



The effects of increased exposure time to UV-B radiation on germination and seedling development of Anatolian black pine seeds

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Abstract Exhaustion of stratospheric ozone found at a height of 10–30 km around the world causes the solar UV-B (280–320 nm) radiation to penetrate through the atmosphere more, and thus to reach the Earth's surface quicker. The protective ozone layer gets damaged by human activities constantly, and the increasing levels of UV radiation present threats to all life forms, plants, animals, and even microorganisms. However, the studies conducted on the effects of UV radiation on plants, and especially forest trees, are rather limited. In this study, it was aimed

to identify the effects of UV-B radiation on some germination and seedling characteristics of Anatolian black pine seeds. Within the scope of the study, seeds were exposed to UV-B radiation for 5, 10, 20, 30, 40, 50, and 60 min for germination experiments; and the germination speed (GS) was calculated as the ratio of the germinated seeds to the solid seeds at the end of the 7th day, whereas the germination percentage (GP) was calculated as the ratio of the germinated seeds to the solid seeds at the end of the 35th day. The seeds reserved for the seedling experiment were exposed to UV-B radiation for 1, 3, 5, and 7 h. With the measurements made at the end of the day, the seedling length (SL), the terminal bud length (TBL), the branch number (BN), the root collar diameter (RCD), the stem fresh weight (SFW), the root fresh weight (RFW), the stem dry weight (SDW) and the root dry weight (RDW), and the rooting percentage (RP) were determined. Variance analysis and Duncan test were applied to the obtained data with the help of SPSS package program. The study results revealed that the exposure time to increased UV-B radiation significantly affected all characters; the least affected character was RP, and that the most affected characters were RDW, SDW, and RCD. As a result of the study, it was found that even the applications with the lowest intensity took effect in most of the characters, that the seedling development decreased by more than 80% in terms of some characters at the end of 7-h application, and that even the decrease in the RP character,

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which was the least affected by the 7-h UV-B application, was above 50%.

Keywords Germination speed · Growth · Morphological characters · *Pinus nigra* Arnold · Radiation · UV-B application · Rooting percentage

Introduction

Today, the worldwide population growth is regarded as the cause of many important problems around the world. While the world population was only around 717 million in the 1750s, it exceeded 7.7 billion in 2020 (Batir, 2019; Worldometers, 2020). In addition to the human population growth in the world, the endless wishes and desires of humans have caused an excessive use of the limited resources of the planet. This process created great pressure on the ecosystem and caused the delicate balances to begin to deteriorate. Basically, some of the most important problems caused by human beings are environmental pollution, increased CO₂ concentration in the atmosphere, decreased living spaces of many living things, and thus the loss of species, and global climate change.

One of the impacts occurring on a global basis during this process is the exhaustion of the stratospheric ozone layer. This situation is closely related to global climate changes, and is one of the main threats to life in the world. Exhaustion of stratospheric ozone layer at a height of 10 to 30 km around the world causes the solar UV-B (280–320 nm) radiation to penetrate through the atmosphere more, and to reach the Earth's surface quicker. The protective ozone layer is constantly damaged by human activities, in other words, the substances that thin the ozone layer, including chlorofluorocarbons and other industrial products containing halogen. The increasing levels of UV radiation may be harmful to all life forms, plants, animals, and even microorganisms (Shaukat et al., 2013). For this reason, identification of the current and possible effects of UV radiation on living things is crucial both for understanding the importance of the subject and for taking the necessary precautions by determining the possible future effects.

The studies conducted reveal that advanced UV-B radiation can have important effects on plants' growth, development, biomass accumulation, yield, and metabolism. Some of these effects can be listed

as inhibition of root growth, increased leaf thickness changes in the cuticle and decreased biomass, and leaf area (Kobzar et al., 1998; Gwynn-Jones, 2001; Ravindran et al., 2008). In spite of various studies carried out on the physiological responses of plants to UV-B radiation, the studies on this subject are still quite limited, and the studies on forest trees are a lot fewer. This study aims to identify the effects of UV-B radiation on some seedling characters of Anatolian black pine seeds.

Black pine (*Pinus nigra* Arnold.) is the most important species which can be spread to the steppe regions in Turkey. Away from its native areas, Black pine is planted for its ornamental value and timber production purposes (Yigit et al., 2016; Fagarazzi et al., 2020). It is extensively used in schoolyards, university campus areas, urban afforestation areas, and amelioration works of abandoned mining sites and is recommended in such projects (Topacoglu et al., 2016; Dassot & Collet, 2020). UV-B radiation is stressful, and plants illustrate the effect of slowing growth (Benca et al., 2018; Santos et al., 2021). More importantly, a small increase in UV-B radiation can have significant biological effects because of the UV-B radiation. It is readily absorbed by a number of important macromolecules such as nucleic acids, proteins, lipids, and phytohormones (Kataria et al., 2015) negatively affecting plant morphology, physiology, and development in addition to photo-oxidative damage (Passaglia et al., 2009). UV-B radiation reduces the photosynthetic activity (Bondarenko & Savchuk, 2018). It is also stated that the climate change alters the exposure of living things to UV-B radiation. Climate change is seen as the most important threat on forests existence and structure (Bornman et al., 2019; Varol et al., 2021). Therefore, determining the threats that UV-B stress will pose on plants, especially during the global climate change process, is extremely important in terms of determining the measures to be taken.

Materials and method

Material

The study was conducted on the seeds with Anatolian black pine (*Pinus nigra* Arnold.) provenances collected from the Araç district of Kastamonu province.

The stand, where the cones were collected, was located in the northwest stand and was at the elevation of 630 m. The cones were collected in November 2019, and the seeds were obtained by drying the cones brought to the laboratory. Afterwards, the seeds were checked and the healthy ones were separated, and the study was carried out on those seeds.

