https://doi.org/10.46813/2023-143-104

INFLUENCE OF DIELECTRIC BARRIER DISCHARGE ON BEET SEEDS GERMINATION

O.A. Nedybaliuk, I.I. Fedirchyk, M.S. Maruschak, D.L. Chernolutsky

Taras Shevchenko National University of Kyiv, Kyiv, Ukraine

E-mail: oanedybaliuk@knu.ua

The effect of dielectric barrier discharge (DBD) treatment on the germination of beet seeds under different conditions was investigated. The emission spectra of the DBD plasma were measured under various operating conditions. It is shown that the main components of the emission spectra are nitrogen (N_2) bands. The rotational (T_r) and vibrational (T_v) temperatures of the DBD plasma are determined from the N_2 bands under different operating conditions. The dependences of the germination percentage of beet seeds at different time intervals of DBD treatment were obtained. The optimal time for treating beet seeds was determined.

PACS: 52.50.Dg, 52.80.-s, 52.77.−j

INTRODUCTION

The control of plant diseases is essential for sustainable food crop production [1]. Many plant disease management strategies have played significant roles in reducing the 20...30% loss of crop production still occurs annually because of plant diseases. Particularly, the current global climatic change makes disease control more complicated and difficult. The elevation of temperature and CO_2 concentration can change the susceptibility of plants to specific pathogens, leading to the emergence of new diseases [2]. Under the current circumstances, traditional disease management strategies have often shown limitations in control efficiency and have multiple drawbacks. Chemical-based methods are most frequently applied for plant disease control; however, the emergence of pathogen resistance and environmental pollution make this strategy less reliable. The induction of plant resistance through species breeding and genetic engineering has been considered as a stable and long-lasting method for plant disease control. Public view on genetically modified organisms is still a barrier for popular use [1].

One of the goals of sustainable development is to eliminate world hunger [3, 4]. Fungi on seeds can affect the quality of the crop and cause spoilage and damage to the embryos during storage. They can infect food grains, producing toxins that cause diseases in humans or animals using these grains as food [5].

One method to prevent fungi's negative impact on plant growth and storage is plasma treatment [6]. Nonequilibrium atmospheric pressure plasma has many applications in various fields, such as surface treatment, combustion enhancement, bacterial inactivation [6-8], and contamination reduction [9]. Plasma is an effective sterilization method and can be used as an alternative to chemical seed disinfection [10]. One of the sources of nonequilibrium atmospheric pressure plasma can be a dielectric barrier discharge (DBD).

This work is devoted to studying the effect of DBD treatment on the germination of beet seeds.

1. EXPERIMENTAL SETUP AND METHODOLOGY

Fig. 1 shows a schematic representation of a plasma system with a DBD designed for treating beet seeds before planting. The DBD system is made using a Petri dish lid. The bottom metal electrode (1) is placed on the lower plane of the glass lid. It is made of a copper wire in the form of a mesh placed on a 2 mm thick dielectric glass (2), which separates it from the upper metal electrode (3). The upper metal electrode is in the shape of a disk with a diameter of 30 mm and is made of copper. The disk is covered with a dielectric made of epoxy resin (4). The power supply of the dielectric barrier discharge consists of three units: a TES 13 DC power source (5), a GZ-109 low-frequency signal generator (6), and a unit containing a transformer and an amplifying circuit (7). The DC source (5) makes it possible to regulate the power of the dielectric barrier discharge in the range of 0…20 W. With the help of a low-frequency signal generator (6), the frequency can be adjusted within the 0…20 kHz range. The seeds (8) were treated in a Petri dish (9).

Optical emission spectroscopy of plasma radiation was carried out using an optical fibre (10), placed at a set distance h from the surface of the copper mesh, and a Solar TII S-150-2-3648 USB spectral device (11). The light guide was oriented along the beam of vision perpendicular to the surface of the glass plate on which a copper mesh was placed. Emission spectra were processed using a PC. The obtained optical emission spectra were used to determine the rotational and vibrational temperatures of nitrogen (N_2) in plasma. The temperatures were estimated by comparing the experimental optical emission spectra with the spectra simulated using the SpecAir 2.2 program [11]. More information about this method is available in our previous works [12-14].

