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FEATURES CHOICE OF LIGHT SOURCES FOR BIO-TECHNICAL LIFE SUPPORT SYSTEMS FOR SPACE APPLICATIONS

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ABSTRACT

The historical aspects and prospects of the use of artificial light sources in the biological and technical systems of life support for space applications are considered. According to the given data, the most promising for such systems are LED light sources. Based on the results of photobiological studies it is shown that radiation, perceived by a man as white, in his spectral efficiency unreliable differs from radiation, a spectral curve similar to the average action spectrum of photosynthesis the green sheet ("Phyto"). In accordance with this, the possibility of choosing either a phyto spectrum or a spectrum close to the equal energy for the cultivation of plants in life support systems is justified.

Keywords: light sources, light spectral composition, LEDs, LED lamps, life support systems

1. INTRODUCTION

Active researches on **b**io-**t**echnical **l**ife **s**upport **s**ystems (BTLSS) began in the 60-s years of the last century after the first human flight into space and are continuing to the present time in Russia, USA, China, EU, Japan, etc. In fact, all the established BTLSS provide for the use of artificial lighting, which is energetically used as a light power for the functioning of the phototrophic link that provides humans with plant food, water, regenerates the atmosphere and participates in the involvement in the circular process of organic waste.

The first real operating BTLSS for man was created in the Physical Institute of the USSR in the middle of the 60-s years of the last century. In the first such system ("BIOS-1") as a source of water and regenerator of the atmosphere for humans Chlorella was used [1]. Xenon lamp with water cooling DXt-6000 was selected as a light source for such systems [2]. The reasons for the choice of this source were mainly: – A large radiation flow in the area of photosynthetically active radiation (PAR), which causes a high photosynthetic activity (in this case, Chlorella) in the production of oxygen for humans and utilization of carbon dioxide released during its breathing; – The spectral composition of the PSAR, like sunlight, is conducive to the photosynthesis of Chlorella; – High sustainability of the design (the destruction of the lamps does not add toxic substances in BTLSS); – Easy operation (the lamp is compact enough, and therefore several lamps of this type easily fit into the internal space of cultivators for plants (in this case Chlorella). The practice of using Xenon lamp 6000W in "BIOS-1" was so successful that in the next, more advanced system " BIOS-2", containing Chlorella or higher plants (wheat and a number of vegetable crops), we used lamps of this type. At the same time, these plants, cultivated under the light of these lamps, showed good growth, development and productivity. Based on these results, the xenon lamps 6000 W were further used in the creation of a full-scale closed ecosystem "BIOS-3" for the cultivation of both Chlorella and a whole set of grains, oilseeds and vegetables, providing a complete plant-based diet of man. Xenon lamps 6000 W radiation, which has a spectrum in the visible region close to the Sun one, provided high productivity levels of wide range of cultivated plants [3]. At the same time attempts were made to create BTLSS with a person in the Institute of biomedical problems of Ministry of health of the USSR. As light sources in such systems, incandescent lamps with water cooling were initially used, and xenon lamps were used later [4]. These studies have not received further development, as the Institute focused mainly on the study of medical and biological problems to ensure human flight in microgravity. Life support systems with a person were created and tested in the United States in the 90-s years of XX century. A special chamber ("NASA's Biomass Production Chamber"), in which various species of higher plants were cultivated as the basis of the photosynthetic link of a closed ecosystem [6, 7], was functioning in the Space centre named by Kennedy [5], USA, in 1988–2000, as part of the NASA program. Metal halide lamps (MHL) with white radiation and high-pressure sodium lamps (HPSL) were used in these studies for the cultivation of plants. Further researches on justification of possibility of use of blue-red radiation in life support systems [8] were conducted in this organization. At the same time the research on the creation of BTSA with a person when using higher plants was conducted in the Houston space centre of L. Johnson [9]. The MHL with radiation perceived by the eye as white was used for growing wheat plants, and LEDs, which give combined radiation in the blue and red regions of the spectrum [10], was used for growing lettuc.

At the same time BTLSS, which used either artificial or natural or mixed light for the cultivation of plants, was created in Japan. Only artificial light created by HPSL was used in a number of "compartments" of this system [11].

