

Effect of ionizing radiation with 1 MeV on phenology of potatoes inhabited by fungi *Rhizoctonia solani* Kuhn

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Abstract. The study perpersents the influence of electron irradiation on on the phenology and productivity of potatoes inhabited by the fungus *Rhizoctonia solani* Kuhn. Potato samples were irradiated with the doses ranging from 0.02 kGy to 3.0 kGy. It was found that the pre-planting irradiation of seed potato tubers with the doses of 0.02-0.15 kGy led to a delay in plant development, and irradiation of tubers with over 0.2 kGy resulted in the death of plants. The maximum number of large tubers was obtained from samples irradiated with the dose of 0.15 kGy. The yield of potato tuber samples irradiated with the dose of 0.02 kGy corresponded to that of the control samples. Irradiation of potato seed tubers with a dose of 0.04 kGy led to a significant decrease in the colonization of the surface of tubers of the new crop with *Rhizoctonia solani*, while irradiation of potato tubers with a dose of 0.15 kGy completely eliminated the pathogen.

1 Introduction

Currently, the total world harvest of potatoes is about 368 million tons (according to FAOSTAT data for 2018) [1], of which about 20 million tons are produced in Russia [2]. However, compared to 2019, the potato yield in Russia in 2020 decreased by 8% (from 280.9 thousand tons per hectare to 256.5 thousand tons per hectare) [3]. One of the reasons for the reduction of yield is a wide range of fungal, viral, and bacterial diseases affecting potato tubers [4, 5]. In Russia, there are more than 30 diseases of potato tubers, the annual yield losses from which range from 10 to 60% [6]. One of the most common and harmful diseases is black scab. The annual global losses from this disease are 7-36%, and in Western Siberia, up to 50% of production and more are lost annually [7-9].

Considering that the existing chemical means of suppressing potato diseases are dangerous for people's health and the natural environment, ionizing radiation is actively used as an alternative to chemical fumigants [10]. At the same time, in various doses, ionizing radiation is able to both ensure inhibition of dangerous types of diseases [11, 12] and solve problems arising during storage of tubers, such as germination, loss of shape, moisture, and nutrients [13-17].

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The purpose of this work is to determine the effect of electron radiation on the phenology and productivity of potatoes inhabited by the fungus *Rhizoctonia solani* Kuhn.

2 Materials and methods

2.1 Material

The object of this study was seed tubers cv. Agata (*Solanum tuberosum* L.) naturally infected by the fungus *R. solani* Kuhn. The potato tubers had been grown in the experimental field of Siberian Federal Scientific Centre of Agro-BioTechnologies of the RAS (SFRCA of the RAS) at experimental station Elitnaya (Krasnoobsk, Russia). During the storage period (from October to April), the tubers were kept at the temperature of +(2-4) °C, and then, until planting, at the temperature of +(18-22) °C.

For the experiment, 160 tubers of approximately the same size, 3 cm in diameter, and with the average weight of 40 g were randomly selected and sent for irradiation to the Skobel'syn Institute of Nuclear Physics, Lomonosov Moscow State University. Since the end of the storage period before irradiation and 36 days passed (potato sprouts were about 5 mm). Planting was carried out on the 7th day after irradiation.

2.2 Irradiation

Potato tubers samples were exposed to electron radiation at doses of 0, 0.02, 0.04, 0.1, 0.15, 0.2, 0.5, 1.0, 2.0, and 3.0 kGy. Irradiation was performed on a continuous linear electron accelerator UELR-1-25-T-001 with a beam energy of 1 MeV and an average beam power of 25 kW. Eight tubers were randomly selected for each radiation dose. Samples were laid on a duralumin plate 35 cm * 3 cm directly under the beam's exit from the accelerator, following the scheme shown in Fig. 1. The charge absorbed by the duralumin plate during irradiation, time exposure, and beam current, were measured during each session. The irradiation was performed at room temperature of 18 °C. The control potato tubers samples were under the same conditions as the samples exposed to electrons. For uniform irradiation, potato tubers were irradiated on one side for half the time for each dose, then turned over and irradiated the remaining time from the opposite side.