Methodology

The seeds were first sterilized with 0.5% sodium hypochlorite for 2 min and then rinsed. Afterwards, they were kept in distilled water for 2 h, and then, 20 seeds were placed in a 9-cm diameter sterile glass petri dish. While the seeds were placed in glass petri dishes, one group was reserved for germination experiments, and the other group was reserved for seedling experiments. Later, the seeds were exposed to UV-B radiation in the radiation chamber. The radiation chamber used in the study is a room equipped with an UV-B fluorescent tube (40W/12 TL, Philips, Eindhoven, the Netherlands) that installs from 280 nm to a maximum of 312 nm (real UV-B range 280 to 320nm).

Germination experiment

The seeds reserved for germination experiment were exposed to UV-B radiation for 5, 10, 20, 30, 40, 50, and 60 min inside the glass petri dish. In order to be able to compare the study results, UV-B radiation was not applied to the control group seeds. Each application was performed in five repetitions (a total of 100 seeds including 20 seeds in petri dishes in each repetition, and for 8 treatments, a total of 800 seeds were used), according to the procedures of ISTA (2005). The seeds exposed to radiation were placed in petri dishes with Whatman no. 1 filter paper, in a way that they did not touch each other, and were moistened. The experimental design of germination for the seeds was exposed to UV-B radiation for 5, 10, 20,30,40,50, and 60 min and the control (8 treatments). The petri dishes were taken into germination cabinets, and germination experiments were made. The germination cabinets were set at an average temperature of 29.3 °C, 61.4% humidity, and 1000 lux light. With the counts made each day, the seeds, which gave rootlets at least as

long as the seed size, were considered germinated, taken from petri dishes and recorded. At the end of 35 days, the study was terminated, and the seeds, which were not germinated, were cut with a scalpel and checked whether they were filled or not. The germination speed (GS) was calculated as the ratio of the germinated seeds to the solid seeds at the end of the 7th day, whereas the germination percentage (GP) was calculated as the ratio of the germinated seeds to the solid seeds at the end of the 35th day. At the beginning of the study, the seeds were checked visually and healthy seeds were selected. At the end of the germination trials, it was decided that non-germinating seeds were cut with the help of nester and the non-full seeds were not included in the calculations. However, in the evaluation, it was determined that all the seeds were full.

Seedling experiments

The seeds reserved for seedling experiment were exposed to UV-B radiation for 1, 3, 5, and 7 h. In order to be able to compare the study results, UV-B radiation was not applied to the control group seeds. Each application was performed in a total of 450 seeds, which were used for 5 treatments and 3 replications and each replication being thirty seeds. The study was conducted using a randomized plot trial design. The seeds were then placed in 2 × 2 × 12-cm polyethylene tubes filled with germination peat and were moistened by covering them with 1–2 mm thick peat. The tubes were placed in germination cabinets set at 29.3 °C temperature, 61.4% humidity, and 1000 lux light, and the seedlings were observed for 45 days. At the end of 45 days, the seedlings were carefully removed, and the seedling length (SL), the terminal bud length (TBL), the branch number (BN), and the root collar diameter (RCD) were determined, and then, the seedlings were cut from the root collar. The stem fresh weight (SFW) and the root fresh weight (RFW) were measured in the cut seedlings. Afterwards, the seedlings were dried at 105 ± 2 °C for 24 h, and the stem dry weight (SDW) and the root dry weight (RDW) were measured. The rooting percentage (RP) was calculated as the ratio of the number of healthy capillary roots to the number of all roots as a result of the counts made at the end of the 7th day. (During the

seedling experiments stage, there were no seeds that did not germinate, all seeds were germinated.)

Statistical analyses

The data obtained as a result of the study were evaluated with the help of the SPSS package program, the variance analysis was applied to the data, and in the case of a significant difference at $p < 0.05$ level, the homogeneous groups were formed by applying Duncan test, and the results were interpreted. The mean values of the variable were compared with the Duncan test for the germination experiment and the Tukey test for the seedling experiment. As the recorded data are in percentage, it is important to transform them accordingly before performing the variance analysis. The GS was calculated as the ratio of the germinated seeds to the solid seeds at the end of the 7th day, whereas the GP was calculated as the ratio of the germinated seeds to the solid seeds at the end of the 35th day.

Results

As a result of the germination experiments performed within the scope of the study, the effects of the applications on the GS and GP values were statistically evaluated, and the results obtained are given in Table 1.

Table 1 Changes of germination values on the basis of applications

Application time	(%) GS	(%) GP
Control	39.10a	97.30a
5 min	31.60b	94.80a
10 min	28.30c	91.10ab
20 min	25.80c	86.53bc
30 min	22.17d	79.47cd
40 min	18.93e	74.77d
50 min	16.33e	66.23e
60 min	11.33f	47.20f
St. deviation	7,62	5,53
F value	81.617***	44.024***

***significant at 0.001 level. The letters a, b, c, etc. means according to Duncan test results; show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a, the numerical value grows. Means within each column followed by the same letter are not significantly different ($p < 0.05$)

As can be seen from the results in Table 1, the effect of UV-B applications on GS and GP values is statistically significant ($p < 0.001$). It is seen that GS and GP values decrease as the application time increases. While the effect of UV-B applications on GS values stands out even after 5 min of application, the effect on GP value starts to stand out after 20 min of application. The proportional calculations made by accepting the values obtained in the control group as 100% in order to ease the interpretation of the data are given in Table 2.

When Table 2 is examined, the effects of UV-B applications on GS values are seen to be more severe than the effects on GP values. After 10 min of application, GP values decreased down to 93.63% of the control application, while this value decreased down to 72.38% in GS. As a result of the 60-min application, which was the most severe application, the GP value decreased down to 48.51% of the control group, while GS value decreased down to 28.98% of the control application. The graph created to evaluate the proportional change of GS and GP values relative to the control is given in Fig. 1.

