Effect of ultraviolet radiation the germination rate of tree seeds

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Abstract. Extensive use of conifers is highly advisable for urban landscaping, since they are
ever-green, low exploited and long-living compared to their deciduous counterparts. The paper
presents the effect of ultraviolet (UV) radiation on the germination rate of Thuja
occidentalis (2014), Picea fennica (2016) and Pinus sylvestris (2016) seeds exposed to environmentally
friendly UV light-emitting diodes (LEDs). We used two sources of UV: the first one consisted
of 54 LEDs with power of 2 W, the second one – 81 LEDs of 3 W. UV radiation was mostly
within the A range (> 90%) and had a length of 315 nm. It was found out that UV radiation
improved the germination rate of Picea fennica seeds from Quality Class 2 to Quality Class 1,
i.e. from 75% to 86%, thus reducing the planting rates and, subsequently, the planting costs.
After being exposed to the UV dosage of 2 kJ/m², Thuja occidentalis seeds had 12.8% better
germination rate than the control sample, resulting in faster growth and earlier full-grown
shoots. UV-A radiation did not have identifiable positive effects on the pine seeds.

1. Introduction
Anthropogenic impact on the nature can be both positive and negative. Negative anthropogenic impact
includes deforestation due to highway construction; soil pollution due to using chemicals and
fertilizers; reduction in animal populations due to expansion of agricultural land, which requires
deforestation and deprives animals of their natural habitat, causing their death. Human significantly
alters the environment and inhibits adaptation of biological species. This makes it imperative to
develop and implement special measures to save the Earth’s biological resources. These matters were
discussed in 1992 at the United Nations Conference on Environment and Development (the Rio de
Janeiro Earth Summit) in Rio de Janeiro. The Conference adopted the Convention on Biological
Diversity. The Russian Federation’s documents built upon the framework of this Convention are the
programs Biological Diversity of Russian Forests (1995) and Russian Forests (1997).
Conifers are popular not only with private households, but also for large-scale urban landscaping. They are rather low-maintenance in terms of urban environment, as they tolerate fumes, dust, and smog very well. It should also be born in mind that according to forestry experts, conifers detain 30 times as much dust as the aspen and 12 times as much as the birch, while their production of phytoncides is 2 times that of deciduous trees. Extensive use of conifers is preferable for urban landscaping, as they are indeciduous (ever-green), low-maintenance, live longer than their deciduous counterparts, and retain their decorative quality all the year round [1-5]. In accordance with the Russian Rules of Reforestation, forest reproduction must make use of location-adapted seeds.

There are different ways to affect seeds. In the literature [6] investigated the effect of g-irradiation on the energy of rice seeds, estimated using infrared spectroscopy. Results showed that with increase of irradiation dosage and storage age, seed injury increased resulting in reduced seed vigor and seedling height. In the literature [7] study was aimed at investigating the effect of gamma irradiation at various doses (0.5, 1.0, 1.5 and 2.0 kGy) on protein characteristics and functional properties of sesame seeds. It is concluded that gamma radiation improves the protein and functional properties of sesame flour and, thus, can be used as an effective method of preserving sesame flour and its products. In the literature [8] study Effect of X-ray irradiation on wheat seed growth characteristics. The results showed that increasing the radiation dose leads to a decrease in seed energy. In the literature [9] study Mutagenic potential of lettuce grown from irradiated seeds. The study was aimed at analyzing the mutagenicity of Lactuca sativa, developed in a greenhouse and obtained from gamma-irradiated seeds. Based on these results, it has been established that, although radiation is a useful method in plant breeding programs, it is extremely important to estimate the dose of radiation that guarantees the welfare of the end user. According to the study of mutagenic potential of lettuce grown from irradiated seeds irradiated at doses of 25, 50, 75, 150 and 300 Gy [10], it was concluded that in plant breeding programs, it was extremely important to estimate the radiation dose.

Most part of Russia has moderate or moderately cold climate, where conifers grow. The Udmurt Republic is at the same latitude as Canada or Finland. Most of Udmurtia is covered with coniferous spruce forests. Therefore, taking into account the local climate, the problem of obtaining high-quality trees from seeds is relevant.