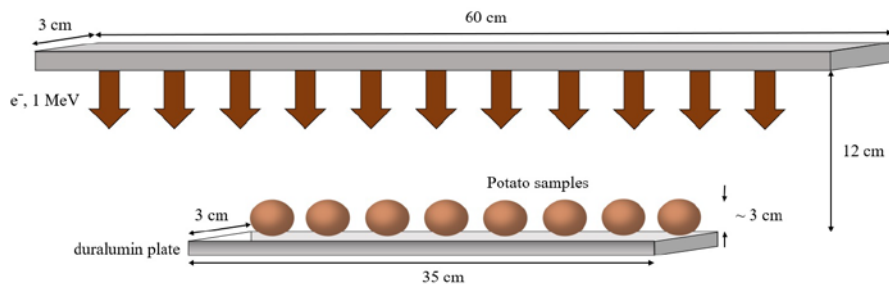


Fig. 1. Scheme of irradiation of potato tubers samples by the accelerated electrons with a beam energy of 1 MeV

2.3 Dose control

The doses absorbed by potato tubers were determined using computer simulation with the program code GEANT 4, based on the Monte Carlo method. The simulation was carried

out taking into account the geometry of the samples and the technical characteristics of the accelerator, such as the spectrum of electrons obtained from it, in line with the method described in [18].

Potato tubers samples were modeled as water spheres with an average diameter of 3 cm. To ensure the applicability of the statistical error in determining the dose absorbed by the samples, 10^8 electrons were used in our model calculations. All possible interactions between electrons and matter were considered in this program. The error of their interaction cross-section did not exceed 2%.

2.4 Analysis

Field studies were carried out in the Novosibirsk region on the experimental field of SFRCA of the RAS at experimental station Elitnaya in the soil and climate conditions typical for the forest-steppe zone of Western Siberia. The soil of the station is leached chernozem, which is typical for the region, with the following agrochemical characteristics of the arable soil layer (0-30 cm): humus (according to Tyurin - GOST 26213-93) about 5.0%, total nitrogen (according to Kjeldahl - GOST 26889-86) – 0.34, phosphorus and potassium content (according to Chirikov - GOST 26204-91) – 29.0 and 13.0 mg / 100 g of soil respectively, pH salt 6.7-6.8 according to the TsINAO method (GOST 26483-85).

In the field experiment, the pre-planting effect of radiation doses on potato tubers was assessed. The phenology of potato plants, the prevalence of forms of black scab disease, as well as the productivity of the culture were studied [19]. The experiment was repeated 2 times for each dose. The density of planting was 35.7 thousand tubers/ha, the feeding area was 0.35 m * 0.7 m. The number of plants mortality and their reasons were estimated in the phase of full sprouting [19].

During the growing season, phenological observations of the crop were carried out by calculating the percentage of plants in the phase from the total number of potato tubers planted on the plot. The following periods and phenophases were distinguished in the development of potatoes [20]: sprouting – at this time, a rosette is formed, during the entire period of germination, the growth of stolons occurs. The number of emerged plants in the phase the beginning of sprouting – 25%; mass sprouting – 50%; full sprouting – 75%. Budding is the appearance of buds on the tops of the stems. The number of plants that formed buds in the phase: the beginning of budding – 25%; mass budding – 50%; full budding - 75%. During bud-formation – the beginning of blooming, the size of the tubers grows. Flowering or shedding of buds in non-flowering varieties – by the number of flowering plants or by the number of fallen buds in the phase: the beginning of blooming – 25%; mass blooming – 50% (during this period, the tops are closing); full blooming – 75%. At the end of blooming, the tuber mass begins to grow.

The biological productivity was determined using the gravimetric method [19].

Analysis of the fractional composition of the crop was carried out in the post-harvest period on the following grading scale: tuber weight less than 40 g - small, from 40 to 80 g - medium, and more than 80 g - coarse fraction. At the same time, the percentage of tubers inhabited by sclerotia was counted for the cases when more than 1/10, 1/4, and 1/2 of the surface was affected as well as for single occurrences: with deep spotting, deformed tubers, tubers with cracks or with several manifestations of black scab disease at the same time.

2.5 Statistical analysis

Statistical analysis of the obtained data on the yield of potatoes was carried out using the Fisher-Snedecor software package, based on the use of standard methods of mathematical processing [21].

2.6 Weather data

The meteorological data for the growing season of 2020 significantly differed from the long-term average values in terms of the temperature regime and the amount of precipitation.

May 2020 stood out especially in terms of temperature and humidification regime. On average per month, the air temperature and the amount of precipitation exceeded the long-term average values by 6.2°C and 18.4 mm respectively. The temperature regime in June was at the level of average annual values, but the amount of precipitation was 34 mm below the norm. In turn, the temperature regime in July exceeded the long-term average indicators by 0.6°C, while in the first and second decades the air temperature was higher than the norm by 2.1 and 2.3 °C, and in the third one, it was lower by 1.9°C. The amount of precipitation in this period turned out to be 13 mm higher than the norm. August 2020 was quite warm: the air temperature exceeded the long-term average values by 2.8°C. The arrival of atmospheric moisture in the first decade of the month was 10 mm below the norm, and in the second decade, it was 6 mm more. At the same time, at the end of the second decade, 26.0 mm (out of 43.0 mm) fell in the form of heavy rain and hail.

