Synergistic effect of the simultaneous exposure to ultraviolet radiation and nano-silicon preparation to increase the rate of seed germination

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Abstract. The article presents studies on the impact of ultraviolet light-emitting diodes and silicon-containing preparation “Nanosilicon” on the germination of seeds of meadow clover ‘Ranny 2’, alfalfa (Medicago varia) ‘Victoria’ and fodder galega ‘Yaltinsky’. The purpose of the studies was to investigate the synergism of the simultaneous exposure to ultraviolet radiation and nanosilicon to increase the rate of seed germination. The study was investigating ultraviolet radiation zone "A" (UV-A) for a period of 5 minutes. The average irradiance was 3.137 W/m². A decrease to 2-3% of the amount of hard seeds of meadow clover was noted in the variants: first treatment was with ultraviolet light, and then with “Nanosilicon” (UV irradiation + “Nanosilicon” and vice versa: first, treatment was with “Nanosilicon”, and then with ultraviolet (“Nanosilicon” + UV irradiation). In addition, a decrease to 7.9-9.5% of the seeds contamination was detected for fodder galega in almost all studied variants. The use of the preparation “Nanosilicon” and UV radiation on the seeds of alfalfa contributed to an increase in the length of the sprout up to 2.4 cm, the root up to 1.5 cm, the degree of development of seedlings up to 3.0 points, the growth rate up to 29.8%.

1. Introduction

Pre-sowing treatment of agricultural seeds is aimed at improving of their quality. The main (traditional) methods of preparing seeds for sowing are dressing (treatment with pesticides), as well as air-thermal heating. Therefore the search of new methods of pre-sowing treatment is important for increasing the productivity of the seeds [1].

Seed growth processes can be activated in various ways. There are different ways to affect seeds. The effect of g-irradiation on the energy of rice seeds, estimated with infrared spectroscopy is shown in [2]. Results showed that with an increase of irradiation dosage and period of storage, seed injury also increased, resulting in reduced seed vigor and seedling height. A research was carried out to study gamma irradiation in various doses (0.5, 1.0, 1.5 and 2.0 kGy) on protein characteristics and functional properties of sesame seeds [3]. A conclusion was made that gamma irradiation improves the protein...
and functional properties of sesame flower, thus can be used as an effective method of preserving sesame flower and its products. As well the effect of X-ray radiation on the characteristics of wheat seed growth was examined [4]. The results show that the increase of the radiation dose leads to the decrease in seed energy. One more study [5] examined the 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 the study results it was 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 the mutagenic potential of lettuce grown from irradiated seeds irradiated at doses of 25, 50, 75, 150 and 300 Gy [6]. It was concluded that in plant breeding programs it is extremely important to estimate the radiation dose.

Nowadays, pre-sowing treatment of seeds with microelements, as well as their ultraviolet irradiation, is relevant. These are inexpensive environmentally friendly methods that are based on natural mechanisms and therefore do not harm human health. We used ultraviolet to irradiate spruce seeds, and it showed positive results. Any plants need silicon to improve the consumption of nitrogen, phosphorus and potassium. It stimulates growth process, accelerates the onset of phases, which is related to the increase of energy for metabolic processes and sugar synthesis.

The use of nanostructured materials reduces the loss of nutrients, increases productivity, affects seed germination, and root germination. These additives in plants are capable of interacting with UV radiation [7]. A microprocessor system to monitor the dose of ultraviolet radiation was developed [8]. Ultraviolet irradiation of seeds (UV, photostimulation) refers to "green technologies" and provides activation of the biological parameters of the processed material. It is wellknown ozone has a disinfecting effect that can completely replace the widely used seed dressing, as it is an environmentally friendly and does not have a harmful effect on seeds and plants. The basis for UV irradiation of seeds is the method of pre-sowing photostimulation under the influence of solar radiation, known to our ancestors as well. Ultraviolet irradiation of seeds ensures the activation of hidden biological reserves of plants, which has a positive effect on their germination and germination intensity. The use of ultraviolet radiation for pre-sowing seed treatment has a positive effect, since germination is activated, as well as disinfection from pests and seed infection [1].

The choice of nanosilicon as a colloidal solution is based on several reasons. First, silicon is the most abundant chemical element in soil. This element is familiar to all plants and is not perceived by them as an alien. The energy of impact on a biological object is provided in this case not by the chemical nature of nanoparticles, but by the size of this particles. Therefore, it is advisable to use this system. Secondly, the raw material for obtaining the nano-solution in our case is ordinary river sand. Thirdly, the technology for preparing a nano-solution in the variant we have chosen is the simplest and most accessible.

