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Research Article

APPLICATION OF LOW-ENERGY X-RAYS TO STIMULATE MOSS APPLIED IN ENVIRONMENTAL MONITORING

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ABSTRACT

Low-dose radiation stimulates plant growth, particularly in mosses, enhancing their ability to absorb airborne elements using the moss bag technique. An experiment was conducted to investigate the effects of low-energy X-ray radiation (1-20 Gy, with a 1 Gy interval) on the growth of Babular indica moss. The results revealed that doses ranging from 2 Gy to 16 Gy improved moss growth compared to the non-irradiated control. The optimum stimulatory effect was observed at 14 Gy, as morphological characteristics, moss weight, and chlorophyll content indicated. Consequently, 14 Gy was selected as the irradiation dose for moss in the monitoring environment. Analysis of element concentrations using Total Reflection X-ray Fluorescence (TXRF) demonstrated that the irradiated moss exhibited significantly improved element absorption compared to the non-irradiated moss, although still lower than that of natural moss. This study emphasises that low-dose (14 Gy) radiation treatment of mosses holds promise for achieving more accurate results and a closer reflection of real air conditions in environmental monitoring using the moss bag technique.

Keywords: Environmental monitoring; irradiated moss; non-irradiated moss; low-energy X-ray; moss bag; natural moss

1. Introduction

The moss bag technique has been used for the past half-century and has become the most common type of active biomonitoring method utilising mosses to monitor air quality. Numerous previous publications have reported on this technique. In 1969, mosses were

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considered indicators of the environment (Rühling, 1969). After that, using moss material from *Hypnum cupressifolium* species for air quality monitoring was originally introduced by Goodman and Roberts (Goodman & Roberts, 1971), and since then, it has been continuously improved and developed. The moss bag technique is one such modification that involves exposing moss samples to absorb contaminants from the air. This technique has become a useful tool for biological monitoring of components caused by atmospheric contamination, such as heavy metals and other elements. While native moss is more appropriate for extensive research in naturally large areas, the moss bag technique is useful for conducting detailed surveys of pollution in urban and industrial areas where moss is rarely present (Ares, 2012). The moss bag technique has the disadvantage of lower moss growth and reduced accumulation of chemical elements compared to natural moss, leading to inaccurate assessment results for air pollution. A standardized protocol was proposed by Ares (Ares, 2012) to address this limitation.

The effects of radiation on plants have been investigated around the world for various purposes, including mutation breeding, stimulation of seed germination and seedling growth, microbial inactivation, and sprouting inhibition in agricultural products (Beyaz, 2016) Gehrke (Gehrke, 1999) used ultraviolet-B radiation to simulate the conditions of ozone depletion when researching the growth and development of two moss species. Generally, the findings among these studies on plants differ considerably, with stimulation of growth at low doses and negative effects at higher doses.

Radiation at high doses can cause many negative impacts on plants were reported in previous studies, such as inhibiting plant growth and organs due to the expression of specific cell cycle and developmental genes (Fina, 2017), causing cell and plant death, or inducing mutations by DNA double-strand and single-strand breaks (Forster, 2019), the appearance of *de novo* copy number variants and insertion/deletion events and other mutations (Gregersen, 2011).

Low-dose radiation can cause stimulatory effects on plants has been reported in many previous studies. Irradiation with low doses can enhance the germination percentage of seeds, reduce the time of germination (Beyaz, 2016), and stimulate the germination of seeds stored for long periods (Marcu, 2013). Seedlings from seeds irradiated with a low dose can grow better than the control in terms of physiological parameters including number, weight, and size of organs such as weight and size of the whole seedling, root, plumule, hypocotyl, etc. (Marcu, 2013). Plants induced from low-dose irradiated materials such as bulbs, and seeds may also grow better and bloom earlier (Sax, 1955) with improved plant height, shoot number, panicle length, and seed number per panicle, and increased number of fruit and total production (Toni A, 2013).

Miller and Miller consulted the series of studies related to plant growth stimulation by exposure of seeds or plants to low doses of ionizing radiation and showed that the magnitude of the effects is usually small, being about 10% of control values (Miller & Miller, 1987). According to these authors, there had been no understanding of the mechanisms of such responses of the cellular and physical factors related to the induction of such effects yet.