Voltage oscillograms were recorded by an oscilloscope (12) using a voltage divider made of resistors R_1 and R_2 (R_1:R_2 = 1000000:1). The effect of

DBD plasma on seed germination was investigated using beet seeds as a model. During the experiment, atmospheric air was used as a feed gas for DBD.

Fig. 2 shows photographs of the DBD electrode system. Before the treatment with DBD, beet seeds were placed in a Petri dish, as shown in Fig. 3. The Petri dish was placed under the plasma system. The distance from the lower plane of the glass flange to the bottom of the Petri dish was 10 mm. The seed treatment time varied from 0 to 4 min with a step of 1 min.

After the DBD treatment, the seeds were planted in special containers (Fig. 4,a) with soil-filled cells. A control group of untreated seeds was planted in the containers alongside treated seeds. 20 beet seeds were planted in each cell of the special container (see Fig. 4,b).

The containers with planted beet seeds (Fig. 5) were placed inside a box and illuminated with phytolamps during the workday (from 9:00 to 18:00). The room temperature was maintained at 20°C.

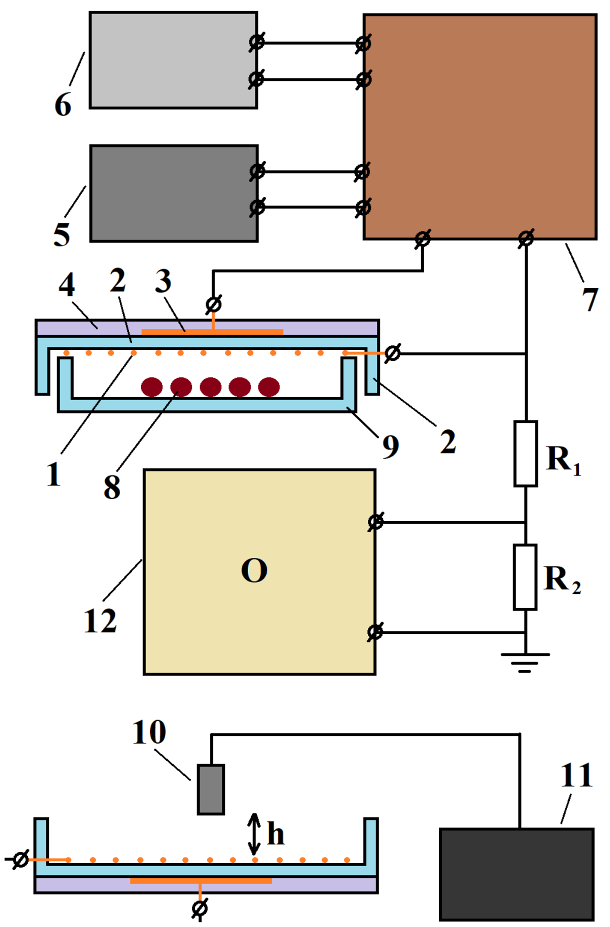

Fig. 1. Scheme of plasma system with DBD designed for treating beet seeds before planting:
1 – copper wire used as a lower metal electrode;
2 – dielectric; 3 – disk-shaped copper upper electrode;
4 – epoxy-based dielectric; 5 – DC power source;
6 – low-frequency signal generator; 7 – unit with transformer and amplifying circuit; 8 – seeds;
9 – Petri dish; 10 – light guide; 11 – spectrometer;
12 – oscilloscope (O);
R_1 and R_2 – voltage divider resistors

Fig. 2. Photos of DBD electrodes system designed for treating seeds before planting: lower electrode (a); upper electrode covered with epoxy resin (b); DBD during operation (c)

Beet seed germination was monitored 15 days after planting. After 15 days, germinated and ungerminated beet seeds were dug up, washed with water, and their photographs were taken and analyzed.

