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Effect of fullerene C_{60} on morphometric parameters of microgreen peas (*Pisum sativum*) under water deficit conditions

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Abstract. The relevance of this study was to investigate the impact of abiotic stress, specifically fullerene C_{60} and drought, on the morphometric characteristics of pea microgreens. Drought negatively affects the growth and development of agricultural plants, leading to reduced yields. Carbon nanoparticles, particularly fullerene C_{60}, due to their unique physical, chemical, and biological properties, may serve as modulators of resistance to stressful conditions such as drought, enhancing the physiological and biochemical processes at both the cellular and whole plant levels. This research aimed to investigate the effect of fullerene C_{60} on the morphometric parameters of microgreen peas (*Pisum sativum*) of the ECO variety under water deficit conditions. Structured water-soluble carbon nanoparticles of fullerene C_{60} were employed. C_{60} molecules were transferred from an organic solution into the aqueous phase, followed by ultrasonic treatment. The morphometric indicators evaluated in the microgreen peas included shoot height, shoot diameter, number of leaves, leaf weight, plant weight, and root length.

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The experiment was conducted on the 14th day after treating pea seeds with an aqueous solution of fullerene C_{60} at concentrations of 0.1, 0.2, 0.5, and 1.0 µg/mL with planting in substrates of both linen mats and a soil mixture. Chemical, physical, and physiological methods were employed. Fullerene C_{60} at the given concentration range (0.1-1.0 µg/mL) did not exhibit negative phytotoxic effects on pea microgreens. Moreover, the drought-induced physiological state of the microgreens was restored by pre treatment of the seeds with the fullerene C_{60}. The results demonstrated the absence of phytotoxic effects and confirmed the protective effects of fullerene C_{60} against drought stress in pea microgreens, suggesting the potential of using structured carbon nanoparticles in agrobiotechnologies to regulate stress resistance mechanisms in crops

Keywords: agricultural plants; carbon; nanoparticles; drought; young sprouts

INTRODUCTION

Pea microgreens are a promising crop for cultivation in vertical farms, urban greenhouses, and home gardens, due to their high nutritional value and rapid growth cycle. The study of morphometric indicators enables researchers to assess the overall health of plants and their ability to adapt to various growing conditions. This is particularly important in urban agriculture, where efficient use of space and resources is a key factor. Plants, as living organisms, respond to changes in climatic conditions, and drought is one of the most significant factors affecting their development and functioning. Authors K.-J. Dietz *et al*. (2021) demonstrated that water deficit in the soil can lead to water stress in plants, resulting in stunted growth, reduced yields, leaf loss, and even plant death. Researchers K. Abbass *et al*. (2022) found that drought can also pose a threat to biodiversity, as vulnerable plant species may not be able to adapt to rapid climate change. Additionally, water deficit can deteriorate soil quality and cause erosion, which in turn leads to the reduction of soil fertility and ecosystem stability. Young plants and seedlings are particularly vulnerable to drought due to their limited resources for adapting to water shortages.

Authors C. Ingrao *et al*. (2023) noted that there are several causes of water deficit, such as low rainfall, extreme temperatures, high light intensity, and salinity. On the other hand, the water in the soil may be sufficient, but the plants cannot absorb it. Water stress of this type is referred to as physiological drought (or pseudo-drought). Drought stress leads to changes at the physiological, morphological, ecological, biochemical, and molecular levels in plants. Researchers G.G. Haile *et al*. (2019) demonstrated that drought negatively impacts the quantity and quality of plant growth and yield. The response of plants to water deficit depends on the duration and intensity of the deficit, as well as on the species, age, and stage of plant development. Scientists A. Gupta *et al*. (2020) proved that most plants have developed drought stress resistance mechanisms, which are diverse and species-dependent. Author T.R. Ault (2020) demonstrated that drought also has significant global consequences, affecting various aspects of ecosystems and human life. One of the primary issues is the decline in agricultural productivity, which can lead to food shortages, a food crisis, higher food prices, and famine, especially in crop-growing regions. Simultaneously, drought causes soil degradation, impairing its long-term fertility. Climate change, including rising temperatures and decreases in the amount of precipitation, can contribute to the spread of deserts and the expansion of arid zones.

