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Study of spectral and luminescent characteristics of wheat seeds after laser radiation

The spectral and luminescent properties of wheat seeds were studied after laser radiation. The radiation of wheat seeds by monochromatic radiation was performed using a continuous semiconductor laser within the generation wavelength of λgen = 650 nm. The radiation power density in working area is 2.3 mW. The excitation and luminescence spectra of wheat seeds were measured. It was shown that after the radiation of wheat seeds by monochromatic radiation the luminescence intensity was increased to critical value. It has been established that radiation intensity of wheat seeds depends on the laser radiation time duration. The dependences of germination and sprout energy of wheat seeds from laser radiation time duration were studied. The dependences of luminescent intensity of wheat seeds correlate with germination and sprout energy data. The obtained results can be used for laser processing of wheat seeds of agricultural crops.

Keywords: coherent radiation, luminescence, excitation spectra, irradiation, wheat seed, germination, sprout energy.

1 Introduction

Nowadays, interest is rapidly growing up to the action of coherent radiation on plant organisms. The main issue in this problem is a need to clarify the fundamental aspects of coherent laser radiation interaction with biosystem, and applied tasks [1, 2]. Thus, the interaction of coherent laser radiation with biological objects leads to certain photobiological reactions. Herewith the physiological status of plant organisms largely depends on the light intensity, its spectral composition, and radiation dose and irradiation frequency [3, 4].

A relevant issue in this paper becomes the study of plant organism's luminescence characteristics. Luminescence spectra often provide detailed information about fluorescent molecules, their conformations, binding sites and interactions with cells and tissues [5, 6]. The luminescent characteristics of plant organisms are sensitive to various factors as well. Therefore, we studied the luminescence of wheat seeds in different humidity [7]. The results showed that the wheat seeds luminescence depended on the structure and time of soaking. Thus, the study of the biological effects of coherent laser radiation on plant organisms may attract not only identifying the optimal conditions for use in practical purposes, but the fundamental laws of lights action on plant organisms. The luminescence level can be considered as indicators of the cellular metabolisms intensity.

The most important of them are methods of spectral analysis, which allow studying the physicochemical processes that directly take place in the living cell and its organoids. The possibilities of spectral analysis are primarily associated with the circumstance that many molecules perform as a part of the functional mechanisms of cells that possess very characteristic absorption spectra and luminescence. In some cases, these spectral characteristics exposed significant changes, reflecting those changes in the structure of given molecules and its environment, which serve the physicochemical basis of biological function. Thus, the study of luminescent characteristics of plant organisms is particularly relevant due to the fact, that luminescent characteristics of wheat seeds can provide information about their physiological states and properties.

This paper presents the results of study of the influence of laser radiation on wheat seeds spectral-luminescent properties and photo-induced reactions.

2 Experimental

The selection form of wheat seeds were irradiated in an air-dry state. Irradiation of wheat seeds with monochromatic radiation was carried out using a continuous semiconductor laser with a generation wave-

length λ_{gen} = 650 nm. The density of radiation power in working area is 2.3 mW. The radiation power density was recorded using a measuring instrument IKT-1N laser radiation meter. The irradiation exposure times of wheat seeds were 10 to 900 seconds.

Registration of excitation and fluorescence spectra of the samples were performed by spectrometer SM2203 (Solar). The excitation and fluorescence spectra of wheat seeds were measured in holders for solid samples. The relative error of spectral measurements on spectrophotometer CM2203 does not exceed 2 %. Measurement accuracy of absorption spectra is ± 2 nm, and measurement accuracy of fluorescence spectra is ± 1 nm.

The luminescence decay kinetics of wheat seeds were measured on a pulsed spectrofluorometric with picoseconds resolution and recording in the time-correlated photon-counting mode. Fluorescence of the samples were excited using a pulsed semiconductor laser with generation wavelength λ_{gen} = 488 nm with pulse duration at half-height τ = 40 ps.

