Influence of electronic irradiation on the affection of barley by root rot

N N Loy¹, N I Sanzarova¹, S N Gulina¹, M S Vorobiyov², N N Koval², S Yu Doroshkevich², T V Chizh¹ and O V Suslova¹

¹ Russian Institute of Radiology and Agroecology, 109 km Kievskoe shosse, Obninsk, 249032, Russia
² Institute of High Current Electronics SB RAS, 2/3 Akademichesky ave., Tomsk, 634055, Russia

E-mail: loy.nad@yandex.ru

Abstract. The paper displays the results of the study of the effect of pre-sowing irradiation of spring barley of the Vladimir variety with a low-energy electron beam in a wide dose range from 1 to 8 kGy and a dose rate of 500 Gy/imp on seed infestation by root rot and sowing qualities. It has been shown that the development of the disease depends on both the radiation dose and the post-radiation period (PP). The most effective was the effect of irradiation on Helminthosporium sativum (synonymous with Drechslera teres) at PP of 4 days: there was observed a reduction in the damage degree by 33–48% and the disease incidence – by 29–46% at doses of 4–8 kGy. At the PP of 7 and 11 days, the irradiation of seeds with doses of 3–5 kGy reduces the degree of damage to the seedlings by Helminthosporium sativum by 30–37% and 28–41%, respectively. With an increase in PP up to 14 days, a decrease in the damage degree of seedlings by root rot by 33% was observed only at an irradiation dose of 4 kGy, which indicates a reduction in the efficiency of irradiation with increasing PP. The prevalence of the disease decreased at PP of 4 days by 28–46% (doses of 4-8 kGy), at PP of 7 days – by 30–37% (doses of 2–6 kGy), at PP of 11 days – by 26–48% (doses 3, 4 and 7 kGy) and PP 14 days – by 33% at a dose of 4 kGy. It has been established that electron irradiation stimulates laboratory germination of seeds at PP of 7 days by 22–25% at doses of 1, 2, 4 and 5 kGy and, on the contrary, reduces it by 19–24% at PP of 4 days and doses of 3, 5 and 8 kGy. At doses higher than 4 kGy, irradiation inhibits sprout length by 12–39%, roots – by 9–15%, and also at doses of 2–8 kGy, it reduces the wet weight of seedlings by 10–50%. Thus, it was shown that pre-sowing electron irradiation of spring barley of the Vladimir variety reduces the resistance of Helminthosporium sativum and can be used to combat the pathogenic microflora of the grain.

1. Introduction
Damage to plants caused by competition from weeds, diseases and pests significantly impairs their productivity and, in some cases, can destroy the crop. Today, reliable yields are obtained through the use of disease-resistant varieties, biological control methods and the use of pesticides to combat plant diseases, insects and weeds.

For about 100 years, breeding for disease resistance has been an important component of agricultural productivity worldwide. But the successes achieved by plant breeding, to a large extent, can be short-term due to the changing nature of pathogens and other pests. Therefore, the chemical
method is still dominating among other modern protection methods, and it is often used without an environmental impact assessment.

Nevertheless, in recent years in Russia, there has been a sharp deterioration in the quality of grain and its technological indicators. Crop losses from diseases in the country were about 10%.

Currently, there is a change of technologies and methods that ensure high efficiency of disinfection of grain and its products. When growing crops in ecological farming, new, more effective methods of the fighting against pathogenic organisms are being searched for, providing a better quality of grain and its environmental safety. Such methods include presowing treatment of seeds with ionising radiation.

The impact of ionising radiation on the pathogen leads to various deviations in its development. In their sensitivity to radiation, spores of various pathogens differ from each other by tens and even hundreds of times. Factors affecting resistance are multicellularity, multi-core, ploidy, etc. [1].

Among individual groups of microflora contaminating wheat seeds, bacteria were the least and fungi were most resistant to the action of $^{60}$Co gamma rays and X-rays [2].

