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NEW LEDs LIGHT MODULE DEVELOPED UNDER THE *GREENHOUSE-MARS* PROJECT

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Abstract

According to the Greenhouse-Mars Contract for scientific cooperation between the Space Research Institute, Sofia, and the Institute of Biomedical Problems, Moscow, Bulgarian scientists developed a new Light Module on light-emitting diodes (LM-LED). A new LM-LED was developed with monochromatic LEDs (Cree® XLamp® 7090 XR) emitting in the red, green and blue (RGB) spectral range. DMX control unit was used to set up a predefined Photosynthetic Photon Flux Density (PPFD) within the range of 0-400 µmol.m^{-2}.s^{-1}. Laboratory technical and biological tests of the LM-LED were completed using the equipment of the SVET-2 Space Greenhouse (a prototype of the one flown onboard the MIR Orbital Station). Two one-month experiments with lettuce and radicchio plants were carried out with the new LM-LED (spectral composition - 70% red, 20% green and 10% blue light) and PPFD – 400 µmol.m^{-2}.s^{-1} (high light) and 220 µmol.m^{-2}·s^{-1} (low light). Plant growth and some biochemical parameters were evaluated and compared to the results from similar experiments carried out with SVET-2 SG Light Module on fluorescent lamps (OSRAM DS 11/21). The paper includes a review of our research and development activities under the Greenhouse–Mars Project during the past 3 years (2006-2008).

Background

The *Mars-500* Experiment is under development by the Russian State Scientific Center - Institute of Biomedical Problems (IBMP), Russian Academy of Sciences, Moscow. During the experiment, six volunteers will be locked for 500 days in a mock-up of the space station modules to Mars in an effort to mimic the stresses and challenges of a long manned mission and how they affect the human crew. The simulation of a manned flight to Mars is planned to start in the late 2009 or early 2010. During the 500-day study, the life of the six men will depend on a preset limit of supplies, including about 5 tons of food and oxygen and 3 tons of water. A doctor will accompany the volunteers inside the module to treat illnesses or injuries. Volunteers will only be allowed to quit the experiment if they develop a severe ailment or psychological stress. A large greenhouse will be installed inside, supporting the life and the health of the "crew", providing them with fresh food and relaxing "green view".

A research team from the Space Research Institute (SRI), Bulgarian Academy of Sciences, Sofia, has been participating in the Russian Program for preparation of a human spaceflight to Mars for 25 years already. The first small-size (0,1 m^2) SVET Space Greenhouse (SG) was created in the 80's under a Joint Scientific Project with the IMBP in the framework of the *Intercosmos* Programme, aiming to study the ways and methods for the use of higher plants in space Biological Life Support Systems (BLSS). The subject of the project was to develop biotechnology for higher plants growing in microgravity with the prospects to use it in the future long-term manned mission to Mars. SVET SG was launched onboard the MIR Orbital Station (OS) in 1990 when the first two-month vegetable plant experiments were carried out to provide vitamin addition to the astronaut food [1]. Artificial lighting was provided by fluorescent lamps mounted in the Light Unit (LU). A new modification, SVET-2 SG, with optimized parameters of all units and systems (including new LU-2) was developed and launched onboard the MIR OS in 1996, which was funded by NASA [2]. A number of successful plant experiments and research were carried out under the fluorescent lamps lighting of the SVET-2 SG equipment in 1996-2000. The unique scientific results obtained in the field of Gravitational Plant Biology proved that there were no "show-stoppers" for plant growth and development in microgravity [3, 4].

Plants need light of definite quantity and quality. They consume light energy mostly in two spectral bands - blue and red (around 450 and 650 nm) to carry out their fundamental biological processes, such as photosynthesis (production of biomass and air cleaning) and phototropism (orientation towards the light in weightlessness). The intensity of these physiological processes with light of various wavelengths is shown in Fig. 1

(curve 1 - phototropism and curve 2 - photosynthesis). To provide experimentally defined light conditions of irradiance, spectral quality, and duration is one of the major engineering requirements of any controlled environment plant chamber [5].

The Bulgarian-made LU with lighting area of 330x330 mm can be moved vertically in the Plant Chamber of SVET SG and adjusted at three different levels: 20, 30 and 40 cm from the plant seedling surface in order to provide best light intensity without overheating, depending on the plant development stage. A fan cooling the lamps and the air in the shoot zone is mounted on the upper bearing plate together with a panel for LU control (manual or automatic).

