The use of laser radiation to stimulate the growth of kohlrabi cabbage

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Abstract. The paper analyzes data on the use of laser radiation to stimulate the growth and development of crops, describes the biochemical basis for the transmission of coherent radiation to the cell and the cellular response. The positive effect of using a semiconductor laser with a red spectrum of action with a wavelength of 658 nm is shown by the example of kohlrabi cabbage. An increase in the mass of stems, as well as an increase in the content of proteins and carbohydrates when using laser radiation, was shown.

1. Introduction

Crop production, as one of the fastest growing sectors of agriculture, is undergoing tremendous changes. The development of the industry as part of the implementation of the State Program for the Support of Agriculture has led to a systematic increase in production and growing consumption of food products. The ongoing changes are associated with territorial and climatic features, socio-economic development factors and the introduction of innovative production technologies. It is worth noting that scientific and technological progress in the cultivation of crops allows one to increase the profitability of agricultural producers, reduce the cost of production and increase its competitiveness, including in the world market. To do all of the above, it is necessary to create highly effective and environmentally friendly methods that will allow one to switch to the group of organic farming.

One of the effective methods is the method of physical impact, which compares favorably with chemicals in a high degree of environmental safety and manufacturability against the background of low energy costs. In practice, the effectiveness of the use of electromagnetic radiation of the visible area of light as an epigenetic method for regulating biosystems has been proved, which makes it possible to control gene expression without changing the hereditary program of a living organism [1].

Light for photosynthetic plants is not only a source of energy, but also an important regulator of all biological processes. The light exposure is based on the resonance absorption of photons by specific chromoproteins, such as phytochrome and cryptochrome of higher plants. The studies of such scientists as G. Mora, S.V. Konev, I.D. Volotovsky and others showed the influence and the path of transformation of the light signal into a chemical signal, activation and increase of bioenergy potential, leading to a higher effect of phytochrome, phytohormone and enzymatic systems, stimulation of their biochemical and physiological processes [4].
Speaking about the effect of light on the phenological stage of plants during their growth, it is important to have a certain photoreceptor at the molecular level. For the red and near-infrared spectral regions (600–750 nm) phytochromes are such photoreceptors. Being photoreceptive proteins, they are responsible for conducting numerous photosensitive processes in plants, such as seed germination, seedling deethiolation and its growing towards the light. Activation of phytochromes by coherent radiation, in particular laser radiation, allows improving the survival of plants in the field and has a positive effect on germination, energy, stress resistance, plant health, yield and crop quality. Achieving good results according to these criteria allowed the introduction of laser technology in agriculture, since they make it possible to realize the genetic potential of cultivated plants more fully against the background of a decrease in the use of growth stimulants and pesticides [2].

However, one cannot consider the problem of increasing the productivity of agrocenoses through the influence of laser radiation resolved due to the low productivity of the proposed equipment and the imperfection of processing modes. Therefore, it is important to select the optimal parameters of the laser system and the irradiation method to achieve the maximum result.

2. The experimental part

To date, there are installations that affect coherent light on seeds and vegetative plants. For the first time, serial production of laser treatment plants, including for seed and soil treatment, using a He-Ne laser, was launched at the Polyaron SCR (Lviv). This installation was part of the transport and technological module, mounted on a tractor and controlled from the cab of the energy module by the operator (driver). The time of irradiation varied from 3 to 20 minutes; over this time, growth processes were inhibited and plants were inhibited in general. Power and wavelength were selected separately for each culture. The technology of laser stimulation of seeds and plants was introduced in both the Krasnodar Krai and Kazakhstan, as well as in Europe and Asia. Irradiation is carried out in the dark, as a result of which negative consequences of treatment often occur causing injuries to the plants. In addition, an increase in exposure time led not only to an improvement in the economic characteristics of plants, but also to damage and fixation of chromosomal mutations.

Since the beginning of the 2000s, on the basis of Yaroslav-the-Wise Novgorod State University, scientists M.G. Danilovskikh have developed and tested an optomechanical device for controlling a laser beam, which differs from its analogues in small overall dimensions and low energy costs. Numerous laboratory experiments made it possible to select the optimal dose and exposure of irradiation and proceed to field trials.