Authors X. Yang *et al*. (2021) observed that drought stress results in a loss of biodiversity, as many plants and animals cannot adapt to such conditions and are forced to migrate or become extinct. The study of the impact of drought on the morphometric parameters of plants has become an urgent issue, as water deficits cause significant changes in plant biomass, size, and organ shape. In this context, it is important to consider various aspects of the impact of drought on the morphometric parameters of plants to understand the adaptation strategies of plant organisms to extreme climatic conditions and to develop effective measures to preserve plant cover in the face of climate change. A pressing task in agrotechnology is to study the methods and mechanisms for modulating stress resistance in agricultural plants under water deficit conditions. Researchers S.V. Prylutska *et al*. (2022) proved that structured water-soluble carbon nanoparticles, specifically fullerene C_{60}, are promising in this regard due to their unique biological and physicochemical properties, including hydrophobicity.

Scientist N. Gopalakrishnan (2018) noted that carbon nanomaterials are widely used across various industries, particularly as lubricants, in fuel cells, electronics, cosmetics, theranostics, food additives, and antioxidants, among others. The C_{60} molecule, due to its antioxidant activity, can absorb oxygen and nitrogen free radicals and influence plant growth and development, particularly by reducing abiotic-induced oxidative stress, such as water deficit. In addition, authors A. He *et al*. (2021) showed that the hydrophobic C_{60} molecule can interact with cell membranes and affect their permeability; whether this influence is positive or negative depends on the concentration and mode of administration of the nanoparticles. Researchers P.R. Riley & R.J. Narayan (2021) and M. Gaur *et al*. (2021) noted that fullerene C_{60} have promising applications in medicine and pharmaceuticals due to their ability to deliver drugs in a targeted manner and control their release. Thus, fullerene C_{60} is a unique molecule with numerous potential applications in materials science, as well as in both biological and agricultural research. Consequently, the aim of the study was to evaluate the impact of fullerene C_{60} on the morphometric parameters of microgreen peas (*Pisum sativum*) of the ECO variety under drought conditions. The objectives of the study were to assess the dose-dependent effect of fullerene C_{60} on the growth of microgreen peas under regular watering or water deficit when germinated on different substrates, as well as to evaluate the potential phytotoxic and protective effects of the nanoparticles.

MATERIALS AND METHODS

Synthesis and characterisation of structured C_{60} molecules. An aqueous colloidal solution of fullerene C_{60} (150 μg/mL initial concentration) was synthesised and characterised at the Institute of Chemistry and Biotechnology of the Technical University of Ilmenau (Germany) following the method of transferring the C_{60} molecule from an organic solution into the aqueous phase, followed by ultrasonic treatment (Schuetze *et al*., 2011). The structure and size of C_{60} nanoparticles, as well as their stability in aqueous solution, were estimated using microscopic and spectroscopic measurements. An aqueous colloidal solution of fullerene C_{60} was prepared in concentrations of 0.1, 0.2, 0.5, and 1 μg/mL. Pea (*Pisum sativum*) of the ECO variety was chosen as *the object of the study*. Category CH1 seeds (certified seeds of the first generation) from the 2022 harvest, supplied by the private enterprise "ABINA", were used. The drought resistance of this variety is rated at 8.3-8.5 points out of 9, indicating high drought resistance (Sowing peas, 2018).

Conditions of the experiment. Pea seeds were washed to remove contaminants under running water. Damaged seeds with visible signs of pest damage or shell imperfections were discarded. The seeds were then soaked in a 20 g/L NaCl solution for 10 minutes. The seeds that settled at the bottom of the NaCl solution were used for cultivation. To promote faster germination, the seeds were soaked in a 0.02% H_3BO_3 solution for 25 minutes and then washed three times under running water. Subsequently, the seeds were sterilised in 3% H_2O_2 for 15 minutes and washed three times under running water (Fig. 1).