Russian fluorescent lamps LB 8-6 (12 pieces) developed specifically for the MIR OS board were used in the 1990 experiment. The spectral-response characteristic of LU using this kind of lamps is shown by curve 3. It is seen that almost the whole luminous energy is concentrated in the plants' lower sensibility area. This appreciable discrepancy between the light source and plant needs was due to the lack of special lamps (during the period of development) with appropriate characteristics which necessitated a great enough stock in case of breaking a lamp. The fluorescent lamp DS 11/21 of OSRAM (6 pieces) was chosen as featuring the most appropriate spectrum for LU-2 (curve 4) – intensive photosynthesis and providing phototropism of the plants, which are so important in space flight conditions [6].

Considerably (2.5 times) improved brightness characteristics of LU-2 were obtained at a distance of 15 cm from the illuminants, the intensity being 27,000 lx (under 12,000 lx in SVET SG in 1990). In these circumstances, we could expect considerable increase of plant productivity (biomass quantity) in the future experiments.

The larger warranted duration of work of the lamps DS 11/21 (8,000 hours) results in 5-fold increase of the equipment's reliability. Apart from this, the new LU-2 features appreciably better electrical characteristics, which is of great importance because it used to be the greatest energy consumer within SVET SG. For example, the supply current of the unit (under 27V onboard supply voltage) is 2.5 times lower (3.5A under 9A in SVET SG) and the starting current is almost equal to the normal one [7].

Unfortunately, the lighting systems based on white fluorescent lamps used in plant growing facilities were developed more for human and not for plant lighting purposes, since the well-lit green plants have very positive psychological effect on the space crew. Nevertheless, such lighting systems have found extensive use in terrestrial facilities with controlled environment.

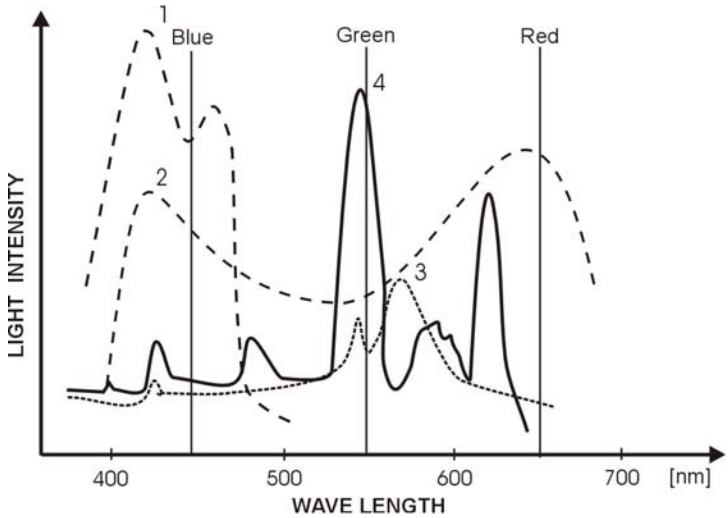

Fig. 1. Light wavelength necessary for plants: 1 - phototropism and 2 – photosynthesis; Spectral characteristics of the fluorescent lamps used in 3 - SVET SG (LB 6-8) and 4 – SVET-2 SG (DS 11/21) and of the new blue, green and red LEDs

Regarding the use of fluorescent lamps in space-based plant chambers there are serious limitations relating to both the power utilization and the safety requirements of the space hardware. The mercury contained in the lamps may be a serious safety hazard, if a lamp is broken. The LU-2 OSRAM lamps were hermetically sealed in specifically developed light bodies that ensure maximum light characteristics. The safety requirements are adequately addressed but the irradiance of these lighting systems is greatly decreased and the volume required by such a system is difficult to accommodate in the very limited LU space.

Lighting system on light-emitting diodes

The plant will be an important component of the future BLSSs for the long-term space mission to Mars as a source of food and air cleaning. The lighting systems intended for long-term plant growing should be light-weight, reliable, and durable, and light-emitting diodes (LEDs) possess all these characteristics. The development of LED-based LUs for space greenhouse facilities started in USA in the 90's in relation with the Space Shuttle missions [8].