To clearly explain the effects of radiation on the growth and development of the plant, detailed knowledge about the mechanisms of the processes that occur at the genetic and physiological levels, as well as their interplay is necessary because there have been a lot of studies demonstrated that radiation can affect the hormonal and antioxidant systems, the processes of biosynthesis, photosynthesis, respiration, and the genetic regulation of physiological processes in plant (Gudkov, 2019).

Mosses belong to one of three groups of non-vascular land plants (Bryophytes), and in principle, they can be affected by radiation as other plants. Accordingly, radiation at low doses may stimulate the growth of mosses, and this is the initial idea for the current study aimed to improve the absorption of chemical elements of moss used in the moss bag technique.

The criteria of the biomonitoring species have been indicated in previous studies, including being common in the area of interest, available for sampling, and tolerant of pollutants at the relevant levels (Chakraborty, 2006). In the case of the biomonitoring species mosses, the selection of the species should consider the following criteria: preference for widely distributed and pleurocarpous mosses, selected species should possess the ability to efficiently uptake contaminants from the atmosphere, and should be one of the previously used with the available related information (Goodman & Roberts, 1971). The species used in the moss bag technique are different depending on places of application in the world. Because their distribution and abundance are different, species belonging to the genera *Sphagnum*, *Hypnum*, *Pseudoscleropodium*, *Pleurozium*, *Taxithelium*, *Hylocomium*, etc. are often mentioned in related studies (Goodman & Roberts, 1971). Recently, species of *Barbula indica* have been successfully used in natural moss to investigate airborne trace element pollution in Vietnam (Nguyen, 2022). Therefore, this species was chosen as the material for the current study. Moreover, *Barbula indica* is a species that possesses a relatively wide distribution in Vietnam.

The contaminants in the air can be investigated with moss bag techniques including both inorganic and organic contaminants, but almost all previous studies focused on metals and metalloids (Goodman & Roberts, 1971). The number of chemical elements surveyed using *Barbula indica* moss has been increasing continuously, and recent studies showed that 30 elements including 22 metal elements (Le, 2020) resulted in air pollution in urban areas of Vietnam.

After exposure to absorb the contaminants in the air, the moss materials could be analyzed for the composition and concentration of chemical elements by various methods such as proton-induced X-ray emission, using Inductively coupled plasma mass spectrometry (ICP-MS), Neutron Activation Analysis (NAA), X-ray fluorescence (XRF) quantitative analysis, Electrothermal Atomic Absorption Spectrometry (AAS) and Flow Injection Mercury System (FIMS) (Castello, 2007). Every of the above methods possesses its pros and cons. In general, they have been used successfully for quantitative assessment.

To overcome the weak moss growth when applying the moss bag technique for environmental monitoring, demonstrate the stimulant effect of radiation on the growth of moss in the moss bags, and increase their ability to absorb chemical elements from the air, in the current study, a low energy X-ray source was used to irradiate the moss to investigate the effect of radiation on moss growth and determine the optimal irradiation dose for the growth of moss. The moss was treated with optimal irradiation dose and then was used as a bioindicator. The achievements from this research can be applied in environmental monitoring to increase the accuracy and practicality of the moss bag technique.

2. Materials and Methods

2.1. Moss sample preparation

In this study, *Babular indica* moss was chosen as a bioindicator for environmental monitoring in Vietnam due to the favorable conditions present. Moss samples were collected from areas with minimal pollution to reduce the background chemical element concentration. The moss was collected from the Đung K'No mountains in the Bidoup Nui Ba National Park located at latitude 12.188447^o North and latitude 108.463527^o East. This species of moss grows throughout the year due to the high humidity in the area.

After collection, the moss was treated as follows: old and broken moss branches were removed, and moss branches of approximately 1.5 cm in length were selected. Five grams of the chosen moss branches were then placed in each 16-mesh bag with a size of 7 cm × 7 cm (Figure. 1).

Figure 1. *Moss bags*

Six hundred and sixty moss bags were prepared for the experiment investigating the effects of radiation doses on moss growth, while 60 moss bags were prepared for the experiment investigating and comparing the ability to absorb chemical elements in the air. In the latter experiment, 30 moss bags were irradiated with an optimal X-ray dose, and 30 moss bags were non-irradiated. The moss branches collected from the Đung K'No mountains that met the same criteria for the experiment were kept in zip bags for chemical background concentration detection.