Fig. 3. Photo of beet seeds placed in Petri dish before treatment with DBD

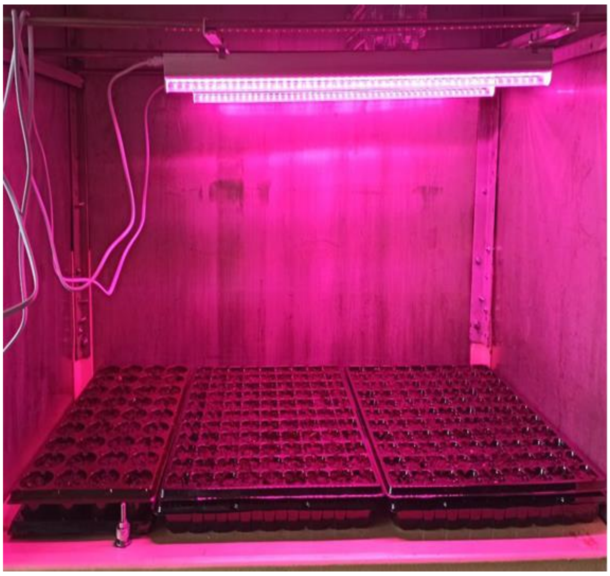

Fig. 5. Photo of a box where special containers with planted beet seeds were illuminated with phytolamps

Fig. 4. Photo of typical container with soil-filled cells (a) in which both untreated and treated with DBD beet seeds (b) were planted

2. RESULTS AND DISCUSSION

A typical plasma emission spectrum of a DBD with air as feed gas is shown in Fig. 6. The emission spectrum is composed chiefly of N_2 bands due to it being the main component of air. The appearance of the molecular N_2 band indicates that the rotational temperature is quite low compared to the rotating temperature of rotating gliding discharges [12-15].

Rotational and vibrational temperatures of N_2 molecules in plasma were determined from the nitrogen N_2 bands by comparing the experimentally measured optical emission spectra with the ones simulated using the SpecAir 2.2 software [11]. Fig. 7 shows the dependence of the rotational and vibrational temperatures of N_2 on the DBD power. When the discharge power is increased threefold, the rotational temperature does not change and remains at the level of room temperature $T_r = 300$ K, while the vibrational temperature increases somewhat and is in the range of $T_v = 2500...3000$ K. In the case of DBD, the rotational temperature is at the level of room temperature, unlike a rotating gliding discharge where the rotational temperature is an order of magnitude higher [15], and treated seeds will not be burned due to thermal effects. The significant difference between the rotational and vibrational temperatures, which are almost an order of magnitude different, indicates the non-equilibrium of the DBD plasma.

Fig. 8 shows typical DBD voltage waveforms at different timescales. The discharge power was 6.3 W, and the frequency was set to 4 kHz using a low-frequency signal generator, which corresponds to the waveforms shown in Fig. 8. The presence of peaks on the envelope of the voltage signal is typical for a DBD.

Fig. 9 shows the percentage of germination of beet seeds measured 15 days after planting under different operating modes of the plasma system with a DBD. The power of the DBD was 6.3 W, the frequency was 4 kHz, and the treatment time varied from 0 to 4 min in

1-minute increments. The control group was not treated and corresponds to a treatment time of 0 min. The results show that the germination of beet seeds in the case of DBD treatment for 1, 2, 3, and 4 min is better than in the case of no treatment. In the case of beet seed treatment for 4 min, the percentage of germination of beet seeds is twice as high as in the case of no treatment.