Over the last few years new modern BTLSSs were created in Beijing and Shenzhen (China). Both of these systems are equipped with irradiators with LEDs, giving a combination of blue-red and white radiation for the cultivation of plants [12, 13]. In spite of the fact that the prospects for the use of LED in future BTLSS is no objection, now still there is no clear idea of what type should be the emission spectrum of these lamps in conditions BTLSS. The first attempts to use LED-lamps in BTLSS were made at the turn of the 80–90-ies years, when the first samples of irradiators with red LED lamps were tested on irradiation of plants in BTLSS [14, 15]. However, these attempts were not widespread, since the first samples of LED-lamps gave too weak, practically only red radiation that did not provide a light flow full-fledged for the production process in various plant species. Further progress in the improvement of irradiation technology with LED lamps primarily associated with the creation of blue LEDs allowed LEDs irradiators creation with virtually unlimited possibilities of variation of the visible radiation spectrum. The understanding of high spectral efficiency of radiation, similar in the structure of the spectrum of the green leaf photosynthesis [16, 17], has led to the fact that the lighting industry began to mass-produce irradiators, giving blue-red radiation, supplying photo spectrum. Experience in the use of such irradiators for the cultivation of plants has shown that it is not always the LEDs of photo spectrum deliver higher plant productivity than the white LEDs deliver it. Comparable productivity results are often obtained. In particular, such results are obtained on salad [18].

To find out how this may relate to other cultures within the main range of phototrophic link BTSA, we carried out experiments on the cultivation of wheat line 232, chufa and radishes in a temperature controlled, sealed growing chambers with LED-reflectors, giving a white and blue-red radiation spectrum.

2. EXPERIMENTAL TECHNIQUE

Plants were grown by hydroponic method using a standard nutrient solution (Knop medium with the addition of citrate of iron and trace elements). The air temperature in the chambers was maintained within (23 ± 1) °C. The selected plant species were successfully cultivated in a closed ecosystem "BIOS-3" [3]. To conduct the experiments, the company used the lamps of the company "LED-ENERGOSERVICE", Ltd. (trade mark "OPTOGAN"), giving the radiation perceived by the eye as white, and lamps, giving mainly blue-red radiation (Fig. 1). The density of photosynthetic photon flux for radish was 750 μmol/m^2•sec, and for more light-loving crops (wheat, chufa) – 1000 μmol / m^2 •sec. In radiometric measurements the "LI-250A" (LiCOR, USA) was used. The spectrum of radiation produced by irradiators (Fig. 1) was measured by the spectrometer "AvaSpec-ULS2048-USB2" (Avantes, Netherlands). More detailed methods and methods of cultivation of plants are described in articles [19, 20].

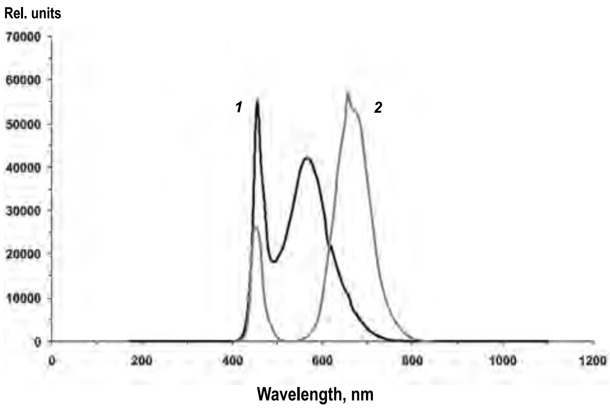

Fig.1. The relative spectrum emission of the irradiators, supplying white (1) or blue-red (phytospectrum) (2) radiation

3. EXPERIMENTAL RESULTS AND THEIR DISCUSSION

The results obtained (Fig. 2) show that the differences in the production characteristics of the studied plant species are within the measurement error. A similar conclusion was obtained for the salad in [18].