We used the effect of exposure to excess surface energy of colloidal particles and UV radiation in various versions.

| Study objective | Methodology | Result |
|-----------------|-------------|--------|
| Increase rate of seed germination | Ultraviolet radiation and nanosilicon preparation | Positive effect |
| Disinfecting effect on seeds | Ultraviolet radiation | Positive effect |

The purpose of the study was to investigate the synergism of the simultaneous exposure to ultraviolet radiation and nanosilicon preparation to increase the rate of seed germination. Research objectives were: to establish the laboratory germination of seeds of meadow clover, alfalfa and fodder galega, depending on UV irradiation and treatment with the “Nanosilicon”; to reveal the influence of UV and “Nanosilicon” treatment on the formation of seedlings of perennial legumes.

2. Materials and methods

The study was performed in the laboratory of the Udmurt Research and Development Agricultural Institute of the Udmurt Federal Research Center of the Ural Department of the Russian Academy of Science. The seeds of perennial legume crops were germinated, namely ‘Ranny 2’ meadow clover, ‘Victoria’ alfalfa and ‘Yalginsky’ fodder galega. Before the germination, the seeds were treated with ultraviolet radiation at the Department of Automated Electric Drives of Izhevsk Agricultural
Academy, as well as with the “Nanosilicon” at the Chemistry Department of Izhevsk Agricultural Academy (figure 1).

![Figure 1. Ultraviolet radiation of seeds before planting.](image)

Ultraviolet radiation of the A zone (UV-A) lasted for 5 minutes; the average irradiance was 3.137 W/m². The silicon containing preparation “Nanosilicon” was used as 0.1% solution (0.1 ml in 10 l per 1 ton of seeds).

The technology for obtaining a solution is reduced to mixing crushed sand (silicon oxide) with an organic reagent - triethanolamine. Ammonium bases are capable of dissolving silicon dioxide. The reagent obtained by dissolving silicon dioxide in triethanolamine, when mixed with water, readily gyrolizes. That leads to the formation of a colloidal solution - a solution of nanosilicon. It is known that colloidal solutions are capable to diffuse light. To confirm the colloidal nature of the organosilicon solution obtained after hydrolysis, a light beam from the laser was passed through it. A bright trace was observed in the solution on the path of the beam, which indicated the colloidal nature of the resulting solution.

The following five variants were compared:
- Variant 1 – monitoring.
- Variant 2 – ultraviolet radiation only.
- Variant 3 – “Nanosilicon” only.
- Variant 4 – ultraviolet first, followed by “Nanosilicon” (UV-radiation + “Nanosilicon”).
- Variant 5 - “Nanosilicon” first, followed by ultraviolet (“Nanosilicon” + UV-radiation).

Each variant contained 100 seeds. The experiments were carried out with four repetitions. The seeds were germinated in rolls of humidified filter paper, which were installed into the thermostat at the temperature of 20 °C. On the seventh day, the laboratory germination was defined (figure 2), infection with diseases (fusarium) and the seeds were assessed according to the morph physiological parameters of the seedlings [9]. The achieved results were analyzed and processed with the analysis of variance method [10] using the Microsoft Office Excel 2010 program.
Figure 2. Setting the laboratory experiment and the determination of laboratory germination of seeds (‘Ranny 2’ meadow clover).

3. Results and discussion
In the practice of seed control, to determine the sowing qualities of seeds, indicators of germination energy and laboratory germination are used, which indicate the ability of seeds to germinate in a certain period of time under conditions optimal for a particular crop. The impact of UV radiation and the “Nanosilicon” on laboratory germination is shown in table 1.

Table 1. The impact of UV radiation and the “Nanosilicon” on laboratory germination and contamination of perennial legumes seeds.

| Pre-sowing treatment          | Laboratory germination, % | Contamination, % |
|------------------------------|----------------------------|------------------|
|                              | total                     | incl. hard seeds |                  |
| ‘Ranny 2’ meadow clover      |                            |                  |
| No treatment (monitoring)     | 54                        | 6                | 0.6              |
| UV radiation                 | 28                        | 7                | 1.0              |
| “Nanosilicon”                | 35                        | 9                | 1.1              |
| UV radiation + “Nanosilicon”  | 38                        | 3                | 1.0              |
| “Nanosilicon” + UV radiation | 34                        | 2                | 1.0              |
| LSD05                        | 3                         | 2                |                  |
| ‘Victoria’ alfalfa           |                            |                  |
| No treatment (monitoring)     | 75                        | 32               | 0                |
| UV radiation                 | 70                        | 27               | 0.5              |
| “Nanosilicon”                | 79                        | 38               | 0.5              |
| UV radiation + “Nanosilicon”  | 71                        | 35               | 0.5              |
| “Nanosilicon” + UV radiation | 81                        | 32               | 2.1              |
| LSD05                        | 4                         | 3                |                  |
| ‘Yalginsky’ fodder galega    |                            |                  |
| No treatment (monitoring)     | 75                        | 32               | 10.1             |
| UV radiation                 | 62                        | 37               | 9.5              |
| “Nanosilicon”                | 72                        | 33               | 8.9              |
| UV radiation + “Nanosilicon”  | 56                        | 34               | 7.9              |
| “Nanosilicon” + UV radiation | 56                        | 31               | 12.2             |
| LSD05                        | 8                         | F1 < F1          |                  |