2.2. Irradiation process of moss sample

The X-ray generator model MBR-1618R-BE is used to irradiate moss. The generator was operated in a voltage range of 35 - 160 kV and a current range of 1 - 30 mA. The moss samples were arranged on the rotating table inside the irradiation room, at a distance of 250 mm from the source for radiation exposure (Figure 2).

In the experiment to investigate the effects of radiation doses on the moss growth, the applied X-ray doses range from 1 Gy to 20 Gy, 1 Gy-interval, at a dose rate of 0.5 Gy/min in the conditions of room temperature. In the experiment to investigate and compare the ability to absorb chemical elements, the moss bags were irradiated by an optimal X-ray dose for moss growth with the same dose rate and temperature.

a) X-ray generator sharp *b) Irradiation room* *c) Irradiation angle*

Figure 2. *MBR-1618R-BE X-ray generator and geometry irradiation*

2.3. Radiation dose effects on the moss growth

After being irradiated with the above 20 doses and 30 bags per dose, all moss bags were horizontally hung in the same natural condition (**Fig. 3**), at 2 meters from the ground together with the control sample (non-irradiated moss sample).

Figure 3. *Moss bags during exposure*

After 30-day exposure, the moss bags were measured for the chlorophyll concentration (using chlorophyll meter model CCM300 Opti-sciences, USA) and weight of moss in each bag (using the electronic scale model Presica LC220A, Swiss), then were observed and photographed by using a microscope model Olympus SZX16 (Japan). The optimal dose for moss growth was determined by the highest total chlorophyll concentration and weight. This optimal dose was used to treat the moss bags for setting up the next experiment to compare the ability to absorb chemical elements.

2.4. Investigation of the ability to absorb chemical elements

The chosen area for setting up the experiment to investigate and compare the ability to absorb chemical elements among irradiated, non-irradiation mosses used in the moss bag technique and local natural moss is located at latitude 10.5852^o North and longitude 106.4910^o East, namely Long Thanh Airport (Dong Nai province, Vietnam) where *Babular indica* moss grow naturally. The survey period elongated into three months, from July to September 2021. After exposure, 30 irradiated moss samples and 30 non-irradiated moss samples used in moss bag techniques were collected together with 30 local natural moss samples for subsequent treatment and analysis. In this case, moss from each moss bag was considered as one separate sample. The moss samples were dried at 40^{o}C for 50 hours then crushed and homogenized to a powder in an AS 300 control analytical sieve shaker for 30 minutes. The weight of 1g powder of each sample was homogenized with the Gallium internal standard solution for chemical analysis. The concentration of chemical elements deposited in the air was determined for three types of samples: non-irradiated, irradiated by X-ray at optimal dose for moss growth, and local natural mosses by Total Reflection X-ray Fluorescence (TXRF) technique using Bruker S2 PICOFOX spectrometer.

2.5. Data processing

Data were measured and recorded separately for each repetition for each treatment in all experiments before processing. The concentrations of chemical elements that the moss used in the moss bag technique absorbed during the exposure time were calculated by subtracting the total concentration in the sample from the pre-determined background concentration. The concentrations of chemical elements absorbed by local natural moss were directly measured in samples because this material only appeared and experienced growth during the experimental set-up. The data were processed using ANOVA analysis tools of Microsoft Excel software; basic statistics were performed with significant differences calculated at $p < 0.05$ level.

3. Results and Discussion

3.1. The effects of X-ray doses on moss growth

After 30 days of hanging in the same condition as the natural condition, there were variations in morphological characteristics among mosses irradiated by different doses. Microscopy images of moss in each of the treatments and the control samples are shown in Figure 4.

