Influence of UV Radiation on Physical and Biological Properties of Rapeseed in Pre-Sowing Treatment

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The effect of ultraviolet radiation on pre-sowing treatment of seeds of the winter cultivar Lembke and cultivars treated with fungicides DK EXODUS, DK Exquisite and DK Exprit was studied. Experimental studies show a positive effect of UV irradiation in pre-sowing treatment of winter rapeseeds on seed vigour and germination, both when irradiated in region C (200-280 nm) and in region B (280-320 nm). It was found that UV radiation has a positive effect on the sowing qualities of winter rapeseeds varieties Lembke and DK EXODUS (treated with fungicides) when irradiated with a dose of 120 J/m²: seed vigour increased by 11% in the variety DK EXODUS and 16.9% in the variety Lembke, germination on average by 13% compared to control samples. At doses of 250 and 500 J/m², a decrease in the sowing quality of seeds is observed. The main parameters of kinetic values of hydration were determined: moisture content and hydration rate. It was found that the rate of hydration increased sharply in the initial phase and gradually and slowly decreased in the middle and final phases of the hydration procedure, respectively, in order to achieve a saturated moisture content. Irradiated seeds at a dose of 120 J/m² showed a higher rate of water absorption than the control, both in the early and later stages of the hydration procedure. It is established that UV-C irradiation changes the kinetics of water absorption by B. napus seeds at low doses of irradiation, causing faster penetration of water into the seeds and more efficient hydration of tissues, positively affecting sowing qualities and biometrics. It has been suggested that water uptake by UV-irradiated B. napus seeds causes excessive imbibition damage at higher doses of UV radiation, as the germination potential decreases and improves at low doses. No significant changes in biometric parameters were detected during UV irradiation of rapeseed varieties DK Exquisite and DK Exprit treated with fungicides and dyes.

Keywords : rapesseds, seed vigour; germination; UV-C radiation; moisture content (MC); hydration rate (HR).

I. INTRODUCTION

According to the OECD-FAO Agricultural Forecast for 2019-2028, oil production will grow by 1.4% per year over the next decade [1], reflecting slower growth over the last ten years due to declining demand for rapeseed oil in Europe, as a raw material for biodiesel production. Among oilseeds, rapeseed is preferred, which is grown to obtain vegetable oil and feed protein. Brassica oilseeds have long been the third most important source of edible vegetable oils in the world [2, 3]. Currently, there are three main areas of application of rapeseed oil: 1 - edible oil from varieties "Canola" [4]; 2 - oil with a high content of erucic acid [5]; 3 - rapeseed for biodiesel production [6]. Rapeseed oil is well known for its antioxidant properties [7], in addition, it is used for technical and food purposes, and waste in the production (cake and meal) is used as an additive in the production of feed concentrates for animals and poultry. The creation of high-yielding varieties of winter rapeseed has given a powerful impetus to increase its production. This has led to the development of new and improvement of existing cultivation technologies. However, according to the modern market conditions, it is important not only to increase the yield of rapeseed, but also to obtain high quality products at lower costs, which makes it more competitive [8]. One of the most effective ways to increase the yield and quality of the seed is the impact on the seeds with various priming methods, designed to improve the parameters of germination and seedling growth [9]. It is known that the inflow of the water to the seeds is an important condition for the beginning and successful completion of the germination process; therefore, improved germination and growth parameters may be the result of improved water absorption [10]. The main feature of hydroprying is the enhanced growth of seedlings, which correlates with increased water absorption of seeds [11]. Despite numerous studies and progress in recent years in understanding the mechanisms underlying seed priming, a common understanding of the physiological and biochemical changes responsible for germination, plant growth, and resistance to abiotic stress remains understudied. For solving this problem in order to improve the sowing qualities of seeds, scientists and agricultural specialists are constantly improving the methods of pre-sowing seed treatment using physical methods [12]. The advantage, has recently been given to optical radiation - pre-sowing treatment of crop seeds with ultraviolet radiation [13, 14, 15]. Thus, in [16] peanut and Mung bean seeds were treated with ultraviolet radiation for 0, 5, 10, 15, 20, 30 and 60 minutes, which improved growth parameters. A significant increase in the similarity of Mung beans was observed when the seeds were treated for 30 minutes. However, maximum ladder length, shoot weights, and root weights were observed when Mung beans UV-C seeds were treated for 15 minutes, while root weights increased when seeds were treated for 30 minutes (leaf area and tuber numbers were maximal when Mung beans treated with UV-C for 10 and 30 minutes, respectively. The authors of article [17] found that treatment with ultraviolet radiation contributed to an increase in the length of shoots and the mass of pea plants.

