra of such light sources are shown in Fig. 2

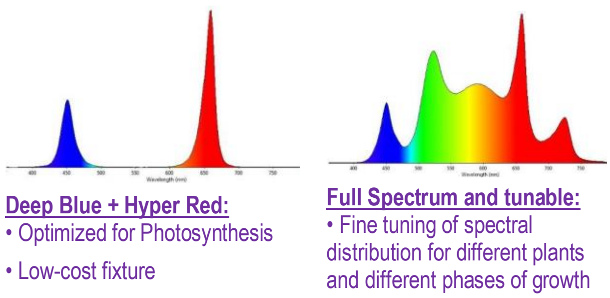


Fig. 2. Variants of emission spectra of specialized luminaires for photosynthesis

Advantages of LEDs in the field of plant cultivation are that a single-color LED emits light in a narrow spectral band, resulting in a saturated color. Reproduction of several spectra with single-color leds is also possible.

Realization

In order to study which part of the spectrum most strongly influences the photosynthesis in research laboratory "Lighting Technology" at the University of Mining and Geology "St. Ivan Rilski ", in 2015 a specialized lighting system was created. It consists of 18 LED luminaires, each of which emits in a narrow area of the spectrum and the intensity of photosynthetic radiation of 300 - 500 µmol /s.m^2 (Velinova, 2015).

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

The following species were selected for study: lettuce (Lactuca sativa), cloves (Dianthus caryophyllus), tagetes (Tagetes patula), tomato (Solanum lycopersicum). The following morphological indicators were studied: plant height; leaf mass development; number of developed leaves; stem length; leaf length and width; length and development of the root system.

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

In the above-discussed LED lighting system, the volume of the chambers and respectively the size of the studied plants is limited to dimensions of about 30x30x40 cm. Therefore, in 2019 in RL "Lighting Technology" was created another specialized lighting system (Fig. 3).

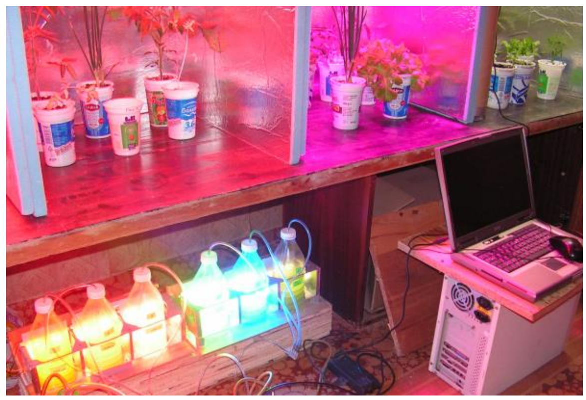


Fig. 3. Specialized lighting system 2 – 2019 year

It is an improved version and functional continuation of the one 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 (Table 1, Fig.3 and Fig. 5).

Table 1

Chamber №	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

A specialized LED luminaire designed 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. 4).

Fig. 4. Chamber № 7 with neutral white LED light.

The dimensions of the cabins are suitable for growing plants and the study of their full life cycle, which includes not only the obtained biomass, but also quality indicators such as color, odor, taste and others. A more detailed description of this lighting system is given in (Velinova, 2019).