Major advances have been achieved in semiconductor technology and this has led to the availability of LEDs having sufficient photon output and electrical efficiencies making them an excellent light source for plant growing facilities. Mounting the LED chip on a highly thermally conductive ceramic substrate which is bonded to a metal heat sink allows the device to operate at high normal current with high photon output, while maintaining the temperature of the LEDs close to the ambient temperature, resulting in prolonged life and constant photon output.

Since, in contrast to other lamps, LEDs emit photons within a specific spectral range, they should be carefully selected, so that the levels of the provided photosynthetically active, photomorphogenic, and phototropic radiation meet the plant requirements. Photons in the red spectral range are most efficient as a source of photosynthetically active radiation (Fig. 1). Thus, LEDs having a peak emission around 650 nm appear to be the most efficient source providing photons for the photosynthesis, which coincides with the red absorption peak of chlorophyll. Irradiance levels of 0-500 $\mu mol.m^{-2}.s^{-1}$ in the red spectral range can be achieved using an LED plant lighting unit. Light in the blue spectral range (400 to 500 nm) featuring low irradiance levels (0-80 $\mu mol.m^{-2}.s^{-1}$) is generally considered to be involved in the photomorphogenic and phototropic responses. The light requirements involved in the phytochrome responses can be easily met by low light levels with wavelengths of 630 and 680 nm. Supplementing the red photon LEDs with others emitting in the blue (450 nm) and infrared (735 nm) spectral range would meet plants' light requirements in a controlled environment facility [9].

A Light Unit with 90% red and 10% blue LEDs was used in the American ASTROCULTURE™ Greenhouse flight unit during three Space Shuttle missions, STS-57, STS-63, and STS-73, as well as in the commercial ADVASC flight unit on ISS [10]. The video from the board showing the dark-violet coloured plants was terrible, but fortunately, they were not visible for the crew in the closed chamber. In terms of photon output, the performance of the LED unit while in a space environment was the same as the performance while tested on the ground. In addition to being used as a lighting source in plant growth chambers, the LEDs can be a very effective photon source for photosynthetic research to study electron transport, carbon metabolism and trace gas emission.

A greenhouse with large plant area of 3 m^2 will be mounted “onboard” during the *Mars-500* Experiment (in a module of 250 m^3 volume) together with the required water and food supplies to ensure fresh vitamin addition to the “cosmonaut” food. A Contract for scientific cooperation on the *Greenhouse-Mars* Project between the SRI and the IBMP was signed in the framework of an agreement between the Bulgarian and the Russian Academy of Sciences in the field of Fundamental Space Research for the period 2006-2010 [11]. According to this Contract, part of the Greenhouse equipment, Light Units with different spectra (combinations of LEDs) intended for the scientific plant experiments during the *Mars-500* were developed.

Previous studies demonstrated that the combination of red and blue light was an effective light source for several crops. Yet, the appearance of plants under red and blue lighting is purplish-gray making visual assessment difficult. The addition of green light would make plant leaves appear green and normal, resembling a natural setting under white light, and may also offer a psychological benefit to the crew which is very important for long-term living in a closed system surrounded by technical equipment only [12].

Green supplemental lighting could also offer benefits, since green light can better penetrate plant canopy and potentially increase plant growth by increasing photosynthesis in the lower canopy leaves. The American experimental study proved that plants treated with red and blue LEDs and with additional green fluorescent lamps produced more biomass than the plants grown under white fluorescent lamps [13]. Now, it is not clear enough what the optimal spectra of the future LED LUs should be to achieve maximum plant productivity.

Technical characteristics of the new LM-LED

The Bulgarian team of experienced engineers and young biologists from the SRI developed at the beginning only one small Light Module on LEDs (LM-LED) [14]. The technical specifications for them were set by the Russian experts from the IBMP. The most important requirement was to ensure highly reliable, continuous and flawless operation for at least 18-24 months, so we took special measures to cool the unit, so as to maintain constant electrical and thermal characteristics.