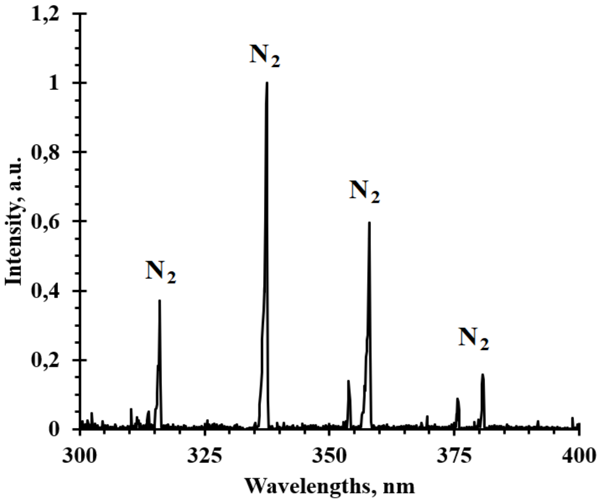

Fig. 6. Typical emission spectrum of DBD plasma: discharge power – 6.3 W; frequency – 4 kHz

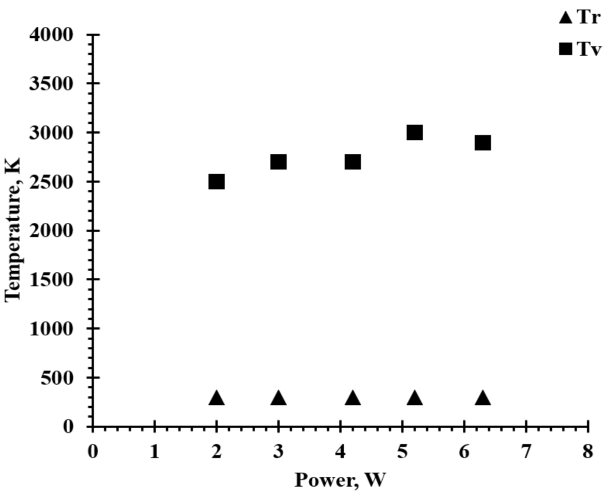

Fig. 7. Dependence of rotational (T_r) and vibrational (T_v) temperature of DBD plasma for discharge power: frequency – 4 kHz

Fig. 10 shows photos of the beet seeds dug up on the 15th day after planting. The same number of seeds was planted for each treatment time. Seeds that did not germinate or have become rotten were not photographed. The number of beet seeds that germinate in case treated with DBD plasma is higher than in case when seeds were not treated. When considering the development of the beet stem, the optimal time for the treatment with DBD is 1...2 min (see Fig. 10,b-c).

These findings can significantly impact the agricultural sector, as the described treatment method is independent of logistics (all that is needed is air and electricity) and does not require the purchase of pesticides. Also, this method reduces harmful emissions into water (chemical industry waste) and air (waste from transportation), which, together with independence from the delivery of chemical treatments, is extremely important.