The analysis of table 1 shows that the laboratory germination of ‘Ranny 2’ meadow clover in the reference sample (without treatment) was relatively low (54%). While treating the seeds with UV rays
and with the preparation "Nanosilicon", there was a significant decrease in laboratory germination by 16-26% with LSD_{0.05} – 3%. The laboratory germination of ‘Victoria’ alfalfa in the reference sample was 75%. A significant 6% increase in this parameter was revealed when treating seeds with the “Nanosilicon” and UV radiation with LSD_{0.05} – 4%. In other variants (excl. the UV radiation variant) the laboratory germination of 71-79% was at the level of the reference sample. While treating fodder galega seeds, the relatively high laboratory germination of 72% was detected in the “Nanosilicon” variant. This equals to the level of the reference variant (without treatment).

The meadow clover showed a relatively lowest seed hardness, 2-9%. A combination of UV radiation and the “Nanosilicon” contributed to the significant decrease of this parameter by 3-4% (LSD_{0.05} – 2%). A seed hardness of alfalfa and fodder galega was higher, 27-38% and 31-37% respectively. UV treatment contributed to a 5% decrease in the amount of hard seeds in alfalfa with LSD_{0.05} – 3%.

When studying the sowing qualities of seeds of perennial grasses, it is advisable to take into account their contamination with the most harmful diseases, in particular, *Fusarium* - pathogens of root rot that affect the yield of grass seeds. In addition, it is possible for seeds to become infected with ascochitis, stemphiliosis, bacteriosis and molds. Seeds of meadow clover and alfalfa in the Non-Chernozem zone are affected by diseases on a small and medium scale. The maximum contamination of perennial grasses is 10-16%. The permissible rate of contamination of grass seeds is 5-10%. High contamination of seeds, 7.9-12.2%, was detected in galega seeds. Almost every studied method of presowing treatment of fodder galega seeds provided the decrease of contamination by 0.6-2.2%. The exclusion was the combination of “Nanosilicon” + UV radiation: galega seeds and alfalfa seeds showed a 2.1% increase in contamination.

In agricultural practice, it is important to consider not only the number of the planted seeds, but also which of them will form seedlings and whether they can develop into productive plants and give a high yield. In this regard, to assess the yielding qualities of seeds, many researchers suggest indicators of the degree of development of seedlings, the symmetry factor and the vigor [11]. The determination of the degree of development of germs is shown in figure 3.

![Figure 3](image)

**Figure 3.** Determination of the degree of development of germs: 
a) ‘Ranny 2’ meadow clover; b) ‘Yalginsky’ fodder galega.

Table 2 shows the results of the impact of UV radiation and the “Nanosilicon” on germ formation and the vigor.
Table 2. The impact of UV radiation and the “Nanosilicon” on germ formation and the vigor of perennial legumes.

| Pre-sowing treatment | Germ length, cm | Root length, cm | Degree of development of germs, points | Symmetry factor | Vigor, % |
|----------------------|----------------|----------------|----------------------------------------|----------------|---------|
| ‘Ranny 2’ meadow clover |                |                |                                        |                |         |
| No treatment (monitoring) | 3.1           | 1.5           | 3.0                                   | 2.06           | 28.5    |
| UV radiation | 2.5 | 0.8 | 2.0 | 3.12 | 6.5 |
| “Nanosilicon” | 2.0 | 1.0 | 2.3 | 2.00 | 10.5 |
| UV radiation + “Nanosilicon” | 2.6 | 1.3 | 2.7 | 2.00 | 20.5 |
| “Nanosilicon” + UV radiation | 2.8 | 0.8 | 2.2 | 3.50 | 13.0 |
| LSD05 | 0.3 | 0.4 |    |      |        |

‘Victoria’ alfalfa

| Pre-sowing treatment | Germ length, cm | Root length, cm | Degree of development of germs, points | Symmetry factor | Vigor, % |
|----------------------|----------------|----------------|----------------------------------------|----------------|---------|
| No treatment (monitoring) | 2.2           | 1.3           | 2.5                                   | 1.69           | 21.4    |
| UV radiation | 2.2 | 1.6 | 2.8 | 1.37 | 20.6 |
| “Nanosilicon” | 2.1 | 1.2 | 2.5 | 1.75 | 18.4 |
| UV radiation + “Nanosilicon” | 2.3 | 1.5 | 2.8 | 1.53 | 19.7 |
| “Nanosilicon” + UV radiation | 2.4 | 1.5 | 3.0 | 1.60 | 29.8 |
| LSD05 | F_t < F_s |    |      |      |        |