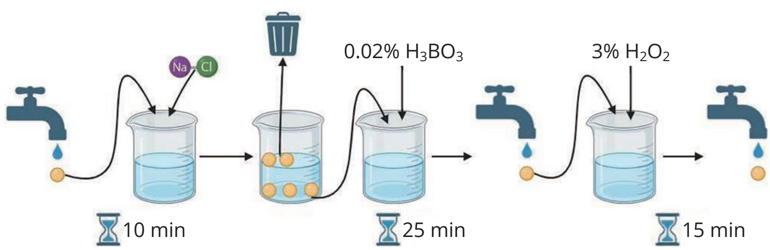

Figure 1. Scheme of pea seed preparation (*Pisum sativum*)
Source: created by the authors

Each sample contained 30 g of seeds, which were pre-soaked for 3 hours in the following solutions: control – distilled H_2O, experimental samples – fullerene C_{60} colloidal aqueous solution at concentrations – 0.1, 0.2 μg/mL, 0.5, and 1 μg/mL. The pea seeds were then transferred to the appropriate containers on the substrate and evenly distributed over the surface (Fig. 2). Containers with seeds pre-treated with carbon nanoparticles (CNPs) were stored for 4 days at room temperature (24°C) in a dark place to allow for germination, then exposed to light/dark conditions of 12/12 hours.

Figure 2. Scheme of treatment and planting of pea seeds (*Pisum sativum*)
Source: created by the authors

To evaluate the growth advantage of microgreen peas, seeds were planted on different substrates: a linen mat (Experiment No. 1) and a universal soil mixture from the manufacturer "Florida" (Experiment No. 2) consisting of turf, raised peat, lowland peat, river sand, mineral fertilisers (Potassium, Sodium, Phosphorus), and microelements (Iron, Zinc, Boron, Copper, Molybdenum, Manganese), with a pH value of 5.5-7.5 (Universal soil mixture, n.d.).

Simulation of drought under laboratory conditions. For the germination of microgreen peas with limited moisture on linen mats (Experiment No. 1), spraying with water was carried out after 3 days. When growing pea microgreens on the soil mixture (Experiment No. 2), drought was simulated using Tumanov's wilting method (Kirichenko *et al.*, 2016), with spraying stopped on the 2nd day after seed germination. Watering of the samples was resumed 1 day before the experiment. Spraying of experimental samples without drought simulation was carried out regularly – every other day. *The assessment of the morphometric indicators of peas* was conducted on the 14th day after seed planting (Fig. 3).

Experiment #1 (linen mats) Experiment #2 (soil mixture)

Figure 3. Photos of microgreen pea plants (*Pisum sativum*) on the 14th day of the experiment in the control groups (under regular watering)
Source: created by the authors

The following parameters were evaluated: plant height, diameter of the main shoot, number of leaves, root length, total plant weight, and leaf weight. Additionally, the ratio of leaf weight to plant weight (as an indicator of photosynthetic effort), the ratio of shoot length to plant weight (as an indicator of relative shoot growth), and the ratio of shoot length to its diameter were determined (Penkovska, 2019). The sample size for the experiments was 10-15 seedlings. The research was conducted in the Educational Scientific Laboratory of Biochemistry and Phytobiotechnology, Department of Physiology, Plant Biochemistry and Bioenergetics, Faculty of Plant Protection, Biotechnology and Ecology at the National University of Life and Environmental Sciences of Ukraine. Experimental studies with plants were conducted following ethical standards (United Nations Convention No. 995_030 "On the Conservation of Biological Diversity", 1992).

Statistical analysis of the obtained research results was conducted using methods of variational statistics, particularly with the t-test and one-/two-way analysis of variance (ANOVA). Differences in indicators with values of $p \leqslant 0.05$ were considered statistically significant (Prylutskyi *et al.*, 2017). Experiments were conducted in at least three replicates for each variant. Graphing and data analysis were performed using Microsoft Excel 2010 and GraphPad Prism 7 software. The results are presented as M (Arithmetic Mean) ± SD (Standard Deviation).

