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Effect of laser irradiation on the processes involved in growth of mustard and radish seeds

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Abstract. Horticulture as a branch of agriculture was developed as a means of increasing the crop productivity and economic feasibility of agricultural production. Advancement of various agricultural technologies, such as chemical and biological growth promoting substances and application of fertilizers, pesticides, substances that protect plants from diseases, causes ecological imbalance. For this reason, it is essential to perform the task of developing new technological methods that make it possible to unlock genetic potential of plants and get higher yields avoiding any environmental impact. Laser irradiation is one of such methods. Pre-sowing seed treatment with low-intensity red spectrum laser irradiation positively affects the growth and development of plants. This research paper conveys the study of the effect of red spectrum laser irradiation that allows one to irradiate mustard and radish seeds with continuous light using left and right rotating laser beam sweep in order to activate chemical matter with L- and D-conformations in plants. The effect of this treatment on germination capacity and energy was studied as well.

1. Introduction

Many years of selection of various crops for special purposes led to these crops partially losing their adaptive qualities. As a result, it became impossible to maintain a high productivity of agrocoenosis without various kinds of protective technology applied. However, application of these technologies implies using toxic and carcinogenic chemical inputs that cause harm to the environment. As reducing the quantity of pesticides used is essential, new research and technology areas are brought into focus. Currently, methods of biological [1] and biophysical effects [2] are found the wide application. These technologies are utilized in order to unlock genetic self-potential of plants and obtain environmentally friendly crop production.

Growth and development of plants is affected by a great variety of factors. One of the most important of them all is light. Of all the living systems of our planet, plants are the most evolutionally adapted to absorption and transformation of light. For this reason, the study of the effect of different light spectra on plant body is of special interest.

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According to extensive research, low-intensity laser irradiation proved to have high biological efficiency. Such an environmentally friendly and low energy consuming control factor is of apparent interest for farming industry [3].

The effect of red light spectrum is not destructive, if one keeps the timing of irradiation. On the contrary, exposure to polarized electromagnetic radiation with a wavelength of 630-700 nm during the night, when photosynthesis in plants stops, stimulates phytochromes. Phytochromes are a special group of photoreceptor proteins responsible for light-sensitive processes in a cell. These processes unlock seed germination and chlorophyll synthesis in etiolated seedlings [4]. Exposure to the laser irradiation does not lead to environmental contamination by xenobiotics and this allows us to obtain ecologically-friendly products.

Fundamental research on application of laser treatment of seeds of different crops allows one to introduce this method into practice with the purposes of finding solution to the most essential agro-ecological and socio-economic challenges.

2. The experimental part

The results of numerous experiments held by Russian and foreign scientists proved that seed germination is accelerated when the seeds are exposed to laser irradiation (LI) of specific wavelengths. The efficiency of electromagnetic stimulation depends on the right choice of optical parameters, dose, time of irradiation and methods of irradiated material storage.

The major part of research is devoted to the description of the operation of He-Ne laser installations. However, due to a large size and high energy expenditures, industrial application of this equipment is challenging. For this reason, small semiconductor laser setups able to generate rays of specific wavelengths are of great practical interest [3–17].

It's common knowledge that living organisms consist of polymers. L-type amino acids, monomers that build proteins, are levorotatory isomers. D-type carbohydrates are dextrorotatory isomers. Both of them are biologically significant and take part in biochemical processes of a living organism. For this reason, it is of interest to study the reaction of these L and D forms of molecules to being treated with a circular sweep of low-level laser irradiation.

Seeds of radish (Raphanus sativus L.) and mustard (Brassica juncea L.) were chosen to be the objects of research. The plants belong to the same botanic family. This relation indicates common botanical characteristics.

Radish is annual or biennial plant of Raphanus genus. Its light-brown seeds have irregular ovoid shape. Its thousand-seed weight is 8-10 g. Root crops of round varieties form mainly from mesocotyl.