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Irradiation of agricultural plants with UV-C radiation is effective for improving their growth parameters and reducing disease damage. Various types of pathogens (Fusarium Patch; Fusarium oxysporum Schltdl and Fusarium solani (Mart.) Sacc. cause root and stem rot in a wide variety of plants [18].

Root rot of cultivated plants depends on the defeat of pathogens that affect the intensity of the disease of many crops [16]. The article [19] by American scientists reports that the inactivation of Escherichia coli on alfalfa seeds by UV-C irradiation, which increased yields.

Therefore, it is assumed that irradiation of agricultural plants with UV-C radiation is effective for improving growth parameters and reducing disease infection. It is noted that ultraviolet radiation is lethal to bacteria, viruses, mold spores, yeast and algae, but the doses required for inactivation of microbial spores are significantly different [20].

As the analysis of literature sources [12-19] shows, the authors do not always provide information on the parameters of the experiment. However, it was found that the pre-sowing UV irradiation of seeds, the amount of energy, spectral composition, processing time are different for each crop, so the choice of irradiation requires a detailed study and a differentiated approach.

II. MATERIALS AND RESEARCH METHODS

Samples of different varieties of winter rapeseed were taken for the study: Sherpa (Lembke) and varieties DK EXODUS, DK Exquisite, DK Exprit, treated with fungicide MAXIM XL-combined action.

In the study, ultraviolet lamps with different radiation ranges, namely LE-30 (UV-B) [21] lamps and ZW20D15W (UV-C) lamps [22]. Irradiation was carried out in the following doses: 50, 120, 250, 500, 1000 and 3000 J/m^2. Measurements of doses of UV radiation in different energy regions of the ultraviolet range were performed using a radiometer "Tensor-31".

Germination of control (without irradiation) and irradiated samples was determined by germinating 4 samples of 50 seeds in Petri dishes on moistened filter paper in accordance with the ISTA standard.

The content of photosynthetic pigments in rapeseed leaves in the phase of three true leaves was determined using a spectrophotometer by the three-wave method, determining the optical density of chlorophyll extract at 665, 649, and 440 nm (absorption maxima of chlorophyll a (Ca), chlorophyll b (Cb), and carotenoids (Cc), respectively. The concentration of pigments was calculated using the following formulas [23]:

$C_a = 11{,}63D_{665} - 2{,}39D_{649}$, mg/l

$C_b = 20{,}11D_{649} - 5{,}18D_{665}$, mg/l

$C_к = 4{,}695D_{440} - 0{,}268C_{a+b}$, mg/l

To determine the moisture content (hydration) of rapeseed samples in the amount of 10 ± 0.5 g was soaked in 200 ml of distilled water at each value of the dose of UV radiation. Soaked samples were removed from the water at intervals of half an hour and an hour.

The samples were placed on adsorbent paper to remove excess water, and then weighed using precision electronic scales, model WLC 0.2, TM Radwag, Poland with an accuracy of 0.001 g. Accordingly, the moisture content of the MC and the rate of hydration HR were calculated based on the following equations [24]:

$$MC = \left(\frac{W_f - W_i}{W_i}\right) \times 100\% \text{ (d. b. \%)}$$

$$HR = \frac{MC_{(t+\Delta t)} - MC_{(t)}}{\Delta t} \text{ (d. b. \%/min)},$$

where MC is the moisture content (d b.%), Wf is the mass of wet rapeseed (g), Wi is the initial mass of rapeseed (g); Δt - time interval; MC (t) - moisture content at time (t) (d. B.%), MC (t + Δt) moisture content over time (t + Δt) (d. B.%).

At each value of the dose of UV radiation, a hydration procedure was performed, which lasted 12 hours. At this stage, the change in weight and, accordingly, the content of saturated moisture in the sample was determined. At this stage, the change in weight and, accordingly, the content of saturated moisture in the sample was determined. In order to reduce the error of measurement of hydration parameters, the studies were performed three times. The experimental data were confirmed by statistical processing of the obtained results.

III. RESULTS AND DISCUSSION

A. Determination of seed vigour and germination

Analysis of literature sources [17, 18, 19, 25] shows the dependence of sowing qualities of seeds of agricultural crops on the energy dose and the range of ultraviolet radiation.

In this regard, we studied the effect of UV-C and UV-B radiation at the same dose - 120 J/m^2 in pre-sowing treatment of rapeseed varieties "Sherpa" to determine the seed vigour and germination [26].