There are multiple various ways to boost seed germination; we herein propose the environmentally-friendly pre-planting irradiation of seeds by means of UV light-emitting diodes (LEDs) [11, 12]. This light electric technology is low-cost and non-hazardous to humans, as it is based on natural mechanisms [13,14]. Further, UV exposure on seeds cause accelerating the synthesis of functional agents by triggering the phenolic metabolism in plant cells [15]. Literature review and earlier studies show that exposing the seeds of agricultural plants to UV radiation has positive outcomes, improving their germination rates [16-18].

Studies into improving the germination rates of tree seeds by means of pre-planting UV irradiation are aimed at bolstering the forest reproductivity; this is of great scientific and applied importance not only for the Russian Federation, but also for Northern countries. The effects of UV radiation have not been sufficiently studied for Thuja occidentalis, Picea fennica, or Pinus sylvestris (Scots pine) seeds. It is therefore a scientifically relevant problem to analyze the effects of UV LEDs when used for the pre-planting processing of conifer seeds. The goal of this study is to analyze how ultraviolet radiation affects the germination rates of tree seeds.

2. Materials and methods
The Department of Automated Electric Drives, Izhevsk State Academy (Russia) has spent over 10 years to study pre-planting exposure of seeds to UV radiation [17, 18]. The first experiments used environmentally hazardous mercury-vapor lamps. In 2016, they designed a small-sized UV LED lamp with size of 50×40×40 mm. The lamp consisted of 54 low-power LEDs able to evenly irradiate the working surface (figure 1).
The total power of the 54-LED lamp was 2 W. Cf. the earlier 24- to 400-W earlier mercury-vapor designs. Based on the positive results obtained in 2017, this lamp was made more powerful by increasing the number of LEDs to 81 (figure 2). This lamp had the power of 3 W and had the size of 70×60 mm and was 20 mm higher. TKA-ABC radiometer (Limited Liability Company "Scientific and Technical Enterprise" TKA ", Russia, St. Petersburg) was used to measure the UV irradiance in UV-A, UV-B, and UV-C ranges (figure 3).

The composition of the UV radiation was measured five times (table 1). The results showed that approximately 90% is the energy in the UV-A zone.

| UV radiation | Spectral range, nm | Irradiance, W/m² |
|--------------|-------------------|------------------|
| UV-A         | 315...400         | 3.5              |
| UV-B         | 280...315         | 0.087            |
| UV-C         | 200...280         | 0.013            |

The seeds for experiments were provided by the Autonomous Institution Udmurtles (Udmurt Republic, Russia). Germination rate was measured by [19, 20, 21] method. Thuja Occidentalis seeds were prepared in the Zavyalovsky District (Udmurt Republic, Russia) in 2014. Picea fennica seeds were collected in January 2015 in the Zavyalovskoye Forestry. According to passport data (April 2, 2015) the Picea fennica seeds were of Quality Class 2 with 79% germination rate, 92.5% purity, and germination energy of 71%. Pinus sylvestris seeds were collected in December 2013 in the Zavyalovskoye Forestry (March 20, 2014, Quality Class 3, 71% germination rate, 96.3% purity, germination energy of 41%).
In February 2018, the research team carried out experiments irradiating Thuja occidentalis seeds by means of the improved UV LED lamp. Seeds for analysis had been selected by [19-21] method. Seeds was germinated in Petri dishes on a bed of 0.5% KMnO₄ (Odikhim Limited Liability Company, Russia, Moscow) at 22±2 °C. Each variant had 400 seeds. In one Petri dish placed 100 seeds on a bed of filtered paper. The experiments were repeated 4 times. Statistical processing was carried out according to Student's criterion: \( t_{\text{actual}} = 4.71 \) is greater than \( t_{\text{table}} = 2.57 \). Based on the results of experimental studies using the least squares method, we found a mathematical dependence on the effect of the ultraviolet irradiation dose (\( N_{\text{UFO}} \), kJ/m²) on the germination of Picea fennica seeds (\( G \), %):

\[
G\%, = -0.012 \cdot (N_{\text{UFO}})^3 + 0.244 \cdot (N_{\text{UFO}})^2 - 0.278 \cdot (N_{\text{UFO}}) + 74.962, \quad (1)
\]