In 2019, the planted seedlings of kohlrabi cabbage of the Ukza F1 variety became the experimental field test object for the laser beam control device. Cabbage “Ukza F1” is a hybrid; it belongs to the early ripening varieties of kohlrabi cabbage with a round purple stem crop. The bedding was carried out at the beginning of June on the territory of the planted acreage of PF (peasant farm) Pavlyuk, village of Ermolino, Novgorod Region, Northwest of Russia. The average daily temperature at the time of disembarkation was in the range of +17 ... +19°C, at night of +11°C. This temperature regime is optimal for kohlrabi cabbage, allowing plants not to stretch into the stems, but to create edible spherical thickenings.

The laser treatment was performed twice in the dark by a semiconductor laser of the red range with the following parameters: power density - 44 mW/cm², radiation dose varied from 160 mJ/cm² to 1.32 J/cm², wavelength - 658 nm, pulse duration - 62.5 μs, pulse frequency - 1000 Hz, radiation power - 150 mW, radiation exposure - 30 sec. The first treatment was carried out on June 5th, the second was carried out in 12 days – on June 17th.

After the treatments, the area of the leaf surface of the kohlrabi was measured according to the standard method:

\[ S = 0.75 \times a \times b, \]

where a is the leaf length, cm; b is the width in the widest part of the leaf, cm.
The leaf plate, being the main assimilating organ of plants, accumulates synthesized organic substances, which serve as a structural and energetic material for the entire plant organism. The square of a single leaf and the total leaf surface of the plant allows for evaluating the photosynthetic potential and the intensity of its work. After the harvest, which took place on 07/07/2019, control measurements of the stem crops and their biochemical analysis were carried out.

3. Results and discussion
The surface measurements of the leaf plate were carried out three times during the entire growing season – June 15th, 22th and 29th.

Measurements taken on June 15th, 2019 showed that, on average, the leaf surface area of the kohlrabi of the control group was 2078.78 cm$^2$, and that of the experimental group was 2296.22 cm$^2$, which is 218 cm$^2$ more than the leaf area of the control samples.

Such an increase of the leaf square after treatment is associated with the activation of biochemical processes in cabbage due to the exposure to laser irradiation. It is proved that such effects are possible only with thermodynamic disturbance arising from the absorption of laser irradiation by intracellular components. Even with short-term heating, changes occur both in the group of chromophores and in the areas surrounding them. This leads to a change in the physicochemical properties of the molecule, as a result of which the cascade mechanism of reactions induced by laser radiation is triggered. Insignificant local disturbances do not lead to the transfer of the molecule to a new conformational state, but the effect can significantly change the configuration of the molecules. In this case, the molecule rotates around the single bonds of the main chain, which significantly affects their functioning. Energy transfer leads to the movement of protein macromolecules, activating the biochemical processes. By stimulating Ca$^{2+}$ dependent processes, there is an increase in the synthesis of DNA and RNA, an increase in the redox potential of mitochondria, and an increase in the synthesis and accumulation of ATP [3]. As a result, the synthesis of protein molecules is activated and, as a result, the growth and development of plants are accelerated.

The measurements carried out to determine the square of the kohlrabi leaf surface from 06/22/2019 showed a slight gap in the indicator – 2477.64 cm$^2$ versus 2561.23 cm$^2$ in the control and experimental groups, respectively. The average daily air temperature during the day during this period varied from +17°C to +28°C. Against the background of slight deviations of the leaf surface square of the cabbage of the experimental group from the control group cabbage, thickening of the stem and the formation of purple stem crop in irradiated plants were noted, while the plants of the control group differed only by large leaves of dark green color (in Figure 1 the left row is the experimental group).
**Figure 1.** The formation of a stem crop on plants of the experimental group (left row) and the control group of plants (right row).