Based on the morphological characteristics, the main differences among the treatments were the colour and the dryness of the branches, the entirety of rhizoids, and the growth of the phyllids. Even without irradiation, the moss in the control did not grow well, became dry, and turned brown. In the treatment with 1 Gy irradiation, there was no change in the status of moss compared to the control. When treated with X-ray radiations at doses from 2 Gy to 15 Gy, the moss grew better than the control, kept green, and the phyllids became larger. Significantly, at doses of 14 Gy and 15 Gy, the moss grew best with the occurrence of new shoots and phyllids; the caulis and phyllids kept the fresh status with a dark green colour, and the rhizoids and branches were not broken. Although better than the control, the growth of moss treated with irradiation at 16 Gy was inferior to that of 14 Gy and 15 Gy, as shown by phyllids and caulis that were pale green and less fresh. The growth of moss irradiated with doses in the range of 17 Gy – 20 Gy was worse than that of the control; the branches and phyllids became dry, lightly crispy, and discolored, and several rhizoids and phyllids were broken.

Although the moss weight and initial moss status of the moss bags were the same (weight of 5.00 ± 0.05g, total chlorophyll content of 350.92 ± 15.23mg/m^2 of phyllid), after 30 days of the experiment, the moss weight, as well as the total chlorophyll content in the moss samples, were different among the treatments. These differences follow both uptrend and downtrend and reflect the effects of irradiation doses on moss vitality and growth, as shown in Table 1.