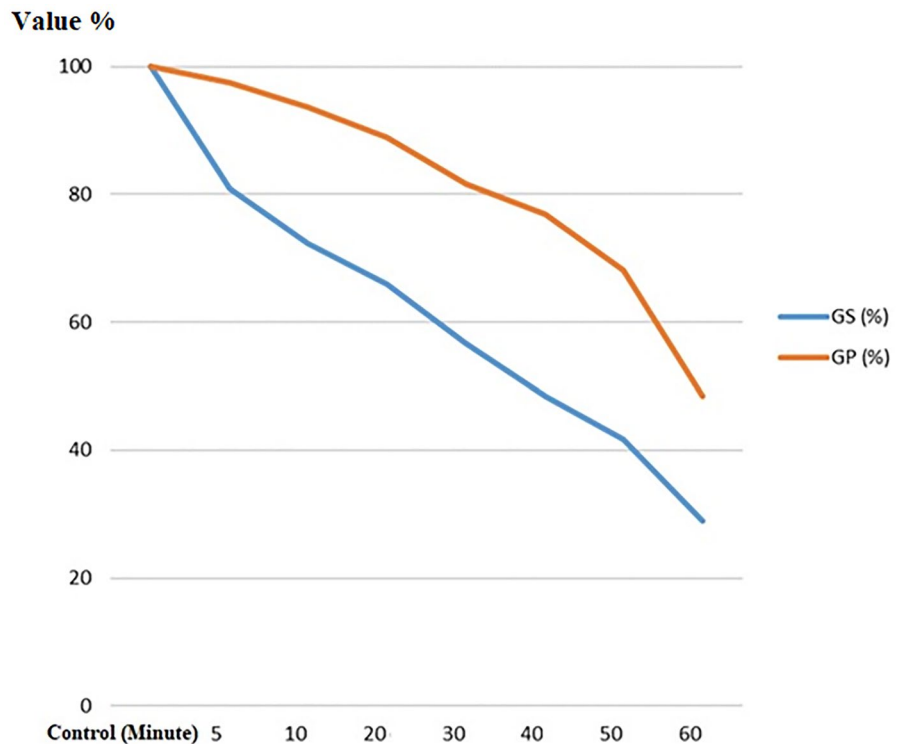
The changes of seedling characters considered within the scope of the study on the basis of applications were evaluated statistically, and the results are given in Table 3.

Table 2 Proportional changes of germination values to the control

Application time	(%) GS	(%) GP
Control	100.00a	100.00a
5 min	80.86b	97.43a
10 min	72.33c	93.60ab
20 min	66.0d	88.90b
30 min	56.66e	81.63c
40 min	48.43f	76.83c
50 min	41.80g	68.03d
60 min	29.00g	48.50e
F value	533.706**	59.591***

***significant at 0.001 level. The letters a, b, c, etc. means according to Duncan test results; show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a, the numerical value grows. Means within each column followed by the same letter are not significantly different ($p < 0.05$)

Fig. 1 The proportional change of GS and GP values relative to the control group



When Table 3 is examined, it is seen that all the seedling characters subjected to the study are affected by the applications, and that there is a decline in seedling development. When the Duncan

test results are examined, it is seen that the effects in RP took effect after 5 h of UV-B applications, and SL and SFW characters took effect after 3 h of UV-B applications, while the values obtained as

Table 3 Changes of seedling characters on the basis of applications

Characters	UV-B application time					F value
	Control	1 h	3 h	5 h	7 h	
RP (%) The rooting percentage	27.80a	26.54a	23.82a	18.35b	13.66c	16.011***
TBL (mm) The terminal bud length	24.45a	19.55b	16.85bc	14.59cd	11.30d	18.183***
BN (number) The branch number	4.63a	3.85b	2.54c	1.92cd	1.36d	44.835***
SDW (g) The stem dry weight	6.97a	5.45b	3.73c	2.50d	1.35e	59.286***
RDW (g) Root dry weight	3.46a	2.98b	1.86c	0.87d	0.63d	71.803***
SL (cm) The seedling length	15.89a	13.66a	10.50b	7.41c	4.26d	41.074***
RCD (mm) The root collar diameter	6.76a	4.94b	2.57c	2.19cd	1.43d	68.361***
RFW (g) The root fresh weight	5.86a	4.74b	3.57c	2.80c	1.94d	34.489***
SFW (g) The stem fresh weight	8.67a	7.51a	5.23b	4.38b	2.46c	38.986***

***significant at 0.001 level. The letters a, b, c, etc. means according to Duncan test results; show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a, the numerical value grows. Means within each column followed by the same letter are not significantly different ($p < 0.05$)

Table 4 Proportional changes of the seedling characters relative to the control group

Characters	UV-B application time					F value
	Control	1 h	3 h	5 h	7 h	
RP (%) The rooting percentage	100a	95.5b	85.7c	66.0d	49.1e	22,695,105***
TBL (mm) The terminal bud length	100a	80.0 ^b	68.9c	59.7d	46.2e	12,505,465***
BN (number) The branch number	100a	83.2b	54.9c	41.5d	29.4e	848,490***
SDW (g) The stem dry weight	100a	78.2b	53.5c	35.9d	19.4e	1,816,600***
RDW (g) Root dry weight	100a	86.1b	53.8c	25.1d	18.2e	558,876***
SL (cm) The seedling length	100a	86.0b	66.1c	46.6d	26.8e	8,108,749***
RCD (mm) The root collar diameter	100a	73.1b	38.0c	32.4d	21.2e	2,712,119***
RFW (g) The root fresh weight	100a	80.9b	60.9c	47.8d	33.1e	1,841,627***
SFW (g) The stem fresh weight	100a	86.6b	60.3c	50.5d	28.4e	2,760,988***

***significant at 0.001 level. The letters a, b, c, etc. means according to Duncan test results; show that the group is located. It is statistically different from the values contained in different groups, starting with the letter a, the numerical value grows. Means within each column followed by the same letter are not significantly different ($p < 0.05$)

a result of 1 h applications in other characters are in homogeneous groups that are different from the control group according to the Duncan test. In order to be able to evaluate the effects of applications on characters more easily, the proportional changes were calculated by proportioning the value changes as a result of the applications to the control group, and the results are given in Table 4.