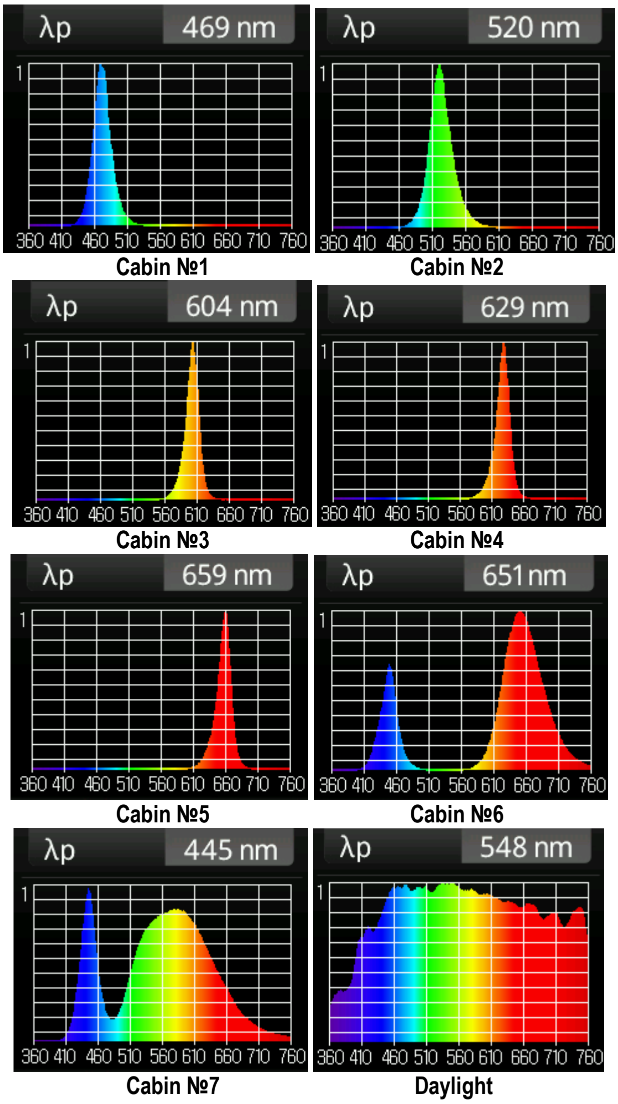


Fig. 5. Emission spectra cameras VS spectrum of daylight

The problems and questions that arise during such experiments are the following:

- Selection of suitable plant species: The aim is to use those that have a strong reaction to light as a factor; be suitable both for indicators and for growing in the conditions of the available cabins, if possible to be self-pollinating (or at least monoecious) and last but not least, those that are suitable for consumption;
- Providing appropriate conditions such as temperature, humidity, light regime and intensity, CO_2, nutrients, pollination and retention of fruits, protection and control of pathogens and pests, etc. These parameters are kept constant and are the same for each cabin.
- Use of appropriate assessment methods at each stage of plant development: The light spectrum in nm and the PHAR intensity in µmol / s.m2 were measured in each cabin (Table 1) using a Specbos 1201 spectroradiometer. The evaluation of growth and development is performed by measuring certain qualitative and quantitative indicators (plant height, stem thickness, number of leaves, leaf size, number of stalks or stems, number of flowers, number of ties, number of fruits managed to ripen, qualitative evaluation of fruits, etc.); visually - by assessing the general habitus of the plants and assessing their health (relative visual assessment).
- Objective interpretation of the results of the experiment: The results are presented in tables and graphs, and it is still too early to draw definite conclusions due to insufficient statistical material and too many factors that influence the experiments, despite the desire to unify them.

Preliminary experiments carried out in 2019

In 2019, some preliminary (pilot) experiments were performed in the newly created lighting system. Tomatoes (Solanum lycopersicum) - variety "Milyana" (Fig. 6) and strawberries (Fragaria sp.) - self-pollinating variety were used as experimental species. (Fig. 7).

Fig. 6. Tomato plant from the experiments in 2019.

Feeding of the plants was hydroponic, using nutrient solutions according to recipes recommended by (Simidchiev Hr., V. Kanazirska, 2017). Such a feeding method is more suitable for constant circulation of the solution. Unfortunately, in our case there was no possibility for this and unicellular algae stuck to the walls and bottom of the containers, so for the next experiments in 2020 the cultivation and feeding of the plants was in containers with soil-fertilizer mixture and liquid fertilizers.

Fig. 7. Strawberries fed hydroponically -experiments in 2019.

When growing strawberries in the cabins, it was found that the conditions there were not suitable for these crops: insufficient ventilation, relatively high temperatures and the appearance of mites greatly compromised the strawberrie plants and the further conduct of the experiment with it. For future experiments with strawberries, it is necessary to provide better ventilation, carrying them out during the colder months of the year and last but not least - good sterilization of the room and the soil substrate.

On the other hand, tomato plants responded quite well to the same conditions in the cabins where strawberries were grown, so experiments with them were continued in 2020, but with a different variety (Rugby), which was considered more suitable as an object for research and evaluation.

Experiments carried out in 2020.

As experimental species were used tomatoes (Solanum lycopersicum) - variety "Rugby" (Fig. 12), onions (Allium) (Fig. 9), lettuce (Lactuca sativa) (Fig. 9), and tagetes (Tagetes patula) (Fig. 11).