3 Results and discussion

The development of potato plants in the field conditions were assessed depending on the radiation dose (Fig. 2).

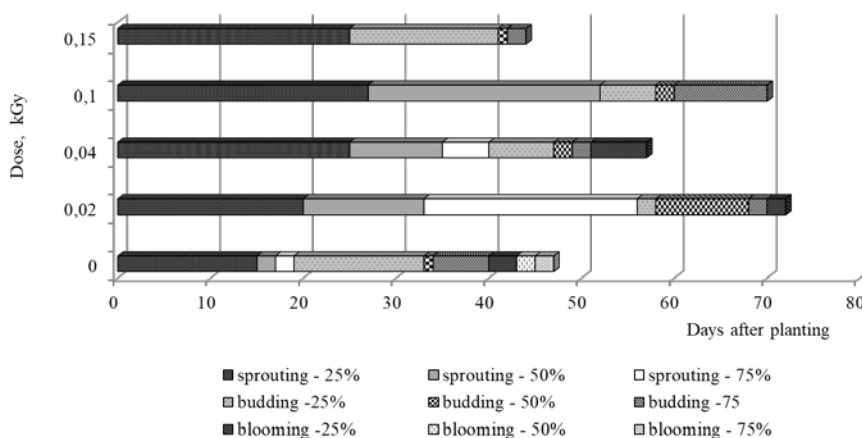


Fig. 2. Phenology of potatoes after irradiation of planting material

Beginning of sprouting development of unirradiated seed potato tubers was recorded on the 15th day after planting. Sprouting of irradiated potato tubers came later: at a dose of 0.02 kGy – 5 days later, at 0.04 and 0.15 kGy – 10 days, and at 0.1 kGy 12 days later than in case of the control tubers. During the growing season, a significant delay in the plant development was observed in irradiated potato plants even at the lowest doses. Thus, at doses of 0.02 and 0.04 kGy, mass sprouting were recorded on the 33rd and 35th days, and full – on the 56th and 40th days from planting respectively. At the same time, in the control tubers samples, these phenophases occurred on the 17th and 19th days after planting. Mass sprouting of potatoes, grown from planting tubers, irradiated at a dose of 0.1 kGy, were observed on the 52nd day, and the phase of full sprouting didn't come. A dose of 0.15 kGy prevented the potatoes from reaching the phases of mass and full emergence. Exposure to seed tubers at a dose of 0.2 kGy and more completely inhibited germination of tubers.

The tendency of lagging behind was observed in the development of potato plants and continued in the budding phase of potatoes. The beginning of blooming was recorded on the 72nd and 57th days after planting only in samples irradiated by 0.02 and 0.04 kGy respectively. Moreover, in the control, this phenophase occurred on the 43rd day after planting, which is 29 and 14 days earlier than in samples irradiated by 0.02 and 0.04 kGy respectively. Radiation treatment of tubers with doses of 0.1 and 0.15 kGy did not allow the plants to bloom.

The number of plants emerging and subsequently fully vegetating was different. In samples of seed material irradiated with doses of 0.02 and 0.04 kGy, the number of emerging plants was less than the control values within 12%. The maximum reduction in plant density of 75% was observed in samples irradiated with the dose of 0.15 kGy (Fig. 3).

Thus, ionizing radiation in the dose range from 0.02 to 0.15 kGy had a negative impact on the growth and development of the potato culture. Doses over 200 Gy resulted in complete inhibition of tuber germination.

During phytomonitoring of plantings, it was found that non-sprouted potato tubers died from *Fusarium* fungi that cause dry rot.