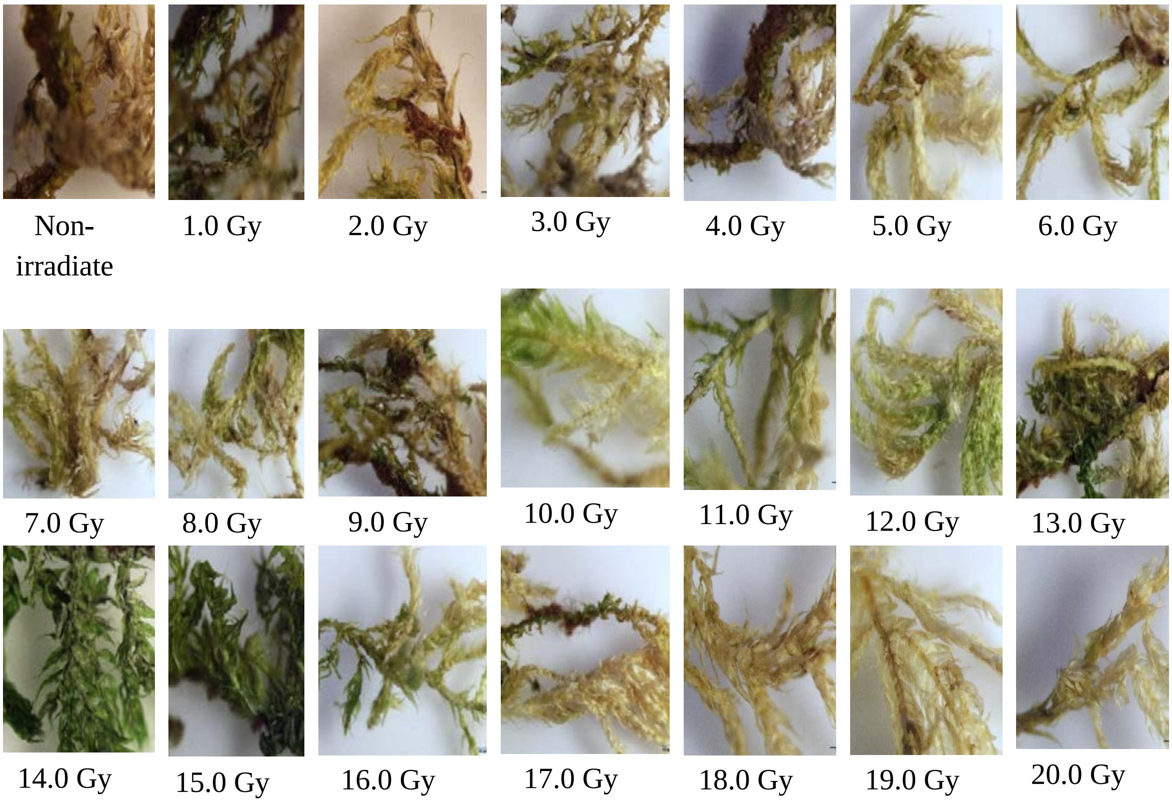

Figure 4. *Effects of X-ray doses on the moss growth and survivability*

It can be recognised that there was a close correlation between the morphological characteristics recorded with the parameters of weight and total chlorophyll content under the influence of different irradiation doses. While morphological expression in the moss in control and in the treatments using doses of 1 Gy and from 17 to 20 Gy showed poor growth; growth was improved at irradiation doses from 2 to 15 Gy, and the best doses were between 14 Gy and 15 Gy; the stimulant effect of radiation began to decrease quickly at a radiation dose of 16 Gy; both weight and total chlorophyll content of moss also reduced in the control sample, and moss irradiated at doses of 1 Gy and 17-20 Gy; gradually increased from 2 to 15 Gy and peaked at 14 and 15 Gy and suddenly lowered at 16 Gy. Although there was a general variation trend, the variation in total chlorophyll content under the influence of the irradiation doses was more significant than the variation in weight.

While the poor growth of non-irradiated and treated with low doses at 1 Gy mosses could be explained by habitat transfer and insufficient radiation to stimulate growth, poor growth of mosses irradiated at doses ranging from 17 Gy to 20 Gy should be explained by both habitat changes and the inhibitory effect of sufficiently high doses of radiation (Fina, 2017, Forster, 2019).

The X-ray stimulatory effect on moss growth occurring in the irradiation dose range from 2 Gy to 16 Gy can be explained by the phenomenon of hormesis induction (Miller & Miller, 1987).

The stimulatory at low doses and inhibitory at higher doses effects of radiation on moss growth in the current study have also been described in various previous studies in a variety of plants (Gudkov, 2019).

The above-obtained results indicate that X-ray irradiation at doses of 14 Gy and 15 Gy had good stimulatory effects on the growth of moss. However, the total chlorophyll contents in these irradiated mosses were still much lower than in natural moss (350.92 ± 15.23 mg/m^2) and this shows that even after being stimulated by irradiation with suitable doses, the growth level of moss used in the moss bag technique cannot reach the growth level as natural moss. In terms of specific values, the 14 Gy irradiation dose was optimal and was chosen to apply for the subsequent experiment to compare the ability to absorb elements in the air of irradiated moss.

Table 1. *The weight and total chlorophyll of moss bags after irradiation*

Irradiation dose (Gy)	Weight of moss (g/bag)	Total chlorophyll content (mg/m^2)
0 (non-irradiated)	4.91 ± 0.28	43.40 ± 2.29
1	4.92 ± 0.14	42.77 ± 2.29
2	5.04 ± 0.14	52.99 ± 2.50
3	5.15 ± 0.24	63.84 ± 2.71
4	5.26 ± 0.25	76.98 ± 3.34
5	5.37 ± 0.20	92.84 ± 3.96
6	5.48 ± 0.30	111.83 ± 4.38
7	5.59 ± 0.35	134.77 ± 6.68
8	5.71 ± 0.44	162.52 ± 7.72
9	5.81 ± 0.45	195.69 ± 8.55
10	5.92 ± 0.40	212.59 ± 11.06
11	5.96 ± 0.17	246.39 ± 11.47
12	6.17 ± 0.25	247.23 ± 12.94
13	6.38 ± 0.10	273.72 ± 13.14
14	6.59 ± 0.28	307.94 ± 14.81
15	6.45 ± 0.18	307.52 ± 17.11
16	5.21 ± 0.15	121.84 ± 4.38
17	4.86 ± 0.22	48.19 ± 3.13
18	4.81 ± 0.21	47.57 ± 3.13
19	4.76 ± 0.27	44.02 ± 2.92
20	4.71 ± 0.21	43.40 ± 2.71
p-value	0.003	0.003

3.2. The ability to absorb the chemical elements from the air of irradiated moss, non-irradiated moss, and natural moss

After determining the optimal irradiation dose for moss growth, the moss bags were prepared in two series including irradiated moss bags treated with 14 Gy irradiation and non-irradiated moss bags. These bags were then hung in the same place where the local mosses appeared to assess their ability to absorb chemical elements deposited in the air. After three months of exposure, the samples were collected, treated, and analysed by using the TXRF technique to determine the concentrations of the elements. The concentrations of chemical elements in moss samples are shown in Table 2.

