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Low-energy electron beams for protection of grain crops from insect pests and diseases

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Abstract. The study demonstrates the effect of a low-energy (up to 160 keV) repetitive pulsed electron beam extracted into ambient air on the disease incidence and sowing quality of spring barley seeds and on the viability of insect pests during crop storage. Irradiation of barley seeds 5 days prior to sowing greatly decreases the disease incidence on their shoots (p<0.05): for Drechslera teres, the incidence decreases 2.1-3.2 times depending on the dose and dose rate, and for Penicillium sp, it decreases 3.5-13.7 times at all doses and rates used. The incidence of Fusarium sp is unaffected by radiation. The spread of disease decreases 1.5-3.2 times for Drechslera teres and 4-8 times for Penicillium sp. Electron beam irradiation 28 days prior to sowing shows similar suppression (2.2-3.1 times) only for Drechslera teres at a dose of 1.0 kGy. The sowing quality of seeds increases after irradiation 5 days prior to sowing and decreases after irradiation 28 days prior. The viability of Oryzaephilus surinamensis imagines in infested grains is completely inhibited after irradiation at 0.2-1.0 kGy. Thus, on the example of spring barley seeds, our experiments prove the efficiency of low-energy electron beam irradiation for inhibiting the viability of disease agents and insect pests.

1. Introduction
Recently, the problem of crop protection has come to the foreground due to critical levels of pathogenic microflora in soils and on sowing materials. In the seed stock of most farms, almost each batch of seeds is infected to one extent or another by pathogenic microorganisms, and failure to provide proper cultivation aggravates the situation from year to year. Annually, 8.5 to 25 mln tons of grains with an average of 18.3 mln tons are lost in Russia and only due to plant diseases [1]. Half of the all plant diseases is transmitted by seeds. It is the seeds which are a source of dangerous and harmful diseases affecting the crop production. Therefore, in many countries, presowing seed treatment for plant protection is not only necessary but compulsory.

In Russia, almost all seeds are infected, and their infestation in vegetation periods can reach 70 %. Barley seeds are infected mostly by Bipolaris sorokiniana (Sacc.) Shoemaker, species of Alternaria and Fusarium. In humid years, the occurrence of Bipolaris sorokiniana, Alternaria, and Fusarium species on barley seeds can reach respectively 47.6, 31.7 and 17.5% of the total fungi. For winter wheat, the incidence of Alternaria and Fusarium on its seeds is 51.7 % and up to 15%, respectively, and for varieties of spring wheat, it lies in the range 47.5-62.3% of which 23-37.5% falls on Fusarium and 10-34.4% on Alternaria [2].
In the second half of the 20th century, it was proposed to use a radically new method – electromagnetic radiation – for presowing seed treatment. This method, along with conventional hot air treatment and solar heating, opens up new ways of solving important agroecological and socioeconomic problems toward higher crop production, lower energy consumption, and environmental pollution prevention.

For reliable seed disinfection, chemicals such as insecticides are conventionally used. However, fumigation is not always efficient against internal infection, and its mass use results in pest forms resistant to chemicals [3].

After harvesting, agents of fungus and bacterial diseases remain on seeds and affect their plants after sowing, suppressing the growth of plants and decreasing the crop productivity and yield.

Therefore, many scientists and specialists put their efforts to find new seed disinfection methods free of toxic chemicals. Compared to chemical methods, radiation disinfection and disinfestation of agricultural products is economically beneficial and advantageous as it excludes environmental pollution and toxic chemical residues in irradiated products [4-6].

Here we analyze the effect of presowing treatment of spring barley with a broad low-energy repetitive pulsed electron beam extracted into ambient air on the viability of phytopathogenic species, sowing quality of seeds, and viability of insect pests during crop storage.

2. Materials and methods

The test material was spring barley *Hordeum vulgare* L (Nur variety, elite, harvest 2015).

