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BIOCHEMICAL ASSESSMENT OF ABYSSINIAN NIGER SEED TO PRODUCE MICROGREENS USING ETHOXYSILATRANE AND GERMATRANOL UNDER SYNERGOTRON CONDITIONS

L.G. ELISEEVA[1], D.V. SIMINA[1*], V.N. ZELENKOV[2,3], V.V. LATUSHKIN[4], V.V. KARPACHEV[5], V.P. BARYSHOK[6], P.I. TOKAREV[1], and M.N. ELISEEV[1]

[1]Federal State Budgetary Educational Institution of Higher Education, Plekhanov Russian University of Economics, Moscow, Russia
[2]All-Russian Scientific Research Institute of Medicinal and Aromatic Plants, Moscow, Russia
[3]All-Russian Scientific Research Institute of Vegetable Growing, FSBSI - Federal Scientific Center of Vegetable Growing, Moscow Region, Russia
[4]Independent NPO Institute for Socio-Economic Strategies and Development Technologies, Moscow, Russia
[5]Lipetsk Research Institute of Rapeseed, – FSBSI V.S. Pustovoit Federal Research Center, Lipetsk, Russia
[6]Irkutsk National Research Technical University, Irkutsk, Russia
*Corresponding author's emails: daria.simina@mail.ru, motyleva_svetlana@mail.ru
Email addresses of co-authors: eliseeva-reu@mail.ru, zelenkov-raen@mail.ru, slavalat@yandex.ru, karpachevv@gmail.com, baryvik@yandex.ru, tokarev.pi@rea.ru, eliseev.mn@rea.ru

SUMMARY

Biologically active substance uses identify the most effective options for various fruits, vegetables, and green crops. The most promising silicon preparation (1-ethoxysilatrane) application as an organoelemental biologically active substance confirmed its high efficiency in producing traditional plants. Silicon preparations and organosilicon esters of triethanolamine-silatranes synthesis by Russian scientists led by M.G. Voronkov became widely used biological active substances in crop production. With an organoelemental biologically active substance, the effectiveness of the drug germanium (1-germatranol) gained scrutiny. Germatrane ($RGe(OCH_2CH_2)_3N$) synthesis immediately followed the preparation of silatranes; however, studying its effectiveness as phytoinducers for microgreens has just begun. The presented research comprised the technology for producing Abyssinian Niger seed plant (*Guizotia abyssinica*) microgreens grown in an urban-type synergotron specified conditions and climate chamber regimes with LED and fluorescent lighting using pre-sowing treatment of plant seeds with 0.001% solutions of 1-ethoxysilatrane and 1-germatranol.

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Keywords: Abyssinian Niger seed plant (*Guizotia abyssinica*), microgreens, 1-ethoxysilatrane, 1-germatranol micro- and macronutrients, vitamin hunger, functional ingredients, fortified foods

Key findings: By using biologically active substances based on silicon and germanium at the stage of pre-sowing seed treatment, the biochemical composition of Abyssinian Niger seed plant microgreens (nitrogen content, chlorophyll, carotenoids, total antioxidant activity) succeeded in evaluation. Germatranol positively affected the growth dynamics of Abyssinian Niger seed microgreens, revealing 53.3% compared with the control sample. The mass indicators of microgreens treated with germatranol exceeded the control sample by 24.3%. Higher antioxidant content was evident than the control treatment for microgreens treated with germatranol (57.5%) and ethoxysilatrane (9.6%).

INTRODUCTION

Improvement in quality and universal availability of safe and nutritious food is relevant to many countries, including the United Nations, the World Health Organization, and UNICEF. The Global Nutrition Report 2020 indicates that the global hunger problem resolution can result in the approved diet quality suitable for different communities. In addition, this report estimates that such a shift could minimize healthcare costs associated with unhealthy diets. According to statistics, in 2030, such expenses will reach USD 1.3 trillion yearly. Based on the research of the analytical company Euromonitor International, the healthy food sector grows by 4% annually worldwide because of the increased demand for healthy food products and regulations adopted by different states globally. Food products with the highest nutrients are essential for reducing the deficiency of nutrients in the diet and preventing the development of nutritional diseases. It is a promising sector for establishing the Russian agro-industrial complex.

Plants in the first stages of vegetation (sprouts and microgreens) began to appear in restaurants in the 1980s in the United States. The first research on sprouts commenced in the 1990s. Thus, published studies concerning the microbiological safety of sprouts (NACMCF, 1999) emerged in 1999. Since then, publications of studies on microgreens and sprouts have become periodic. One of the most significant microgreen research materialized in the United States in 2012, which observed that microgreens have higher organoleptic and physicochemical properties than adult plants. According to Xiao *et al.* (2016), a plant becomes a microgreen when it produces its first complete leaf. Microgreens are edible shoots of various crops with a height of 5–12 cm, differing from traditional crops in their delicate consistency, pronounced taste, aromatic characteristics, and a higher content of biologically active compounds than customary analogs. Microgreens also contain enhanced physicochemical properties, antioxidant activity, and photosynthetic pigments, surpassing traditional analogs for polyphenol content (Sun *et al.,* 2013; Choe *et al.,* 2018).