The results from Table 2 show that in the moss bag technique, while all concentrations of 24 elements were detected in irradiated samples (including Al, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Br, Rb, Sr, Y, Ag, Sn, Sb, Ba, and Pb), only 21 elements were determined in non-irradiated moss samples, Co, Ni, and Rb are three elements below the limit of detection. The ability to absorb chemical elements deposited in the air of non-irradiated moss was significantly lower than that of X-ray irradiated moss during exposure, namely from 3.8 to 4 times lower for the elements of Al, P, S, Cl, K, Ti, Sr, Y, Ag, Ba, Pb; from 3.4 to 3.6 times lower for the elements of Ca, Fe, Cu, Zn, Br, Sn, Sb, 3.2 times lower for Cu element; and 2.4 times lower for V element.

The difference in the ability to absorb elements between irradiated and non-irradiated moss is entirely explained because the growth of moss irradiated by the optimal dose is superior to that of non-irradiated moss. In previous studies related to the moss bag technique, when arranging exposure to moss bags, many solutions were applied to enhance moss's vitality and growth, such as watering, shading, using shelter systems, etc. (Goodman and Roberts, 1971). The current study is within the above purpose, but the new solution is to stimulate moss growth by low-dose radiation.

In general, the ability to absorb elements in the air of irradiated moss was lower than natural moss, namely 96% for P and Ca elements, 91% to 95% for elements of S, Cl, K, Ti, Mn, Sr, Ag, Sn, Ba, Pb; 86% to 89% for elements of Al, Fe, Zn, Br; 80% to 81% for elements of Cu, Y; about 89% for Sb element, and 59% for V element compared with natural moss. Comparing the correlation among groups of irradiated moss, non-irradiated moss, and natural moss, a p-value below 0.05 indicates that there is a statistically significant correlation.

Table 2. *Concentrations of chemical elements deposited in the air that are absorbed by irradiated moss, non-irradiated moss bag, and natural moss*

No.	***El.***	**Concentration (mg/kg)**			**P_1 value**	**P_2 value**	**P_3 value**
		Irradiated moss in moss bag technique	Non-irradiated moss in moss bag technique	Natural moss			
1	Al	2,643.25 ± 145.12	661.54 ± 5.97	3,074.75 ± 2.50	3.78E-07	1.68E-17	0.002
2	P	603.06 ± 19.19	155.69 ± 2.80	629.28 ± 14.24	1.29E-08	4.07E-14	0.042
3	S	1,497.21 ± 31.64	374.81 ± 8.73	1,599.44 ± 2.23	1.53E-09	3.26E-13	0.001
4	Cl	612.56 ± 16.82	153.21 ± 1.68	648.43 ± 2.60	4.06E-09	1.23E-13	0.011
5	K	838.44 ± 20.81	216.32 ± 0.93	879.76 ± 2.60	2.74E-09	1.11E-14	0.014
6	Ca	782.36 ± 10.73	200.72 ± 2.03	811.15 ± 2.60	2.41E-11	5.38E-14	0.005

7	Ti	293.51 ± 16.99	78.37 ± 1.46	320.08 ± 2.60	3.71E-07	7.90E-12	0.001
8	V	3.11 ± 1.07	1.28 ± 0.16	5.23 ± 1.31	8.33E-04	2.07E-03	0.054
9	Cr	4.78 ± 0.72	1.50 ± 0.15	6.09 ± 0.79	3.79E-05	6.24E-05	0.033
10	Mn	88.32 ± 6.71	22.11 ± 0.34	97.18 ± 2.60	2.10E-07	3.88E-09	0.038
11	Fe	2550.43 ± 99.37	718.28 ± 1.62	2,950.68 ± 2.60	2.08E-06	1.36E-17	0.001
12	Co	1.23 ± 0.44	ND	1.87 ± 0.15	4.07E-04	4.12E-07	0.002
13	Ni	2.16 ± 0.35	ND	3.08 ± 0.66	8.59E-06	2.00E-04	0.048
14	Cu	12.65 ± 0.79	3.72 ± 0.16	15.76 ± 2.02	3.48E-07	3.47E-05	0.047
15	Zn	345.28 ± 57.68	96.44 ± 4.10	392.04 ± 1.54	4.87E-05	2.51E-11	0.000
16	Br	2.9 ± 0.24	0.80 ± 0.11	3.26 ± 0.16	4.82E-06	6.01E-07	0.038
17	Rb	2.15 ± 0.29	ND	2.76 ± 0.22	1.74E-06	3.84E-07	0.021
18	Sr	40.18 ± 3.15	10.21 ± 0.18	43.70 ± 1.41	1.51E-06	8.19E-09	0.015
19	Y	6.34 ± 0.43	1.59 ± 0.34	7.83 ± 0.88	2.78E-06	5.04E-06	0.011
20	Ag	55.47 ± 1.57	14.65 ± 0.91	58.75 ± 1.31	1.18E-08	3.62E-09	0.033
21	Sn	82.75 ± 1.51	22.72 ± 0.94	87.21 ± 2.60	2.28E-10	1.34E-08	0.041
22	Sb	39.35 ± 1.01	11.03 ± 0.16	44.30 ± 2.60	1.04E-09	4.66E-07	0.024
23	Ba	39.15 ± 1.81	10.32 ± 0.78	43.17 ± 2.60	2.57E-08	6.51E-07	0.047
24	Pb	3.57 ± 0.18	0.94 ± 0.10	3.93 ± 0.20	3.54E-07	1.63E-08	1.84E-08