In studying the effect of X-ray and gamma-radiation on the development of chlamydospores of 3 kinds of fungi (Tilletia foetida, T. triticoides, T. nanifica), parasitic on wheat, and 3 types of other fungi (Ustilago hordei, U. nuda, U. nigra), parasitic on barley, the reduction of the germination of chlamydospores from a dose of 100 Gy was shown, however, the percentage of germination of grains remained quite high up to a dose of 1250 Gy. The germination of seeds was noted even at 7000 Gy and was completely inhibited only at a radiation dose of 10000 Gy. The most resistant was the fungus U. nigra. In Tilletia species, a noticeable decrease in the percentage of irradiated chlamydospores was observed at a dose of 100 Gy, at 1250 Gy, germination decreased by 50%, and at 5000 Gy, except for the most resistant T. nanifica, germination completely stopped [3].

The study of the effect of ionising radiation on the pathogen Puccinia graminis tritici showed that the infectivity of uredospores increases 1.5–2.5 times with doses of 400–800 Gy and decreases 1.8–2.8 times with doses of 1800–2500 Gy [4].

As a result, it can be stated that with an increase in the dose of radiation, a decrease in the resistance of many diseases of various grain crops occurs. However, the downside of such irradiation is a decrease in grain germination, which the authors of many works associate with the death of a seed germ as a result of its irradiation, which, in turn, is associated with a high (> 1 MeV) energy of particles influencing the grain. The mean free path of electrons with such high energy exceeds the diameter of a single grain, thereby the electrons “blast” the grain through, leaving some of its energy in the germ, delivering the dose to it, which leads to its death. This phenomenon leads to the impossibility of using high-energy electron accelerators and gamma facilities for presowing grain disinfection and creates conditions for searching for new electron accelerators that generate low-energy (up to 200 keV) electron beams with the possibility of their release into the atmosphere.

Thus, using an electron accelerator with a plasma cathode and the output of a generated beam to the atmosphere, it was previously shown that the exposure of barley seeds to a low-energy electron beam before sowing contributed to a decrease in the development of Helminthosporium sativum on seedlings [5].

This is precisely why the aim of the current research was the study of the effect of pre-sowing irradiation of spring barley with a low-energy electron beam in a wide dose range on seed infestation by root rot.

2. Materials and methods
Spring barley (Hordeum vulgare L.) of the Vladimir variety, the harvest of 2017, was selected as the object of the study, the reproduction was elite.

As in [5], grain was irradiated on a “Duet” wide-aperture electron accelerator with a mesh plasma cathode and output of a generated beam of large cross-section into the atmosphere [6]. These experiments were also carried out with a single accelerating voltage $U_0 = 160$ kV, and a single
duration and amplitude of the beam current. The total given dose was gained by repeated exposure of the grain to the electron beam with the parameters summarised in table 1.

| Accelerating voltage (kV) | Beam current density (mA) | Pulse duration (µs) | Pulse recurrence frequency (s\(^{-1}\)) | Dose rate per pulse, (Gy/imp) |
|---------------------------|---------------------------|---------------------|----------------------------------------|-----------------------------|
| 160                       | 24                        | 200                 | 1                                      | 500                         |

In contrast to irradiation in [5], in this work, barley seeds with a total mass of \( m = 15 \) g were fixed with adhesive tape of 50 µm thick, which made it possible to put down the grain in one layer at a distance of 20 mm from the accelerator exit window. At introducing a half dose, the value of which varied in the range (1–8) kGy with a step of 1 kGy, the sample was turned over to the other side to level the given dose in each seed.

After irradiation, the seeds were germinated in rolls of filter paper for 7 days in a thermostat at a temperature of + 24°C according to the methodology [7]. When conducting laboratory experiments, the following indicators were taken into account: laboratory germination (BV), sprout and root length, wet and dry weight of seedlings, percentage of water content in seedlings. Accounting of seedlings infestation by diseases was carried out according to generally accepted methods [8, 9].

The experimental results were processed using Microsoft Excel 2003 software.