Leaf mustard belongs to Brassica genus included into the family of the same name. It is an annual herbaceous plant. Its reddish-brown or deep brown seeds are faveolate. A seed diameter is 1 – 1.3 mm, thousand-seed weight – 2–4 g.

Seeds of those plants were divided into two groups, control and experimental, threefold repetitions of 100 seeds each. Seeds from the experimental group were for 30 seconds exposed to laser irradiation. The treatment was performed using 5 mW semiconductor laser with a 658 nm wavelength. The time of exposure was determined experimentally [18].

In a laser treatment installation, there is a rotating laser beam sweep, that allows one to irradiate the seeds with continuous light, and left and right rotating laser beam sweeps. Irradiation was performed once and lasted 30 seconds (figure 1).

Dry seeds of the crops under study were analyzed in order to determine the necessary direction of laser beam rotation. The amount of carbohydrates in radish seeds was higher than the one in mustard seeds, which was 0.12 g/100 g and 0.07 g/100 g respectively. The protein content varied as well: 0.9 g/100 g in radish seeds vs 1.3 g/100 g in mustard seeds. Hence, the amount of compounds with D-configuration prevailed in radish seeds. For this reason, when these seeds were irradiated, the laser was rotated to the right. L-compounds prevailed in seeds of mustard; therefore, the laser beam was rotated to the left in process of irradiation.

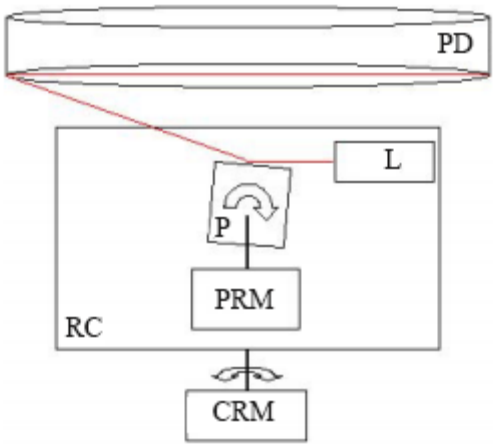


Figure 1. A diagram of stimulation of radish and mustard seeds.

PD – Petri dish with seeds, L – laser, P – tetrahedral mirror prism, PRM – prism-rotating motor, CRM – carriage-rotating motor, RC – rotating carriage.

The seeds were germinated in compliance with terms and requirements set by the national standard of the Russian Federation (GOST 12038-84) for each crop [19].

It is worth noting that all the seeds were placed in thermostats for germination. In the course experiment, the level of moisture in the mat (filter paper) was kept under control preventing both excessive moistening and drying up. It is also worth mentioning that seeds germinated in darkness. Temperature control was performed 3 times a day at the same time.

The germinated seeds were assessed at fixed times.

Note that the seeds that germinated well were counted twice: once to define germination energy and for the second time to define germination capacity.

Only normally germinated and clearly rotten seeds were counted and removed in order to measure germination energy. To measure germination capacity, imbibed, hard, rotten, normally and abnormally germinated seeds were counted separately.

We measured the content of protein, glucose and lipids in seeds. Glucose content was measured using the protometric glucose oxidase test (500 nm wavelength) and protein content was measured using the biuret method (the formation of colored complex with Cu^{2+} ions in alkaline medium). The intensity of the color of reaction medium depended on crude protein concentration. All the measurements were performed photometrically (540 nm wavelength).

3. Results and discussion

Germination energy and capacity were determined in vitro. At the same time, shooting phase was checked visually. It is worth noting that germination energy is understood as the ability of seeds to germinate rapidly and simultaneously.

