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Assessment of the effect of graphene oxide on morphometric parameters of common cabbage (*Brassica oleracea*) for different processing methods

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Abstract. The growth of the world's population and the reduction of fertile soil areas due to global climate changes require advanced scientific solutions to increase the yield of major food crops to ensure food security. The purpose of the study was to investigate the effect of graphene oxide nanoparticles at different concentrations and processing methods on the linear and weight parameters of common cabbage seedlings (*Brassica oleracea*) of the ultra-early variety 'Iyunska'. Physiological research methods were used to determine the morphometric parameters of plants and seed germination. Nanostructured colloidal solutions in the concentration range of 20, 50, and 70 µg/mL and two treatment methods – seed priming and root application – were used to evaluate the effect of graphene oxide. It was found that graphene oxide stimulated the germination of cabbage seeds when soaking the seeds in solutions of all the concentrations under study. The highest seed germination rate was observed in the group where a solution with a nanoparticle concentration of 20 µg/mL was used for priming. It was in this group that the seed germination rate was 83%, which significantly exceeds this indicator in the control group – 56%. Root application of graphene oxide solutions of similar concentrations did not cause significant changes in the specified indicator, which remained within the control values. In this paper, it was proved that the morphometric parameters of cabbage seedlings reacted more positively to the action of nanoparticles during seed priming in contrast to the application by irrigation. Priming cabbage seeds with different concentrations of graphene oxide caused an increase in the linear characteristics of seedlings, which was most pronounced mainly at a concentration of 20 µg/mL: the total length of plants increased by 32.8%, the length of the STEM by 26.8%, the average length of the roots by 37.7% compared to the control group. The average plant weight and root weight showed the greatest growth when treated with seeds in a graphene oxide solution with a concentration of 70 µg/mL. The only indicator that reacted negatively

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to nanoparticle priming is the weight of the seedling stem, which decreased at all concentrations. The use of carbon nanoparticles in crop production is a promising area of agricultural technologies, which can provide not only high seed germination rates, but also stimulate the growth and development of food crops with properly selected concentrations and processing methods

Keywords: carbon nanoparticles; nanopriming; plants; seed germination; growth rates

INTRODUCTION

Recent global trends in the agricultural sector have led to an increase in interest in innovative approaches in agricultural technologies that would improve the growth, increase the yield and stress resistance of food crops without negatively affecting the quality and safety of final products. Cabbage is an important food crop that is in high demand in domestic and international markets. It is grown in both northern and southern countries. The area occupied by cabbage is estimated by FAOSTAT to be 2.6 million hectares (Food and Agriculture Organisation of the United Nations, 2025). Cabbage consumption differs significantly in quantitative indicators in different countries of the world, which is conditioned by the culinary traditions of the population. It is used fresh for cooking, and in processed form (fermentation, canning).

According to L. Ray *et al*. (2021), extracts and phytocomponents isolated from *B. oleracea* var. *capitata,* has antitumour, antihypertensive, anticholesterolemic, antioxidant, anti-inflammatory, antibacterial, anticoagulant, and haepatoprotective effects. J.J. Uuh-Narvaez & M.R. Segura-Campos (2021) indicated that cabbage is a food product that can be used in food therapy, and as a preventive ingredient for type 2 diabetes. The main bioactive compounds present in cabbage varieties are phenolic acids, flavonoids, anthocyanins, and fibre, which help inhibit amylolytic enzymes responsible for converting carbohydrates into sugars.

As noted by O. Statilko *et al*. (2024), different varieties of cabbage differ in the composition of biologically active compounds. Thus, for varieties *B. oleraceae* var. *capitata* f. *rubra* it is characterised by a high content of phenolic compounds, in particular anthocyanins, and for varieties *B. oleraceae* var. *capitata* f. *alba* – glucosinolates. The level of these compounds also varies depending on the variety. According to W. Wu *et al*. (2021), ten glucosinolates were found in red cabbage, including 4-methoxyglucobrasicin, neoglucobrasicin, glucoalisin, glucobrasicin, glucoraphanin, glucoiberin, progoitrin, gluconapine, and sinigrin, have antibacterial, anti-inflammatory, and antioxidant properties. Y. Gelaye & E. Tadele (2022) noted that the cultivation of cabbage and its productivity depends on many factors, in particular, soil fertility, proper agronomic practices – pinching, thinning. According to research by M. Saba *et al*. (2025), organic cabbage cultivation is becoming increasingly popular, as it has higher levels of essential nutrients, antioxidants, and phytochemicals than traditionally grown counterparts. This is achieved by not using chemicals to treat plants and fertilise the soil.

