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AKADÉMIAI KIADÓ

The impact of irrigation with harvested rainwater containing asbestos cement matrix on the germination characteristics of *Solanum lycopersicum*

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RESEARCH ARTICLE

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ABSTRACT

The study aims to investigate how the transfer of matrix materials from eroded asbestos cement products induces stress responses in plants. The paper evaluates the exposure and risk factors of plants, water, and soil to asbestos cement materials. Additionally, the experimental results provide empirical evidence for plant stress responses based on physiological and germination parameters. Contamination of irrigation water with asbestos cement raises environmental concerns due to its potential toxicity to plants and soil quality. Asbestos in irrigation water can lead to toxic stress for plants, affecting germination processes and growth. The paper analyzes the effects of preset doses of irrigation water containing asbestos cement matrix on the germination process and physiological parameters of *Solanum lycopersicum* in a controlled experiment setting. This research proposes methodological developments that could be valuable for environmental plant protection professionals.

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KEYWORDS

asbestos cement matrix, irrigation water, germination characteristics, *Solanum lycopersicum*

INTRODUCTION

Asbestos minerals are commonly found in the environment (Mahini, 2005). According to Lewis et al. (1996), asbestos is a general term that encompasses two groups of fibrous minerals with different crystalline and chemical properties: amphiboles (crocidolite, amosite, anthophyllite, actinolite, tremolite) and serpentine (chrysotile). These minerals have specific forms which provide them with elasticity (tensile strength), high surface area, and resistance to heat and chemical degradation (Van Orden, 1964). Nayak (2016) defines asbestos as a broad term encompassing six types of fibrous materials primarily composed of silica, magnesia, and crystalline water.

According to Tóth and Weiszburg (2011) asbestos fibers are characterized as fibers with a length exceeding 5 μm and a diameter less than 3 μm, but with a length-to-diameter ratio greater than 3:1. These fibres are chemically inert - they do not evaporate, dissolve or release into the environment to any significant extent (Mahini, 2005). Due to their microscopic size, these fibers can be easily inhaled and deposited in various parts of the respiratory system, including the air sacs (Douguet et al., 2013). Asbestos is commonly used in producing insulation, textiles, building materials and various appliances. Inhaling asbestos fibers can lead to health issues such as asbestosis and lung cancer, pleural fibrosis and mesothelioma; although peritoneal mesothelioma occurs less frequently (Lotti and Bergamo, 2014; Mossman et al., 1996).

Cement composite containing asbestos fibres has been widely used in many countries around the world since the Second World War (Stevulova et al., 2022), and asbestos cement products have since become a popular construction material, with the most commonly used product forms accounting for 70% of the world's asbestos production (Ingham, 2013), rather over 90% (Stevulova et al., 2022). The global use of asbestos increased exponentially between 1940 and 1980, until it peaked in 1980 (Virta, 2006). Despite the fact that the manufacture and sale of asbestos-cement products is now banned or restricted in most countries, the use of previously installed products remains unregulated, which is particularly true for asbestos-cement roofing elements with corrugated characteristics, which are also widely used as roofing for agricultural facilities, or even for pressure pipes.

Bassani et al. (2007) suggest that asbestos cement is intrinsically brittle, with limited resistance to impact, making it vulnerable to cracking and fracturing from minor impacts, repeated loading, or failed fasteners. Deterioration and erosion of asbestos products lead to the release of asbestos fibres into the air and stormwater, which eventually contaminate the soil indirectly (Van Orden, 1964). The well-documented transformation process for these products involves fragmentation, cracking and spalling caused by external or human-induced factors (Burragato et al., 2010; Bint et al., 2017). Chrysotile accounts for about 95% of the asbestos used in building materials, while other amphiboles are seldom used due to their extreme brittleness and thinness – a characteristic also seen in Hungarian products (Bassani et al., 2007). Chrysotile has the potential to be carried into water systems, and its physical properties can lead to some dissolution in aquatic environments, particularly at low pH levels (Van Orden, 1964). Research by