Considering the effects of UV-B applications on the characters, it is seen that the least affected character is RP, and the most affected characters are RDW, SDW, and RCD. While it is seen that even 1 h of UV-B application, which has the lowest intensity, takes effect in most of the characters, as a result of the 7-h application, the development of seedlings decreased by more than 80% in terms of some characters. Even the decrease in the RP character, which is the least affected character from the 7-h UV-B application, is above 50%. The graphic created in order to evaluate the proportional change of seedling characters relative to control is given in Fig. 2.

Discussions

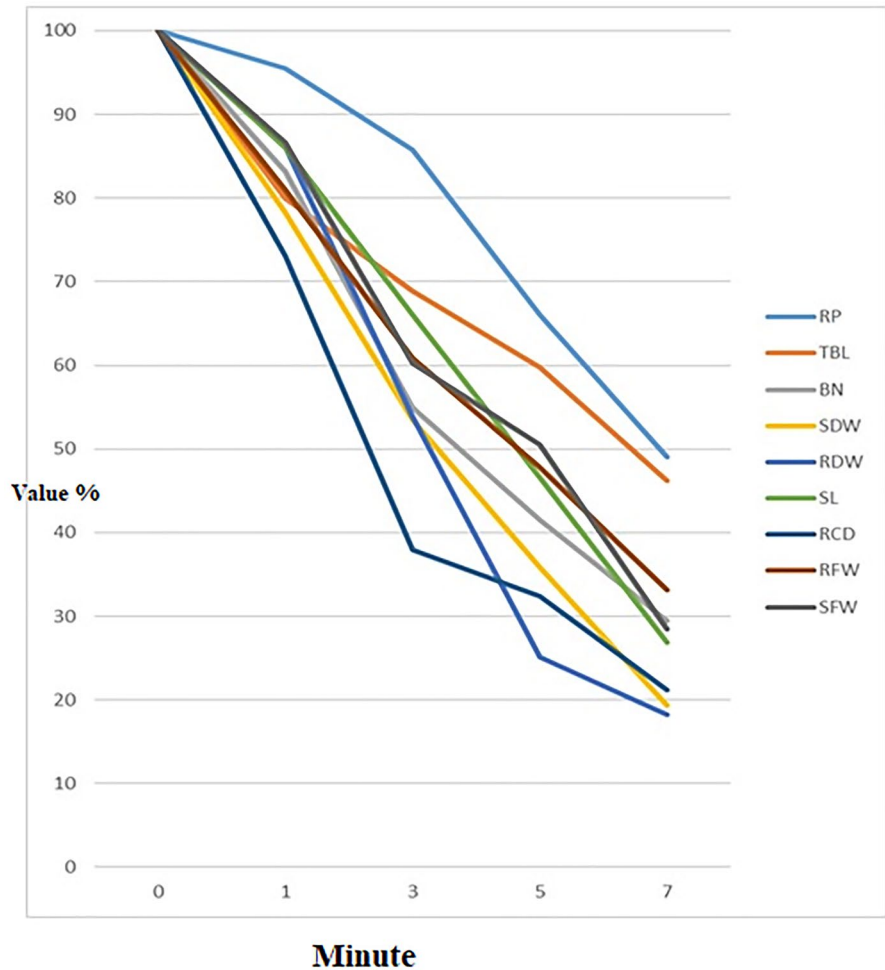
As a result of the study, it was found that both germination values (GS and GP) and seedlings characters were dramatically affected by UV-B application, and that as UV-B application time increased, both

germination values and seedling characters were affected negatively. Similar results were obtained in various studies conducted on this subject. In studies aiming to identify the effects of UV-B radiation on plant growth and development, it was found that increased UV-B radiation caused loss of diameter, height, number of leaves, biomass (Liu et al., 2016; Fu & Shen, 2017; Skórska et al., 2019), and even plant phenology (Stromme et al., 2019) in plants.

It is reported that being exposed to UV-B radiation may damage DNA, proteins, cell membranes, chloroplasts, and associated pigment system (Shaukat et al., 2013), may suppress the absorption of nutrients and water that affect photosynthesis and growth of above-ground parts (Wang et al., 2013; Yu et al., 2014), and may affect morphological, biochemical, and cytological parameters (Kumar & Bhardwaj, 2019).

Studies carried out on different species reveal that the responses of species to increased UV-B radiation can be at different levels (Li et al., 2010; Newsham & Robinson, 2009). This situation may be related to plant metabolism and habitus, primarily. The studies conducted show that plant size and leaf thickness affect the amount of UV-B radiation exposed in nature, which then causes the effect of radiation on the plants to differ (Liu et al., 2011; Fu & Shen, 2017). Studies conducted on this subject show that the responses of plant species to different stress levels

Fig. 2 The proportional change of seedling characters relative to the control group



vary to a considerable extent, and this may be related to plant morphological characteristics such as plant sizes, leaf surface, and leaf thickness (Turkyilmaz et al., 2018; Aricak et al., 2019; Sevik et al., 2020). Therefore, it is inevitable for the form and severity of being affected by UV-B radiation to be related to plant morphological characteristics and habitus. This is related to the stress-protective mechanisms of the plant as well (Kozłowska et al., 2007; Ravindran et al., 2008).

Studies conducted on the subject also reveal that the effect of UV-B radiation on plants varies significantly depending on environmental conditions. As Watermann et al. (2020) state that the effects of UV-B radiation vary depending on altitude, Fu and Shen (2017) state that UV-B radiation has different effects on grasslands and forests, that the effect of UV-B radiation on alpine plants varies according to ecosystem

types, and that the climatic conditions are a determining factor in the effects of UV-B radiation on alpine plants. In numerous studies conducted on this subject, it is reported that the climatic conditions are determinant in terms of the response of plants to stress levels (Turkyilmaz et al., 2019; Ozel et al., 2020) as well as the plant morphological, anatomical, and physiological characteristics (Cetin et al., 2018a, b).