The main technical characteristics of the LM-LED are as follows:

- Lighting area's size - 33x33 cm, same as the size of the LM on fluorescent lamps. The new LM-LED replaced it without any problem in SVET-2 SG, where we conducted the tests. Nine modules with these dimensions will be sufficient to build 1 m^2 of lighting area;
- Distance from the LM-LED to illuminated area – up to 50 cm. The distance could be varied within 20-50 cm, with step of 10 cm, so as to use the full power of the LEDs in the different plant development stages;
- Light intensity required for smooth running of plant processes Photosynthetic Photon Flux Density (PPFD) – 350-400 $\mu mol.m^{-2}.s^{-1}$;
- Spectral characteristics: blue (450 nm), green (550 nm), red (650 nm), ±30 nm (see Fig. 1);
- Simulation of the following spectral ranges, by changing the light intensity or the number of switched on LEDs at any moment:
  1. 50% blue, 20% green, 30% red;
  2. 30% blue, 20% green, 50% red;
  3. 10% blue, 20% green, 70% red;
  4. 10% blue, 90% red.

Since the emission intensity of the LEDs for the different spectral ranges is different, a different number of them are switched on for the different colours.

A special facility was developed for experimental measurements of PPFD. Portable measuring system LI-6400 - LI-COR was used. A series of measurements of the intensity of different commercially available types of LEDs were made.

Based on these measurements, we chose XLamp XR produced by the US company *Cree*, which matched best the technical requirements [15]. This choice reduced significantly the total number of LEDs and simplified the design of the LU. The XLamp XR type of LEDs were among the newest products from this family. They can be operated with currents up to 700 mA (equivalent to the power of 3 W), which allows variation of light intensity within a wide range to achieve the objectives of the planned experiments. Based on long-term reliability testing and standardized forecasting methods, the LEDs of this series will keep up to 70% of their light intensity after

50,000 hours of work, provided that the solder place temperature does not exceed 80°C.

Prismatic optical system developed by *Polymer Optics Ltd.* [16], mounted in front of each LED spot generates homogeneous light beam.

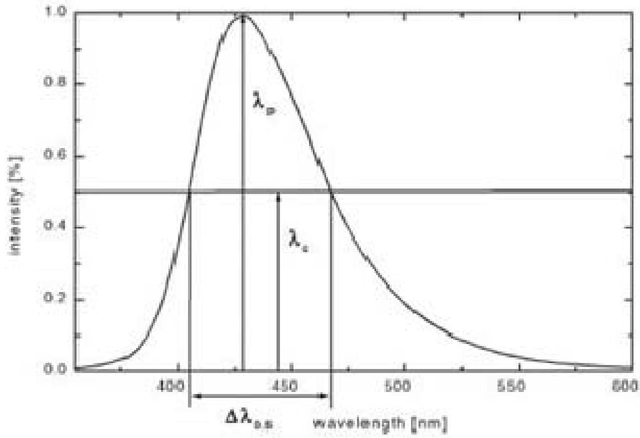

Fig. 2. Calculating FWHM (full width at half maximum)

The spectral distribution of the LEDs differs in many aspects from that of conventional light sources. It is not monochromatic, as laser emission, or with a broad spectrum, as most light sources with incandescent wire. LED has a typical spectral width - FWHM (full width at half maximum) of 15 to 60 nanometres (Fig. 2). In this case, the spectral width of the LED emission for normal distribution ($\Delta\lambda_{0.5}$) is calculated by finding the difference ($\Delta\lambda_{0.5}$) between the wavelengths with ½ of the maximal intensity λ_p, i.e. $\lambda'_{0.5}$ and $\lambda''_{0.5}$:

$$\Delta\lambda_{0.5} = \lambda'_{0.5} - \lambda''_{0.5}$$

For the selected LEDs, we obtain the following:

LED (color)	λ_p	$\lambda'_{0.5}$	$\lambda''_{0.5}$	$\Delta\lambda_{0.5}$
Blue	468	455	480	25
Green	525	505	545	40
Red	632	625	640	15

There is relative overlap between the spectra from the technical requirements and the spectra of the selected LEDs.

Construction and methods of control

In order to describe better the structure and control of LM-LED, we will introduce the following basic concepts:

Fig. 3. Photo of the LM-LED and the DMX Control Unit

- Light source (LS) – a powerful LED with red, green or blue colour;
- Element – a light source with unique identification number (from 1 to 255);
- LED spot – a spot containing three elements;
- Group – a set of elements arranged in one or more spots which are controlled jointly. It is possible to define up to 255 groups. Each element can participate in one or several groups.

The Block Diagram of the LM-LED is shown in Fig. 4. 36 LED spots are installed on a metal plate with heat sinks to maintain optimal temperature during continuous operation. A standard Power Supply of 500W, 24V, 20A is used.