### 3. Results and discussion

In studies [5], which we carried out earlier, we studied the effect of presowing electron irradiation at doses of 1, 5 and 8 kGy on the infestation of barley seeds by diseases and on sowing qualities [5]. It was established that at PP of 5 days, presowing irradiation of seeds statistically significantly (at \( p < 0.05 \)) reduced the degree of damage to seedlings by \textit{Drechslera teres} 2.1–3.2 times depending on the dose and dose rate, it also reduced contamination by \textit{Penicillium} sp. 3.5–13.7 times for all studied doses and dose rates and did not affect the infestation of the seedlings by \textit{Fusarium} sp. The decrease in the incidence of diseases varied from 1.5 to 3.2 times for \textit{Drechslera teres} and from 4 to 8 times for \textit{Penicillium} sp.

In the case of PP = 28 days, the inhibition of development (2.2–3.1 times) was observed only for the pathogen of the helminthosporium disease \textit{Drechslera teres} mainly at a dose of 1 kGy. Furthermore, it was shown that at a post-radiation period of 5 days, electron irradiation stimulates, and at PP of 28 days, it inhibits the sowing qualities of seeds.

In the framework of this experiment, we set the task to investigate the effect of the same dose range of electron irradiation (from 1 to 8 kGy), but with a finer gradation – with a step of 1 kGy, i.e. 1, 2, 3, 4, 5, 6, 7 and 8 kGy at PP of 4, 7, 11 and 14 days after irradiation.

The results of phytoexamination of seedlings laid on sprouting at different PPs showed that the most effective was the irradiation exposure at the PP of 4 days – the maximum decrease in the degree of seedling damage was noted – 33–48% for \textit{Helminthosporium sativum} (synonym \textit{Drechslera teres}) at doses of 4–7 kGy (figure 1). At the PP of 7 and 11 days, the irradiation of seeds was the most effective at doses of 3, 4 and 5 kGy; there was the reduction in the degree of damage to the seedlings by \textit{Helminthosporium sativum} by 30–37% and 28–41%, respectively. With the increase in PP up to 14 days, there was a reduction in the irradiation effectiveness – the degree of damage to seedlings by root rot decreased by 33% only at a dose of 4 kGy (figure 1).
The degree of damage, % of control

Figure 1. Effect of irradiation on the damage of barley by *Helminthosporium sativum* depending on the post-radiation period.

The prevalence of root rot also depends on the radiation dose and the value of PP (figure 2).

![Graph showing the effect of electron-beam irradiation on the prevalence of Helminthosporium sativum.](image)

**Figure 2.** Effect of electron-beam irradiation on the prevalence of *Helminthosporium sativum*.

It was established that the prevalence of the disease decreased at PP of 4 days by 28–46% (doses from 4 to 8 kGy), over 7 days after the irradiation it decreased by 30–37% (doses from 2 to 6 kGy), over 11 days – by 26–48% (doses 3, 4 and 7 kGy) and over 14 days – by 34 % at a dose of 4 kGy (figure 2).

The data obtained from the study of the effect of radiation dose and the duration of the PP on the prevalence of the disease show that a similar relationship has been established, as in the study of the effect on the degree of seedlings damage by *Helminthosporium sativum*. 

---

4
The presence of *Helminthosporium sativum* infection on barley seeds established by phytoexamination leads to a reduction in field germination rate of seeds, plant productivity, and commercial and nutritional quality of grain deteriorates.

The use of a low-energy electron beam for presowing irradiation at high doses (from 1 to 8 kGy) is possible due to the fact that electrons penetrate only into a thin surface layer of the caryopsis, without damaging the seed germ.

Nevertheless, from figure 3 it can be seen that the presowing irradiation of the seeds of spring barley of the Vladimir variety with a low-energy electron beam affected the laboratory germination of seeds.

It was shown that laboratory germination changed depending on the radiation dose and the duration of PP: at PP of 7 days, there was a statistically significant increase of the indicator by 22-25% at doses of 1, 2, 4 and 5 kGy and, on the contrary, a decrease by 19-24% at PP of 4 days and doses of 3, 5 and 8 kGy (figure 3).

![Figure 3. Effect of electron-beam irradiation on laboratory germination of seeds.](image)

At PP of 11 days, a significant decrease in laboratory seed germination by 42% was observed only at a dose of 8 kGy. At 14-day PP, no significant differences in laboratory germination from control were found at all radiation doses.