As well as fulfilling a wide range of ecological, economic, and social functions (Yucedag et al., 2019; Ertugrul et al., 2019), plants are the source of life, and all living things in the world are directly or indirectly dependent on plants (Sevik et al., 2020). The fact that plants are the sources of food makes the studies on all kinds of factors affecting the health and development of plants valuable. For this reason, the effects of UV-B radiation on plants should be investigated from many different aspects. It should not be ignored

that UV-B radiation may also have positive effects on plants. For instance, despite the fact that UV-B radiation damages plant tissues, it is determined that it can also promote the accumulation of antioxidant and UV protective molecules in some plants used as food (He et al., 2019). It is also stated that UV-B may have positive effects on total isoflavone accumulation (Jiao et al., 2015; Ma et al., 2019).

Studies conducted show that UV-B radiation significantly affects plants' morphological characteristics as well as the invisible micro-morphological characteristics (Zhao et al., 2019). Micro-morphological characteristics are an important indicator of the plants' responses to stress factors (Yigit et al., 2016; Sevik et al., 2019a). However, the studies on the effect of UV-B radiation on plant micro-morphological characteristics are limited. In order to reveal the effects of UV-B radiation on plants clearly, it is necessary to study the effects of increasing radiation level on plant chemical structure as well as plant micro-morphological characteristics. In the studies conducted, it is stated that the PAL activity increases in response to UV-B stress, and the increase in PAL activity is a sign of plant tissue exposed to stress (heavy metals, disease, injury, heat shock, UV-B radiation, etc.) (Chmielowski et al., 2008; Fu & Shen, 2017).

It is stated that UV-B radiation also affects the germination and seedling characteristics of pine species. Kondrateva et al. (2019) It has been determined that UV radiation increases the germination rate of *Picea fenica* seeds from 75 to 86%, thus reducing planting rates and subsequent planting costs. In the same study, after exposure to UV dosage of 2 kJ/m², *Thuja occidentalis* seeds were found to have a 12.8% better germination rate, resulting in faster growth and earlier full-growing shoots. It is stated that seedlings exposed to UV rays in some species exhibit increased growth due to stimulation of gibberellin synthesis as well as ethylene. It is stated that ethylene synthesized in seedlings exposed to UV-B rays regulates many development processes of the plant life cycle, including responses to biotic and abiotic stresses such as seed germination, flower development, aging, drought, and injury (Olsen & Dineva, 2017). However, it is stated that UV-B radiation does not have a positive effect on the germination of *Pinus sylvestris* seeds (Kondrateva et al., 2019).

In pine species, it is stated that UV-B radiation generally affects plant growth negatively. Stefi et al. (2017a, 2017b) stated that *Pinus halepensis* seedlings

exposed to UV-B rays had losses up to 25% in fresh stem weight, 40% in stem biomass, 40% in root fresh weight, and 50% in root biomass. Similar results were obtained in plants such as *Vigna radiata* (Sharma et al., 2009), *Arabidopsis thaliana* (Stefi et al., 2016), and *Zea mays* (Stefi et al., 2017a, b). It is also stated that UV-B radiation affects flower size and number (Van de Staaij et al., 1997; Barbir et al., 2014), such as direct or indirect exposure to radiation, plant stress, and vegetative tissue, as well as the structure and number of blooms and flowers. It is emphasized that it is effective on plant morphology (Ballare et al., 2011; Llorens et al., 2015; Ozel et al., 2021).

UV-B radiation is an important stress-causing factor in plants (Yan et al., 2016). The responses of plants to stress factors are mainly shaped by the interaction of various factors such as environmental factors, plant genetic structure, plant metabolism, and stress level (Sevik et al., 2019b; Cetin et al., 2020; Aricak et al., 2020). However, the number of studies conducted on these subjects is also very limited. For this reason, it is recommended to diversify and increase the number of studies on this subject.

Conclusions

The study results reveal that the increased exposure time to UV-B radiation significantly and negatively affects the morphological characteristics of both germination and seedlings in Anatolian black pine. This situation can be interpreted as a great risk for forests especially when considered in terms of the potential effects of ozone layer degradation as well as global climate change. For this reason, the studies on the subject should be extended, the subjects of how possible changes can affect the levels of UV-B radiation and the reactions of the forests at these levels should be investigated, and strategies should be developed against risks. For instance, it can be suggested to identify the tree species to be least affected by these negativities and to use those species in afforestation studies and similarly to identify the most durable population and individuals and to use the seeds of those populations and individuals seeds in sapling production.

In the studies conducted, it is revealed that even though the UV-B radiation is a stress-causing factor in plants, it may also have positive effects. Especially with studies on plants consumed as food, the effects

of UV-B should be investigated in terms of subjects such as the production of genotypes that will least suffer from the effects from global climate change; the development of plants' antioxidant, antimicrobial, antifungal, etc.; contents; and development of individuals resistant to other stress factors.

Author contribution Halil, Adel, Hakan, and Ilknur designed the study and performed the experiments; Hakan, Ilknur, and Mehmet performed the experiments, analyzed the data, and wrote the manuscript.

Data availability All data are given in manuscript.

Declarations

Conflict of interest The authors declare no competing interests.

References

Aricak, B., Cetin, M., Erdem, R., Sevik, H., & Cometen, H. (2019). The change of some heavy metal concentrations in Scotch pine (*Pinus sylvestris*) depending on traffic density, organelle and washing. *Applied Ecology and Environmental Research*, 17(3), 6723–6734. http://www.aloki.hu/pdf/1703_67236734.pdf

Aricak, B., Cetin, M., Erdem, R., Sevik, H., & Cometen, H. (2020). The usability of Scotch pine (*Pinus sylvestris*) as a biomonitor for traffic-originated heavy metal concentrations in Turkey. *Polish Journal of Environmental Studies*, 29(2), 1051–1057.