Spurny (1989) suggests that the surface of an asbestos-cement slate slab may experience corrosion of approximately 0.01–0.024 mm per year due to weathering changes. According to (Spurny, 1989; Suzuki et al., 2005) indicate that a square meter of corrugated asbestos-cement sheet could lose several grams of asbestos annually, with up to 3 g being released from its matrix structure. While it is claimed by many that asbestos fibres emitted from these products do not present health or environmental risks, it should be acknowledged that a significant portion of the population resides or works in affected areas; hence unknown risks persist as an area for concern rather than justification for assurance (Kottek and Yuen, 2022). The primary factors contributing to the release of asbestos fibres from the matrix structure include weather events, extreme weather conditions, and sudden increase in precipitation attributed to climate change (Bornemann and Hildebrandt, 1986). While asbestos fibres from asbestos cement may not accumulate in the air (Tóth and Weiszburg, 2011), they can be discharged into rainwater leading to water contamination, subsequently causing soil pollution and phytotoxic stress on vegetation. The potential hazard of asbestos cement contaminating rainwater presents a risk due to prolonged drought resulting from climate change, as well as the shift towards using agricultural and horticultural irrigation for other purposes.

The process of asbestos contamination involves a complex mechanism with one crucial element being its stress-inducing effect. Trivedi and Ahmad (2011) have previously highlighted that water and soil contaminated by asbestos result in toxicity that hinders germination processes while affecting seed quality characteristics. O'Dell and Claassen (2006) also indicated that chrysotile asbestos-contaminated soil creates a challenging environment for plant growth, impacting productivity through disruption of nutrient levels. The adverse impacts were gauged through parameters such as shoot height, root length, biomass, chlorophyll, and plant protein content (Trivedi et al., 2004, 2007; Trivedi and Ahmad, 2011, 2013). It is now commonly understood that chrysotile asbestos has unfavorable implications on the growth and nutrient absorption of *Panicum virgatum* and *Phleum pretense*, affecting all morphological aspects. Furthermore, there was a notable increase in the uptake of metals like Cr, Mn, V, As and Ba too (Saleem et al., 2022).

MATERIAL AND METHOD

The research examined and assessed the germination characteristics and their variability in four types (Manó, Vilma, Kecskeméti 549, Mobil) of *Solanum lycopersicum* to confirm the harmful effects of irrigation water contamination by asbestos cement on plant growth through a simulated distilled water experiment.

Experimental arrangement and conditions for germination

Four varieties of *S. lycopersicum* (Manó, Vilma, Kecskeméti 549, Mobil) were examined to study the impact of stress induced by varying doses. The *S. lycopersicum* seeds underwent surface sterilization using 2.0% NaOCl for 2 min, followed by three rinses with sterile distilled water. Subsequently, 10 batches of 10 seeds each were placed in separate sterile petri dishes containing moistened cotton disc. The petri dishes were then kept at room temperature and the germination process was observed. To calculate the germination percentage, the number of germinating seeds was divided by the total number of seeds and multiplied by 100%, as per the method of Ranganathan and Thavaranjit (2015).

$$\mathrm{GR} = \frac{\mathrm{NGS}}{\mathrm{NS}} \times 100 \tag{1}$$

Where: GR-germination rate (%), NGS- number of germinated seeds, NS- number of seeds. To examine the harmful impacts of chrysotile asbestos, a type of asbestos used in cement products, on *S. lycopersicum* (tomato plant), it underwent testing for 31 days with alternating periods of 16 h of light and 8 h of darkness while maintaining controlled humidity levels.

Preparation of sample solutions, doses

Samples of asbestos cement products commonly utilized in Hungary were examined for this study. These Hungarian asbestos cement products contained chrysotile asbestos with an average content of 8.00–10.0%, alongside a composition of 90.0–92.0% cement. Investigating these specific attributes simultaneously was essential due to the combined impact on matrix loss from the erosion and degradation of the products. Concentrations of solutions were prepared in the laboratory at 1.00, 2.00, 5.00, 10.0, 25.0 and 50.0 mg L^{-1} in a volume of doubly distilled water. The control was a double distilled water treatment, furthermore a harvested rainwater sample was included in the experiment too. The seeds received treatment twice weekly based on the corresponding dosage for their specific treatment method.

Germination analysis

Sowing 10 seeds per petri dish resulted in a total of 400 seeds ($N = 8 \times 50$), and the continuous measurement of seed germination was carried out for 31 days after sowing for all four seed types. The analyses included 5 petri dishes for each treatment dose ($N = 5 \times 10$). For one set of samples, a harvested rainwater sample from eroded and degraded asbestos cement roof structure with corrugated characteristics was used. Throughout this period, the germination rate, time taken for germination, as well as root length and shoot height were continuously monitored. The measurements for root length included the part just touching the surface of the cotton disc and tip of the main root while shoot height measurements considered the part just touching the surface of the cotton disc along with the tip of the plant at day 31. Each treatment comprised multiple replicates, and the findings are displayed as the mean plus standard error. The data underwent statistical analysis and assessment of statistical correlations.