Its grains were irradiated with a broad electron beam extracted into ambient air on a DUET electron accelerator with a grid plasma cathode [7]. Compared to other accelerators, this accelerator has the advantage of varying the beam parameters over a wide range and almost independently of each other. Our experiments were performed at a constant accelerating voltage $V_0=160$ kV but at different pulse durations and amplitudes of the beam current. The irradiation modes are tabulated in table 1. For technical reasons, the pulse of duration longer than 100 µs loses its quasi-rectangular shape and decays linearly by 50 % toward the end of the beam current.

| Mode | Accelerating voltage, kV | Beam current density, mA | Pulse duration, µs | Repetition frequency, Hz | Dose rate, Gy/pulse |
|------|--------------------------|--------------------------|--------------------|--------------------------|---------------------|
| 1    | 160                      | 10                       | 8                  | 1                        | 10                  |
| 2    | 160                      | 10                       | 62                 | 1                        | 100                 |
| 3    | 160                      | 24                       | 200                | 1                        | 500                 |

Barley seeds of total mass $m=15$ g were placed in plastic bags of dimensions about 25×5 cm$^2$ (about three grain layers per bag) at 20 mm from the accelerator output window. After irradiation with half the dose in each mode, the bags were tuned over to level the dose in each seed.

The treated seeds were germinated on filter paper in an incubator at 24°C for 7 days, as described elsewhere [8]. In laboratory tests, we assessed the seed germinability, shoot and root lengths, fresh and dry weights of shoots, and their water content. The disease incidence on shoots was assessed as described elsewhere [9, 10].

Barley grains infested by imagines of saw-toothed grain beetles (*Oryzaephilus surinamensis*) were irradiated with a dose of 0.2-1.0 kGy at the same dose rate equal to 50 Gy/pulse, and the total dose was provided by the proper number of pulses. The incidence of grain pests was assessed by a standard procedure [11].
3. Results and discussion

In studying the effect of ionizing radiation on plants and disease agents, it is extremely important to account for post-irradiation periods. In our experiments, the post-irradiation period was 5 and 28 days.

The results of examination show that when barley seeds are irradiated 5 days prior to sowing, the disease incidence on their shoots depends on the radiation dose and dose rate. Irradiation mode 1 provides a statistically significant decrease: the incidence of *Drechslera teres* decreases 3.2 times at a dose of 5 and 8 kGy. Modes 2 and 3 decrease the incidence of *Drechslera teres* 2.1 times at 1.0 and 5.0 kGy and 2.5 times at 8.0 kGy, respectively (table 2).

### Table 2. Disease incidence and spread on barley (%) for 5-day post-irradiation period.

| Dose, kGy | Irradiation mode | *Drechslera teres* | *Fusarium sp* | *Penicillium sp* |
|-----------|------------------|--------------------|---------------|------------------|
|           | Incidence | Spread | Incidence | Spread | Incidence | Spread |
| 0 (control) | 17.00 | 39.33 | 1.33 | 3.33 | 2.33 | 5.33 |
| 1.0 | 14.00 | 29.33 | 1.17 | 6.00 | 0.33* | 1.33* |
| 5.0 | 5.33* | 12.00* | 1.67 | 4.00 | 0.17* | 0.67* |
| 8.0 | 8.00* | 26.00* | 0.50 | 2.00 | 0.17* | 0.67* |
| 1.0 | 16.00 | 34.00 | 0.50 | 2.00 | 0.17* | 0.67* |
| 5.0 | 19.33 | 39.33 | 0.83 | 2.67 | 0.33* | 1.33* |
| 8.0 | 16.50 | 32.67 | 0.50 | 1.00 | 0.00* | 0.00* |
| HCP05 | 5.82 | 11.11 | 1.44 | 3.06 | 1.03 | 2.78 |

*significant difference from control at p<0.05

After low-energy electron beam irradiation of barley seeds, the incidence of *Penicillium sp* on their shoots decreases 3.5-13.7 times at all doses and dose rates studied. For the incidence of *Fusarium sp*, any significant difference from the control was not found (table 2).

In all cases where irradiation 5 days prior to sowing shows disease suppression, the statistically significant decrease in the spread of *Drechslera teres* and *Penicillium sp* varies from 1.5- to 3.2-fold and from 4- to 8-fold, respectively.

For the post-irradiation period of 28 days, compared to 5 days, the effect of electron beam irradiation on the disease incidence in spring barley is much less efficient (table 3).