The plants are moved under the lamps at a stage of development seedlings - after the growth of the first true leaf. They are selected so that they are relatively the same size. At certain intervals (two to three weeks) they are measured and photographed. During each measurement, the temperature and humidity of the air in the cabins are taken into account (the average temperature is maintained around 20-25^{o} and the humidity 55-60%). The light regime in the cabins is 18 hours light / 6 hours dark, in order to bring the light conditions close to the natural ones for the plants.

Growing Egyptian onions (Allium cepa var. multiplicans). Egyptian onions are grown mainly for their leafs similar to some other species of onions, with the difference that it withstands low temperatures and can overwinter outdoors. Instead of flowers, a group of bulbs is formed directly on the tops of the flowering stems, which weigh, bend the stem and when in contact with the ground put down roots, thus multiplying - hence the name "creeping onion".

On 24.01.20 the plants were placed under the lamps in the cabins – one bucket with 3 bulbs each. The following indicators were measured: plant height (the aboveground part) in centimeters; number of leaves; thickness of the stem in its thickest part in mm.

Results for height and relative visual assessment are presented in (Fig. 8) and (Fig. 10).

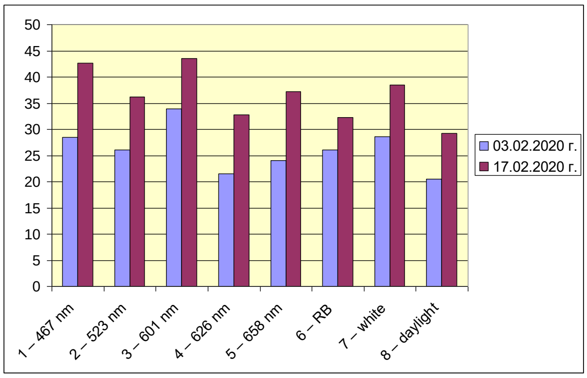


Fig. 8 Egyptian onion - plant height in cm - 03.02 and 17.02.20.

The plants formed edible leaves after about two weeks. Measurements were made, after which the leaves were cut, leaving one leaf at a time. After about a month, they grew back to approximately the previous level. The best growth was observed in the blue (1), combined RB (6) and white LED (7) spectrum.

Fig. 9 Leafy vegetables - 19.03.2020

Growing lettuce (Lactuca sativa) - variety "Oak leaf".

On 20.02.20 the plants were placed under the lamps. The following indicators were measured: height and width (diameter) of the aboveground part of the salad in cm and number of leaves. Results for relative visual assessment are presented in (Fig. 10).

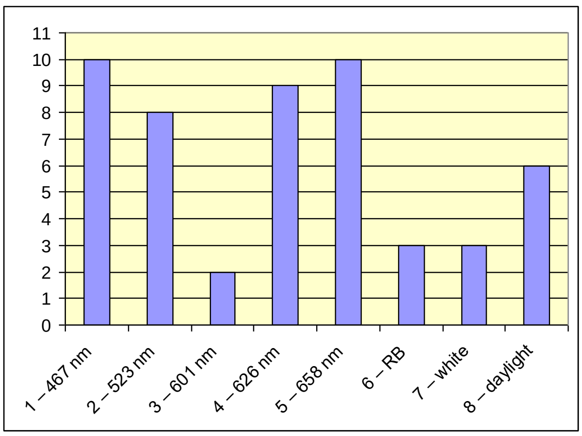


Fig. 10 Lettuce and leafy vegetables - relative visual assessment from 1 to 10 on 19.03.2020.

The salads reached an edible size after about a month. The most satisfactory results were in the blue (1), red (4 and 5) and somewhat green (2) spectrum.

Growing tagetes (Tagetes patula) On 17.06.20, 9 buckets were placed under the lamps in a cabin. (Fig. 11). After a month they were in the flowering stage. No visible differences in plant growth and development were observed in the different light spectra.