J.D. da Silva Fonseca *et al*. (2024) determined that the rapid development of nanotechnologies leads to an increase in the popularity of using metal and nonmetal nanoparticles in crop production, in particular, as pesticides, nanofertilisers, and elicitors. Nanoparticles (NP) obtained from organic substances by "green" synthesis can improve nutrient absorption, soil quality, seed germination, and plant growth. L. Xuan *et al*. (2023) indicated the ability of metal nanoparticles to pose a potential threat to the environment due to accumulation in soils and bio-objects and public health as a result of their migration in food chains. Risks of using carbon nanoparticles, according to N. Xin *et al*. (2023), still being studied. Information on the optimal application rates of carbon nanoparticles, their agronomic efficiency, influence on the physiology of agricultural crops, and the biochemical quality of soil is very limited.

Undoubtedly, graphene/graphene oxide has significant application potential in various industries and medicine, as it has a number of advantages. However, according to the study by A.N. Ghulam *et al*. (2022), its exposure to the environment can affect the soil microbiota, plants, and animals. That is why it is important to find out the consequences of this effect, since graphene nanoparticles are of increasing interest for use in agricultural technologies. According to X. Zhang *et al*. (2022), in scientific studies, there are mixed data on the effect of these nanoparticles on the plant body. Some researchers note the positive effects of graphene on the growth and development of various plant species, while others note the toxic effect, which manifests itself in the form of physical (mechanical damage and blocking) and physiological and biochemical effects (activation of the development of reactive oxygen species, a decrease in the activity of antioxidant enzymes, and effect on the photosynthetic apparatus of plants).

Elucidating the mechanisms and consequences of graphene exposure on plants will weighing all the benefits and risks of its use and making appropriate decisions on the further use of these nanoparticles in the agricultural sector. The purpose of the study was to evaluate the effect of graphene oxide on the morphometric parameters of common cabbage (*Brassica oleracea*) varieties 'Iyunska' by soil application and seed priming.

MATERIALS AND METHODS

The research was conducted in the educational and scientific laboratory "Biochemistry and phytobiotechnology" at the Department of Physiology, Plant Biochemistry, and Bioenergetics of the National University of Life and Environmental Sciences of Ukraine in May-June 2024. *Object of research* was a common cabbage (*Brassica oleracea*) of the ultra-ripe variety 'Iyunska'. Seeds were sown in a universal substrate of the following composition: riding peat, lime flour, perlite, river sand; macronutrients: nitrogen (N) – 80-140 mg/L, phosphorus (P_2O_5) – 100-150 mg/L, potassium (K_2O) – 140-180 mg/L, trace elements. A 3% solution of hydrogen peroxide (H_2O_2) and 0.006% solution of boric acid (H_3BO_3) were used for pre-sowing seed treatment. Pre-sowing seed treatment was carried out according to the following scheme (Fig. 1). Further treatment of seeds and plants was carried out with colloidal solutions of graphene oxide.

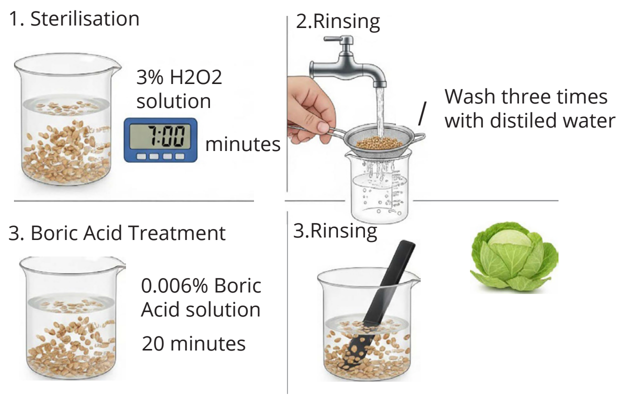

Figure 1. Pre-sowing treatment of cabbage seeds
Source: created by the authors

Synthesis and characterisation of structured graphene oxide nanoparticles. Samples of highly stable water-soluble dispersed graphene oxide (GO) nanoparticles at an initial concentration of 4 mg/mL were provided by Graphenea S.A. (San Sebastian, Spain). The authors confirmed the structural organisation and stability of the samples using high-resolution microscopy and dynamic light scattering. The studies used an aqueous solution of GO in the concentration range: 20, 50, and 70 μg/mL.