RESULTS AND DISCUSSION

Microgreens are a resilient crop, requiring minimal attention to weather conditions, environmental composition, and growing circumstances, making them easy and quick to cultivate under home or laboratory conditions (Michell *et al.*, 2020). The physiological state of plants was studied during the germination stage, which does not require large reserves of nutrients, water, or light. Accordingly, the objective of this study was to evaluate the effect of biotic factors such as carbon nanoparticles (CNPs) and drought on the early stages of plant growth, particularly the vegetative organs of peas (root, stem, leaves) and the mass of plants and leaves. The research showed that by the 14th day after pea seed germination, differences in morphometric indicators were observed between the control group (under regular watering) and different substrates (Table 1, Table 2).

Table 1. Morphometric indicators of microgreen peas on the 14th day after germination on a linen mat (Experiment No. 1) under regular watering and water deficit (M ± m, n = 15)

Morphometric indicators	Regular watering (control)	Water deficit
The height of the main shoot, cm	10.2 ± 1.7	6.5 ± 0.58
The diameter of the main shoot, mm	1.8 ± 0.255	1.7 ± 0.03
The number of leaves, pcs	4.0 ± 0.35	2.0 ± 0.17
The total plant mass, g	0.812 ± 0.065	0.715 ± 0.680
The mass of all leaves, mg	44.0 ± 0.039	20.0 ± 0.18
The root length, cm	15.4 ± 3.4	12.6 ± 1.7

Source: created by the authors

The morphometric indicators for plants grown on the soil mixture (Experiment No. 2) were significantly higher compared to those grown on the linen mat (Experiment No. 1). Specifically, the height of the main shoot was 1.5 times greater, the diameter of the main shoot and the number of leaves were 1.7 times greater, the total plant mass was 1.9 times higher, and the leaf mass was 4.3 times greater in Experiment No. 2 compared to Experiment No. 1 (Table 1, Table 2). Therefore, microgreen pea germination is more effective in the soil mixture, which allows for the production of higher-quality plant material under laboratory conditions.

Table 2. Morphometric indicators of microgreen peas on the 14th day after germination in the soil mixture (Experiment No. 2) under regular watering and water deficit (M ± m, n = 15)

Morphometric indicators	Regular watering (control)	Water deficit
The height of the main shoot, cm	15.5 ± 1.46	5.7 ± 0.54

Table 2. Continued

Morphometric indicators	Regular watering (control)	Water deficit
The diameter of the main shoot, mm	3.0 ± 0.29	2.2 ± 0.17
The number of leaves, pcs	7.0 ± 0.66	5.0 ± 0.376
The total plant mass, g	1.543 ± 0.11	0.795 ± 0.055
The mass of all leaves, mg	191.0 ± 18.6	46.0 ± 3.82
The root length, cm	13.2 ± 1.29	8.3 ± 0.75

Source: created by the authors

Under water-deficit conditions, on the 14^{th} day after pea seed germination, a significant decrease in the studied morphometric indicators of pea plants was observed both on linen mats (Experiment No. 1) and in the soil mixture (Experiment No. 2). In particular, with insufficient substrate hydration, a decrease was noted in the height of the main shoot by 1.6 times (Experiment No. 1) and by 2.7 times (Experiment No. 2), the diameter of the main shoot by 1.4 times (Experiment No. 2), the number of leaves by 2 times (Experiment No. 1) and by 1.4 times (Experiment No. 2), the total plant mass by 1.9 times (Experiment No. 2), the mass of all leaves by 2.2 times (Experiment No. 1) and by 4 times (Experiment No. 2), and the root length by 1.2 times (Experiment No. 1) and by 1.6 times (Experiment No. 2) compared to plants grown under regular watering conditions. Thus, under simulated water-deficit conditions, a significant decline in the morphometric indicators of microgreen peas was observed.