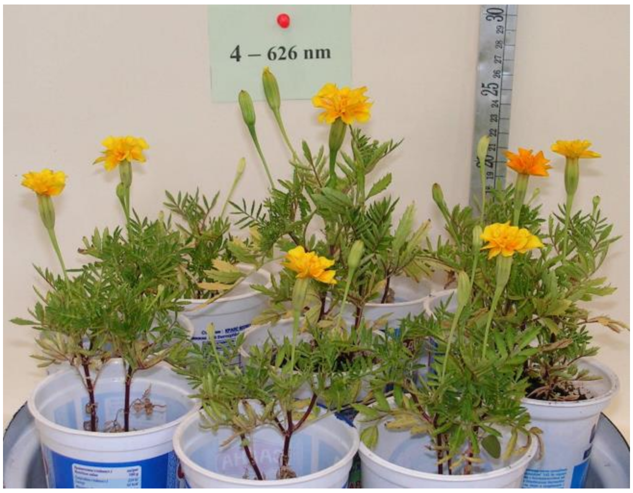


Fig. 11 Tagetes photographed on July 17, 2020

Growing tomatoes (Solanum lycopersicum). On 24.01.20 they were placed under the lamps – 4 plants in a cabin, each planted in a separate container (Fig. 12).

Fig. 12 Tomatoes photographed on March 6, 2020

The following indicators were measured: height of the plant (above-ground part) in cm. (Fig. 14); thickness of the stem in its thickest part in mm (Fig. 13); number of leaves (with stalks) (Fig. 16); length of the largest leaf in cm.; number of stalks; number of flowers (flower buds) (Fig. 13 и Fig. 17); number of ties (Fig. 13) and number of ripe fruits (Fig. 13). A relative visual assessment of 1 to 10 was also made (Fig. 15).

Fig. 13 Some of the measured indicators

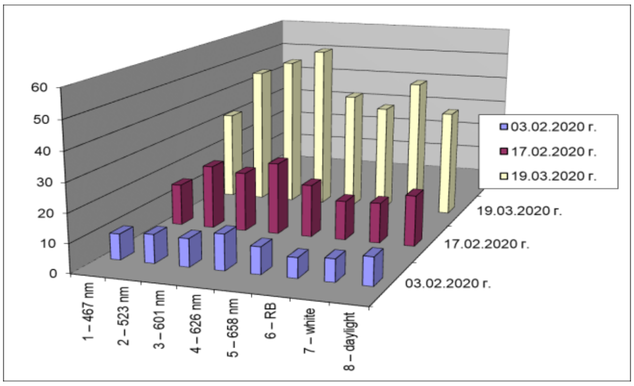


Fig. 14 Tomatoes - stem height in cm measured on 03.02, 17.02 and 19.03.20.

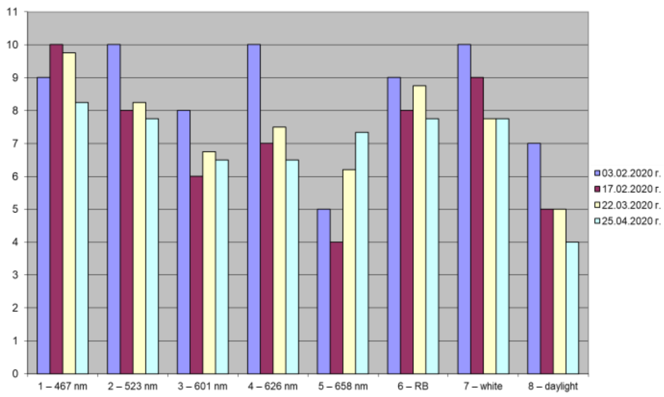


Fig. 15 Tomatoes - Relative visual assessment from 1 to 10 made on 03.02, 17.02, 22.03 and 25.04.20.

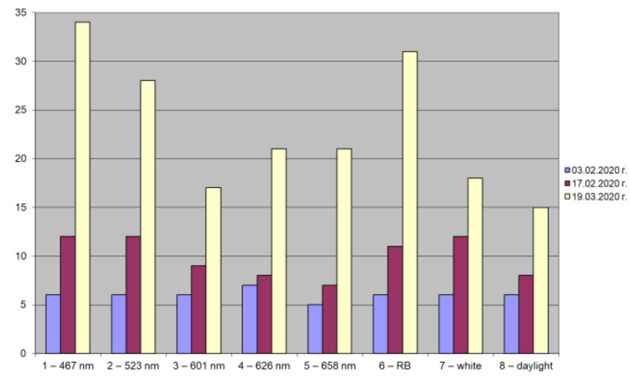


Fig. 16 Tomatoes - Number of leaves (with stalks) on 03.02, 17.02 and 19.03.20.