Ballare, C. L., Caldwell, M. M., Flint, S. D., Robinson, S. A., & Bornman, J. F. (2011). Effects of solar ultraviolet radiation on terrestrial ecosystems. *Patterns, Mechanisms, and Interactions with Climate Change. Photochemical & Photobiological Sciences*, 10, 226–241. <https://doi.org/10.1039/c0pp90035d>

Barbir, J., Dorado, J., Fernandez-Quintanilla, C., Blanusa, T., Maksimovic, C., & Badenes-Perez, F. R. (2014). Wild rocket-effect of water deficit on growth, flowering, and attractiveness to pollinators. *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science*, 64, 482–492. <https://doi.org/10.1080/09064710.2014.925575>

Batr, D. (2019). Heavy metal accumulation in some edible landscape plants breeding in Eskişehir. Kastamonu University Graduate School of Natural and Applied Sciences Department of Landscape Architecture, MSc Thesis, Kastamonu, Turkey.

Benca, J. P., Duijnste, I. A., & Looy, C. V. (2018). UV-B–induced forest sterility: Implications of ozone shield failure in Earth's largest extinction. *Science Advances*, 4(2), e1700618.

Bondarenko, S. L., & Savchuk, D. A. (2018). Response of conifers to UV-B and climate in mountain areas. *Global Journal of Environmental Science and Management*, 4(3), 299–314.

Bornman, J. F., Barnes, P. W., Robson, T. M., Robinson, S. A., Jansen, M. A., Ballaré, C. L., & Flint, S. D. (2019). Linkages between stratospheric ozone, UV radiation and climate change and their implications for terrestrial ecosystems. *Photochemical & Photobiological Sciences*, 18(3), 681–716.

Cetin, M., Sevik, H., & Yigit, N. (2018a). Climate type-related changes in the leaf micromorphological characters of certain landscape plants. *Environmental Monitoring and Assessment*, 190(7), 404. <https://link.springer.com/article/https://doi.org/10.1007/s10661-018-6783-3>

Cetin, M., Sevik, H., Yigit, N., Ozel, H. B., Aricak, B., & Varol, T. (2018b). The variable of leaf micromorphological characters on grown in distinct climate conditions in some landscape plants. *Fresenius Environmental Bulletin*, 27(5), 3206–3211.

Cetin, M., Sevik, H., & Cobanoglu, O. (2020). Ca, Cu, and Li in washed and unwashed specimens of needles, bark, and branches of the blue spruce (*Picea pungens*) in the city of Ankara. *Environmental Science and Pollution Research*, 27, 21816–21825. <https://link.springer.com/article/https://doi.org/10.1007/s11356-020-08687-3>

Chmielowski, J., Deckert, J., & Diaz, J. (2008). Activity of peroxidase and phenylalanine lyase in lupine and soybean seedlings treated with copper and an ethylene inhibitor. *Biology Letters*, 45, 59–67.

Dassot, M., & Collet, C. (2020). Effects of different site preparation methods on the root development of planted *Quercus petraea* and *Pinus nigra*. *New Forests*, 1–14.

Ertugrul, M., Ozel, H. B., Varol, T., Cetin, M., & Sevik, H. (2019). Investigation of the relationship between burned areas and climate factors in large forest fires in the Canakkale region. *Environmental Monitoring and Assessment*, 191(12), 737. <https://link.springer.com/article/https://doi.org/10.1007/s10661-019-7946-6>

Fagarazzi, C., Marone, E., Giovannini, M. R. M., Riccioli, F., De Meo, I., Paletto, A., & Fratini, R. (2020). Thinning in black pine (*Pinus nigra* JF Arnold) forests: the economic sustainability of the wood-energy supply chain in a case study in Italy. *Annals of Silvicultural Research*, 46(1).

Fu, G., & Shen, Z. X. (2017). Effects of enhanced UV-B radiation on plant physiology and growth on the Tibetan Plateau: A meta-analysis. *Acta Physiologiae Plantarum*, 39(3), 85. <https://link.springer.com/article/10.1007%2Fs11738-017-2387-8>

Gwynn-Jones D. (2001) Short-term impacts of enhanced UV-B radiation on photo-assimilate allocation and metabolism: A possible interpretation for time-dependent inhibition of growth. In: Rozema J., Manetas Y., Björn LO. (eds) Responses of Plants to UV-B Radiation. Advances in Vegetation Science, vol 18. Springer, Dordrecht. https://doi.org/10.1007/978-94-017-2892-8_7

He, W., Wang, Y., Dai, Z., Liu, C., Xiao, Y., Wei, Q., Song, J., & Li, D. (2019). Effect of UV-B radiation and a supplement of CaCl2 on carotenoid biosynthesis in germinated corn kernels. *Food chemistry*, 278, 509–514. <https://www.sciencedirect.com/science/article/abs/pii/S0308814618320351>

ISTA. (2005). The International Rules for Seed Testing (ISTA Rules). Handbook of Method Validation. ISTA, Bassersdorf, Switzerland.

Jiao, J., Gai, Q. Y., Wang, W., Luo, M., Gu, C. B., Fu, Y. J., & Ma, W. (2015). Ultraviolet radiation-elicited enhancement