It is known that drought slows down plant development by reducing the evaporative surface, which inhibits the growth of leaves and shoots (Priadkina *et al.*, 2022). This, in turn, leads to a decrease in plant mass, particularly the leaves. During droughts, the plant allocates its resources towards the development of the root system to search for water at greater depths. It was shown, that under drought conditions, the ratio of root length to shoot height in peas was 1.9 times and 1.5 times greater in Experiment No. 1 and Experiment No. 2, respectively, compared to the control (regular watering) (Table 1, Table 2). Drought poses a significant threat to agriculture, leading to a reduction in crop yields, loss of soil fertility, and ecosystem imbalances (Hoffmann *et al.*, 2018). Water deficit in the soil results in stunted plant growth, reduced crops, leaf loss, and the eventual death of plants (Mukarram *et al.*, 2021). A current priority is the study and modulation of stress resistance mechanisms in plants induced by water deficit. To increase the resistance of agricultural crops to drought, fullerene C_{60} carbon nanoparticles were used.

The effect of fullerene C_{60} on the morphometric parameters of peas germinated on different substrates under regular watering conditions was investigated. It was shown that fullerene C_{60} had a substrate- and dose-dependent effect on pea microgreens (Fig. 4). Thus, under germination conditions on linen mats (Experiment No. 1), a decrease in leaf mass was observed after treatment with 0.2, 0.5, and 1 μg/mL fullerene C_{60} by 29%, 32%, and 31%, respectively, compared to the control without the addition of CNPs (Fig. 4). Under germination conditions on the soil mixture (Experiment No. 2), after treatment with 0.5 and 1 μg/mL fullerene C_{60}, a decrease in total plant weight by 24% and 32% and in leaf weight by 23% and 24%, respectively, was observed compared to the control without the addition of CNPs (Fig. 4). In addition, fullerene C_{60} at 0.1 and 0.2 μg/mL concentrations did not affect the studied morphometric indicators of microgreen peas.

Therefore, fullerene C_{60} in the studied concentration range (0.1-1 μg/mL) did not cause a negative phytotoxic effect on pea microgreens. Next, the effect of fullerene C_{60} on the morphometric parameters of peas under water-deficit conditions was investigated (Fig. 5). For this, a model of drought tolerance of microgreen peas on a soil mixture was used, as plant growth indicators were more markedly reduced on this substrate. The physiological state of microgreen peas of the ECO variety, induced by drought, was restored after the seeds were pre-treated with fullerene C_{60} (Fig. 5). The protective effects of CNPs are evidenced by the increase in the studied morphometric indicators. Thus, the height of the main shoot and the weight of the leaves after treatment with 0.1, 0.2, and 0.5 μg/mL fullerene C_{60} were twice as high compared to the respective indicators under water deficit without the addition of CNPs. It was also noted that the root length in plants treated with 0.1 μg/mL, 0.2 μg/mL, and 0.5 μg/mL fullerene C_{60} was 51%, 22%, and 20% longer, respectively, compared to untreated plants. The diameter of the main shoot increased slightly (Fig. 5). Fullerene C_{60} helps maintain water balance and assists plants in better retaining water, improving the condition of cell membranes and increasing the efficiency of water use. Together, these mechanisms provide plants with better drought tolerance by preserving or even improving morphometric indicators (Kovač *et al.*, 2021).