For evaluation of the germination of seeds, they were germinated in 50 pieces in triplicate on moistened 2-ply filter paper in Petri dishes at room temperature in the climate chamber. Wheat seeds were considered germinated, if it had a sprout and root, more than 1 cm and there were no signs of infection. Control and irradiated seeds were kept at the same constant temperature and humidity. The study of germination and seed sprout energy was carried out according to the methodological instructions of M.S. Zorina and S.P. Kabanov [8].

3 Results and discussion

Figure 1 demonstrates the excitation and luminescence spectra. It can be seen from the figure that the excitation spectrum intensity has a maximum at a wavelength of λ = 436 nm. The photo-excitation of wheat seeds luminescence was carried out at a wavelength λ equal to 440 nm. The wheat seeds luminescence spectrum has a intensity maximum at a wavelength λmax= 505 nm, and half width of spectrum $\Delta\lambda_{1/2}^{emiss}$ = 72 nm.

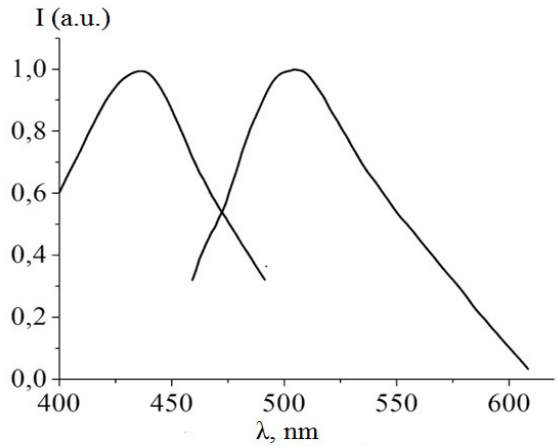


Figure 1. Wheat seeds excitation and luminescence spectra

Figure 2 demonstrates the dependence of wheat seeds emission intensity from various duration exposures by laser radiation. It can be seen from the figure that the emission intensity increased when photo excitation of the wheat seeds was observed. The intensity of wheat seeds luminescence increases to some critical value (t = 240 s), and a further increase seeds exposures radiation time leads to a decrease luminescence intensity by 1.5 times. In this case, the maximum position of luminescence bands and its half width does not change (Table). According to the reason of the increase of plant biosystem luminescence intensity is an increase enzymatic reaction rate [9]. However, on prolonged laser radiations exposure, it leads to the decrease of wheat seeds luminescence intensity, which is probably associated with oppressive action of laser radiation.

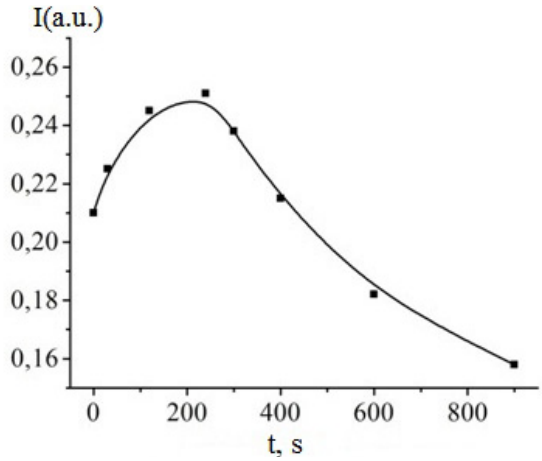


Figure 2. Dependence of wheat seeds emission intensity from laser (λgen = 650 nm) radiation exposure time

T a b l e

Influence of coherent radiation on wheat seeds luminescence characteristic

Radiations exposure duration time, s	$I^{lum}_{\max}$, o.e.	$\lambda^{lum}_{\max}$, nm	$\Delta\lambda^{lum}_{1/2}$, nm
0	0,212	505	72
30	0,225	505	72
120	0,245	505	72
240	0,251	505	72
300	0,238	505	72
400	0,215	505	72
600	0,182	505	72
900	0,158	505	72

Measurements of luminescence kinetic characteristics by the time-correlated photon counting method when samples were excited by a diode laser (λgen = 488 nm, τ = 40 p.sec.) showed that the logarithmic decay curves of unirradiated wheat seeds have a non-linear relationship over the entire time range of the measurements. In this case, in kinetics one can distinguish two linear regions with different luminescence lifetime (Fig. 3). The lifetimes of the excited states, obtained by approximating the decay curves by an exponential function, were τ1 = 0.55 ns and τ2 = 1.65 ns, respectively. After laser radiations exposure on wheat seeds, the luminescence lifetime does not change.