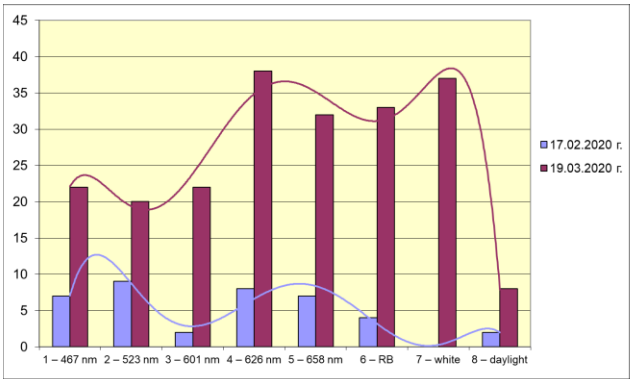


Fig. 17. Tomatoes - Number of flowers (flower buds) on 17.02 and on 19.03.20 the graph is for the total number in each cabin

Number of tied fruits. In the case of tomatoes as cross-pollinated plants, artificial pollination had to be carried out. The number of tied fruits as of 19.03.20 was the largest in cabins (1) - blue, (4 and 5) - red and (6) RB spectrum.

Fig. 18 Tomato plant photographed on April 21, 2020

A qualitative evaluation of the ripe fruits was made by tasting by three evaluators. There was no relationship between the taste of the fruit and the spectrum of light under which it was grown.

Conclusions and guidelines for future work

- The main observations so far are that during the different stages of plant development a somewhat different spectrum of light is required. It is recommended to add other spectra (blue, red and green) to the main white light.
- Growing plants in artificial light in the above lighting system is more suitable and effective for young plants up to the seedling stage (for about 1-2 months). Problems arise when growing adult plants for a long period of time: there is a depletion and weariness of plant resources after the first harvest, which slows down and stops later growth.
- It is desirable to carry out the experiments in the cooler months of the year in order to more easily provide appropriate temperature and humidity conditions. (the cooling of the lamps additionally heats the cabins). In this way, the danger of diseases and pests, which usually occur in warmer and drier environments, is avoided.
- Objective interpretation of the results of the experiment and drawing the appropriate conclusions are still a problem.

Acknowledgements. *Research Laboratory "Lighting Equipment", Assoc. Prof. Dr. Eng. Krasimir Velinov, Prof. Dr. Veselina Ilieva, Prof. Dr. Hristo Simidchiev, Prof. Dr. Vasily Goltsev, Assoc. Prof. Dr. Eng. Svetlana Bratkova.*

References

Aleksandrov, N., 2012. Fundamental theory of colors ed. East-West, ISBN: 978-619-152-110-4, p. 255.

Angelov, V., Irradiator for growing plants without sunlight, 2018,VII Balkan conference on lighting - Balkanlight 2018, 04-06 june, Sofia, ISBN 978-954-353-347-3, 161-164.

Blankenship R., 2014. Molecular mechanisms of photosynthesis, WILEY Blackwell, Washington University in St.Louis, Missouri, USA, ISBN 978-1-4051-8975-0

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, p. 197

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, ISSN 1314-0787, 184-187

Ilieva, V., S. Velinova LED-technology in greenhouse horticulture, 2018,VII Balkan conference on lighting - Balkanlight 2018, 04-06 june, Sofia, ISBN 978-954-353-347-3, 157-160.

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

Rossi, M., D. Casciani. 2018. Lighting design research for horticultural vegetables growing: A case study (in English), VII Balkan conference on lighting - Balkanlight 2018, 04-06 june, Sofia, ISBN 978-954-353-347-3, 145-149.

Simidchiev H., V. Kanazirska, 2017. For hydroponics from A to Z, Kota publ., ISBN 13 9789543054381, p. 496

Velinova, S., 2015. LED Lighting system for the study of the photosynthesis, 58th International Scientific Conference, October 20, Sofia, Yearbook of Mining and geological university "St. Ivan Rilski ", vol. 58, scroll III, ISSN 1312-1820, 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, ISSN 1313-230X, vol. 1, 148-153.

Velinova, S., Growing plants on artificial lighting. 2018. VII Balkan conference on lighting - Balkanlight 2018, 04-06 june, Sofia, ISBN 978-954-353-347-3, 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, ISSN 1314-0787, 55-61

Velinova, S., 2019 Lighting system for studying plant growth, 62th International Scientific Conference, October 20, Sofia, Journal of Mining and geological sciences, vol. 62, scroll III, ISSN 2682-9525, 132-137.