Currently, the most popular microgreens are basil, arugula, radish, amaranth, peas, daikon, pak choi, broccoli, and peas (Ebert, 2022). However, consumer interest in microgreens continues to grow, leading scientists to explore new crops uneaten as microgreens before. Such crops include the Abyssinian Niger seed plant (*Guizotia abyssinica* [L.f] Cass). Xiao *et al.'s* (2016) findings revealed a new type of product that has high nutrient properties and examined a new, previously unexplored type of microgreen Niger seed plant. Likewise, according to Simina *et al.* (2023), it has good indicators for the content of chlorophyll, carotenoids, phenolic compounds, vitamin C, and antioxidants.

The Abyssinian Niger seed plant (*G. abyssinica*) is one of the new and promising plant crops for producing microgreens. Its cultivation is in India and African countries, including Ethiopia. In other countries, the Niger seed plant is unfamiliar, with less cultivation in Europe. Botanically, the Niger seed plant belongs to the family Compositae and the genus *Guizotia*. Currently, this genus has 11 known species. Planting the species *G. abyssinica* is often as an oilseed, including other species like *G. Sohimperii Schul., G. Schulzii,* and *G.G. Villosa Schul.,* as microgreens have a delightful spicy taste, contain aromatic oils, and high iodine content. Niger seed plant is a promising source for enriching food products with iodine, which provides a piquant taste and aroma.

Microgreens are also several times superior to mature leaves in micronutrient content (Yadav *et al.,* 2019). From facts by Pinto *et al.* (2015), Huang *et al.* (2016), Choe *et al.* (2018), and Ebert (2022), microgreens have the highest nutrient status and are a 'superfood.' Introducing them into people's diets will help improve the situation of vitamin and nutritional deficiencies worldwide. In microgreens, the type, variety, and technology producing them influence their nutritious values and biologically active substances. Manufacturing crop products in urban conditions is more progressive worldwide. Specific attention focused on possibly producing environment-friendly products using growing systems for the optimum realization of genetically inherent superior productivity and nutritional values. Optimized crop production in urban conditions comprises growing technologies in isolated automated systems - phytotrons, where the cultivation regimes have a wide range of adjustability.

One of the new ways to grow microgreens is to raise them in synergotrons (one type of phytotrons). Synergotron is a closed system where adjusting light and temperature parameters can establish the most comfortable conditions for the plant's growth and development using AT technologies. The prevalent use of phytotrons of various modifications is beginning to apply in public catering, plant growing, breeding, and the agro-industrial complex. Since microgreens have a short shelf life and lose their consumer properties during storage (Kou *et al.,* 2013), therefore, it is necessary to investigate how to increase the consumer and physicochemical properties of microgreens at the growing stage in synergotrons by using solutions based on organoelemental compounds to obtain a highly nutritious product.

The novel research focused on probing the characteristics of growing Abyssinian Niger seed plant microgreens in an urban-type synergotron and developing advanced techniques for producing microgreens for their subsequent use as a functional ingredient for enriching consumer products (Eliseeva *et al.,* 2023; Simina, 2023a, b). Additionally, the study sought to investigate the effects of treating Niger seed plant microgreens with preparations based on germanium and silicon. Such a study did not previously exist on microgreens; hence, the pertinent results are new in this field. Similarly, the presented work contains a comparison with the pattern of positive effects on traditional plant treatments with germanium and silicon preparations observed in past studies (Voronkov *et al.,* 1988; Voronkov and Baryshok, 2010; Shigarova *et al.,* 2016; Zelenkov and Potapov*,* 2016).

MATERIALS AND METHODS

The novel study commenced in an urban-type synergotron ISR-0.01, developed by the ANO - Institute of Development Strategies, Moscow, Russia. The Synergotron (ISR-0.01) had the characteristics, i.e., external chamber height - 1800 mm, length - 1000 mm, and width - 500 mm. The chamber has four tiers of shelves, and their internal dimensions are 920 mm × 350 mm. The synergotron design produces different temperatures and light conditions and uses a hydroponic system for watering and feeding the plants. The Synergotron has two ventilation systems and fluorescent (white light) and LED lamps (red and blue light) equipment.

The lighting modes in the experiments are available in Figure 1. Their adjustments comprised combining fluorescent lighting with red, green, and blue LED lights, allowing to obtain an optimal ratio with the emission spectrum close to natural sunlight in the region of photosynthetically active radiation with the ratio on far red (maximum 730–750 nm): red (with a maximum of 630–650 nm): blue (420–450 nm): green spectrum (520–550) - 0.2:1.3:0.6:0.4, respectively, having a