The DMX Control Unit is connected to six DMX LED controllers and six LED spots are coupled to each one. 30 LED spots contain green, red and blue LS, and 6 LED spots - 3 red LSs each. The proposed design allows setting up to 255 different levels of light intensity for each element and provides for easy change of the elements belonging to each group.

This method of work facilitates the variation of spectral characteristics and light intensity within a wide range, which allows to conduct very accurate experiments with different crops to find the optimal regimes for each crop.

Special instructions loaded in the memory of the DMX Control Unit are used to control the spectral characteristics and light intensity of the LM-LED according to a pre-set schedule. Each instruction controls a group of elements, allowing elements from other groups to retain or change its state.

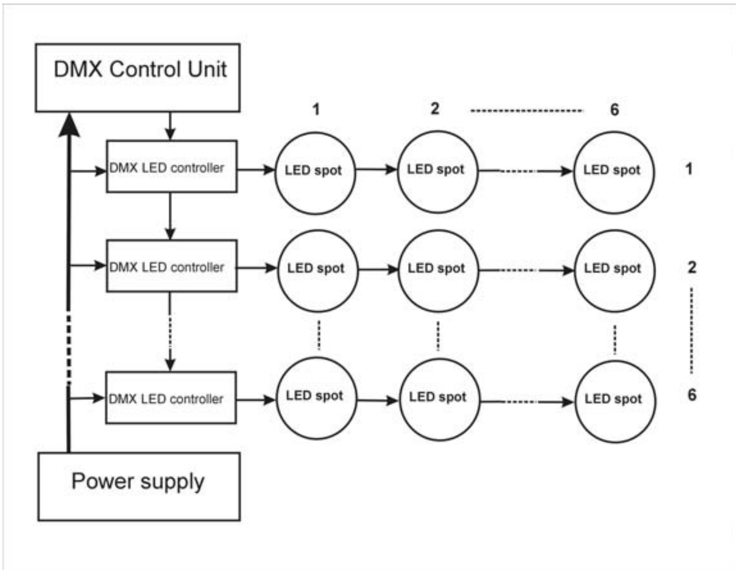

Fig. 4. Block diagram of the LM-LED

The main parameters of the instruction are:

- Instruction number (0-255);
- Group number (0-255);
- Standard program code (0-4);
- Number of cycles (1-255) - indicates how many times to repeat the instruction;
- Initial intensity - red, green, blue (0-255);
- Final intensity - red, green, blue (0-255);
- "Switched on" time (0-25.5 s);
- "Switched off" time (0-25.5 s);

- Start of the allowed astronomical time window (from 00:00 to 23:59) - the instruction is executed only within the allowed astronomical time window;
- End of allowed astronomical time window (from 00:00 to 23:59);
- Active days of the week - the instruction is executed only on the active days of the week.

The available standard programs for the control of LM-LED are:

Program code 0 – Turns all elements of the group into "switched off" state.

Program code 1 – All elements that were switched on by the previous instruction preserve their state. All elements of the group are switched on and shine with constant intensity equal to the value in the field “initial intensity”.

Program code 2 – Switches off all elements that were switched on by the previous instruction. All elements of the group are switched on and shine with constant intensity equal to the value in the field “initial intensity”.

Program code 3 – All elements that were switched on by the previous instruction preserve their state. All elements of the group are switched on and shine with constant intensity equal to the value in the field “initial intensity” for "Switched on" time, and are switched off for "Switched off" time.

Program code 4 – Switches off all elements that were switched on by the previous instruction. All elements of the group are switched on and shine with constant intensity equal to the value in the field “initial intensity” for "Switched on" time, and are switched off for "Switched off" time.

The results of the experiments conducted with the new LM-LEDs will allow us to create a balanced spectral lighting system based on LEDs and to find the optimal ratio between consumed energy and yield.