Presowing electron irradiation of spring barley seeds affected the morphometric parameters of seedlings (figure 4).

The data in figure 4a demonstrate a significant decrease from 12 to 39% of the height of the seedlings, starting with a dose of 4 kGy, and with a growth in the dose, the inhibition of the sprout length increases in comparison with the control values, regardless of the PP value.

The stress effect of presowing electron irradiation for the “root length” indicator turned out to be much weaker than for the “germ length” indicator (figure 4b). A statistically significant reduction in the length of the roots by 8.6–15% was observed at PP = 4 days and radiation doses from 5 to 8 kGy and by 14% – at PP = 14 days and a dose of 7 kGy. In the other experimental variants with irradiation, the values did not differ from the control (figure 4b).

The inhibition of seedling development resulted from the exposure of barley seeds to a low-energy electron beam affected the reduction in the wet weight of the seedlings. At 4 and 14 days of PP, the decrease in the wet weight of the seedlings by 9.6–49.5% and 37–20% was noted at doses from 2 to 8 kGy, respectively, and at PP = 7 days, it decreased by 15.5–23.8% at doses of 4-8 kGy (table 2). The
maximum decrease in wet weight was observed when the seeds were exposed to high radiation doses – 7 and 8 kGy.

At the PP of 11 days, the irradiation did not have a statistically significant effect on the “wet weight” indicator.

The decrease in dry weight of seedlings to a lesser extent depended on radiation and decreased for certain only at PP = 4 days (doses of 3, 5 and 8 kGy) and PP = 14 days by 12–14% at doses of 1–3 kGy (table 2).

![Figure 4](image.png)

**Figure 4.** Effect of electron beam irradiation of seeds on the length of sprouts (a) and roots (b) of barley seedlings.

**Table 2.** The effect of electron irradiation of barley seeds on the wet and dry weight of 7-day-old seedlings depending on the postradiation period.

| Dose of radiation (kGy) | Wet weight of seedlings, in % to control | Dry weight of seedlings, in % to control |
|-------------------------|----------------------------------------|------------------------------------------|
|                         | 4 days  | 7 days  | 11 days | 14 days | 4 days  | 7 days  | 11 days | 14 days |
| 0 (Control)             | 100     | 100     | 100     | 100     | 100     | 100     | 100     | 100     |
| 1.0                     | 101.6   | 95.6    | 91.8    | 80.1*   | 106.8   | 93.8    | 94.0    | 87.7*   |
| 2.0                     | 90.4*   | 97.7    | 82.3    | 79.2*   | 106.1   | 98.8    | 89.7    | 87.5*   |
| 3.0                     | 62.9*   | 110.0   | 82.3    | 78.0*   | 80.6*   | 93.0    | 88.6    | 85.9*   |
| 4.0                     | 88.8*   | 84.5*   | 80.3    | 79.4*   | 105.5   | 100.5*  | 96.0    | 97.4    |
| 5.0                     | 71.5*   | 76.8*   | 83.9    | 76.2*   | 90.4*   | 109.5*  | 98.5    | 99.4    |
| 6.0                     | 70.5*   | 76.3*   | 79.5    | 66.1*   | 100.6   | 103.9*  | 102.0   | 97.2    |
| 7.0                     | 73.0*   | 76.6*   | 88.3    | 63.2*   | 95.0    | 109.2*  | 104.8*  | 96.6    |
| 8.0                     | 50.5*   | 76.8*   | 79.2    | 67.4*   | 80.1*   | 108.3*  | 112.8*  | 99.4    |

* – significant differences from control at \( p < 0.05 \)

At PP of 7 and 11 days, dry weight of seedlings either did not differ from the values of the control or exceeded them by 4–12.8%. Such a slight decrease in the dry weight against the background of a significant decrease in the wet weight of the seedlings is explained by the low water content in the experimental seedlings.

4. Conclusion
As a result of studies on the effect of presowing low-energy electron irradiation in a wide dose range on seed infestation of spring barley of Vladimir variety by root rot and on sowing qualities of seeds, it
was found that the most effective exposure was at PP = 4 days. There was observed the maximum decrease in the degree of seedlings damage by 33–48% of *Helminthosporium sativum* (synonymous with *Drechslera teres*) at doses of 4–7 kGy.