When taking measurements of the leaf square area on June 29th, 2019, an increase in the growth rate was noted – 3197.18 cm$^2$ in the control against 3625.6 cm$^2$ in plants of the experimental group, which is 428 cm$^2$ higher than the control indicator. From the moment of the second measurement and prior to harvesting, significant weather changes occurred, namely, the average daily air temperature decreased by 6–8°C and the air humidity increased to 57–96%.

**Figure 2.** The kohlrabi leaf surface area during the control measurements on June 15th, 22th and 29th, 2019 (1, 2 and 3 measurements, respectively), cm$^2$

At the time of harvesting, the average daily humidity reached 82-96%, which greatly complicated the conduct of harvesting activities. It is worth noting that weather conditions did not negatively affect the marketability of kohlrabi cabbage, stem waterlogging did not occur due to waterlogging of the soil, which positively characterizes the Ukza F1 variety.

Harvested kohlrabi cabbage was cleared of leaves and weighed. The weight of the kohlrabi stem crops in the control group ranged from 283 to 520 g/pc with an average weight of 400 g. In the experimental group, the minimum weight was 490 g, the maximum was 993 g, the average weight of one stalk was 650 g (Figure 3).

**Figure 3.** Harvest of kohlrabi stem crops (1 - control group, 2 - experimental group).
In addition to weight measurements, an analysis was carried out for the content of proteins, fats and carbohydrates in the cabbage (Table 1).

**Table 1.** The content of proteins, fats and carbohydrates in kohlrabi stem crops.

| Indicator       | Protein content, g/100 g | Fat content, g/100 g | Carbohydrate content, g/100 g |
|-----------------|--------------------------|----------------------|-------------------------------|
| Control group   | 1.3                      | 0.04                 | 4.5                           |
| Experimental group | 1.6                  | 0.05                 | 4.8                           |

The protein content in the cabbage of the experimental group was 0.3 g/100 g higher than in the cabbage of the control group. Due to its balance in amino acid composition and with other elements, kohlrabi protein is absorbed by the body very well, so an increase in protein has a positive effect on the quality of the finished product. The amount of fats differs slightly in the cabbage of the experimental group – 0.01 g/100 g higher than that in the control group, which is not significant. An increase in the amount of carbohydrates in the kohlrabi stem crops of the experimental group (by 0.3 g/100 g) indicates an increase in the amount of fiber in the staple fruit, which makes the texture more dense. At the same time, the shelf life and safety of the finished product in a fresh form increased.

Additionally, an analysis was conducted on the content of toxic elements in the stem crops. According to the examination of the sanitary-hygienic laboratory of Rospotrebnadzor, the content of Pb, As, Kd, Hg, nitrates and pesticides was below the maximum permissible values, which indicates the environmental safety of the products.

### 4. Conclusion

In-vivo treatment of kohlrabi cabbage of the Ukza F1 variety with a semiconductor laser there is phytochrome activation due to the action of red coherent light and growth processes. The optimal exposure for this type of plant is a double 30-second treatment in the dark. High commercial quality of the crops, an increase in the mass of the stem crop and the content of proteins and carbohydrates were noted, which significantly increases the profitability of growing kohlrabi in the North-West. Studies have shown that laser stimulation of vegetative plants is the same technological technique that will reduce the technogenic load on the soil and improve the quality of finished products.

### References

[1] Budagovsky A, Solovykh N, Budagovskaya O and Budagovsky I 2015 Response of vegetable organisms to quasi-monochromatic light of different duration, intensity and wavelength *Quantum Electronics* 45 (4) 345–50

[2] Budagovskaya A, Solovykh N, Yankovskaya M, Maslova M, Budagovskaya O and Budagovsky I 2016 Effect of spatial coherence of light on the photoregulation processes in cells *Physical Review* 94 1 012411

[3] Euler Thomas, Detwiler B. Peter and Denk Winfried 2002 Directionally selective calcium signals in dendrites of starburst amacrine cells *Nature* 418 845–52

[4] Moskvin S 2017 Low-level laser therapy in Russia: history, science and practice *Journal of Lasers in Medical Sciences* 8 2 56–65