In this regard, we studied the effect of UV-C and UV-B radiation at the same dose - 120 J/m^2 in pre-sowing treatment of rapeseed varieties "Sherpa" to determine the seed vigour and germination. The irradiation dose of 120 J/m^2 was chosen because at this dose most crops have the maximum values of seed vigour and germination [27, 28]. The seed vigour increased in comparison with the control sample by 30% for area C, and for area B increased by 23%. The germination increases in comparison with control samples by 17% for region C, and for region B by 8.0%.

Thus, the conducted studies of the seed vigour and germination showed that UV irradiation not only in the C region, but also in the B region has a positive effect on the stimulating processes of the seeds.

Comparing the effects of different areas of UV-C and UV-B at the same dose of 120 J/m^2, it was determined that the area of ultraviolet radiation C is more effective in influencing growth processes compared to area B.

Subsequently, studies were carried out on the effect of ultraviolet C radiation on rapeseed with different doses of 0, 50, 120, 250 J/m^2 of the following varieties: Sherpa (Lembke), DK Exodus (DK EXODUS), DK Exquisite (DK Exquisite), DK Exprit, treated with a contact-system fungicide. After the treatment of the seeds of these varieties with different doses of ultraviolet radiation in the area C, positive changes (increased seed vigour and germination) were observed in the Sherpa variety (Lembke) (Table- I) and the DK EXODUS variety (Table- II).

Low doses (50 J/m^2) were ineffective and did not show a significant effect on seed vigour and germination of winter rapeseed varieties Lembke and DK EXODUS. At an irradiation dose of 120 J/m^2, the following results were obtained: the seed vigour increased by 11% in the DK EXODUS variety and 16.9% in the Lembke variety as compared to the control samples, the similarity on average by 13%. At doses of 250 and 500 J/m^2 there is a decrease in sowing qualities of rapeseed, a significant difference in the values of seed vigour and germination compared to control samples is not observed.

Table- I: Influence of UV radiation on sowing qualities of Sherpa winter rapeseeds (Lembke)

Radiation dose,J/m^2	Seed Vigour, %	Germination, %	Mass of seedlings on the 7th day, g
Control samples (without irradiation)	72,0	82,0	1,68
50	73,6	80,6	1,73
120	84,2	92,6	1,95
250	76,6	83,0	1,58
500	68,5	72,4	1,54

Table- II: Influence of UV radiation on the sowing quality of winter rapeseed varieties DK EXODUS

Radiation dose, J/m^2	Seed Vigour, %	Germination,%	Mass of seedlings on the 7th day, g
Control samples (without irradiation)	76,0	86,6	1,77
50	78,6	84,6	1,84
120	84,4	98,0	2,19
250	74,6	78,0	1,61
500	68,9	76,8	1,49

For the other varieties of rapeseed DK Exquisite and DK Exprit no noticeable changes were observed in the entire range of UV irradiation. The reason for such deviations from the general pattern is the treatment of seeds with fungicides and dyes. The combined fungicide MAXIM XL used is a mixture of two chemical compounds (active substance: fludioxonil, 25 g/l + mefenoxam, 10 g/l), the absorption spectra of which have maxima with high extinction coefficients in the UV-C region. This is confirmed by Figure 1 shows the absorption spectra of the dye methylene blue, fludioxonil and several known fungicides [29] for three regions of the UV spectrum: UV-A (320-400 nm), UV-B (280-320 nm), UV- C (200-280 nm). These patterns of overlap of the emission spectra and absorption spectra are the reason for the ambiguous effect of ultraviolet radiation on rapeseed treated with fungicides.

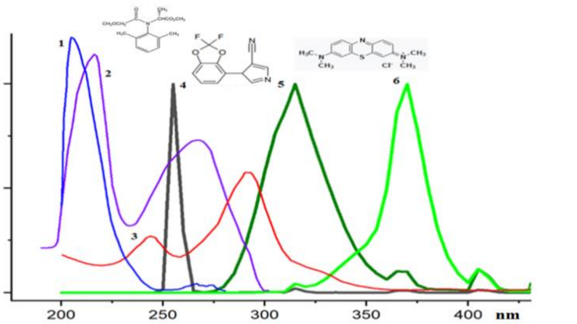

Fig. 1. Absorption spectra: 1 - Metalaxyl (MET) [30]; 2 - Fludioxonyl [31] methylene blue solution [32]; 3 - Methylene blue; 4, 5, 6 - lamp emission spectra: bactericidal, erythematous and ultraviolet, respectively

B. Determination of chlorophyll

The experimentally obtained results of the content of photosynthetic pigments in the leaves of winter rapeseed (phase of three true leaves) indicate a decrease in the concentration of chlorophyll a, b and carotenoids during pre-sowing UV irradiation of seeds (Fig. 2).