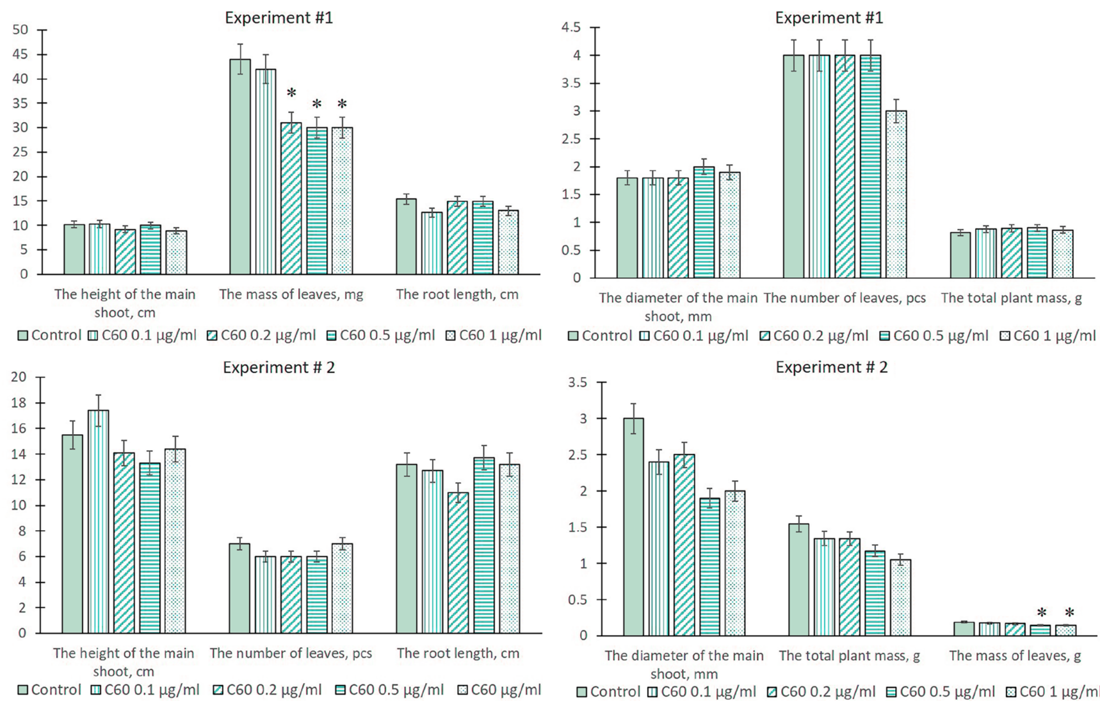

Figure 4. Morphometric indicators of microgreen peas on the 14th day after treatment with fullerene C_{60} and germination on a linen mat (Experiment No. 1) and soil mixture (Experiment No. 2) under regular watering

Note: *P < 0.05 in comparison with control

Source: created by the authors

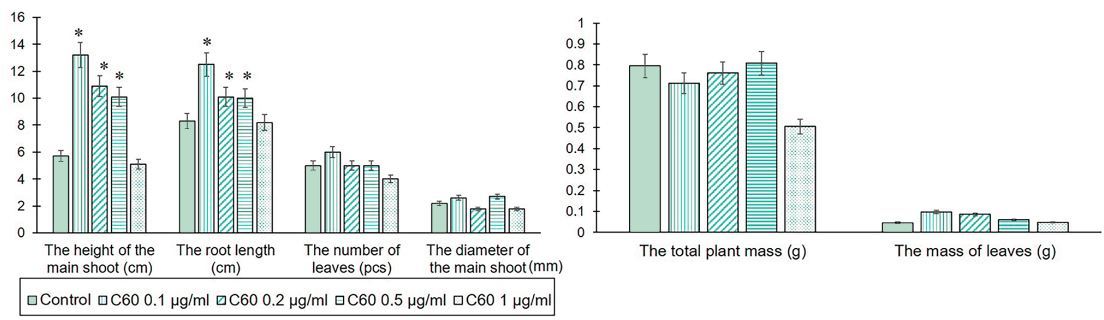

Figure 5. Morphometric indicators of microgreen peas on the 14th day after treatment with fullerene C_{60} and germination on the soil mixture under water deficit

Note: *P < 0.05 in comparison with control

Source: created by the authors

An important task of agricultural technologies is the development of comprehensive approaches that allow for the study of the impact of drought on the physiological state of agricultural plants and their mechanisms of adaptation to extreme climatic conditions, as well as the development of effective biotechnological strategies for plant preservation in the context of climate change. Water deficit causes significant changes in the biomass, size, and shape of plant organs; thus, the study of the impact of drought on the morphometric parameters of plants is particularly relevant (Seleiman *et al*., 2021). Long roots are one of the key morphological features that facilitate adaptation to water deficit. This morphological feature plays an important role in providing drought resistance (Wasaya *et al*., 2018). Long roots ensure stable access to water for plants, even in challenging climatic conditions, thereby contributing to their survival and productivity (Lynch, 2018). In particular, authors M. Rezayian *et al*. (2018), and O. Basal *et al*. (2020) showed that plants under the influence of drought develop a long root system and exhibit better stress tolerance and drought resistance, while plants with short roots are more vulnerable to drought. The authors S. Jafarnia *et al*. (2018) demonstrated that the height of seedlings of the Persian oak (*Quercus brantii*) significantly decreased under water deficit.