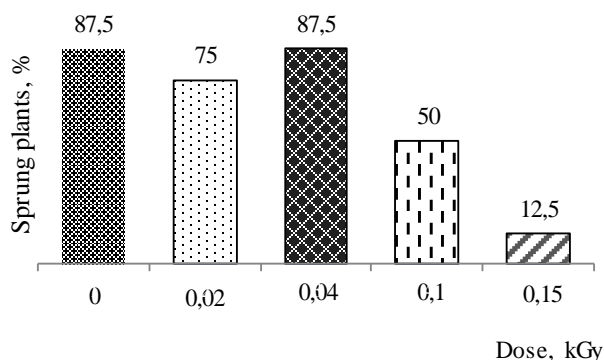


Fig. 3. The effect of radiation on potato seedlings, %

The observed processes in the change in sprouting, budding, and blooming influenced the fractional composition and crop yield. Determination of the fractional composition of the obtained crop showed that in samples irradiated with doses of 0.02-0.1 kGy, there were 3.5-10.3% more small tubers, 5.4-21.5% more medium tubers and 11.8-26.8% less large tubers compared to the control values. In the variants irradiated with the dose of 0.15 kGy, the small fraction of potatoes was completely absent, and the large fraction prevailed (Fig. 4).

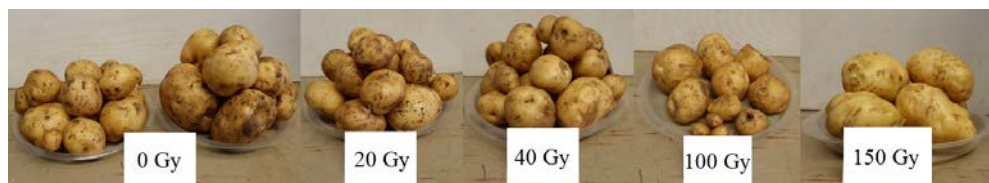


Fig. 4. Photos of the resulting crop of potato tubers

The yield in the control and in the variant with irradiation at a dose of 0.02 kGy was 16.9 t / ha and 15.4 t / ha, respectively. In turn, the yield of plants, grown from seed tubers irradiated at a dose of 0.04 kGy decreased 2.2 times compared to the control and amounted to 7.8 t / ha. The yield of potatoes irradiated with the doses of 0.1 and 0.15 kGy decreased

by more than three times compared to the control samples and amounted to 3.2 and 5.4 t/ha, respectively.

Phytoexpert examination of potato tubers of a new crop showed that all variants were affected by both non-clerocial and sclerocial forms of *R. solani*. Mesh necrosis and fissures prevailed among non-sclerotia forms: 66.6-100% and 6.2-13.0% respectively at doses of 0.02-0.1 kGy. At a dose of 0.02 kGy deformed tubers made up 11.8% and its amount was 9.6% higher than that in the control variant. Deeper spotting was found only in samples irradiated with the doses of 0.02 and 0.04 kGy – 17.6 and 18.7% respectively, which is 72.6-73.7% less than in the control samples. At a dose of 0.15 kGy, unlike other samples, potato tubers were affected only by net necrosis – 66.6%.

Sclerotia forms of *R. solani* were present in almost all samples (except for those irradiated with the dose of 0.15 kGy). To a greater extent this was enabled by the dose of 0.02 kGy, where the prevalence of sclerotia on tubers was 100%, like in the control variant, followed by 56.2% of tubers irradiated with the dose of 0.04 kGy and the smallest amount of tubers – 10.0% affected by sclerotia were those that had received radiation dose of 0,1 kGy. The *R. solani* sclerotia was distributed over 1/10, 1/4 and 1/2 of the surface area of the tuber. In the samples irradiated with the dose of 0.02 kGy, sclerotia occupied 52.9, 41.2 and 5.9% of the tuber surface respectively, with a dose of 0.04 kGy – 25.0, 25.0 and 6.2%, respectively, and the least affected samples were those that had received the irradiation dose of 0.1 kGy – 10.0% (for 1/10 of the tuber surface). Moreover, in the variants irradiated with 0.02 and 0.04 kGy, compared with the control, the prevalence of sclerotia on 1/2 of the tuber surface was 5.9-5.6 times less.

The lesser prevalence of sclerotia on 1/10, 1/4, and 1/2 of the tuber surface in the samples irradiated with the doses of 0.04-0.15 kGy, in comparison with the control, can be explained by a long process of plant formation, a shorter period of tuber accumulation, and, consequently, a shorter period of tuber exposure to *R. solani*.

This study shows that the pre-planting irradiation of seed potato tubers with the doses of 0.02-0.15 kGy led to a delay in plant development, and irradiation of tubers with over 0.2 kGy resulted in the death of plants. The maximum number of large tubers was obtained from irradiated with the dose of 0.15 kGy. The yield of potato tuber sample irradiated with the dose of 0.02 kGy corresponded to that of the control. Irradiation of potato seed tubers at a dose of 0.04 kGy led to a significant decrease in the prevalence of sclerotia of the fungus *R. solani* on the surface of new crop tubers, and at 0.15 kGy to their complete absence.

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