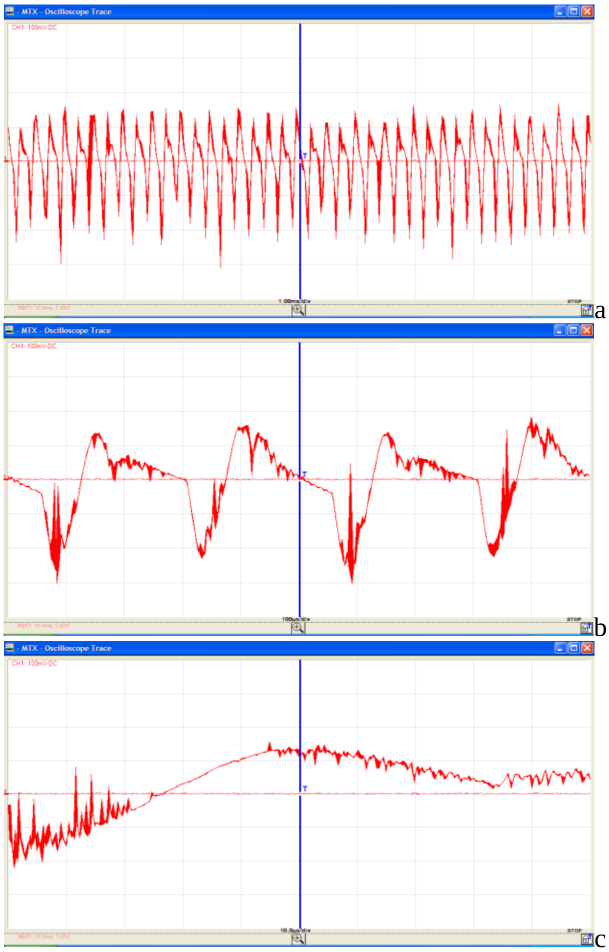

Fig. 8. Typical oscillograms of DBD voltage (discharge power – 6.3 W, frequency – 4 kHz) at different timescales: 1 ms/div (a); 0.1 ms/div (b); 0.01 ms/div (c)

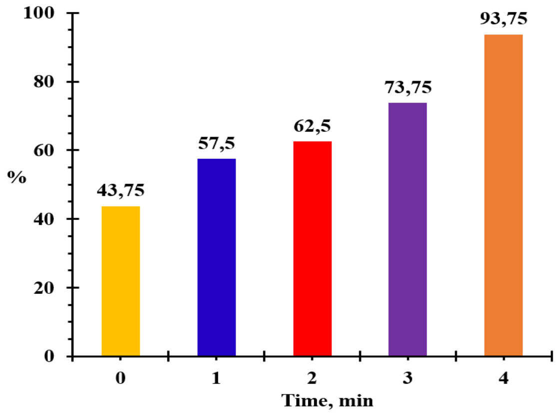

Fig. 9. Dependence of percentage of germination of beet seeds on the 15th day after planting relative to the number of seeds planted for DBD treatment times: 0 (control), 1, 2, 3, 4 min