At the PP of 7 and 11 days, the irradiation of seeds with doses of 3–5 kGy reduced the degree of damage to the seedlings by *Helminthosporium sativum* by 30–37% and 28–41%, respectively. With an increase in PP up to 14 days, a decrease in the damage degree of seedlings by root rot by 33% was observed only at an irradiation dose of 4 kGy, which indicates a decrease in the efficiency of irradiation with increasing PP.

The prevalence of the disease decreased at PP of 4 days by 28–46% (doses 4–8 kGy), over 7 days after the irradiation it decreased by 30–37% (doses 2–6 kGy), over 11 days – by 26–48% (doses 3, 4 and 7 kGy) and over 14 days – by 34% at a dose of 4 kGy (figure 2).

The irradiation significantly increased the laboratory germination at PP of 7 days by 22–25% at doses of 1, 2, 4 and 5 kGy and, on the contrary, reduced it by 19–24% at PP of 4 days and doses of 3, 5 and 8 kGy. At a PP of 11 days, a reliable decrease in laboratory seed germination by 42% was noted only at a dose of 8 kGy, and at the PP of 14 days, no significant differences in laboratory germination from control were found at all radiation doses.

Electron irradiation inhibits the growth of seedlings: their length definitely decreases by 12-39 % starting with a dose of 4 kGy, and with further growth in the dose, the inhibition of the sprout length increases in comparison with the control, regardless of the PP value. A reliable reduction in the length of the roots by 8.6–15% was observed at PP = 4 days and radiation doses from 5 to 8.6 kGy and by 14% – at PP = 14 days and a dose of 7 kGy. In the other experimental variants with irradiation, the values did not differ from the control.

The inhibition of seedling development caused a reduction in the wet weight of the seedlings. At 4 and 14 days of PP, the decrease in the wet weight of the seedlings by 9.6–49.5% and 37–20% was noted at doses from 2 to 8 kGy, respectively, and at PP = 7 days, it decreased by 15.5–23.8% at doses of 4–8 kGy. The maximum decrease in wet weight was observed when the seeds were exposed to high radiation doses – 7 and 8 kGy. At the PP of 11 days, the irradiation did not have a statistically significant effect on the “wet weight” indicator.

The decrease in dry weight of seedlings to a lesser extent depended on radiation and decreased for certain only at PP = 4 days (doses of 3, 5 and 8 kGy) and PP = 14 days by 12–14% at doses of 1–3 kGy. At PP of 7 and 11 days, dry weight of seedlings either did not differ from the values of the control or exceeded them by 4–12.8%. Such a slight decrease in the dry weight against the background of a significant decrease in the wet weight of the seedlings is explained by the low water content in the experimental seedlings.

Thus, it was experimentally shown that presowing low-energy electron irradiation of spring barley of the Vladimir variety reduces the resistance of *Helminthosporium sativum* and can be used to combat the pathogenic microflora of the grain.

References

[1] Sommer N 1973 *Techn. Repts. Ser. Int. Atom. Energy Agency* 149 73
[2] Podyapolskaya T S 1959 *Trudy VIZR* 36 84
[3] Savulescu A and Becerescu D 1962 *Rev. biol. (RPP)* 7 79
[4] Loy N N 1995 *Thesis in candidacy for a degree of Cand. Sc. (Biology)* p 128
[5] Chizh T V, Loy N N, Pavlov A N, Vorobyev M S and Doroshkevich S Yu 2018 *IOP Conf. Series: Journal of Physics: Conf. Series* 1115 022025
[6] Vorobyov M S, Koval N N and Sulakshin S A 2015 *Instrum. Exp. Tech.* 58 687
[7] Seeds of crops. Methods for determining quality. Part 2 1991 State standards of the USSR GOST 12038-84 Moscow 44-101
[8] Seeds of crops. Methods for determining quality. Part 2 1991 State standards of the USSR GOST 12044-81 Moscow 250-251
[9] Voitova L R 1980 *Zashchita Rastenii* (Moscow: Kolos) 2 48