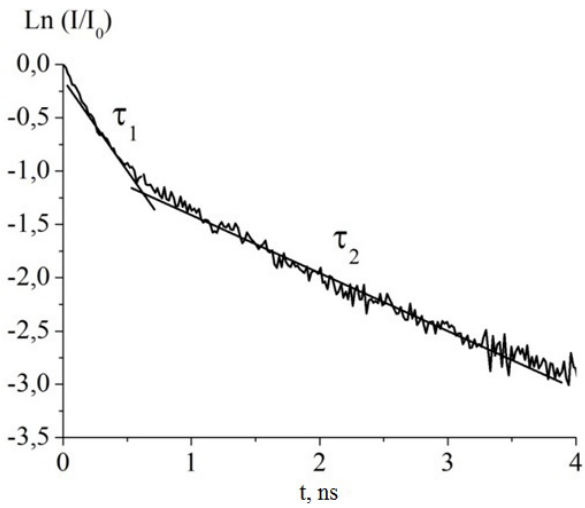
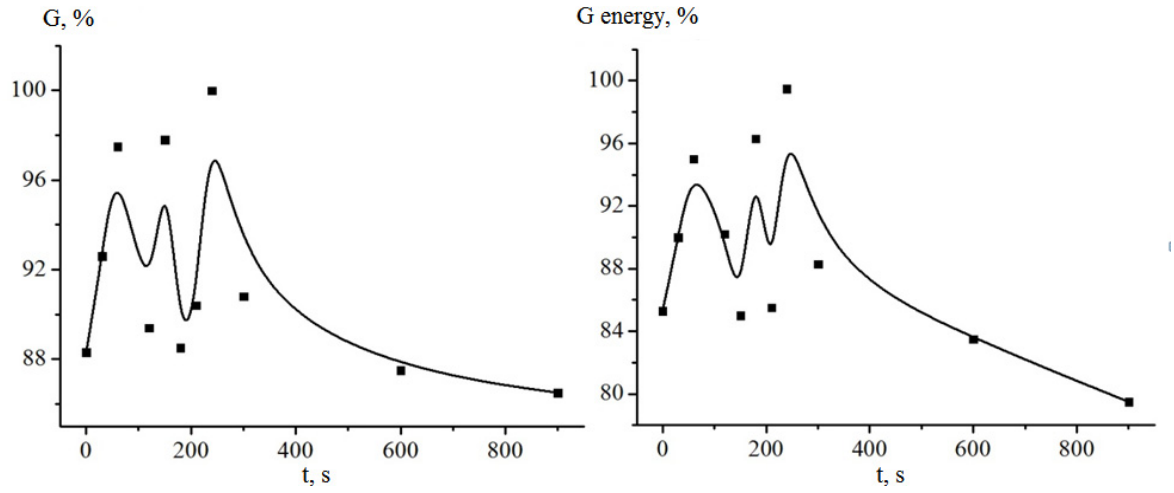


Figure 3. Wheat seeds luminescence kinetics decay

The dependence of wheat seeds germination and sprout energy from laser radiations exposure time duration as illustrated in Figure 4. As it demonstrates that the wheat seeds germination and growth energy from radiation exposure time duration had some extremums. The wheat seeds germination increases with the radiation exposure duration. This mark varies considerably, starting with radiations exposure duration of 30 seconds. The wheat seeds germination and sprout energies maximum value reaches at radiations exposure times of 30, 160, 240 s. In this case, seed germination compared with the control (88.0 %) increased by 12.0 % and amounted to 100.0 % (Fig. 4a). The results showed the similar dependence of germination energy from duration time of irradiation (Fig. 4b). For all curves, the maximum inflection is observed at almost the same radiation exposure time duration. The relative increase in germination energy values also remains, approximately the same.