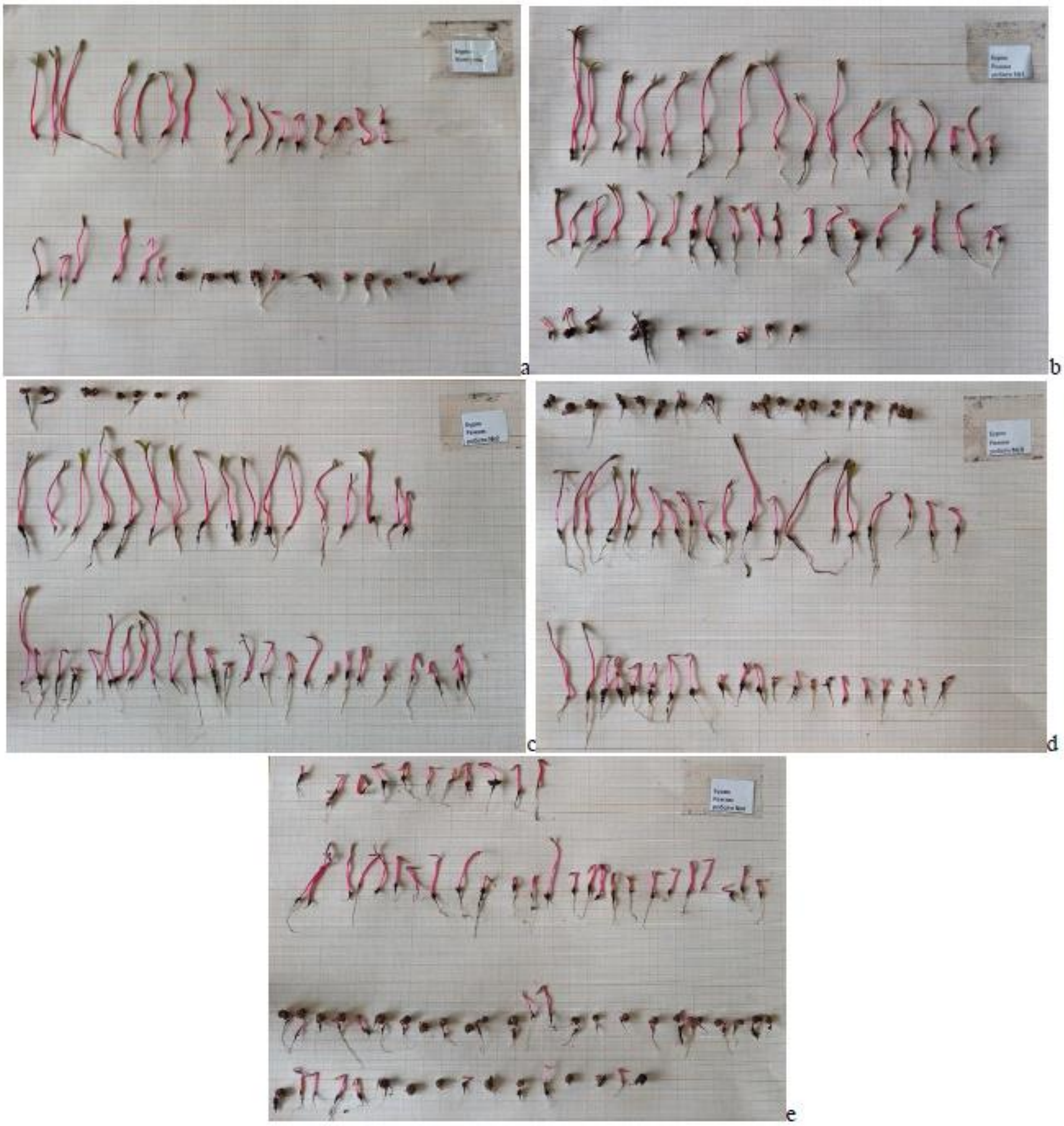

Fig. 10. Photo of beet stems on the 15th day, with a seed treatment time of 0 (a); 1 (b); 2 (c); 3 (d), and 4 min (e)

CONCLUSIONS

The influence of dielectric barrier discharge on the germination of beet seeds was investigated.

The emission spectrum of the DBD plasma was measured, and N_2 was determined as its main component. From the emission spectra, the rotational and vibrational temperatures of N_2 were estimated. The plasma is shown to be non-equilibrium, with the rotational temperature close to room temperature at 300 K.

As of the 15th day after planting, the germination of the beet seeds treated with a DBD, regardless of the treatment time (in the range of 1 to 4 min), was better compared to untreated seeds. Regarding the percentage of germination, the optimal treatment time with a DBD was 4 min. When considering the development of the beet stem, the optimal time of DBD treatment is 2 min.

ACKNOWLEDGEMENTS

This work was supported in part by the Ministry of Education and Science of Ukraine, the National Academy of Sciences of Ukraine, and the Taras Shevchenko National University of Kyiv.

REFERENCES

1. B. Adhikari, K. Pangomm, M. Veerana, S. Mitra and G. Park. Plant disease control by non-thermal atmospheric-pressure plasma // *Frontires in plant Science*. 2020, v. 11, Article 77, 15 p.

2. Y. Elad, I. Pertot. Climate change impact on plant pathogens and plant diseases // *J. Crop Improv*. 2014, v. 28, p. 99-139.