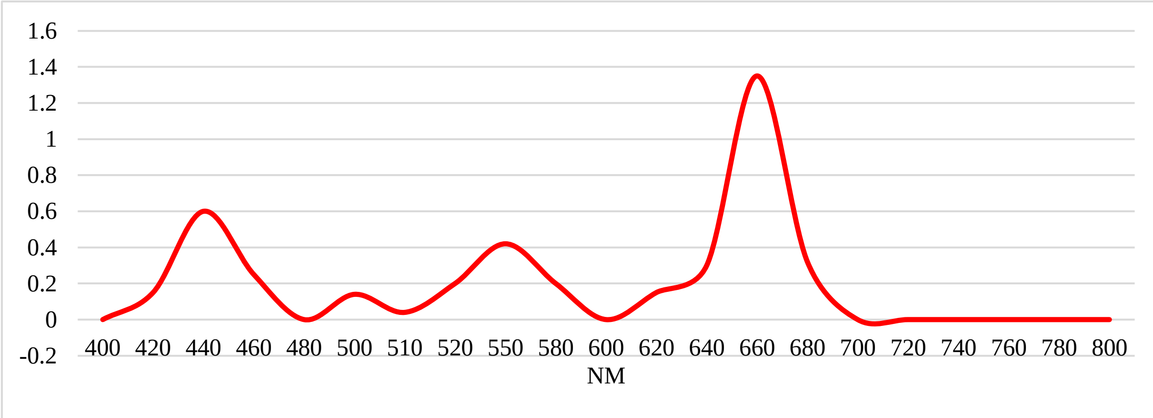

Figure 1. Intensity of illumination spectra in the Synergotron ISR-0.01.

background content of all white light minor spectra. The PFD irradiation intensity across all spectral lines on the synergotron shelves was 148.0 μmol/m^2s. The photosynthetic part of the spectrum of the PPFD synergotron shelves was 134.1 μmol/m^2s. The lighting fixtures included a fluorescent lamp + KTL Rubin 75 LED lamps, consisting of red and blue LEDs + 1 PPG T5i-600 Agro 8W LED plant lamp. The total number of LEDs on the tier was 96, while the red LEDs were 64 and the blue LEDs were 32. The temperature during the experiment was 22 °C–24 °C during the day and 18 °C–20 °C at night. In the ISR 0.01 Synergotron, the daylight duration was 16 hours.

The Abyssinian Niger (*G. abyssinica*) cultivar Lipchanin seeds developed at the Lipetsk Research Institute of Rape and registered in the State Register of Breeding Achievements of Russia in 2017 became samples. The Niger seed plant has good organoleptic and physicochemical properties, including high antioxidant activity, which indicates its prospects for practical use (Zelenkov *et al.,* 2017). Germinating of Abyssinian Niger seed plant seeds continued in trays measuring 35 cm × 16 cm. Jute mats measuring 10 cm × 15 cm and 5 mm thick served as a substrate. The sowing frequency was 840 seeds per mat (56,000 seeds/m^2). Before seed sowing, disinfect the trays employing a disinfectant solution and distilled water. Jute mats sustained thorough moistening in water before spreading in trays at three pieces each. As a phytoregulator, the organosilicon compound used had a silatrane structure, 1-ethoxysilatrane $HOCH_2CH_2Si(OCH_2CH_2)_3N$, patented by Baryshok and Voronkov (2012), and a similar organogermanium compound, 1-germatranol $HOGe(OCH_2CH_2)_3N$, synthesized from the scientific school of Academician M.G. Voronkov.

Niger seed plant seed soaking occurred in solutions of 1-ethoxysilatrane and 1-germatranol at a concentration of 1×10^{-3} for two hours before sowing. The control sample soaking used distilled water. The mass of microgreens observation ensued on the 12th day when the microgreen sprouts appeared. Measurements engaged laboratory scales with an accuracy of 0.0001 g. For measurement, 10 microgreen sprouts taken incurred cuts at a distance of 5 mm from the jute mat and then weighed. Repeating the measurement thrice and then averaging.

The growth dynamics determination of Niger seed plant microgreens continued every day from the moment of sowing. A ruler for measuring had a division value of 0.1 cm. The measurements ensued from 10 microgreen sprouts by placing a ruler next to the sample for measuring and then estimating from the beginning of the stem to the top of the leaf without changing its position. Leaf growth dynamics also transpired by measuring a leaf on graph paper, with the area of sprout leaves summed up. All measurements were in triplicate and averaged.

Determining chlorophyll and carotenoids proceeded by spectrophotometry. The concentration of pigments in microgreen leaves of the Abyssinian Niger seed plant spectrophotometrically used the methods and equations of Lichtenthaler and Wellburn (1983) and Lichtenthaler (1987). An accurately weighed 500 mg sample of fresh plant leaves bore maceration with 5 ml of 96% ethanol, stirring for 5 min, then adding another 5 ml before placing in a dark, closed freezer at -4 °C for 30 min. The homogenized mixture, transferred into 15 mL conical tubes, reached centrifugation at 8000 rpm for 10 min at room temperature. Then, 0.5 ml of the aqueous phase (supernatant) received 4.5 ml of 96% ethanol before mixing thoroughly for three minutes. The samples underwent analysis for the content of total carotenoids and chlorophyll a and b using a spectrophotometer (Shimadzu UV 2401pc UV-VIS, Japan) at wavelengths of A=663, A=645, and A=470 nm. The measurement continued in triplicate and later averaged.