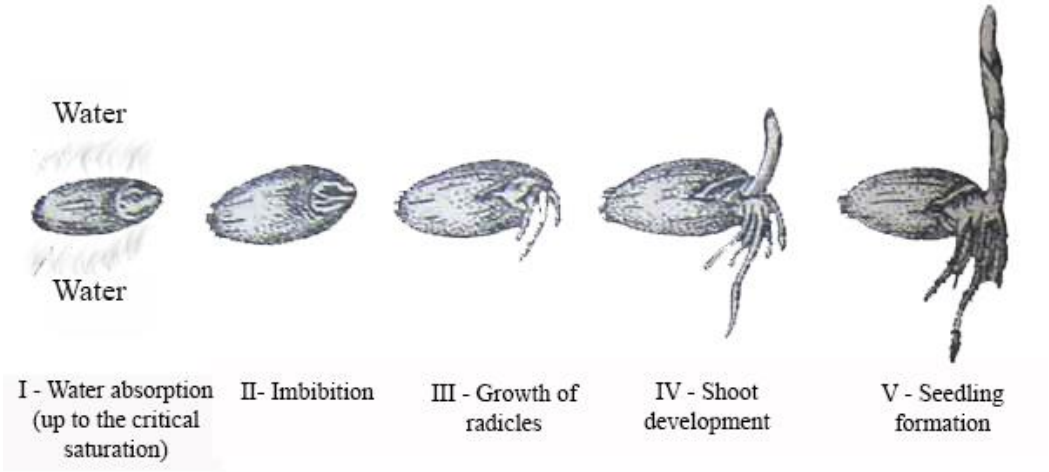


Figure 2. Seed germination phases.

Measurements of germination energy and capacity were performed both for seeds which were not treated with laser irradiation (henceforth referred to as "control"), and for the seeds treated with laser irradiation (henceforth referred to as "experimental group") (table 1).

Obtained data analysis showed that both germination capacity and germination energy of radish seeds are higher for the seeds treated using the laser technology. Notably, strong growth of mold was registered on the seeds which were not irradiated. At the same time, experimental group seeds were more pathogen-resistant. For example, radish germination capacity demonstrated a 20%-rise and its germination energy showed 41%-rise, which indicates a positive effect of laser irradiation and advisability of its use for pre-sowing seed treatment.

The results of control measurements of germination energy of the mustard seeds in experimental group demonstrated a 15%-rise and their germination capacity showed 18%-rise. It was also registered that the irradiated seeds were more resistant to mold formation. Consequently, we can conclude that the treatment with laser irradiation demonstrated a positive effect on the growth of mustard seeds reducing losses at the germination stage.

Table 1. The results of germination energy and capacity measurements for radish *(Raphanus sativus L.) and* mustard (Brassica juncea L.) seeds.

Research object		Time of measurements	The period from the beginning of germination to the final counting, days	Percentage of seed germination, %
Radish seeds	Control group	Time of germination energy measurement	3	52
		Time of germination capacity measurement	6	78
	Experimental group	Time of germination energy measurement	3	93

		Time of germination capacity measurement	6	98
Mustard seeds	Control group	Time of germination energy measurement	3	46
		Time of germination capacity measurement	6	71
	Experimental group	Time of germination energy measurement	3	61
		Time of germination capacity measurement	6	89

The results of measurements of germination capacity and energy of radish and mustard seeds demonstrated a morphological difference between the records of control and experimental groups.

It is notable that the seeds from the control group needed more time for germination than the seeds from the experimental group. Moreover, the seeds treated with laser irradiation had larger roots and their cotyledons were more resistant to infections.

4. Conclusion

The research results showed that the laser irradiation treatment of seeds stimulates the initial growth processes and, consequently, boosts yields. In addition, one must consider the chirality of the molecules prevailing in the crops treated in order to determine and set a suitable direction of laser beam rotation.

There is a higher possibility that the maximum effect can be reached under ecological conditions favorable for the growth and development of the plants. The plants grown from the seeds treated with laser beam demonstrate intensification of metabolic processes at early stages of development. It promoted increase of herbage, enhancement of photosynthesis, altered the moisture regime and mass correlation of underground and overground organs.

It is also possible to make a preliminary conclusion that a short-term exposure to laser irradiation makes plants more resistant to unfavorable factors of the environment, particularly to pathogens. Application of this method on the grounds not contaminated with chemical fertilizers will allow one to obtain ecologically friendly agricultural products of higher quality.

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