Long-term studies on the spectral efficiency of radiation in the production process [21] showed that the correct selection of irradiation levels at the radiation spectrum in the region of HEADLIGHTS (close to the equal energy) allows having a high productivity of virtually all species of cultivated plants [3]. With regard to the achievement of potential plant productivity, it is possible at certain deviations from the energy efficiency of the radiation spectrum. It is also necessary to take in account that to achieve high productivity in the cultivation of crops, the key for the formation of plant based human diet needs a very high irradiance in the PAR range. In this case, phytocenoses must have a high optical density (large sheet index) [22]. These circumstances can significantly affect the shift of the spectral efficiency of radiation from the red spectral region to the shorter-wave part of the PAR region [23, 24]. In this case, there is certain dependence between the radiation spectrum and the plant species [21, 22]. When working in a light environment created by LEDs with a strong difference between their radiation and white radiation, the staff can quickly get tired of vision: colour perception is distorted and there is a feeling of discomfort. This is confirmed by the data that the light sources with a sufficiently large blue component of the PAR spectrum can have a very harmful effect on the structure of the human eye and its physiological state as a whole. In particular, the article [25] is devoted to this issue, which emphasizes that this drawback is typical for LEDs with a share of blue radiation of the order of 30 % or more. Unfortunately, many modern irradiators with LEDs related to the so-called “phyto lamps”, have in the visible spectrum of the blue share of just about 30 % or more, which probably allows us to refer them to the kind of products with an increased risk of negative effects on the human eye. Although for detailed understanding of the mechanisms that underlie this “negative” requires specific additional research for us, while it is clear that for a person it is very undesirable, and for the inhabitants BTLSS, which

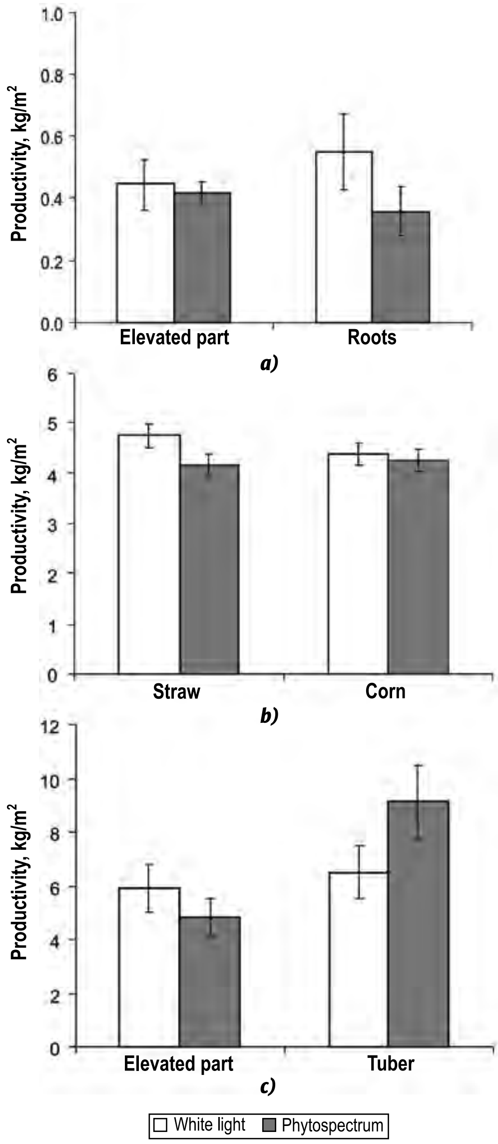

Fig. 2. The productivity of plants when using illuminators with LEDs of different emission spectrum: a – radish; b – wheat; c – chufa

can be isolated out of ground conditions, is unacceptable. Therefore, when using irradiators with LEDs in BTLSS, it is advisable to focus on a close to equal-energy spectrum of their radiation. In this case, two important tasks are solved to create a light environment for plants and humans: high productivity of plants is ensured and the negative impact of visible radiation on the human eye is eliminated. Therefore, now there is a tendency of “escape” from the light environment created in the BTLSS by irradiators with blue-red LEDs. In particular, blue-red radiation in this case is “diluted” by mixing it with white [12, 13, 26].

4. CONCLUSION

Today the reflectors with LEDs have top priority to be used in BTLSS. The selection of the radiation spectrum of such irradiators should be a compromise between the requirements for the spectral efficiency of radiation for different plant species cultivated in BTLSS and the creation of a comfortable light environment for the human eye. Preference should be given to such LED-irradiators, whose radiation is close to white light.

The study of the efficiency of irradiators with LEDs for the cultivation of wheat, radish and chufa was carried out at the Institute of Biophysics of SB RAS with the support of the Russian scientific Fund (project No. 14–14–00599P), and its results correspond to the topic of state assignment VI.56.1.4.

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