The quantitative content of phenolic substances calculation used the Folin-Ciocalteu method (Dai and Mumper, 2010; Di-Bella *et al.,* 2020). The 50 mg dry sample incurred maceration for 5 min with 2 ml of ice-cold 95% methanol using a mortar and pestle. Then, the homogenized mixture centrifugation had a rotation speed of 13,000 rpm for 10 min at a temperature of 23°C. Then, 1 mL of the supernatant continued mixing with 2.5 mL of 10% (w/v) Folin–Ciocalteu reagent. After 5 min, the addition of 2.0 ml (20%) Na_2CO_3 to the mixture sustained incubation at 45 °C for 20 min with occasional stirring. After 90 min of incubation in the dark at ambient temperature, the absorbance detection at 765 nm used a spectrophotometer (Shimadzu UV 2401pc UV-VIS, Japan). Total phenolic content expression was as mg gallic acid equivalents per gram dry weight of Abyssinian Niger seed plant microgreen samples using a gallic acid calibration curve with regression (R2 = 0.978). The measurements were in triplicate.

Total antioxidant activity measurement utilized the coulometric method using an Expert-006 coulometer by Zelenkov and Lapin (2013). In carrying out the said process, 1.0–1.5 g of a fresh sample of Abyssinian Niger seed plant microgreens reached homogenizing in a mortar. A background electrolyte (0.2 M aqueous solution of KBr in 0.1 M solution of H_2SO_4) prepared earlier generated bromine radicals. Following the procedure, 30 ml of a background electrolyte (0.2 M aqueous solution of KBr in a 0.1 M solution of H_2SO_4 H_2SO_4) continued into an electrolytic cell mounted on a magnetic stirrer. Then, when the current indicator in the coulometric cell reached a value of 50 mV, adding a 0.5 g sample of native sprout homogenate ensued with stirring, placed in a background electrolyte, with the measurement carried out.

The detection of total nitrogen used an N-tester device (Geomir, Russia). The device indicators characterize the plant proteins and peptides' synthesis. The measurement included five steps by placing the leaves of the Niger sprouts in the device and taking a series of estimations consisting of 15 measurements. All analyses of the recorded data underwent the Microsoft Excel 2016 software package.

RESULTS AND DISCUSSION

Preparations based on Si and Ge

It is typical that using biologically active substances (BAS) when growing microgreens in closed systems can improve the chemical composition and consumer properties of green products. For these experiments, the choice of 1-ethoxysilatrane (1-ES) depended on past studies proving the effectiveness of the silicon compounds used with a silatrane structure for crop plants in open and protected soil and treating them at different stages of the growing season with seed and foliar treatments at mass flowering (Voronkov and Baryshok, 2005; Zelenkov *et al.,* 2016).

The 1-germatranol (1-GT) used with a structure similar to 1-ethoxysilatrane (1-ES) in treating crop plants at different growth stages has no current sufficient studies, even for applications in open ground. However, the limited data available in the scientific literature confirms the prospects of using 1-germatranol in crop biotechnology. Voronkov *et al.* (1988)

reported that 1-germatranol activates the growth processes and acts as an antioxidant in plant tissues, stimulates plant growth, and slows down lipid peroxidation in mitochondrial membranes and preserves their functioning, activating redox reactions in mitochondria. In addition, Shigarova *et al.* (2016) also observed that germanium-containing preparations, with equal or higher biological activity, proved less toxic than their silicon analogs. In this regard, comparing the biologically active substances of 1-ES and 1-GT on their effect on the growth and accumulation of photosynthetic pigments in Abyssinian Niger microgreens ensued.

According to past relevant literature and preliminary screening studies (Simina *et al.,* 2023) on applied concentrations of 1-ES and 1-GT solutions regarding the germination of Abyssinian Niger seeds under synergotron conditions with various treatments (soaking seeds, foliar, and root treatments), the compound concentration selected for the experiments was 1.0×10^{-3}% of their aqueous solutions. As a result, it was evident that soaking pre-sowing seeds was most effective, providing the best results of sprout productivity and physical and chemical indicators of the microgreens. The best indicators for germination energy, growth rate, and weight and height of microgreens resulted in sample treatment of seeds soaking with 1-ES and 1-GT compounds.

Germination energy and germination

At present, no past occasions on researching Niger seed plant microgreens existed. The results obtained are entirely new and have no analogs worldwide. However, it was possible to compare the treatment effects with those of germanium and silicon preparations on the plants. Figure 2 shows the germination dynamics of the Abyssinian Niger seeds after treatment with various biologically active substances compared with the control variant. Treatment with 1-ethoxysilatrane and 1-germatranol positively affected the germination energy of Niger seeds. During the initial seed germination period (up to three days), a significant change in the seed percent germination relative to the control appeared (Figure 2). The germination period on the third day could be correct for determining the germination energy of Niger seeds. The differences with the control were 3.6% and 7.3% for 1-ES and 1-GT options, respectively.

In the control options and experimental samples of Niger seeds on the fourth day, the dynamics curves reach a plateau for germination percentage. The seed germination time of seven days can considerably be correct (three days from the plateau of the germination dynamics curves for the seeds of all the research options) to determine the germination rate for Niger cultivar Lipetsk seeds.