Experimental Verification Tests of LM-LED

Laboratory technical and biological tests of the LM-LED were conducted using the equipment of SVET-2 SG in the air-conditioned Laboratory of the SRI. The model consists of Control Unit and PGC in which the changeable Root Module and LM are placed. The LM-LED could be used interchangeably with the original LM on fluorescent lamps (LM-FL). The ME-4610 universal data acquisition system *produced by Meilhaus Electronic GmbH* was added to SVET-2 SG to process, store, and visualize the data acquired from the sensors located in the leaf-zone of PGC. The process of monitoring the shoot zone 5 parameters (air temperature and humidity, light intensity, air flow velocity, and air pressure) and the control of RM substrate moisture is automatic [17]**.**

Two one-month experiments with lettuce (*Lactuca sativa L. var. acephala Dill. cv. Lollo Rossa*) and radicchio (leaf chicory) (*Cichorium intybus L. subsp. intybus (Foliosum Group) cv. Bianca di Milano*) were carried out using the new LM-LED [18]. The LM-LED was positioned at 20 cm in the PGC and ensured 400 $\mu mol.m^{-2}.s^{-1}$ PPFD (high light - HL) for the first experiment and 220 $\mu mol.m^{-2}.s^{-1}$ PPFD (low light - LL) for the second experiment and spectral composition of 70% red, 20% green, and 10 % blue light during both experiments. Another two one-month experiments with the same plants but using LM-FL were carried out. In the first experiment, the LM-FL was positioned 40 cm above the seed sowing surface to ensure 120 $\mu mol.m^{-2}.s^{-1}$ PPFD (low light - LL) and in the second one, 20 cm above the seed sowing surface to ensure 220 $\mu mol.m^{-2}.s^{-1}$ PPFD (high light - HL). Both varieties were cultivated together in each of the experiments. Lettuce and radicchio seed germination, seedling height and dry matter accumulation were measured to assess plant growth. Biochemical parameters were also evaluated – Malonedialdehyde (MDA), H_2O_2 and Peroxidase activity (POX) reflect the extent of photodamage on lettuce and radicchio plants. These morphometric and biochemical data were used to estimate the impact of light intensity and spectral composition on cultivated plants.

Results and Discussion

All analyses were made in the end of the experiments, except for seed germination which was evaluated during the first 10 days of each experiment.

When fluorescent lamps are used as a light source, germination rate of lettuce seeds decreases by 27% as PPFD increases from 120 to 220 $\mu mol.m^{-2}.s^{-1}$. The germination period also decreases twice, from 6 to 3 days. Radicchio germination rate shows different dependences on changes in light intensity – the number of germinated plants increases by 16% while the germination period remains the same, although it is shifted one day left at the higher light intensity (Fig. 5). Germination rate of both lettuce and radicchio seeds cultivated on LEDs decreases as PPFD changes from 220 to 400 $\mu mol.m^{-2}.s^{-1}$ by 5% and 14%, respectively. The beginning of the germination period remains the same for each of the varieties and the longevity is statistically equal at the two light intensities (Fig. 6).

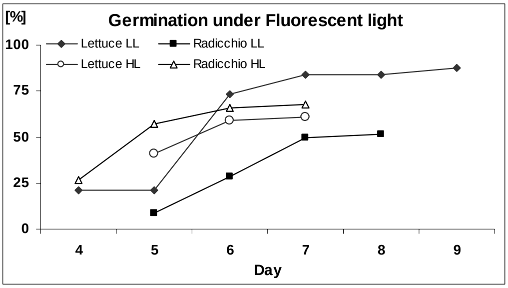

Fig. 5. Lettuce and Radicchio germination rate during experiments using the Light Module on Fluorescent lamps.

Abbreviations:
LL - Low Light Intensity - 120 µmol.m^{-2}.s^{-1}PPFD;
HL -High Light Intensity - 220 µmol.m^{-2}.s^{-1}PPFD.

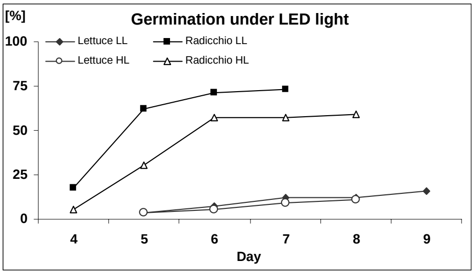

Fig. 6. Lettuce and Radicchio germination rate during experiments using the Light Module on LEDs.

Abbreviations:
LL – Low Light Intensity – 220 µmol.m^{-2}.s^{-1} PPFD;
HL – High Light Intensity – 400 µmol.m^{-2}.s^{-1} PPFD.