Experiment scheme. Cabbage seeds were planted in 7 trays, each of which had 24 wells, 6 seeds in one well: Group 1 – control (without NP treatment); Group 2 – seeds were pre-soaked (priming) in a solution of graphene oxide with a concentration of 20 μg/mL; Group 3 – seeds were pre-soaked in a solution of graphene oxide with a concentration of 50 μg/mL; Group 4 – seeds were pre-soaked in a solution of graphene oxide with a concentration of 70 μg/mL; experimental groups 5, 6, 7 – cabbage seedlings were watered with graphene oxide solution at concentrations of 20, 50, 70 μg/mL, respectively, on days 5 and 10, 5 mL in each well. In addition, all plants were watered at intervals of 4 days with water in the amount of 10 mL per well. The graphene oxide concentrations and application intervals used in the study were selected experimentally, having previously analysed existing scientific data and conducted appropriate pilot studies.

Plants were examined at the stage of 2 leaves (20 days from the moment of planting seeds in the ground). Seed germination was evaluated, and morphometric studies of plants with the determination of such indicators as plant length, stem, root, leaves, weight of plant, stem, and roots. The sample of plants in the study consisted of 30 seedlings from each study group. The results obtained were processed statistically using generally accepted methods of variational statistics by Yu.I. Prylutskyi *et al*. (2017) and using the Microsoft Excel 2010 software suite. Changes in $P \leq 0.05$ were considered statistically significant. The plant research was conducted in accordance with institutional, national, and international guidelines and compliance with the Convention on Biological Diversity (1992) standards.

RESULTS AND DISCUSSION

Carbon nanomaterials have the potential to improve seed germination, nutrient availability, and stress resistance. Increasing crop yields is impossible without developing sustainable agricultural methods, which require additional research into the mechanisms underlying the effects of carbon nanoparticles on plant growth and development. Seed germination is an indicator that is mainly determined by the quality of seed material, and also depends on the cultivation technology, soil and climatic conditions, and other factors. The results of the study showed that the germination rate of cabbage seeds varied significantly in the experimental groups (Fig. 2).

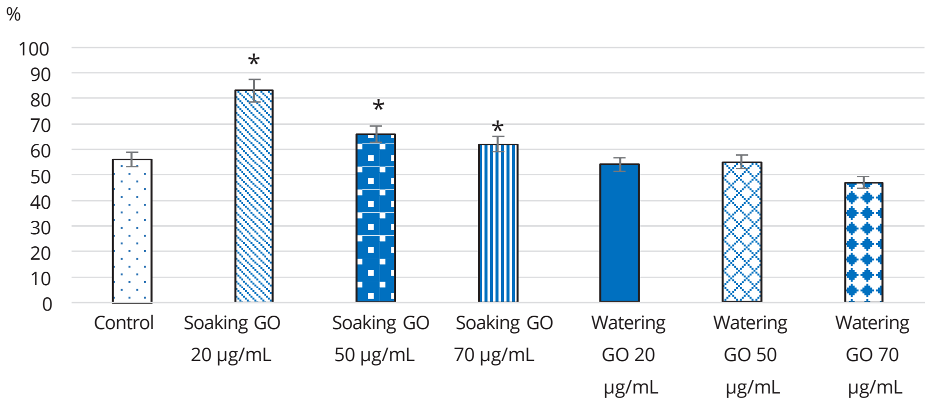

Figure 2. Seed germination (%) of cabbage (*Brassica oleracea*) on Day 20 of cultivation by various methods of treatment with graphene oxide nanoparticles