- of isoflavonoid accumulation, biosynthetic gene expression, and antioxidant activity in *Astragalus membranaceus* hairy root cultures. *Journal of Agricultural and Food Chemistry*, 63(37), 8216–8224. <https://pubs.acs.org/doi/abs/https://doi.org/10.1021/acs.jafc.5b03138>
- Kataria, S., Jajoo, A., & Guruprasad, K. N. (2015). Impact of increasing Ultraviolet-B (UV-B) radiation on photosynthetic processes. *Journal of Photochemistry and Photobiology B: Biology*, 137, 55–66.
- Kondrateva, N. P., Krasnolutskaia, M. G., Dukhtanova, N. V., & Obolensky, N. V. (2019). Effect of ultraviolet radiation the germination rate of tree seeds. In *IOP Conference Series: Earth and Environmental Science*, 226(1), 012049. IOP Publishing.
- Kobzar, E.F., Kreslavsk V.D., & Muzafarov. E.N. (1998). Photomorphogenic responses to UV-radiation and short-term red light in lettuce seedlings. *Plant Growth Regulation*, 26, 73–76. <https://link.springer.com/article/https://doi.org/10.1023/A:1006047327094>
- Kozłowska, M., Brezezińska, E., & Stobiecki, M. (2007). Sensitivity and accumulation of screening compounds in three conifer plants under enhanced UV-B radiation. *Polish Journal of Environmental Studies*, 16, 823–830. <http://www.pjoes.com/Sensitivity-Differences-and-Accumulation-of-r-nScreening-Compounds-in-Three-Conifer,88054,0,2.html>
- Kumar, G., & Bhardwaj, M. (2019). Induced genetic variations in *Cuminum cyminum* through supplemental UV-B radiation. *Journal of Environmental Biology*, 40(3), 342–348.
- Li, F. R., Peng, S. L., Chen, B. M., & Hou, Y. P. (2010). A meta-analysis of the responses of woody and herbaceous plants to elevated ultraviolet-B radiation. *Acta Oecologica*, 36(1), 1–9. <https://doi.org/10.1016/j.actao.2009.09.002>
- Liu, Q., Yao, X. Q., Zhao, C. Z., & Cheng, X. Y. (2011). Effects of enhanced UVB radiation on growth and photosynthetic responses of four species of seedlings in sub-alpine forests of the eastern Tibet plateau. *Environmental and Experimental Botany*, 74, 151–156. <https://doi.org/10.1016/j.envexpbot.2011.05.013>
- Liu, X. B., Qi, Y., & Chin, K. L. (2016). Growth and development responses to UV-B exclusion in crops. *International Journal of Plant Production (IJPP)*, 10(4), 543–550.
- Llorens, L., Badenes-Perez, F. R., Julkunen-Tiitto, R., Zidorn, C., Fereres, A., & Jansen, M. A. (2015). The role of UV-B radiation in plant sexual reproduction. *Perspectives in Plant Ecology, Evolution and Systematics*, 17, 243–254. <https://doi.org/10.1016/j.ppees.2015.03.001>
- Ma, M., Wang, P., Yang, R., Zhou, T., & Gu, Z. (2019). UV-B mediates isoflavone accumulation and oxidative-antioxidant system responses in germinating soybean. *Food Chemistry*, 275, 628–636. <https://www.sciencedirect.com/science/article/abs/pii/S0308814618317369>
- Newsham, K. K., & Robinson, S. A. (2009). Responses of plants in polar regions to UVB exposure: A meta-analysis. *Global Change Biology*, 15, 2574–2589. <https://doi.org/10.1111/j.1365-2486.2009.01944.x>
- Olsen, J. E., & Dineva, S. B. (2017). Effects of chronic ionizing radiation and interactions with other environmental and climatic factors on plant growth and development. *eJournal of Applied Forest Ecology (eJAFE)* 5(1), 31–53.
- Ozel, H. B., Donduran, B., Cakmakli, E., & Sevik, H. (2020). Factors affecting success in natural regeneration works of cedar (*Cedrus libani* A. Rich.) In Kas region of Antalya. *World Journal of Advanced Research and Reviews*, 6(2), 054–059.
- Ozel, H. B., Cetin, M., Sevik, H., Varol, T., Isik, B., & Yaman, B. (2021). The effects of base station as an electromagnetic radiation source on flower and cone yield and germination percentage in *Pinus brutia* Ten. *Biologia Futura*. <https://doi.org/10.1007/s42977-021-00085-1>
- Passaglia, A., da Silva, R., Moreno, K., Jorge, N., & Martins, C. F. (2009). Development of a DNA-dosimeter system for monitoring the effects of solar-ultraviolet radiation. *Photochemical & Photobiological Sciences*, 8, 111–120.
- Ravindran, K. C., Indrajith, A., Balkrishnan, V., Venkatesan K., & Kulandaivelu, G. (2008). Determination of defense mechanism in *Phaseolus trilobus* Ait.: Seedlings treated under UV-B radiation. *African Crop Science Journal*, 16(2), 111–118.
- Santos, D. Y., Ferreira, M. J., Matos, T. M., Sala-Carvalho, W. R., Anselmo-Moreira, F., Roma, L. P., ... & Furlan, C. M. (2021). UV-B and drought stress influenced growth and cellular compounds of two cultivars of *Phaseolus vulgaris* L.(Fabaceae). *Photochemistry and Photobiology*, 97(1), 166–179.
- Sevik, H., Ozel, H. B., Cetin, M., Özel, H. U., & Erdem, T. (2019a). Determination of changes in heavy metal accumulation depending on plant species, plant organism, and traffic density in some landscape plants. *Air Quality, Atmosphere & Health*, 12(2), 189–195. <https://link.springer.com/article/https://doi.org/10.1007/s11869-018-0641-x>
- Sevik, H., Cetin, M., Ozel, H. B., & Pinar, B. (2019b). Determining toxic metal concentration changes in landscaping plants based on some factors. *Air Quality, Atmosphere & Health*, 12(8), 983–991. <https://link.springer.com/article/https://doi.org/10.1007/s11869-019-00717-5>
- Sevik, H., Cetin, M., Ozel, H. B., Ozel, S., & Zeren Cetin, I. (2020). Changes in heavy metal accumulation in some edible landscape plants depending on traffic density. *Environmental Monitoring and Assessment*, 192(2), 78. <https://link.springer.com/article/https://doi.org/10.1007/s10661-019-8041-8>
- Shaukat, S. S., Farooq, M. A., Siddiqui, M. F., & Zaidi, S. (2013). Effect of enhanced UV-B radiation on germination, seedling growth and biochemical responses of *Vigna mungo* (L.) Hepper. *Pakistan Journal of Botany*, 45(3), 779–785.
- Sharma, V. P., Singh, H. P., Kohli, R. K., & Batish, D. R. (2009). Mobile phone radiation inhibits *Vigna radiata* (mung bean) root growth by inducing oxidative stress. *Science of the Total Environment*, 407, 5543–5547.
- Skórska, E., Matuszak-Slamani, R., Romanowski, H., & Szwarz, W. (2019). Impact of a longwave UV-B radiation on soybean plants grown at increased nickel concentration in soil. *Journal of Ecological Engineering*, 20(5)
- Stefi, A. L., Margaritis, L. H., & Christodoulakis, N. S. (2017a). The aftermath of long-term exposure to non-ionizing radiation on laboratory cultivated pine plants (*Pinus halepensis* M.). *Flora*, 234, 173–186.
- Stefi, A. L., Margaritis, L. H., & Christodoulakis, N. S. (2016). The effect of the non-ionizing radiation on cultivated plants of *Arabidopsis thaliana* (Col.). *Flora*, 223, 114–120.