where \( N_{\text{UFO}} \) varies from 5 to 14.5 kJ m². The error of equation (1) is determined by the expression (2)

\[
m_{y\cdot x} = \sqrt{\frac{\Sigma (y - y')^2}{N - n}} = \sqrt{\frac{0.8069}{2}} = 0.64
\]

where \( N \) – sample size (each point was taken in 4 replicates, and in each replicate there were 100 seeds); \( n \) – number of regression coefficients, including the free term; \( y \) and \( y' \) – respectively, the values of experimental and theoretical germination, %.

All the seeds were divided into three samples depending on the UV radiation type; there was also a control sample of non-exposed seeds. Germination rate of Thuja occidentalis seeds was measured on the 20th Day. Germination of Picea fennica seeds was measured on the 15th Day.

3. Results and discussion

The results of experiments on the effects of ultraviolet radiation on the seeds of Thuja occidentalis are given in table 2. It was shown that the exposure of seeds to UV dose of 2 kJ/m² caused Thuja occidentalis seeds to have 12.8% better germination rate than the control sample (table 2, sample 1). Further, we have demonstrated that higher radiation dose leads to inhibition (reduction) of germination. Thus, a twofold increase in the dose leads to an increase in germination of 5% compared with the control.

| Sample | Radiation dose, kJ/m² | Germination successful, % | Germination not successful, % | Germination increase against the control, % |
|--------|-----------------------|---------------------------|-----------------------------|---------------------------------------------|
| Control | 0                     | 78                        | 22                          | 100                                         |
| 1      | 2                     | 90                        | 10                          | 112.8                                       |
| 2      | 3                     | 84                        | 16                          | 107.6                                       |
| 3      | 4                     | 80                        | 20                          | 105.1                                       |

Since, the Picea fennica seeds collected in 2014 had, according to their passport, Quality Class 2 and a greater germination rate (62%, table 3, sample Control 1), they would germinate more actively than the Class 3 pine seeds collected in 2013, which had a germination of 58% (table 3, sample Control 2).

Exposing Picea fennica to UV radiation improves their germination rate, thus raising the quality class (table 3). Thus, the ultraviolet dose of 12 kJ/m² (table 3, sample 2) increases the germination of Picea fennica seeds by 24% compared with the control sample. UV radiation did not have a positive effect on the germination of Pinus sylvestris seeds. It has been shown that prolongation of UV influence cause a slight decrease in germination. Weak responsiveness of Scots sylvestris to ultraviolet irradiation of zone A was traced by us in previous studies [18].
Table 3. Effect of UV radiation exposure on seeds’ germination properties.

| Sample # | Exposure time, min | Germination successful,% | Germination not successful,% | Germination improvement,% |
|----------|-------------------|--------------------------|-----------------------------|--------------------------|
|          |                   | Picea finneca, Quality Class 2 |                             |                          |
| Control 1| 0                 | 62                       | 42                          | -                        |
| 2        | 18                | 86                       | 14                          | +24%                     |
| 3        | 22                | 74                       | 26                          | +12%                     |
| 4        | 26                | 80                       | 20                          | +18%                     |
| Control 2| 0                 | 58                       | 42                          | -                        |
| 5        | 18                | 62                       | 38                          | +4%                      |
| 6        | 25                | 50                       | 50                          | -8%                      |
| 7        | 30                | 60                       | 40                          | +2%                      |
|          |                   | Pinus sylvestris, Quality Class 3 |                             |                          |

4. Conclusion

Studies have shown that the effects of ultraviolet radiation on the seeds of Thuja and Picea had positive results. The impact on the seeds with an ultraviolet dose of 2 kJ/m² led to the fact that the seeds of Thuja occidentalis had 12.8% better germination than the control sample. For Picea finneca seeds, ultraviolet irradiation increased seed germination by 24%. This will reduce the seeding rate. Ultraviolet radiation did not have a positive effect on the germination of the seeds of Scots pine. Thus, ultraviolet irradiation of seeds is a cheap, simple, environmentally friendly way to “awaken” the seeds from dormancy and increase germination.

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