Note: * $p < 0.05$ compared to the control

Source: created by the authors

It was found that the highest percentage of seed germination of 83% was observed in the Group 2, where the seeds were primed (soaked) in a colloidal graphene oxide solution with a concentration of 20 μg/mL. This figure was significantly higher than in the control group (56%), in which the plants were watered only with water. Groups 3 and 4 also showed higher germination rates, namely 66% and 62%, in which seeds were primed with graphene oxide solutions with concentrations of 50 and 70 μg/mL. It is characteristic that in groups 5, 6 and 7, where graphene oxide was introduced by irrigation, the seed germination rate did not exceed that in the control group of plants (Fig. 2). Cabbage plants grown from seeds pretreated with graphene oxide solutions at concentrations of 20, 50, and 70 μg/mL had, on average, a longer overall length than the control group. The greatest increase in this indicator (32.8%) was observed at a low graphene oxide concentration of 20 μg/mL, while nanoparticle concentrations of 50 and 70 μg/mL were slightly lower, but also stimulated linear plant growth by 23.5% and 19.5%, respectively, compared to the control (Fig. 3).

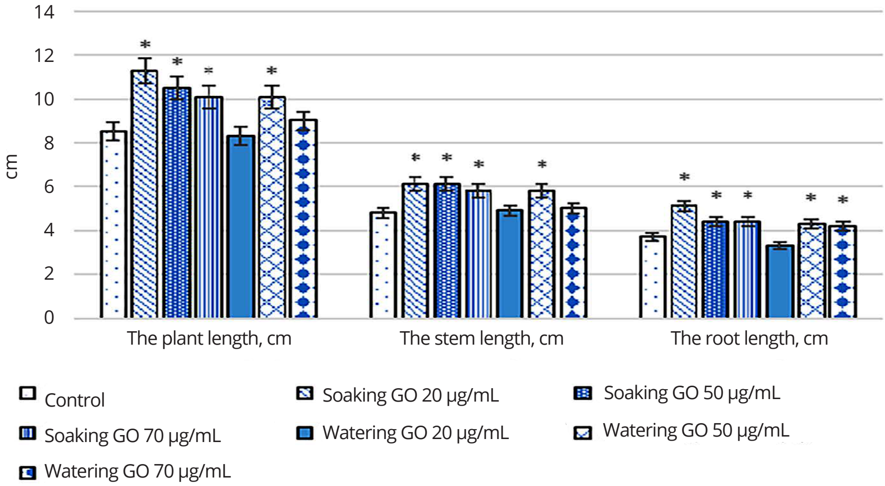

Figure 3. Morphometric parameters (cm) of cabbage (*Brassica oleracea*) on Day 20 of cultivation by various methods of treatment with graphene oxide nanoparticles

Note: * $p < 0.05$ compared to the control

Source: created by the authors

Plant groups in which plants were treated with graphene oxide nanoparticles by irrigation at concentrations of 20 and 70 μg/mL did not have a statistically significant difference in length compared to plants in the control group. However, watering with a colloidal solution with a concentration of 50 μg/mL also stimulated plant growth, since their length exceeded the same parameter of the control group by 19.0%, respectively (Fig. 3). In addition, the length of the STEM and root of plants was estimated by various processing methods. In the groups where seeds were primed with graphene oxide solutions with concentrations of 20, 50, and 70 μg/mL, the average stem length increased by 26.8%, 26.9%, and 20.6%, respectively, compared to plants in the control group. In the experimental groups where graphene oxide root treatment was used by double irrigation, a 21.6% increase in stem length was observed only at a nanoparticle concentration of 50 μg/mL, while no statistically significant changes were observed at other concentrations compared to the plants of the control group (Fig. 3).

According to the data obtained (Fig. 3) experimental groups of cabbage plants in which seeds were primed with graphene oxide nanoparticles with concentrations of 20, 50, and 70 μg/mL showed an increase in the average root length by 37.7%, 19.1%, and 18.1%, respectively, compared with the control group. Those plants that were treated with nanoparticle solutions by irrigation were not characterised by statistically significant changes in root length at concentrations of 20 and 70 μg/mL, and only at concentrations of 50 μg/mL, an increase of 15.5% was noted. Changes in the average length of cabbage leaves were also noted, and depending on the method of treatment with nanoparticles, they were different. In particular, in the groups where seeds were pre-soaked in graphene oxide solutions with concentrations of 20 and 50 μg/mL, the average leaf length was 13.0 and 21.1% longer, respectively, compared to the control group (Fig. 4).