Picture 4. Dependence of wheat seeds germination and sprout energy from laser radiations exposure time duration

Non-linear responsiveness of wheat seeds from action of coherent red radiation associated with radiations exposure time duration and did not obey dose law of Bunsen-Roscoe. The responsiveness of plant organism violates the law of Bunsen-Roscoe as describes in studies [10, 11]. The following increase of the laser radiations exposure duration times that leads to the decrease in wheat seeds germination and sprout energy. When laser radiations exposure time duration achieved limit value, it decreased the stimulation effect which was associated with saturation and oppressive action to cells metabolism [12, 13].

4 Conclusion

From research results, when wheat seeds irradiated by laser radiation, the luminescence intensity increased. The wheat seeds luminescence intensities maximum was observed in radiations exposure time duration up to 240s. The following increase radiation exposure time duration leads to the decrease of the emissions intensity. In this case, the band limits the position, whereas its half width did not change. The excited states lifetimes were $\tau 1 = 0.55$ ns and $\tau 2 = 1.65$ ns, respectively. When wheat seeds are irradiated, the excited states lifetime does not change. The dependence of biological effect from laser radiation exposure time durations had multimodal form with alternative maximum and minimum of stimulation effect. Wheat seeds were studied at laser radiation exposure times duration up to 240s. In this case, seeds germination compared with the control samples increased by 12.0 %. From experiment results, the analogical dependence of seeds germination energy from laser radiation exposure time duration was observed.

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Лазер сәулесімен сәулелендірілген бидай дәнінің спектрлік-люминесценттік қасиеттерін зерттеу

Бидай дәнін когерентті жарықпен сәулелендіруден кейінгі спектрлік-люминесценттік қасиеті зерттелді. Бидай дәнін монохроматты сәулелендіруге, толқын ұзындық генерациясы $\lambda_{ген}$ = 650 нм, үзіліссіз сәуле шығаратын жартылайөткізгішті лазер пайдаланылды. Жұмыс аумағындағы сәулелендіру қуатының тығыздығы 2,3 мВт. Бидай дәнінің қоздыру және люминесценция спектрлері өлшенді. Бидай дәні люминесценциясының қарқындылығы, когерентті сәулелендіруден кейін критикалық мәні артқаны байқалды. Бидай дәнінің жарық шығару қарқыны лазермен сәулелендіру ұзақтығына тәуелді екендігі анықталды. Бидай дәнінің бүршік жаруы мен өсу энергиясы лазерлік сәулелендіру ұзақтығына тәуелді екені зерттелді. Бидай дәнінің люминесценция қарқындылығы бүршік жару және өсу энергиясы деректеріне байланысты.

Кілт сөздер: когерентті сәуле шығару, люминесценция, қоздыру спектрі, сәулелендіру, бидай дәні, бүршік жару, өсу энергиясы.

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Исследование спектрально-люминесцентных характеристик семян пшеницы после облучения лазерным излучением

Спектрально-люминесцентные свойства семян пшеницы были исследованы после облучения лазерным излучением. Облучение семян пшеницы монохроматическим излучением проводилось с помощью непрерывного полупроводникового лазера с длиной волны генерации $\lambda_{ген}$ = 650 нм. Плотность мощности облучения в рабочей зоне составляла 2,3 мВт. Измерены спектры возбуждения и люминесценции семян пшеницы. Показано, что после облучения семян пшеницы монохроматическим излучением интенсивность люминесценции увеличивается до критического значения. Установлено, что интенсивность излучения семян пшеницы имеет зависимость от длительности лазерного облучения. Также были изучены зависимости всхожести и энергии прорастания семян пшеницы от длительности лазерного облучения. Зависимости интенсивности люминесценции семян пшеницы коррелируют с данными по всхожести и энергии прорастания. Полученные результаты могут быть использованы при лазерной обработке предпосевных семян сельскохозяйственных культур.

Ключевые слова: когерентное излучение, люминесценция, спектр возбуждения, облучение, семена пшеницы, всхожесть, энергия прорастания.

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