The study of the effect of nanosized and structured carbon nanoparticles (CNPs) on plants is a significant and promising area of modern agrobiotechnologies. CNPs, due to their nanoscale size and unique physicochemical properties, are capable of altering the morphological, physiological, and biochemical parameters of plants. The results of the research by S.K. Khorrami *et al*. (2020) indicated that MWCNTs at low and medium concentrations (50 and 100 mg/L) had a positive effect on the morphological and anatomical characteristics of both varieties of *Hibiscus esculentus* L. (Bamia and Emerald). However, at high concentrations of MWCNTs (200 mg/L), a negative effect was observed on both varieties of bamia. The authors suggest that the positive effects of MWCNTs can be attributed to their ability to promote water absorption, cell division, and elongation in both okra varieties, while the negative effects may be linked to the destructive impact of MWCNTs on different parts of the cells, particularly on membranes and biological organs. When comparing the effects of natural and synthetic MWCNTs, the authors G. Juárez-Cisneros *et al*. (2020) demonstrated that CNPs formed after forest fires lead to better plant growth and development than chemically synthesised MWCNTs.

Moreover, literature data indicates the potential of carbon nanoparticles to reduce the negative effects of drought and increase the resistance of plants to adverse climatic conditions. The authors J.-L. Xiong *et al*. (2018) studied the germination of *Brassica napus* L. seeds under water deficit conditions after treatment with a water-soluble fullerol derivative at different concentrations (0.01; 0.1; 1; 10; 100; 500; 1,000 mg/L). To simulate drought, rapeseed was germinated in a 15% PEG 6000 medium. It was shown that fullerol in the concentration range of 0.1-100 mg/L had a positive effect on seed germination, while no such effect was observed at high concentrations (500 and 1,000 mg/L). Additionally, fullerol in *B. napus* reduced water stress during seed germination, growth, and photosynthesis.The authors S.Z. Ahmadi *et al*. (2024) demonstrated that, following the application of carbon nanomaterials such as graphene nanotubes and nanoplates at concentrations of 100, 200, and 1,000 mg/L, the number of flowers of *Capsicum annuum* L. increased at both 50% and 100% soil moisture content compared to the control group, which did not receive nanomaterials. Moreover, after the treatment of leaves with carbon nanomaterials, the negative impact of water deficit stress on the mass of roots in both fresh and dry conditions was reduced. After using 200 mg/L GNMs and 1,,000 mg/L MWCNTs at 100% soil moisture content, the number of fruits increased compared to the control group under the same watering conditions. MWCNTs at a concentration of 1,000 mg/L significantly increased the photosynthetic rate and stomatal conductance in both stressed and non-stressed conditions compared to the control. The application of carbon nanomaterials, namely 1,000 mg/L fullerene C_{60}, 200 mg/L graphene nanoplates, and 100 mg/L MWCNTs, increased the amounts of chlorophyll *b*, total phenols, and flavonoids.

MWCNTs have been shown to induce seed germination in oats (Joshi *et al*., 2018b), and wheat (Joshi *et al*., 2018a). It is assumed that MWCNTs, by penetrating through the seed coat and cell walls, form new pores, which increases water absorption and promotes seed germination. Thus, the results obtained and the literature confirm the potential of carbon nanoparticles for regulating the growth, development, and yield of agricultural plants. The effect of carbon nanomaterials on plants depends on the type and concentration of nanoparticles. However, the physiological and biochemical mechanisms underlying the action of these carbon nanostructures are insufficiently understood, which necessitates further research.