In the experimental groups where irrigation was used, on the contrary, a decrease in the average leaf length of 20 and 70 μg/mL was noted by 13.3% (Fig. 4). Soaking seeds in graphene oxide solutions significantly affected the mass of plants. In the control group, the average plant weight was 213.4 mg. In the groups where seeds were primed with colloidal solutions of graphene oxide with concentrations of 20, 50, and 70 μg/mL, this indicator increased by 23.4%, 59.1%, and 68.5%, respectively. However, no statistically significant changes were observed in the groups with root application of nanoparticle solutions in the specified concentration range compared to the control (Fig. 5).

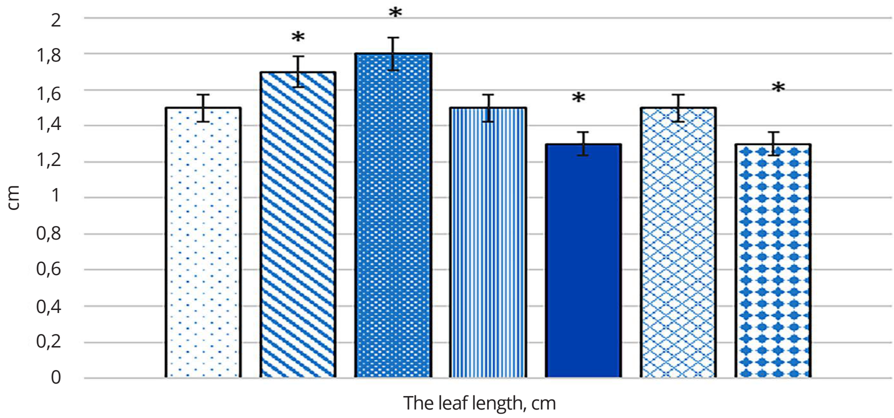

Figure 4. Average length (cm) of cabbage leaves *Brassica oleracea*) on Day 20 of cultivation by various methods of treatment with graphene oxide nanoparticles
Note: * $p < 0.05$ compared to the control
Source: created by the authors

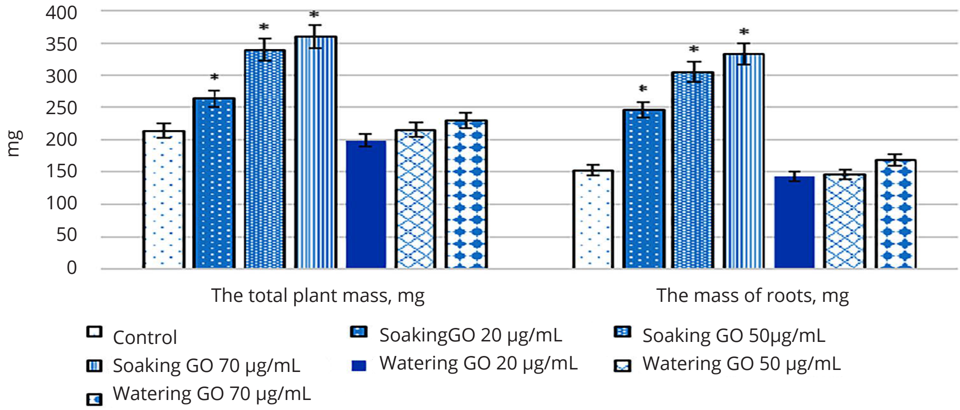

Figure 5. Total weight and root weight (mg) of cabbage seedlings (*Brassica oleracea*) on Day 20 of cultivation by various methods of treatment with graphene oxide nanoparticles
Note: * $p < 0.05$ compared to the control
Source: created by the authors

In addition to the total weight of the plant, the weight of the ground and underground parts of cabbage seedlings was also estimated. According to the results obtained (Fig. 5) the weight of roots differs significantly in the experimental groups. In the control group, the average root weight was 152.6 mg. In the experimental groups where cabbage seeds were primed with graphene oxide solutions with concentrations of 20, 50, and 70 μg/mL, this indicator increased by 1.61, 2.0, and 2.2 times, respectively, compared to the control. No significant changes in this indicator were observed in the experimental groups where irrigation with similar nanoparticle solutions was used compared to the control group. The results of comparing the stem weight showed that cabbage seedlings whose seeds were previously soaked in a graphene oxide solution with a concentration of 20 μg/mL had a stem weight 79.3% lower than that of the control group plants. Similar changes, but less pronounced, were observed in the experimental groups where solutions with concentrations of 50 and 70 μg/mL were used, namely, a decrease in the weight of the ground part of seedlings by 43.1% and 56.6%, respectively (Fig. 6).