‘Yalginsky’ fodder galega

| Pre-sowing treatment | Germ length, cm | Root length, cm | Degree of development of germs, points | Symmetry factor | Vigor, % |
|----------------------|----------------|----------------|----------------------------------------|----------------|---------|
| No treatment (monitoring) | 3.4           | 2.2           | 3.3                                   | 1.54           | 27.8    |
| UV radiation | 2.5 | 1.7 | 2.5 | 1.47 | 13.5 |
| “Nanosilicon” | 2.8 | 2.0 | 3.0 | 1.40 | 24.3 |
| UV radiation + “Nanosilicon” | 2.5 | 1.7 | 3.1 | 1.47 | 13.8 |
| “Nanosilicon” + UV radiation | 2.2 | 1.5 | 2.3 | 1.46 | 11.6 |
| LSD05 | 0.4 | 0.4 |    |      |        |

The analysis of table 2 shows that the largest germ length of meadow clover, 2.8 cm, was detected for the combination of “Nanosilicon” + UV radiation, and the largest root length, 1.3 cm, for the combination of UV radiation + “Nanosilicon”, which correspondingly equals 3.1 cm and 1.5 cm at the reference level (no treatment).

According to [11], seedlings with a developmental degree of 3 points or more are considered strong seedlings. Our degree of development of clover seedlings was 2.0-3.0 points, the vigor (the number of strong seedlings) was 6.5-28.5%. Relatively high parameters of the degree of development of seedlings 3.0 and 2.7 points, the vigor of 28.5 and 20.5%, respectively, were noted in the variants without treatment and the combination of UV radiation + “Nanosilicon”.

An important parameter, showing the yield quality of seeds, is the symmetry factor, calculated as the ratio of germ length to root length. Many scientists found out that the higher this factor, the lower the yield quality of seeds is [10]. It can be assumed that the treatment of clover seeds with the preparation “Nanosilicon”, as well as UV irradiation + “Nanosilicon” will contribute to the formation of a higher yield, since they have the lowest symmetry factor equal to 2.00.
As for alfalfa, the studied methods of seeds treatments did not have any impact on the germ length, 2.1 – 2.4 cm, and on the root length, 1.2 – 1.6 cm. The degree of development of alfalfa germs was 2.5 – 3.0 points, and the vigor was 18.4 – 29.8%. The combination of “Nanosilicon” + UV radiation showed the evident positive tendency for all the studied parameters. According to the results of the experiments, it can be seen that the original assumption of the authors about the possible effect of exposure to the plant of nanoparticles and UV radiation was confirmed. For ‘Victoria’ alfalfa, the most effective of all preparation options was the option of combined exposure to excess energy of nanoparticles and UV radiation.

As for fodder galega, the studied variants resulted in the considerable decrease in the germ length by 0.6-1.2 cm and in the root length by 0.2-0.7 cm. The degree of development of germs was 2.3-3.3 points and the vigor was 11.6-27.8%. The use of the “Nanosilicon” preparation contributed to obtaining the following parameters: the degree of seedling development - 3.0 points, the vigor - 24.3%, the symmetry factor - 1.40, which is slightly higher than the parameters obtained in other variants.

Based on the results obtained, it should be concluded that the mechanism of action of the proposed variant of seed preparation is as follows. The seeds treated with the nano-solution adsorbed silicon nanoparticles on their surface. After evaporation of water, the particles adhere tightly to the surface of the biological object, and the degree of impact on the grain is maximum. Subsequent exposure of the treated surface to UV radiation activated intermolecular bonds. Under these conditions, the susceptibility of a biological object to the effects of excess surface energy has sharply increased. This led to an increase in the rate of seed germination by 40%.

Obviously, the authors can recommend for practical application the method of pre-sowing treatment they have tested: preliminary soaking of seeds in a nanosilicon solution, and subsequent irradiation with an electromagnetic field in the ultraviolet range.

4. Conclusion
Pre-sowing treatment of seeds of perennial legumes with the “Nanosilicon” and UV radiation did not have any impact on the increase of laboratory germination. A decrease to 2-3% in the amount of hard seeds of meadow clover was noted in the variants of UV irradiation + “Nanosilicon” and “Nanosilicon” + UV irradiation, as well as a decrease to 7.9-9.5% of the contamination of the seeds of fodder galega in almost all studied variants. The use of the preparation “Nanosilicon” and UV radiation on the seeds of alfalfa contributed to the tendency to increase the germ length up to 2.4 cm, the root up to 1.5 cm, the degree of seedling development up to 3.0 points, the vigor up to 29.8%.

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