The dynamics of variations in the plant height of Niger seed microgreen seedlings by treating with 1-ES and 1-GT are visible in Figure 3. Both biologically active substances proved effective for the trait by comparing them with the control. However, microgreens obtained by treating seeds with 1-germatranol have significantly higher growth rates from the fifth day after sowing. Thus, one can conclude that germanium-based biologically active substances stimulate the growth of Abyssinian Niger seedlings in the synergotron. For silicon-based biologically active substances, the growth stimulation of Abyssinian Niger seedlings was notable in the initial period of their growth (up to five days, followed by a slowdown in growth with dynamics corresponding to the control variant).

The presented results were also consistent with the studies of Shigarova *et al.* (2016), in which the positive effects were apparent by treating plants with germanium preparations. Their findings further revealed that solutions of 1-germatranol in specific concentrations could have an antioxidant effect, which stabilizes respiration, contributes to the plant's resistance to unfavorable environmental factors, and works as a plant growth activator. The obtained data correlate with these facts; as a result, it can be implicit that treatments with germatranol solutions positively influence the growth and resistance of microgreens to external factors.

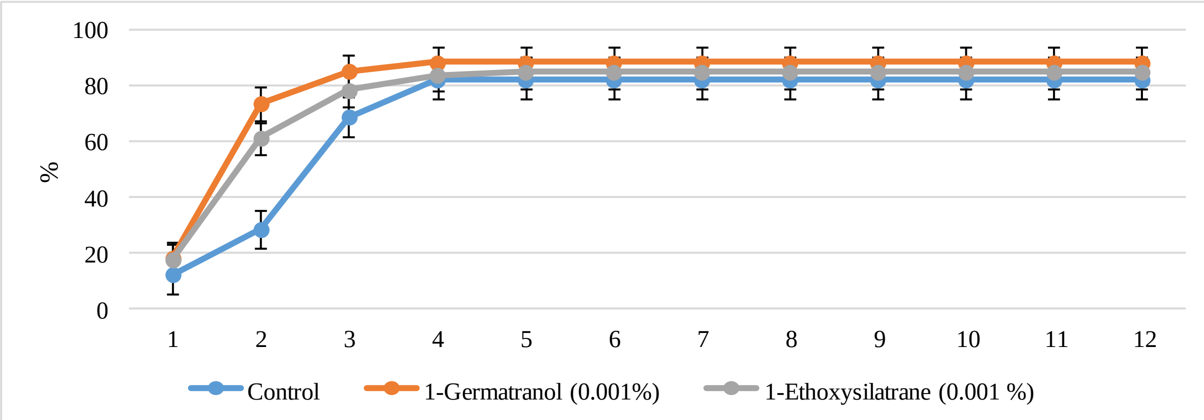

Figure 2. Dynamics of seed germination of Abyssinian Niger seed plant variety *"Lipchanin"* when treated with biologically active substances.

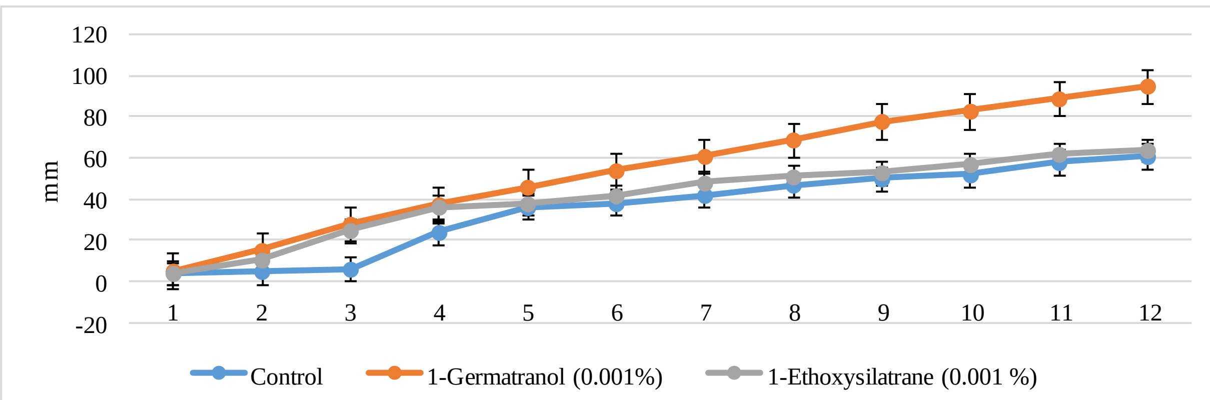

Figure 3. Dynamics of changes in the height of Niger seed plant microgreens when treated with biologically active substances 1-ethoxysilatrane and 1-germatranol.

Leaf area and weight

The leaf area and mass of Niger seed plant microgreens showed a positive effect of the BAS treatment compared with the control sample. Indicators of the dynamics of changes in the leaf area of Niger seedlings during germination indicated a significant increase in Niger seedlings' leaf size by treating with 1-germatranol (Figure 4). This indicator for microgreens treated with 1-germatranol exceeded the control sample and the sample treated with 1-ethoxysilatrane by 50%. The indicators in the control seedlings and by treating with 1-ethoxysilatrane were significantly lower than in the samples treated with germanium-based biologically active substances. The germanium preparation has a superior effect on the positive dynamics of leaf growth in Niger seed microgreens compared with silicon biologically active substance.