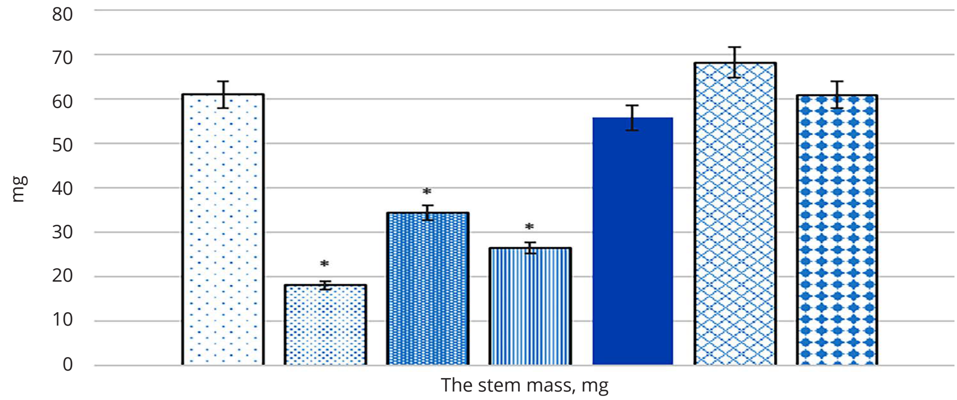

Figure 6. Weight of cabbage seedling stems (*Brassica oleracea*) on Day 20 of cultivation by various methods of treatment with graphene oxide nanoparticles, cm
Note: * $p < 0.05$ compared to the control
Source: created by the authors

No statistically significant changes in stem weight compared to the control were observed in the groups with root application of nanoparticle solutions in the specified concentration range (Fig. 6). Thus, graphene oxide affects seed germination and morphometric parameters of cabbage seedlings (*Brassica oleracea*), in particular, the total length of plants and the length of the stem, root and leaves, and the total weight of plants and the weight of ground and underground parts. The degree of this effect depends on several factors, namely, the concentration of the colloidal solution of nanoparticles and the method of their application.

The study by S. Kondratenko *et al*. (2023) and this study on the effects of graphene oxide share a common goal – to improve productivity of *Brassica oleracea* by using external biologically active factors and assessing their impact on the morphometric parameters of plants. Seed germination is one of the critical points that ultimately determines the quantity and quality of the resulting crop. According to M.T. MacDonald & V.R. Mohan (2025), advanced agricultural technologies involve the use of seed priming to increase its germination and stress resistance. According to M.S. Rhaman *et al*. (2021), seed priming is a physiological method that involves first moistening the seeds and then, usually, drying them, which helps to optimise metabolic processes before germination, increases the percentage and rate of germination, improves plant growth and yield both under optimal conditions and under the action of biotic or abiotic stresses. S. Chakraborti *et al*. (2022) and M.T. MacDonald & V.R. Mohan (2025) note that seed priming can be carried out either with ordinary water or with solutions containing various substances of both biological and chemical origin. Both studies demonstrate innovative approaches to stimulating the growth and development of food crops in the context of contemporary challenges to food security.

As indicated by S. Chakraborti *et al*. (2022), substances of biological origin used for bio-priming include: bacteria, fungi, seaweed extract, humic and fulvic acids, chitosan. Therewith, A. Shelar *et al*. (2021) and M.T. MacDonald & V.R. Mohan (2025) report that chemical priming is carried out using organic acids (ascorbic, salicylic, pyroline), inorganic salts (sodium chloride, potassium nitrate, calcium chloride, calcium sulphate), osmotically active substances (sugar, polyethylene glycol, glycerol, manitglycinbetaine sorbitol), benzimidazoles, synthetic phytohormones, antioxidants, etc. According to A. Shelar *et al*. (2021), recently, seed nanopriming involving engineered nanoparticles, in particular chitosan nanoparticles with copper/zinc or lignin loaded with gibberellic acid, metal nanoparticles, metalloids, and carbon, has become increasingly common. As the results showed, priming seeds with colloidal solutions of graphene oxide of various concentrations (20, 50, and 70 μg/mL) can significantly increase the germination rate of cabbage seeds. The greatest increase in the percentage of seed germination was noted at the lowest studied concentration. The results obtained were confirmed by other studies.