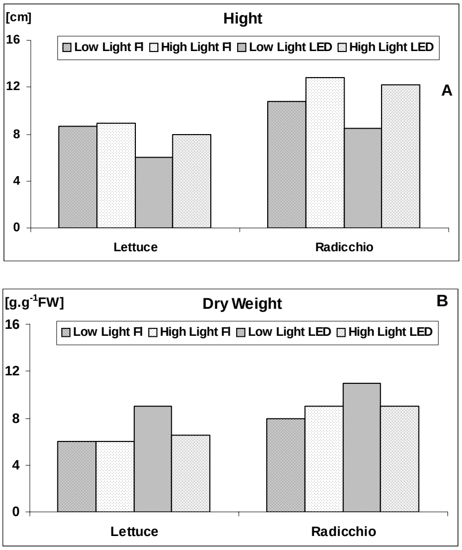

Fig.7. Morphometric characteristics of Lettuce and Radcchio plants during experiments with LM-FL and LM-LED.

7-A: Height and 7-B: Dry Weight.
Used abbreviations are:
Low Light FL (fluorescent) - 120 µmol.m^{-2}.s^{-1} PPFD;
High Light FL (fluorescent) - 220 µmol.m^{-2}.s^{-1} PPFD;
Low Light LED -220 µmol.m^{-2}.s^{-1} PPFD;
High Light LED -400 µmol.m^{--2}.s^{-1} PPFD.

Regardless of the lighting source, plant height within each plant variety is nearly the same in all experiments, except at 220 $\mu mol.m^{-2}.s^{-1}$ LED light when decrease by almost 30% for both plants was observed (Fig. 7-A). Just the opposite effect – increase of dry weight was observed when low intensity of LED light was used (Fig 7-B).

Accumulation of high levels of MDA (Fig. 8-A) and increased POX activity (Fig. 8-C) correlated with decreased endogenous H_2O_2 content (Fig. 8-B) were observed in HL LED grown plants – both lettuce and radicchio. High light is known to induce photodamage in plants by enhancing photooxidation. This could be assessed by changes in MDA, waste product of lipid peroxidation. As seen from Fig. 8-A, B, C, plants grown under

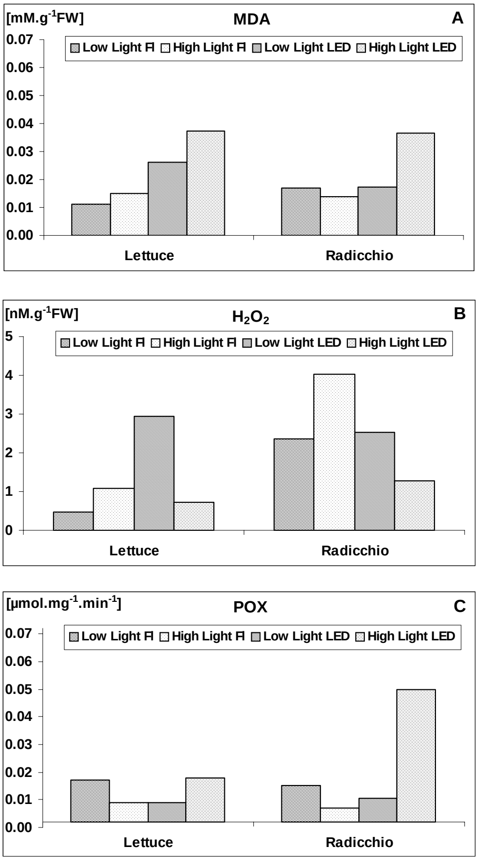

Fig. 8. Biochemical characteristics of Lettuce and Radicchio plants during experiments with LM-FL and LM-LED.

8-A: Malonedialdehyde (MDA), 8-B: Hydrogen peroxide (H_2O_2) and 8-C: Peroxidase activity (POX).

Abbreviations:
Low Light FL (fluorescent) - 120 $\mu mol.m^{-2}.s^{-1}$ PPFD;
High Light FL (fluorescent) - 220 $\mu mol.m^{-2}.s^{-1}$ PPFD
Low Light LED - 220 $\mu mol.m^{-2}.s^{-1}$ PPFD;
High Light LED - 400 $\mu mol.m^{-2}.s^{-1}$ PPFD.

fluorescent light accumulated small amounts of MDA compared even to LL LED grown plants, both lettuce and radicchio. The biochemical set of parameters revealed that low and high LED light induces photooxidation protection reactions in both plants. HL LED grown plants are more sensible to photooxidation but not to a greater extent than the LL LED grown plants.