The mass of Abyssinian Niger seed plants treated with various biologically active substances occurs in Figure 5. According to this indicator, Niger seed microgreens treated with biologically active substances were superior to the control sample by 7.69% for 1-ethoxysilatrane and by 33.9% for 1-

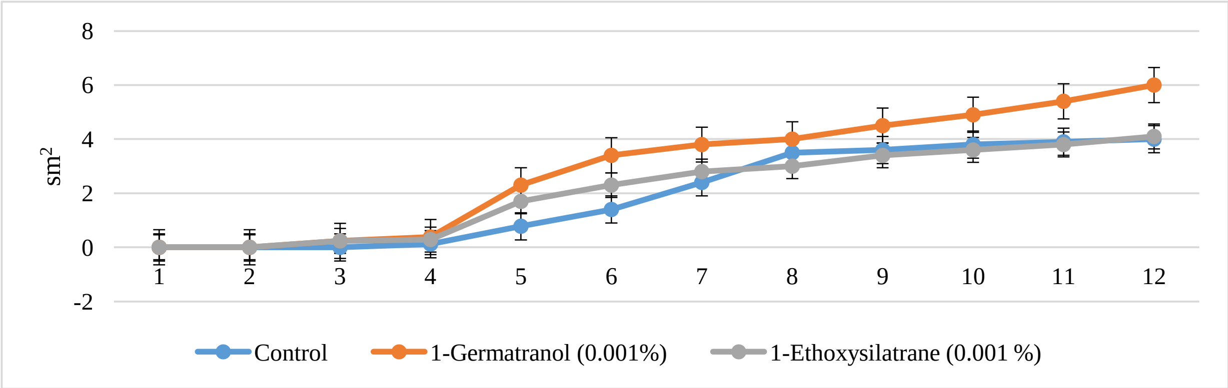

Figure 4. Dynamics of changes in the leaf area of Niger seed plant microgreens during pre-sowing seed treatment with 1-ethoxysilatrane and 1-germatranol.

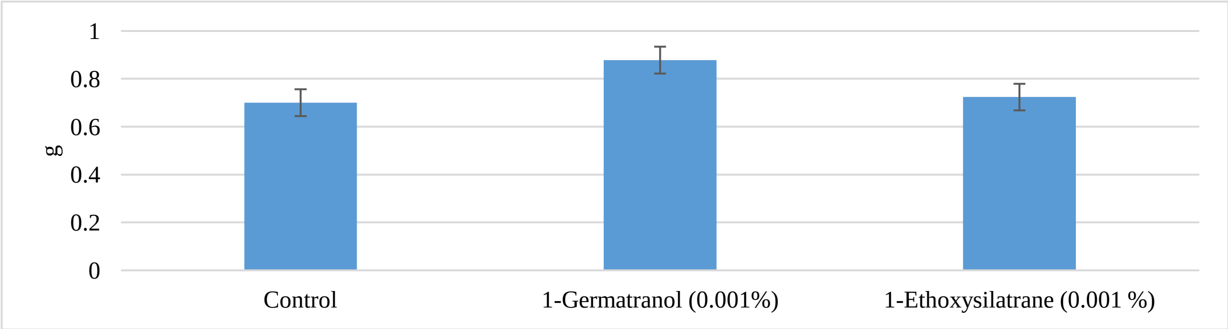

Figure 5. Mass indicator of 10 sprouts of Niger seed plant microgreens when treated with biologically active substances 1-ethoxysilatrane and 1-germatranol.

germatranol. It indicates the positive effects of the BAS treatment on the weight gain of Niger seed microgreens.

Studies by Shigarova *et al.* (2016) noted the advantage of germanium-based drugs was their lower toxicity than silicon drugs. This factor may explain the effect on plant metabolism, which was the reason for more active leaf growth and microgreen mass gain. Zhigacheva *et al.* (2015) also reported that seed soaking in aqueous solutions of germatranes enhanced germination, accelerated the growth of wheat, cucumber, and parsley plants, and promoted leaf growth and weight gain. Similar results are notable in the case of microgreens, which allow the conclusion that germanium solutions contribute to the mass gain of Niger seed microgreens and their growth.

Total nitrogen content

The dynamics of total nitrogen indicators in microgreens of control and experimental variants are available in Figure 6. The obtained data indicated a more dynamic accumulation of nitrogen index in Niger seed microgreens by treating them with biologically active substances based on germanium and silicon. The sample treated with 1-germatranol had a higher nitrogen content throughout the growth period. In comparison with samples treated with 1-ethoxysilatrane, Niger seed samples treated with germanium preparation increased