According to the results obtained by I. Vera-Reyes *et al*. (2024), graphene oxide accelerated seed germination and seedling growth of *S. lycopersicum* at concentrations up to 200 mg of L^{-1} due to an increase in the content of reactive oxygen species (ROS), which led to rapid seed germination and higher germination rates. N. Yan *et al*. (2024) note that priming peanut beans with graphene oxide at a concentration of 400 mg L^{-1} causes activation of the carbon and nitrogen metabolic pathways in seeds. As indicated by L. Yang *et al.* (2024), a possible mechanism of effective action of nanopriming on seed germination is stimulation of aquaporin expression and activation of amylase formation.

The ability of graphene to penetrate the seed shell is also proven, which, according to M. Zhang *et al*. (2015), can disrupt the integrity of the seed coat and thus facilitate water absorption, which ultimately ensures faster germination and higher germination rates. Thus, summing up the analysed literature data, it can be argued that graphene oxide promotes the germination of plant seeds, in particular cabbage, due to the following main mechanisms: accumulation of reactive oxygen species in seeds; increased activity of specific enzymes in places of starch accumulation and activation of a number of metabolic pathways; expression of genes, in particular aquaporin; development of mechanical pores in the seed coat by nanoparticles.

However, A. Srivastava *et al*. (2021) note that seed priming affected not only the germination process, but also the preservation of the stimulating effect and increased stress resistance during plant ontogenesis. According to N. Louis *et al*. (2023), priming-induced epigenetic changes can persist and may further affect the priming-induced transgenerational stress memory of plants. According to the results obtained, soaking cabbage seeds in graphene oxide solutions not only improved its germination, but also contributed to linear plant growth, exceeding similar morphometric parameters of cabbage seedlings of those research groups in which nanoparticles were used by irrigation. However, a decrease was noted in plants obtained from primed seeds compared to the control of only one indicator – the raw weight of stems, which did not change in the experimental groups with watering.

Similar effects of graphene on plant growth have been observed by other researchers. According to M. Zhang *et al*. (2015), tomato seedlings grown from graphene-treated seeds had slightly less biomass accumulation than the control, but had significantly longer stems and roots than the control. Z. Zhou *et al*. (2023) noted that graphene oxide at concentrations of 20, 80, and 140 $mg \cdot l^{-1}$ increased the relative growth rate of *I. pseudacorus* and their dry weight, which, according to the researchers, is associated with improved regulation of photosynthetic electron transfer in PSII, the activity of endogenous endothelial cells, and the efficiency of light energy conversion. However, according to X. Xiao *et al*. (2022), various forms of graphene oxide negatively affected photosynthesis in *Brassica napus* L. plants. Reduced graphene oxide reduced the chlorophyll content and activity of the Rubisco enzyme. Graphene oxide directly affected chloroplast membranes, photosystems, and F-type ATPases, damaged photosystems and chloroplast structure, and inhibited carbon fixation.

However, the T. Lopes *et al*. (2021) found that GO nanoparticles prevent the development of abiotic stress in plants. Thus, graphene oxide in combination with a bacterium *Rhizobium* sp. applied to maize plants, increased osmotic and antioxidant protection under drought conditions. According to L. Zhao *et al*. (2022), graphene oxide increased the activity of protective enzymes in soybean plants, hormone content, and the expression of drought-related genes. M. Mazhar *et al*. (2025) noted that soybean plants treated with graphene oxide nanoparticles at concentrations of 50 and 100 ppm showed better growth parameters, reduced oxidative stress, increased activity of antioxidant enzymes (peroxidase, superoxide dismutase, catalase), and reduced arsenic accumulation in seeds under the action of the corresponding stress factor. Thus, the results of the study, and data from other authors, indicate a predominantly positive effect of graphene oxide nanoparticles on the growth and development of agricultural plants. It should be noted that the use of OG nanoparticles by seed treatment is more effective.