Note: ND: non-detected; P_1: between irradiated and non-irradiated mosses in moss bag technique; P_2: between non-irradiated and natural mosses; P_3: between irradiated and natural mosses.

This shows that moss irradiated with optimal radiation dose had overcome the inefficient absorption of moss elements in the bag. This opens up a prospect of using the irradiated moss in moss bag technique as an upgraded bioindicator to assess the deposition of elements in the atmosphere where natural mosses do not exist.

4. Conclusion

Low-dose X-ray irradiation from 2 Gy to 16 Gy could improve the poor growth of moss, as used in the moss bag technique, and the optimal growth stimulation effect was at 14 Gy.

In the moss bag technique, irradiated moss at the optimal dose can improve the ability to absorb elements deposited in the air during exposure significantly compared to non-irradiated moss, thereby enhancing the accuracy of research results and helping to reflect more realistic environmental conditions.

The findings in this study can be promisingly applied in studies evaluating environmental pollution via the moss bag technique, especially in studies using *Babular indica* moss as a bioindicator.

❖ ***Conflict of Interest:*** *Authors have no conflict of interest to declare.*

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REFERENCES

Ares, A., Aboal, J., Carballeira, A., Giordano, S., Adamo, P., & Fernández, J. (2012). Moss bag biomonitoring: A methodological review. *Science of The Total Environment*, *432*, 143-158.

Beyaz, R., Kahramanogullari, C. T., Yildiz, C., Darcin, E. S., & Yildiz, M. (2016). The effect of gamma radiation on seed germination and seedling growth of lathyrus chrysanthus Boiss. under in vitro conditions. *Journal of Environmental Radioactivity, 162-163*, 129-133.

Chakraborty, U., Chakraborty, B., & Basnet, M. (2006). *Plant growth promotion and induction of resistance inCamellia sinensis by Bacillus megaterium. Journal of Basic Microbiology*, *46*(3), 186-195.

Fina, J., Casadevall, R., AbdElgawad, H., Prinsen, E., Markakis, M. N., Beemster, G. T., & Casati, P. (2017). UV-B inhibits leaf growth through changes in growth regulating factors and gibberellin levels. *Plant Physiology, 174*(2), 1110-1126.

Forster, J. C., Douglass, M. J., Phillips, W. M., & Bezak, E. (2019). Stochastic multicellular modeling of X-ray irradiation, DNA damage induction, DNA free-end misrejoining and cell death. *Scientific Reports, 9*(1). https://doi.org/10.1038/s41598-019-54941-1

Gehrke, C. (1999). Impacts of enhanced ultraviolet-B radiation on mosses in a subarctic Heath ecosystem. *Ecology*, *80*(6), 1844-1851.

Goodman, G. T., & Roberts, T. M. (1971). *Plants and soils as indicators of metals in the air*. *Nature, 231*(5301), 287-292. https://doi.org/10.1038/231287a0

Gregersen, E. (2011). *The britannica guide to the atom* (*10010*, 163). New York, NY: Britannica Educational Publishing in association with Rosen Educational Services.