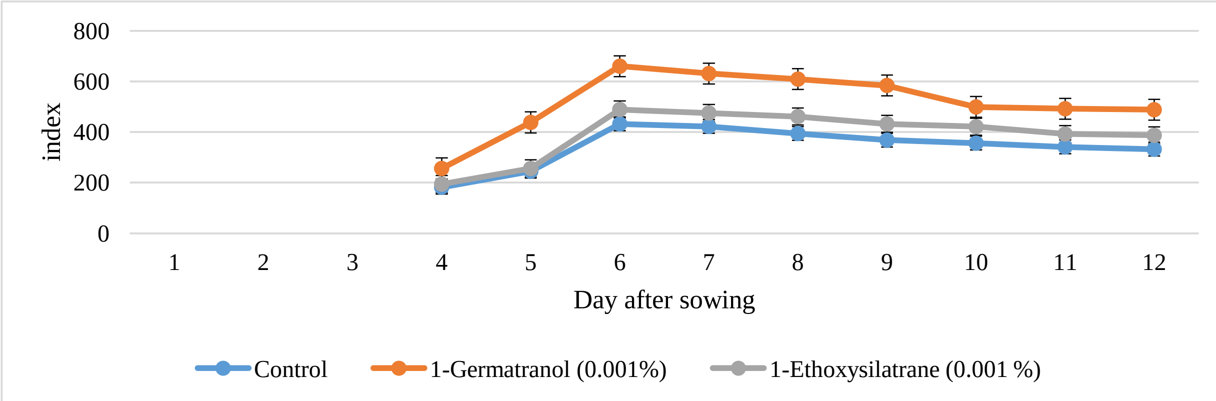

Figure 6. Dynamics of changes in the total nitrogen index in Niger seed plant microgreens when treated with biologically active substances 1-ethoxysilatrane and 1-germatranol.

by 25.6%. However, both treated samples exceeded the control sample in nitrogen content, indicating treatments with biologically active substances based on silicon and germanium promote the best nitrogen accumulation, subsequently contributing to all plant’s metabolic processes.

Throughout the growth period after the leaves appeared, the total nitrogen index in Niger seed microgreens treated with 1-germatranol was higher than in other samples. Studies on the effects of germanium solutions on the total nitrogen index in microgreens and traditional plants have not transpired, and studies on the influences of using solutions of 1-ethoxysilatrane and 1-germatranol on the variations in the total nitrogen index in microgreens are yet to happen. However, silicon is a structure-forming soil element that promotes nitrogen absorption by plants and affects soil fertility levels (Matychenkov *et al.,* 2008; Rahman *et al*., 2022; Zubkova *et al*., 2022). Its deficiency further leads to reduced plant growth and loss of product quality. In this regard, one can conclude that using silicon and germanium solutions with similar structures favorably affects nitrogen absorption by microgreens, ensuring plant growth and development.

Chlorophyll and carotenoids content

The ratios of chlorophyll a and b, total chlorophyll, and carotenoid content in Niger seed microgreens occur in Figure 7. It was notable that the total content of chlorophyll and carotenoids in the control sample of Niger seed microgreens was lower than in samples with pre-sowing treatment with biologically active substances. Thus, the chlorophyll content in samples treated with 1-germatranol exceeds the control sample by 2 mg/g (24.4%) and in those treated with 1-ethoxysilatrane by 1 mg/g (11.3%). In addition, the chlorophyll a/b ratio in samples treated with biologically active substances based on germanium and silicon exceeds the control value by 124.3% and 65.7%, respectively. The carotenoid content in the experimental variants of the obtained microgreens on the 12th day using biologically active substances based on germanium and silicon exceeded the control variant by 47.2% and 18.9%, respectively.

The presented findings were also consistent with past studies of Voronkov *et al.* (1988), Voronkov and Baryshok (2010), and Shigarova *et al.* (2016), which described the effect of silicon and germanium solutions on crop plants. According to these studies,

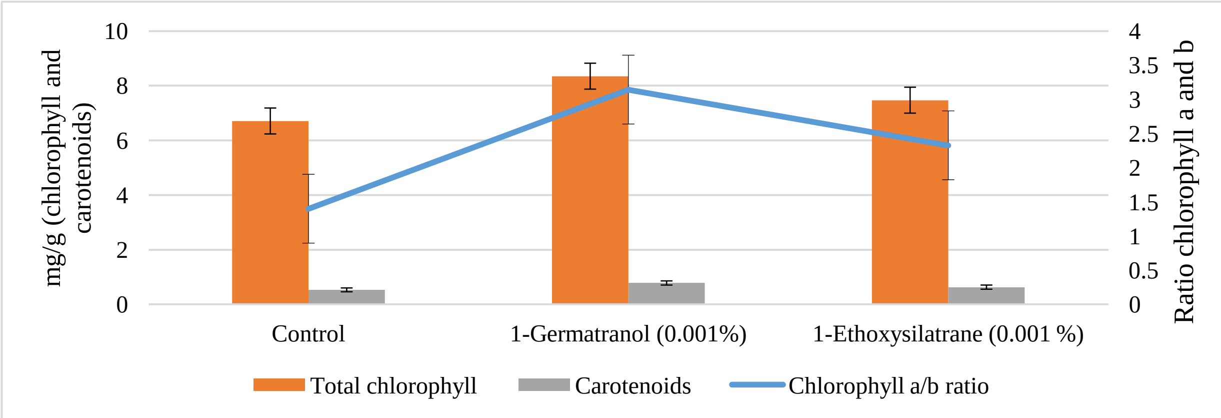

Figure 7. Quantitative indicators of the content of chlorophyll, carotenoids, and the chlorophyll a/b ratio in Abyssinian Niger seed plant microgreens from a 12-day harvest of microgreens in the control and experimental variants (with 1-germatranol and 1-ethoxysilatrane).