### Table 3. Disease incidence and spread on barley (%) for 28-day post-irradiation period.

| Dose, kGy | Irradiation mode | *Drechslera teres* | *Fusarium sp* | *Penicillium sp* |
|-----------|------------------|--------------------|---------------|------------------|
|           | Incidence | Spread | Incidence | Spread | Incidence | Spread |
| 0 (control) | 16.00 | 36.67 | 0.17 | 0.67 | 0.50 | 2.00 |
| 1.0 | 5.17* | 12.67* | 0.17 | 0.67 | 0.33 | 1.33 |
| 5.0 | 11.33 | 24.00 | 0.17 | 0.67 | 0.33 | 1.33 |
| 8.0 | 9.83 | 24.00 | 0.00 | 0.00 | 0.17 | 0.67 |
| 1.0 | 7.17 | 16.67* | 0.00 | 0.00 | 0.17 | 0.67 |
| 5.0 | 9.67 | 18.00* | 0.17 | 0.67 | 0.00 | 0.00 |
| 8.0 | 9.50 | 26.67 | 0.00 | 0.00 | 0.00 | 0.00 |
| 1.0 | 13.33 | 29.33 | 0.00 | 0.00 | 0.00 | 0.00 |
| 5.0 | 7.83 | 18.67* | 0.00 | 0.00 | 0.17 | 0.67 |
| 8.0 | 13.50 | 32.00 | 0.17 | 0.67 | 0.17 | 0.67 |
| HCP05 | 9.29 | 17.50 | 0.35 | 1.39 | 0.44 | 1.76 |

*significant difference from control at p<0.05
The incidence of *Drechslera teres* on shoots reveals a statistically significant 3.1-fold decrease only at a dose of 1.0 kGy (mode 1). In all other cases, the decrease is on the level of tendency. The spread of *Drechslera teres* decreases 2.2-2.9 times at a dose of 1.0 kGy in modes 1, 2 and 2 times at 5.0 kGy in modes 2, 3 (table 3).

For the post-irradiation period of 28 days, any significant difference of the incidence and spread of *Fusarium* sp and *Penicillium* sp from the control is not found.

The morphometric parameters of 7-day shoots grown from irradiated seeds suggest their dependence on the post-irradiation period, dose, and dose rate (tables 4 and 5).

### Table 4. Morphometric parameters of barley (%) for 5-day post-irradiation period.

| Dose, kGy | Irradiation mode | Germinability | Length | Weight | Water content |
|-----------|------------------|---------------|--------|--------|---------------|
|           |                  |               | shoot  | root   | fresh | dry  |               |
| 0 (control) |                  | 100.0         | 100.00 | 100.00 | 100.00 | 100.00 |               |
| 1.0 | 1                | 110.0         | 94.95  | 100.05 | 115.29 | 122.92 | 99.31 |
| 5.0 |                  | 86.0          | 101.65 | 134.22* | 85.84 | 93.20 | 99.13 |
| 8.0 |                  | 73.0          | 97.34  | 131.03* | 62.31* | 71.34* | 98.47 |
| 1.0 | 2                | 117.0         | 96.55  | 138.88* | 127.87* | 116.96 | 100.88 |
| 5.0 |                  | 105.0         | 105.00 | 138.85* | 103.17 | 105.01 | 99.90 |
| 8.0 |                  | 88.0          | 100.66 | 118.61 | 91.69  | 85.39  | 100.88 |
| 1.0 | 3                | 108.0         | 107.82 | 118.32 | 91.74  | 123.67 | 99.40 |
| 5.0 |                  | 89.0          | 97.78  | 120.31* | 91.39  | 110.79 | 97.76* |
| 8.0 |                  | 83.0          | 95.95  | 126.39* | 68.65* | 86.69  | 97.24 |

*significant difference from control at *p*<0.05

After irradiation 5 days prior to sowing, the root length increases by 20-39% at a dose of 5.0 and 8.0 kGy in modes 1, 3 and at 1.0 and 5.0 kGy in mode 2 compared to the control (Table 4). The fresh weight increases by 27.9 % at a dose of 1.0 kGy in mode 2 and decrease by 31.3-37.7% at 8.0 kGy in modes 1, 3. In modes 1, 3 at 1.0 kGy, the fresh weight increases on the level of tendency.