Gudkov, S. V., Grinberg, M. A., Sukhov, V., & Vodeneev, V. (2019). Effect of ionizing radiation on physiological and molecular processes in plants. *Journal of Environmental Radioactivity, 202*, 8-24.

Khiem, L. H., Sera, K., Hosokawa, T., Quyet, N. H., Frontasyeva, M. V., Trinh, T. T., My, N. T., Nghia, N. T., Trung, T. D., Nam, L. D., Hong, K. T., Mai, N. N., Thang, D. V., Son, N. A., Thanh, T. T., & Tien, D. P. (2020). Assessment of atmospheric deposition of metals in ha NOI using the moss bio-monitoring technique and proton induced X-ray emission. *Journal of Radioanalytical and Nuclear Chemistry, 324*(1), 43-54.

Marcu, D., Cristea, V., & Daraban, L. (2013). Dose-dependent effects of gamma radiation on lettuce (Lactuca sativavar. capitata) seedlings. *International Journal of Radiation Biology, 89*(3), 219-223.

Miller, M. W., & Miller, W. M. (1987). Radiation Hormesis in plants. *Health Physics, 52*(5), 607-616.

Rühling, Å., & Tyler, G. (1969). Ecology of Heavy Metals—A Regional and Historical Study. *Botaniska Notiser, 22*, 248-259.

Sax, K. (1955). The effect of ionizing radiation on plant growth. *American Journal of Botany*, *42*(4), 360-364.

Nguyen, A. S., Nguyen, T. N. H., Nguyen, T. M. S., Le, D. D. D., & Le, N. T. (2022). Effects of low energy (160 Kev) X-ray on microbial inactivation, sprouting inhibition and genetic variation in potato. *Food Bioscience, 47*, 101555. https://doi.org/10.1016/j.fbio.2022.101555.

Toni, A., Wiendl, T. A., Wiendl, F. W., Franco, S.S.H., Franco, J. G., Arthur, V., & Arthur, P. B. (2013). Effects of gamma radiation in tomato seeds. *International Nuclear Atlantic Conference, November 24-29, 2013, Recife, Pernambuco, Brazil, 45*, 6p.

ỨNG DỤNG TIA X NĂNG LƯỢNG THẤP ĐỂ KÍCH THÍCH RÊU TRONG VIỆC QUAN TRẮC MÔI TRƯỜNG

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TÓM TẮT

Bức xạ liều thấp kích thích sự phát triển của thực vật, đặc biệt là trường hợp ở rêu, do đó tăng khả năng hấp thu các nguyên tố trong không khí khi sử dụng kĩ thuật túi rêu. Một thí nghiệm đã được tiến hành để khảo sát tác động của bức xạ tia X năng lượng thấp (từ 1 đến 20 Gy, với mỗi lần tăng là 1 Gy) đối với sự phát triển của rêu Babular indica. Kết quả cho thấy, liều chiếu từ 2 Gy đến 16 Gy đã cải thiện sự phát triển của rêu so với mẫu đối chứng không được chiếu xạ. Hiệu ứng kích thích tối ưu được quan sát thấy ở 14 Gy, được thể hiện thông qua các đặc điểm hình thái, trọng lượng rêu và hàm lượng chất diệp lục. Do đó, 14 Gy được chọn làm liều chiếu xạ cho rêu trong môi trường quan trắc. Phân tích hàm lượng nguyên tố bằng cách sử dụng phương pháp huỳnh quang tia X phản xạ toàn phần (TXRF) đã chứng minh rằng rêu được chiếu xạ có khả năng hấp thu nguyên tố được cải thiện đáng kể so với rêu không được chiếu xạ, mặc dù vẫn thấp hơn so với rêu tự nhiên. Nghiên cứu cho thấy việc xử lí rêu bằng bức xạ liều thấp (14 Gy) hứa hẹn là một giải pháp để đạt được kết quả chính xác hơn và phản ánh chính xác hơn các điều kiện không khí thực trong quan trắc môi trường bằng kĩ thuật túi rêu.

Từ khóa: quan trắc môi trường; rêu được chiếu xạ; rêu không được chiếu xạ; tia X năng lượng thấp; túi rêu; rêu tự nhiên