CONCLUSIONS

The influence of abiotic factors, particularly fullerene C_{60} and drought, on the physiological state of microgreen peas (*Pisum sativum*) germinated on two substrates, namely linen mats and a soil mixture, was investigated under laboratory conditions. It was shown that the germination of microgreen peas is more effective on the soil mixture than on linen mats. Morphometric indicators of the vegetative organs of peas (roots, stems, and leaves), as well as the mass of the plants and leaves at the initial stages of growth, were evaluated 14 days after seed germination. Under conditions of simulated water deficit, a significant decrease in the morphometric parameters of microgreen peas was noted, namely, the height of the main shoot decreased by 1.6 times (Experiment No. 1) and by 2.7 times (Experiment No. 2); the diameter of the main shoot decreased by 1.4 times (Experiment No. 2); the number of leaves decreased by 2 times (Experiment No. 1) and by 1.4 times (Experiment No. 2); the total plant mass decreased by 1.9 times (Experiment No. 2); the mass of all leaves decreased by 2.2 times (Experiment No. 1) and by 4 times (Experiment No. 2); and root length decreased by 1.2 times (Experiment No. 1) and by 1.6 times (Experiment No. 2) compared to plants germinated under conditions of regular watering.

Fullerene C_{60} exhibited a substrate- and dose-dependent effect on pea microgreens. Fullerene C_{60} at concentrations of 0.1 and 0.2 μg/mL did not exhibit any negative effects. The study showed that the physiological state of microgreen peas induced by drought was restored after pre-treatment with fullerene C_{60}. The protective effect of CNPs was evidenced by a twofold increase in the height of the main shoot, the mass of leaves, and the length of the pea root compared to the indicators under water deficit without the addition of CNPs. Thus, the absence of phytotoxic effects and the protective effects of fullerene C_{60} against induced drought resistance in microgreen peas indicate the promising use of structured carbon nanoparticles in agrobiotechnologies for regulating stress resistance mechanisms in agricultural plants, which requires further physiological and biochemical research.

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CONFLICT OF INTEREST

None.

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Вплив фулерену C_{60} на морфометричні показники мікрозелені гороху (*Pisum sativum*) за умов водного дефіциту

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Анотація. Актуальність роботи полягає у вивченні впливу абіотичних чинників, зокрема фулерену C_{60} та посухи на морфометричні показники мікрозелені гороху. Посуха негативно впливає на ріст і розвиток сільськогосподарських рослин, що знижує їх врожайність. Вуглецеві наночастинки, зокрема фулерен C_{60}, можна використовувати як модулятор стійкості стресових умов для покращення перебігу фізіологічних та біохімічних процесів як на рівні клітини, так і організму рослин. Однак, внутрішньоклітинні механізми взаємодії вуглецевих наночастинок з рослинами є недостатньо вивчені. Метою роботи було дослідити вплив фулерену C_{60} на морфометричні показники мікрозелені гороху (*Pisum sativum*) сорту ECO за водного дефіциту. У роботі використано структуровані водорозчинні вуглецеві наночастинки фулерену C_{60}. Було оцінено такі морфометричні показники мікрозелені гороху як висота пагона, діаметр пагона, кількість листя, маса листя, маса рослини та довжина кореня. Дослідження проводилися на 14 день після обробки насіння гороху водним розчином фулерену C_{60} за концентрацій 0.1, 0.2, 0.5 та 1.0 мкг/мл та висаджених на різних субстратах – лляних килимках і ґрунтосуміші. У роботі було використано хімічні, фізичні та фізіологічні методи. Було показано, що на 14 день після пророщення насіння гороху у контролі (за умов регулярного поливу) на різних субстратах спостерігаються відмінності у морфометричних показниках. Фулерен C_{60} за концентрацій (0.1-1.0) мкг/мл не спричиняв негативного фітотоксичного впливу на мікрозелень гороху. Тоді як фізіологічний стан мікрозелені гороху сорту ECO індукований посухою відновлювався за попередньої обробки насіння розчином фулерену C_{60}. Відсутність фітотоксичних ефектів та захисні ефекти фулерену C_{60} від індукованої посухи у мікрозелені гороху свідчить про перспективність використання структурованих вуглецевих наночастинок у агробіотехнологіях для регуляції механізмів стресостійкості у сільськогосподарських культур

Ключові слова: сільськогосподарські рослини; вуглецеві; наночастинки; посуха; молоді паростки