A minimal decrease in the concentration of chlorophyll a and chlorophyll b in the leaves of winter rapeseed (respectively by 50.6 and 33.6% relative to control samples) is observed when UV irradiation of seeds at a dose of 250 J/m^2. At this dose of UV radiation, the concentration of carotenoids decreased by 10.5%.

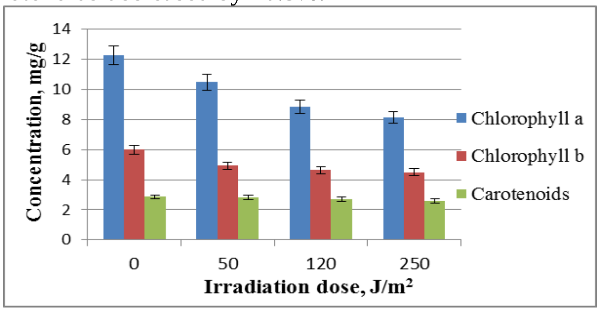

Fig. 2. The content of photosynthetic pigments in the leaves of winter rapeseed DK EXODUS

Similar patterns were observed in [33], where the authors investigated the effect of additional optical radiation of different spectral range for 6 days on some annual plants of the desert: Malva parviflora L., Plantago major L., Rumex vesicarius L. and Sismbrium erysimoids Desf. The results show us that the content of chlorophyll a, b and total chlorophyll decreased under UV irradiation.

C. Determination of hydration kinetics

Most authors determine the impact of pre-sowing treatment of seeds of agricultural crops by biological properties during germination, growth and study the hydration characteristics that affect the biological performance of products [34]. As a rule, for the study of the hydration kinetics using different mathematical models [34]. Thus, the study [35] shows the possibility of using neural models to predict the yield of winter rapeseed in practice on the basis of quantitative and qualitative data. Water has a crucial role in the germination of one of the objectives of this study was to examine the relationship between the biological properties of seed hydration temperature during germination.

For establishing the regularities of the dependence of water absorption, let us analyze the main dependences of the kinetic values of seed hydration depending on the dose of UV radiation. For that, we will conduct the study using rapeseed variety "Sherpa", which is not treated with fungicides, science they suspend water absorption.

In Fig. 3. the kinetics of water absorption by irradiated and control seeds depending on time at different doses of UV-C irradiation is presented.

The moisture content increases with increasing hydration time. Moreover, it was found that water absorption decreases over time with increasing hydration time and radiation dose.

The rate of hydration increased sharply in the initial phase and gradually and slowly decreased in the middle and final phases of the hydration procedure until it reached the content of saturated moisture.

The hydration of seeds was the fastest in the first two hours of swelling and began to slow down markedly after 6 hours, both for control and for seeds irradiated with UV-C.

However, UV-C irradiation of the seeds at a dose of 120 J/m^2 showed a higher water absorption rate than the control, both in the early and in the later stages of suction.

For irradiated (primed) seeds at doses of 120 J/m^2, the amount of water adsorbed after 30 minutes, 1 hour, 4 hours and 10 hours of impregnation was higher compared to non-irradiated by 3.2%, 4.1%, 2, 9% and 4%, respectively (Fig. 3). For irradiated (primed) seeds at doses of 120 J/m^2, the amount of water adsorbed after 30 minutes, 1 hour, 4 hours and 10 hours of impregnation was higher compared to non-irradiated by 3.2%, 4.1%, 2, 9% and 4%, respectively (Fig. 3). At higher doses, the water absorption decreases.