### Table 5. Morphometric parameters of barley (%) for 28-day post-irradiation period.

| Dose, kGy | Irradiation mode | Germinability | Length | Weight | Water content |
|-----------|------------------|---------------|--------|--------|---------------|
|           |                  |               | shoot  | root   | fresh | dry  |               |
| 0 (control) |                  | 100.0         | 100.00 | 100.00 | 100.00 | 100.00 |               |
| 1.0 | 1                | 88.0          | 98.00  | 103.00 | 80.99  | 84.87* | 99.50 |
| 5.0 |                  | 62.0*         | 107.00 | 102.67 | 51.24* | 53.85* | 99.44 |
| 8.0 |                  | 63.0*         | 98.00  | 102.06 | 52.96* | 55.59* | 99.45 |
| 1.0 | 2                | 94.0          | 95.00  | 97.58  | 81.34* | 87.07  | 99.17 |
| 5.0 |                  | 90.0          | 97.00  | 101.23 | 66.56* | 68.76* | 99.59 |
| 8.0 |                  | 61.0*         | 109.00 | 100.75 | 53.11* | 56.63* | 99.25 |
| 1.0 | 3                | 102.0         | 95.00  | 97.90  | 82.67* | 89.36  | 99.04 |
| 5.0 |                  | 86.0          | 89.00* | 102.87 | 64.47* | 74.15* | 98.26* |
| 8.0 |                  | 74.0*         | 92.00  | 102.87 | 67.16* | 76.70* | 98.33* |

*significant difference from control at *p*<0.05
Irradiation 28 days prior to sowing produces an inhibitory effect on 7-day Nur barley (table 5). Irradiation with a dose of 8.0 kGy, irrespective of its rate, decreases the seed germinability by 26.3-39.1%. The fresh and dry weights of barley shoots decrease at all doses studied, whereas the lengths of shoots and roots are mostly the same as their control values.

As the post-irradiation period is increased, the stimulating effect of irradiation decreases and gradually changes for suppression which enhances with time. This is because the physiological aging of seeds is accelerated, decreasing the level of gibberellins and the germination energy [12].

The effect of irradiation with an electron beam on the viability of insect pests was determined. The efficiency of electron beam irradiation is 100% at all doses studied. Even within 15 days after irradiation, all species of *Oryzaephilus* die. The quality of grains irradiated at a dose of 0.2-1.0 kGy does not reveal any significant difference from the control (untreated grains).

4. Conclusion

Thus, our research in the effect of low-energy electron beam irradiation on the disease incidence and sowing quality of seeds and on the viability of insect pests in stored barley grains suggests the following. Irradiation of seeds 5 days prior to sowing causes a statistically significant decrease in the disease incidence on their shoots: for *Drechslera teres*, the incidence decreases 2.1-3.2 times depending on the dose and its rate, and for *Penicillium* sp, it decreases 3.5-13.7 times at all doses and rates studied. For the incidence of *Fusarium* sp on barley shoots, any significant difference from the control is not found in the range of doses and dose rates used.

In all cases where irradiation 5 days prior to sowing shows disease suppression, the statistically significant decrease in the spread of *Drechslera teres* and *Penicillium* sp varies from 1.5- to 3.2-fold and from 4- to 8-fold, respectively.

After irradiation 28 days prior to sowing, the incidence of *Drechslera teres* on shoots reveals a statistically significant 3.1-fold decrease only at a dose of 1.0 kGy in mode 1. In all other cases, the decrease is on the level of tendency. The spread of *Drechslera teres* decreases 2.2-2.9 times at a dose of 1.0 kGy in modes 1, 2 and 2 times at 5.0 kGy in modes 2, 3.

For the post-irradiation period of 28 days, any significant difference of the incidence and spread of *Fusarium* sp and *Penicillium* sp from the control is not found.

After irradiation 5 days prior to sowing, the root length increases by 20-39% at a dose of 5.0 and 8.0 kGy in modes 1, 3 and at 1.0 and 5.0 kGy in mode 2 compared to the control. The fresh weight increases by 27.9% at a dose of 1.0 kGy in mode 2 and decrease by 31.3-37.7% at 8.0 kGy in modes 1, 3.

Irradiation 28 days prior to sowing produces an inhibitory effect on 7-day Nur barley. Irradiation with a dose of 8.0 kGy, irrespective of its rate, decreases the seed germinability by 26.3-39.1%.

Irradiation of barley grains infested by *Oryzaephilus surinamensis* imagines at 0.2-1.0 kGy completely inhibits the pest viability.

Thus, our experiments demonstrate the efficiency of wide-aperture low-energy electron beams extracted into ambient air on the DUET repetitive pulsed accelerator with a grid plasma cathode for inhibiting the viability of disease agents and insect pests on spring barley seeds.

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