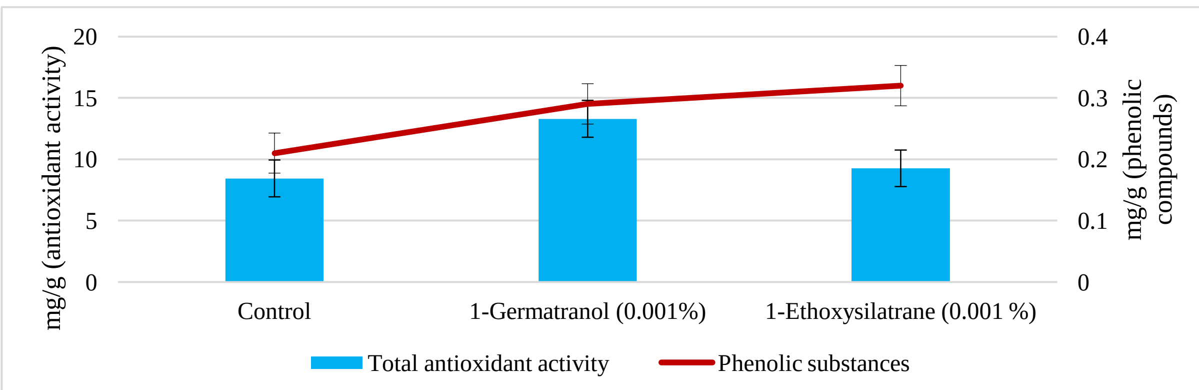

Figure 8. Quantitative indicator of total antioxidant activity and phenolic compounds in Niger seed plant microgreens treated with biologically active substances 1-ethoxysilatrane and 1-germatranol.

solutions based on silicon and germanium have positive outcomes on the metabolism of plants, including photosynthesis. The promising results on Niger seed microgreens further revealed that using germanium and silicon solutions by treating seeds promotes photosynthesis and enhances chlorophyll and carotenoid synthesis. Consequently, it is possible to assume that solutions of 1-germatranol and 1-ethoxysilatrane positively influence photosynthesis in traditional crop plants, including Niger seed microgreens.

Antioxidant activity and phenolic compounds

Indicators' measurement of total antioxidant activity and phenolic compounds in Abyssinian Niger seed microgreens ensued on the 12th day of their cultivation in a synergotron (Figure 8). From the physicochemical analysis results, the Niger seed microgreen samples treated with biologically active substances germatranol and ethoxysilatrane had a higher content of phenolic compounds than the control treatment by 38.1% and 52.4%, respectively. In addition, the best total antioxidant activity emerged in the samples treated with 1-GT (13.3 mg/g), which was 57.5% more than the control sample. Niger seed microgreens treated with 1-ES also surpassed the control sample by 9.6% for the said trait.

Based on the obtained results, one can conclude that 1-ethoxysilatrane and 1-germatranol are effective as biologically active substances for acquiring the microgreens when grown in an urban-type synergotron. Microgreens treated with these biologically active substances have higher values for all physicochemical and plant development parameters than the control sample. Additionally, in the case of microgreens, the most nutritious part of the plant was the leaves, where the most essential micro- and macronutrients accumulate. Thus, the Niger samples treated with 1-ES and 1-GT exceeded the control sample for leaf size by 48.7% and 9.8%, respectively. Silicon preparations and 1-germatranol have a superior effect on the growth of Niger microgreen leaves, indicating their importance by choosing environment-friendly technologies for attaining microgreens for various crop plants using climate chambers.

The dynamics of microgreen growth treated with 1-GT differed significantly from the control samples by 53.3%. The mass values of microgreens treated with 1-GT exceeded the control sample with a significant extent of 24.3%. Microgreens treated with biologically active substances showed higher concentrations of antioxidants than the control sample by 57.5% and 9.6% for 1-GT and 1-ES, respectively. By comparing with the control sample, Abyssinian Niger seeds treated with 1-GT and 1-ES excelled in the content of phenolic compounds by 38.1% and 52.4%, respectively. Shigarova *et al.* (2016) reported that the germanium-based preparation favorably affected plant growth and development and crop plants' photosynthetic and antioxidant activities. Similar results came from a study on the influences of treatment with a germanium-based preparation on Niger seed microgreens, revealing a beneficial effect of these preparations even in the early stages of plant growth.

CONCLUSIONS

Based on the results, the study concludes that using ethoxysilatrane and germatranol as growth regulators proved more effective in growing Abyssinian Niger seed microgreens. Niger seed plant microgreen samples treated with silicon and germanium preparations were superior to control samples in all the traits, declaring the effectiveness of the tested preparations. As a result, an optimal technology for growing microgreens materialized based on identifying the most efficient lighting and temperature system, methods, concentrations, and methods of feeding plants during growth in an urban-type synergotron.

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