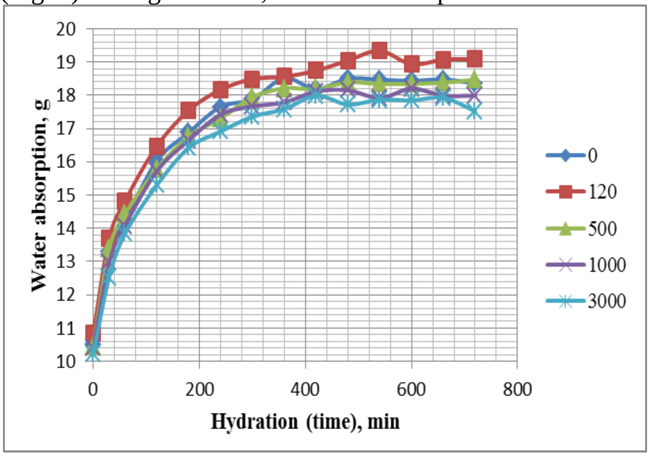

Fig. 3. The dependence of water absorption from the time when radiation doses: 0 - without irradiation; 120, 500, 1000 and 3000 J/m^2

The results of this study showed that UV-C irradiation increases the kinetics of water absorption only at certain doses. In the Fig. 4 and Fig. 5 the dependences of the change of the hydration rate depending on the hydration time or the moisture content are presented on the basis of the best forecast of the artificial neural network (ANN) model [23].

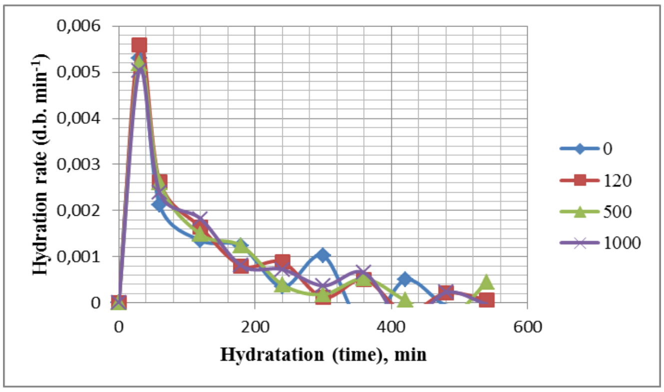

Fig. 4. Dependence of the hydration rate of hydration depending on the time when the irradiation dose: 0 - without irradiation; 120 J/m^2, 500 J/m^2 and 1000 J/m^2

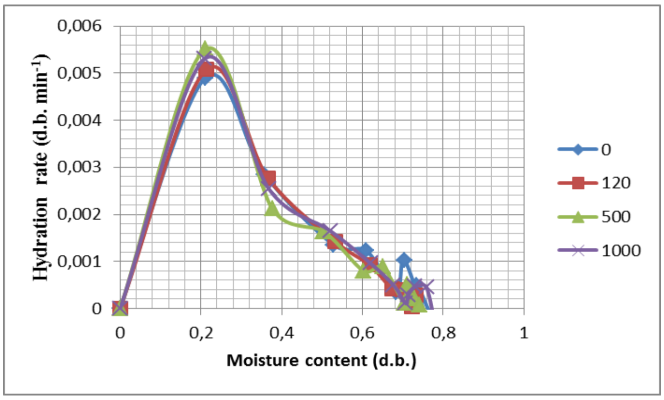

Fig. 5. Dependence of the hydration rate depends on the moisture content at an irradiation dose: 0 - without irradiation; 120 J/m^2, 500 J/m^2 and 1000 J/m^2

The results of this study shows that UV-C irradiation significantly changes the kinetics of water absorption by B. napus seeds. UV-C radiation at certain doses of radiation can cause faster penetration of water into the seeds and more efficient hydration of tissues. At certain doses of UV-C irradiation increases not only the rate of water absorption, but also the amount of water absorbed in the early stages of water absorption. Differences between irradiated and non-irradiated seeds were seen after the first 15 minutes of swelling. Sequential increases in water content at certain thresholds during swelling gradually trigger different types of biochemical and cellular events in germinating seeds. These results are confirmed by recent studies [10], where magnetic resonance imaging (MIR) found that the point of entry of water into rapeseed (B. napus) is a small area of the seed coat, which confirms previous observations obtained for other plant species [36]. This study also shows that in rapeseed B. napus embryonic swelling is a heterogeneous process that begins with root hydration, causing rehydration of other parts of the embryo. In addition, factors that potentially affect hydration during priming seed have been identified. Besides, factors that potentially affect hydration during of germination priming seeds have been identified. It has been shown that UV-C irradiation (I) changes the microstructural features of the seed coat, for example, leads to the formation of microcracks, (II) changes the internal structure of the seed due to the formation of additional voids in the seed, (III) increases vacuolation of cotyledon cells.The first physiological activity that is restored due to water absorption is respiration and amino acid metabolism [37, 38]. In studies of B. napus, respiration recovery begins in the endosperm and spreads according to the water distribution route within the germinating seeds [36]. The preparation of the embryo for emergence depends on the water content, so it is likely that faster and more efficient hydration of embryonic tissues caused by UV-C irradiation can reduce germination time. UV-irradiated B. napus seeds germinate almost twice fast as and more evenly than non-irradiated seeds. These results are consistent with the results of a number of studies [39, 40], where it is shown that UV irradiation promotes the germination of B. napus seeds both under optimal conditions and under stress.