- Stefi, A. L., Margaritis, L. H., & Christodoulakis, N. S. (2017b). The effect of the non-ionizing radiation on exposed, laboratory cultivated maize (*Zea mays* L.) plants. *Flora*, 233, 22–30. <https://doi.org/10.1016/j.flora.2017.05.008>
- Stromme, C., Sivadasan, U., Nissinen, K., Lavola, A., Randriamanana, T., Julkunen-Tiitto, R., & Nybakken, L. (2019). Interannual variation in UV-B and temperature effects on bud phenology and growth in *Populus tremula*. *Plant Physiology and Biochemistry*, 134, 31–39. <https://www.sciencedirect.com/science/article/abs/pii/S0981942818303863>
- Topacoglu, O., Sevik, H., & Akkuzu, E. (2016). Effects of water stress on germination of *Pinus nigra* Arnold. *Seeds Pakistan Journal of Botany*, 48(2), 447–453.
- Turkyilmaz, A., Sevik, H., Isinkaralar, K., & Cetin, M. (2018). Using *Acer platanoides* annual rings to monitor the amount of heavy metals accumulated in air. *Environmental Monitoring and Assessment*, 190(10), 578. <https://link.springer.com/article/> <https://doi.org/10.1007/s10661-018-6956-0>
- Turkyilmaz, A., Sevik, H., Isinkaralar, K., & Cetin, M. (2019). Use of tree rings as a bioindicator to observe atmospheric heavy metal deposition. *Environmental Science and Pollution Research*, 26(5), 5122–5130. <https://link.springer.com/article/> <https://doi.org/10.1007/s11356-018-3962-2>
- Van de Staaij, J. W. M., Bolink, E., Rozema, J., & Ernst, W. H. O. (1997). The impact of elevated UV-B (280–320 nm) radiation levels on the reproduction biology of a highland and a lowland population of *Silene vulgaris*. *Plant Ecology*, 128, 173–179. https://doi.org/10.1007/978-94-011-5718-6_16
- Varol, T., Canturk, U., Cetin, M., Ozel, H. B., Sevik, H. (2021). Impacts of climate change scenarios on European ash tree (*Fraxinus excelsior* L.) in Turkey. *Forest Ecology and Management. Forest Ecology and Management* 491 (2021) 119199. <https://doi.org/10.1016/j.foreco.2021.119199>
- Wang, Z., Luo, T. X., Li, R. C., Tang, Y. H., & Du, M. Y. (2013). Causes for the unimodal pattern of biomass and productivity in alpine grasslands along a large altitudinal gradient in semi-arid regions. *Journal of Vegetable Science*, 24, 189–201. <https://doi.org/10.1111/j.1654-1103.2012.01442.x>
- Watermann, L. Y., Hock, M., Blake, C., & Erfmeier, A. (2020). Plant invasion into high elevations implies adaptation to high UV-B environments: a multi-species experiment. *Biological Invasions*, 22(3), 1203–1218. <https://link.springer.com/article/> <https://doi.org/10.1007/s10530-019-02173-9>
- Worldometers. (2020). World population. Retrieved June 7, 2020, from <https://www.worldometers.info/>
- Yan, F., Liu, Y., Sheng, H., Wang, Y., Kang, H., & Zeng, J. (2016). Salicylic acid and nitric oxide increase photosynthesis and antioxidant defense in wheat under UV-B stress. *Biologia Plantarum*, 60(4), 686–694. <https://link.springer.com/article/10.1007%2Fs10535-016-0622-6>
- Yigit, N., Sevik, H., Cetin, M., & Gul, L. (2016). Clonal variation in chemical wood characteristics in Hanönü (Kastamonu) Günlüburun black pine (*Pinus nigra* Arnold. subsp. *Pallasiana* (Lamb.) Holmboe) seed orchard. *Journal of Sustainable Forestry*, 35(7), 515–526. <https://www.tandfonline.com/doi/abs/> <https://doi.org/10.1080/10549811.2016.1225512>
- Yucedag, C., Ozel, H. B., Cetin, M., & Sevik, H. (2019). Variability in morphological traits of seedlings from five *Euonymus japonicus* cultivars. *Environmental Monitoring and Assessment*, 191(5), 285. <https://link.springer.com/article/> <https://doi.org/10.1007/s10661-019-7464-6>
- Yu, C. Q., Shen, Z. X., Zhang, X. Z., Sun, W., & Fu, G. (2014). Response of soil C and N, dissolved organic C and N, and inorganic N to short-term experimental warming in an Alpine meadow on the Tibetan Plateau. *Science World Journal*, 1–10. <https://doi.org/10.1155/2014/152576>
- Zhao, Y., Cheng, P., Li, T., Ma, J., Zhang, Y., & Wang, H. (2019). Investigation of urediospore morphology, histopathology and epidemiological components on wheat plants infected with UV-B-induced mutant strains of *Puccinia striiformis* f. sp. *tritici*. *Microbiology Open*, 8(10), e870. <https://onlinelibrary.wiley.com/doi/full/> <https://doi.org/10.1002/mbo3.870>

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