Conclusion

Two one-month experiments with the new LM-LED were carried out to study the effect of light intensity and spectral composition on lettuce and radicchio plants. Light intensities were 400 $\mu mol.m^{-2}.s^{-1}$ PPFD (high light - HL) and 220 $\mu mol.m^{-2}.s^{-1}$ PPFD (low light - LL). The spectral composition was 70% red, 20% green, and 10% blue light during both experiments. This spectral composition ensured white light at which plants looked green and pleasant for human eyes. These experiments revealed that LL LED grown plants accumulated the highest dry weight compared to HL LED and cool white fluorescent lamps, both LL (120 $\mu mol.m^{-2}.s^{-1}$ PPFD) and HL (220 $\mu mol.m^{-2}.s^{-1}$ PPFD). The biochemical analyses revealed that light emitted from LEDs unlocks photoprotection reactions in lettuce and radicchio plants cultivated at 70% red, 20% green, and 10% blue light.

Other experiments are carried out to study the different light intensity and spectral composition levels (10% blue, 90% red and 30% blue, 20% green, 50% red) to develop an optimal plant growth technology.

Prospects

Photoprotective plant reactions to high light intensity were observed during the Earth verification tests. Based on these findings a new LM-LED-5, on another type of LEDs (QH513) is under development. The advantages of the new LM are lower price and lower power consumption, light weight and improved effectiveness. The new universal LM, which is sized 40x40 cm and provided with separate pulse power supply of 220V will be tested during the next stage of the *Greenhouse-Mars* Project. Such a module could be easily transported to Moscow by plane to be used in biological and technical tests within the ready-built structure of the experimental model in the IBMP; it is easy to multiply (if funds are available) and to implement it in the two Mars-500 greenhouse facilities with sized 80x160 cm.

The LM-LED-5 composition has been supplemented with white light for psychological effect. Two rows of white LEDs are mounted in the module, which will be switched on when photos are taken or the “crew” observes the plants. The most important task in both ground-based experiments carried out in the SRI and the IMBP is to find the optimal LED composition, so as to achieve the same plant growth as with fluorescent lamp lighting.

Different plant species, mostly lettuce crops, will be grown under different light spectra provided by LEDs with a small viewing angle and maximum light intensity on the plant surface during the experiment. Samples for analysis will be collected at different plant development stages to investigate the influence of light spectrum on plant physiological parameters. The psychological effect on the crew emotional frame (the “plant-operator” dependence) will also be studied during the long-term *Mars-500* Experiment.

Acknowledgments

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НОВ СВЕТОДИОДЕН МОДУЛ ЗА ОСВЕТЛЕНИЕ РАЗРАБОТЕН ПО ПРОЕКТА "ОРАНЖЕРИЯ-МАРС"

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Резюме

Съгласно Договора за научно сътрудничество по Проект „Оранжерия Марс" между Института за космически изследвания, София и Института по медикобиологични проблеми, Москва, български учени разработиха нов осветителен модул на светодиоди (LM-LED). Новият LM-LED е на базата на монохроматични светодиоди (LEDs, тип *Cree® XLamp® 7090 XR*), излъчващи в червената, зелената и синята (RGB) области на спектъра. Блок за управление в DMX стандарт позволява задаване на плътност на фотосинтетичния фотонен поток (PPFD) в границите 0-400 $\mu mol.m^{-2}.s^{-1}$. Бяха проведени лабораторни технически и биологични изпитания на LM-LED с помощта на комплекса апаратура Космическа оранжерия (КО) SVET-2, прототип на летялата на борда на Орбиталната станция МИР. С новия LM-LED бяха проведени два едномесечни експеримента с растенията салата и цикория, със спектрален състав - 70% червена, 20% зелена и 10% синя светлина и PPFD - 400 $\mu mol.m^{-2}.s^{-1}$ (висока осветеност) и 220 $\mu mol.m^{-2}.s^{-1}$ (ниска осветеност). Проследени бяха височините на растенията и анализирани някои биохимични параметри като резултатите бяха сравнени с резултатите от подобни експерименти, извършени със стария Блок за осветление на КО SVET-2 на флуоресцентни лампи (OSRAM DS 11/21). Статията обобщава научно-изследователска работа по проекта "Оранжерия-Марс" за последните 3 години (2006-2008).