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It should be pointed out that improved water absorption during germination after UV-C irradiation cannot be considered as the only factor responsible for enhanced germination of irradiated seeds. It was identified that one of the reasons responsible for the rapid germination of priming seeds is the initiation of processes associated with germination during pre-hydration [10], which allows priming seeds to achieve a higher metabolic state before germination.The increase in seed vigour during UV-C irradiation of seeds is the result of many mechanisms caused by irradiation, including efficient water absorption, which, of course, makes a significant contribution to this effect.On the other hand, the results of other works [41] show that the osmopriming of Solanum lycopersicum seeds leads to a decrease in water absorption during the I phase of germination than the control seeds. Exactly such a dependence - a lower rate of water absorption was found in sweet corn seeds after preliminary priming [42].The authors [10] identified these changes as potential reasons of the observed improvement in the germination of UV-irradiated seeds at certain doses, which reduces early imbibition damage and improves membrane reorganization. Indeed, excessively rapid initial water uptake can lead to so-called imbibition damage to seeds, which is primarily manifested in the violation of the structural integrity of the membranes and leads to leakage of soluble cell contents [43]. The connection between the rate of hydration and the occurrence of imbibition damage has been confirmed in seeds of different species [44, 45, 46]. The results of this study showed that water uptake by UV-irradiated B. napus seeds causes excessive imbibition damage at higher doses of UV radiation, as the germination potential decreases, and at low radiation doses, on the contrary, improves.

IV. CONCLUSIONS

1. Experimental studies show the positive effect of UV radiation in pre-sowing treatment of rapeseed at low doses of radiation on its sowing quality and biometric performance, both when irradiated in region C (200-280 nm) and in region B (280-320 nm). At the same time, the seed vigour and germination capacity increased by 30.0% and 17%, respectively, with irradiation in the UV-C region, and by 23% and 8%, respectively, with irradiation in the UV-B region. The UV region G more effectively when exposed to growth processes as compared with the region B.

2. Under UV irradiation of seeds of cultivars Lembke and DK EXODUS (treated with a fungicide) at a dose of 120 J / m2, the seed vigour increased by 11% in cultivar DK EXODUS and 16.9% in cultivar Lembke compared to control samples, and the similarity increased by 13 %. At doses of 250 and 500 J/m^2 there is a decrease in sowing qualities of rapeseed.

3. No significant changes in biometric parameters were detected during UV irradiation of rapeseed varieties DK Exquisite and DK Exprit treated with fungicides and dyes. The reason of such deviations from the general pattern is the treatment of seeds with fungicides, the absorption spectra of which coincide with the spectra of UV radiation.

4. The content of photosynthetic pigments in the leaves of DK EXODUS rapeseed decreases with increasing dose of UV radiation: at a dose of 50 J/m^2 - chlorophyll a, chlorophyll b by 17, 0% and 21.8%, respectively, and carotenoids by 1.2%; at a dose of 120 J/m^2 chlorophyll a, chlorophyll b by 38, 4% and 29.1%, respectively, and carotenoids by 5.2%, and at a dose of 250 J/m^2 chlorophyll a, chlorophyll b by 50.6% and 33.6%, respectively, and carotenoids by 10.5%.

5. The results of the analysis showed that the rate of hydration of seeds increased sharply in the initial phase and gradually and slowly decreased in the middle and final phases of the hydration procedure until it reached the content of saturated moisture. Irradiated seeds at a dose of 120 J/m^2 showed a higher rate of water absorption than the control, both in the early and later stages of absorption. With increasing radiation dose, water absorption decreased throughout the range of UV radiation.

6. UV-C irradiation changes the kinetics of water absorption by B. napus seeds at low doses of irradiation, causing faster penetration of water into seeds and more effective hydration of tissues, positively influencing sowing qualities and biometric indicators.

7. Pre-sowing treatment of seeds with UV radiation increases the rate of hydration at low doses of radiation, positively affecting sowing qualities and biometrics, and with increasing doses of radiation - decreases.

8. Water uptake by UV-irradiated B. napus seeds causes excessive imbibition damage at higher doses of UV radiation, as the germination potential decreases and improves at low doses.

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