3. THE 17 GOALS | Sustainable Development (un.org).

4. V. Chernyak, O. Nedybaliuk, O. Tsymbaliuk, et al. Plasma chemistry for concept of sustainable development // *Problems of Atomic Science and*

Technology. *Series "Plasma Physics" (107).* 2017, № 1, p. 126-131.
5. O. Schlüter, N. Mistra. Cold Plasma in Food and Agriculture: Fundamentals and Applications // *Academic Press*. 2016, 380 p.
6. N. Hojnik, M. Modic, Yu. Ni, et al. Effective Fungal Spore Inactivation with an Environmentally. Friendly Approach Based on Atmospheric Pressure Air Plasma // *Environ. Sci. Technol.* 2019, № 53, p. 1893-1904.
7. O.A. Nedybaliuk, N.S. Kot, A.V. Kharina and I.I. Fedirchyk. Impact of Corona Discharge on Serratia Marcescens and Pseudomonas // *Problems of Atomic Science and Technology. Series "Plasma Electronics and New Methods of Acceleration" (134).* 2021, № 4, p. 183-187.
8. O.A. Nedybaliuk, Yu.P. Veremii, N.V. Tsvyd, et al. Impact of corona discharge on Aspergilius niger spores and Cyathus olla mycelium growth // *Problems of Atomic Science and Technology. Series "Plasma Physics" (130)*. 2020, № 6, p. 185-189.
9. R. Sheldon. Green Chemistry, Catalysis and Valorization of Waste Biomass // *Journal of Molecular Catalysis A: Chemical.* 2016, v. 422, p. 3-12.
10. C. Varilla, M. Marcone and G. Annor. Potential of Cold Plasma Technology in Ensuring the Safety of Foods and Agricultural Produce: A Review // *Foods.* 2020, v. 9, 17 p.
11. C.O. Laux, T.G. Spence, C.H. Kruger, R.N. Zare. Optical diagnostics of atmospheric pressure air plasma // *Plasma Source Sci. Technol.* 2003, № 2. p. 125-138; SPECAIR: http://www.specair-radiation.net.
12. O.A. Nedybaliuk, P.V. Tyshchuk, T.A Tereshchenko, and I.I. Fedirchyk. Plasma-catalytic system with narrow-aperture rotating gliding discharge // *Problems of Atomic Science and Technology. Series "Plasma Physics" (131)*. 2021, № 1, p. 117-121.
13. O.A. Nedybaliuk, I.I. Fedirchyk, V.Y. Chernyak. Plasma-catalytic system with wide-aperture rotating gliding discharge // *Problems of Atomic Science and Technology*. *Series "Plasma Physics" (118).* 2018, № 6, p. 214-217.
14. O.A. Nedybaliuk, T.A. Tereshchenko, I.I. Fedirchyk, et al. Reforming of ethanol in plasma-catalytic system with DC and AC rotating gliding discharge // *Problems of Atomic Science and Technology. Series "Plasma Physics" (131)*. 2021, № 1, p. 117-121.
15. O.A. Nedybaliuk, L.Iu. Mordvintseva, I.I. Fedirchyk, M.S. Maruschak, D.L. Chernolutsky. Influence of wide-aperture rotating gliding discharge on sunflower seed germination // *Problems of Atomic Science and Technology. Series "Plasma Physics" (142).* 2022, № 6, p. 114-118.

Article received 13.02.2023

ВПЛИВ ДІЕЛЕКТРИЧНОГО БАР'ЄРНОГО РОЗРЯДУ НА ПРОРОСТАННЯ НАСІННЯ БУРЯКА

О.А. Недибалюк, І.І. Федірчик, М.С. Марущак, Д.Л. Чернолуцький

Досліджено вплив діелектричного бар'єрного розряду (ДБР) на проростання насіння буряка за різних умов. Виміряно емісійні спектри плазми діелектричного бар'єрного розряду за різних режимів роботи. Показано, що основною компонентою на емісійних спектрах є смуги азоту (N_2). Визначено обертову (T_r) та коливну (T_v) температуру плазми діелектричного бар'єрного розряду за смугами азоту (N_2) за різних режимів роботи. Побудовано залежності відсотку проростання насіння буряка за різних проміжків часу обробки діелектричним бар'єрним розрядом. Визначено найбільш оптимальний час обробки насіння буряка.