CONCLUSIONS

Seed germination and morphometric parameters of cabbage seedlings (*Brassica oleracea*) were studied by various methods of treatment with a nanostructured aqueous solution of graphene oxide. It was found that colloidal solutions of graphene oxide nanoparticles in the concentration range of 20, 50, and 70 μg/mL during seed priming improve the germination of cabbage seeds, while the lowest studied concentration of graphene oxide showed the best results. The root introduction of NP did not affect the similarity index, which indicates the importance of choosing the method of using nanoparticles to obtain a specific effect of exposure.

It should be noted that other studied indicators of cabbage seedlings also reacted more to the action of graphene oxide during seed priming and did not change much during their root application. In particular, there was an increase in such indicators of cabbage seedlings as the total length of plants (19.5-32.8%), stem length (20.6-26.9%), average length of roots (18.1-37.7%) and leaves (13.0-21.1%), average plant weight (23.4-68.5%, and average root weight (1.6-2.2 times) after soaking cabbage seeds in graphene oxide solutions, while each of them had variable changes depending on the nanoparticle concentration. The only indicator that decreased with both methods of applying graphene oxide was stem weight, which requires further research to determine the cause of this effect. Thus, seed priming has a pronounced effect on the linear and mass parameters of seedlings, and in addition, this method is more convenient for use in crop production due to the ease of reproduction, economical use of nanoparticles, and reducing the risk of soil contamination with carbon nanoalotropes. Research in the chosen area is promising for the development of crop production, increasing the yield and stress resistance of agricultural crops in the conditions of total changes in climatic conditions and soil quality. But given the contradictory results regarding the effectiveness of various methods of graphene oxide applications obtained in this study and by other researchers, it is necessary to further investigate the mechanisms of influence of these nanoparticles and optimise practical methods of application with the selection of appropriate concentrations.

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CONFLICT OF INTEREST

None.

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Оцінка впливу оксиду графену на морфометричні показники капусти городньої (*Brassica oleracea*) за різних способів обробки

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Анотація. Зростання кількості населення у світі та зменшення площ родючих ґрунтів у зв'язку з глобальними кліматичними змінами вимагають сучасних наукових рішень щодо збільшення врожайності основних продовольчих культур з метою забезпечення продовольчої безпеки. Метою роботи було дослідити вплив наночастинок оксиду графену за різних концентрацій та способів обробки на лінійні і вагові показники сіянців капусти городньої (*Brassica oleracea*) ультрараннього сорту 'Іюнська'. У роботі використовували фізіологічні методи дослідження з визначенням морфометричних показників рослин та схожості насіння. Для оцінки впливу оксиду графену використовували його наноструктуровані колоїдні розчини у діапазоні концентрацій 20, 50, 70 мкг/мл та двох способів обробки – праймінгом насіння та кореневим внесенням. Встановлено, що оксид графену стимулював схожість насіння капусти при замочуванні насіння в розчинах всіх досліджуваних концентрацій. Найвищий показник схожості насіння відмічали у групі, де для праймінгу був використаний розчин з концентрацією наночастинок 20 мкг/мл. Саме в цій групі схожість насіння становила 83 %, що суттєво перевищує цей показник в контрольній групі – 56 %. Кореневе внесення розчинів оксиду графену аналогічних концентрацій не викликало суттєвих змін зазначеного показника, який залишався в межах контрольних значень. У роботі доведено, що морфометричні показники сіянців капусти більш позитивно реагували на дію наночастинок за праймінгу насіння в противагу внесенню способом поливу. Праймінг насіння капусти різними концентраціями оксиду графену обумовлював збільшення лінійних показників сіянців, яке було найбільш вираженим переважно за концентрації 20 мкг/мл: загальна довжина рослин збільшилась на 32,8 %, довжина стебла на 26,8 %, середня довжина коренів на 37,7 % порівняно з контрольною групою. Середня маса рослин і маса коренів показали найбільше зростання за обробки насіння в розчині оксиду графену концентрацією 70 мкг/мл. Єдиним показником, який негативно відреагував на праймінг наночастинками, є маса стебла сіянців, яка зменшилась за всіх концентрацій. Використання наночастинок вуглецю у рослинництві є перспективним напрямком агротехнологій, що може забезпечити не лише високі показники схожості насіння, а й стимулювати ріст і розвиток продовольчих культур за правильно підібраних концентрацій та способів обробки

Ключові слова: вуглецеві наночастинки; нанопраймінг; рослини; схожість насіння; показники росту