RESULTS

Figure 1 illustrates the normal germination duration of four varieties of *S. lycopersicum* in the control group. Out of the four groups studied, the germination rate was 90.0% for Manó, Vilma and Kecskeméti 549 and 96.0% for Mobil. Seed germination of *S. lycopersicum* under both light and dark conditions at 25.0 °C was around or above 90.0% for the control group. Onset of germination occurred on days 3rd and 4th on average. In the case of Manó it occurred on day 3rd, Vilma on day 3rd, Kecskemét 549 and Mobil on day 4th under 25.0 °C conditions. An increase in germination was observed on day 10$^{\mathrm{th}}$. In the case of Manó, stagnation, reaching

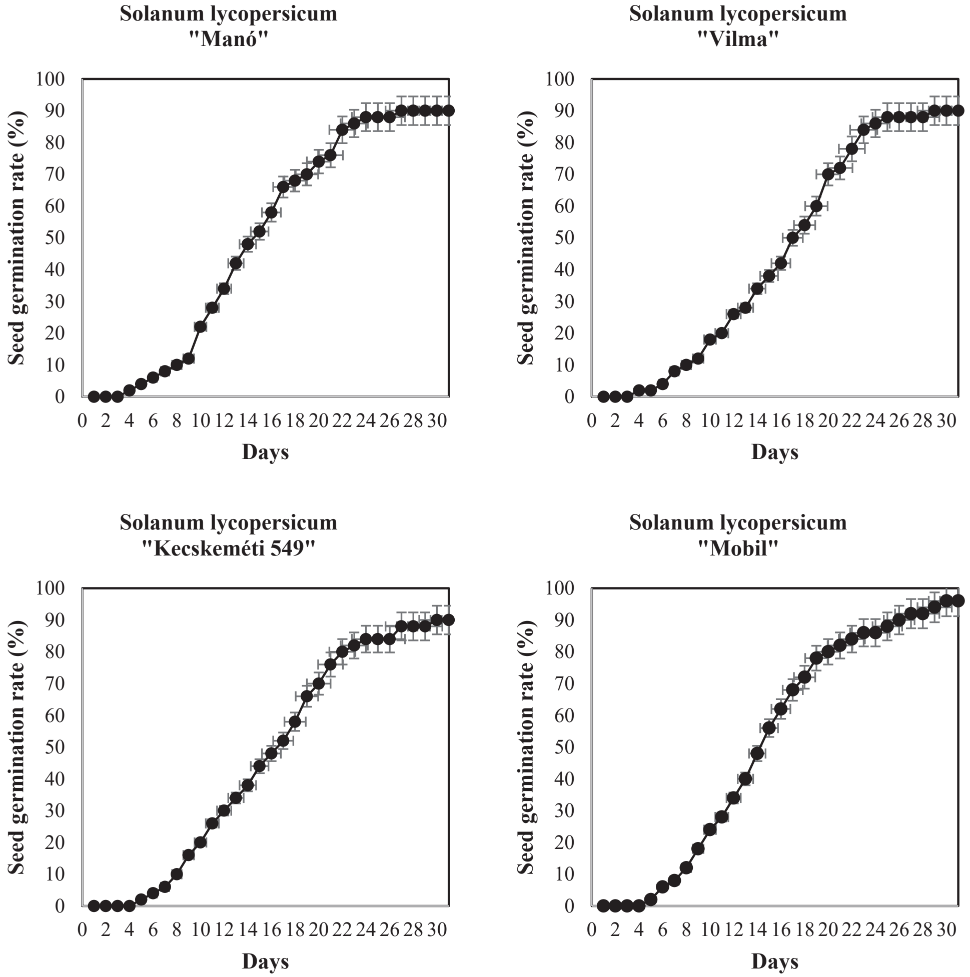

Fig. 1. Comparative analysis of the germination time of the seeds tested

a germination rate of 90.0%, occurred on day 26th. For Vilma, this occurred on day 28th, and for Kecskemét 549 and Mobil, germination rate was reached on day 29th. The germination rate decreased with increasing dose concentrations. The mean germination rate of the entire seed samples is 91.5 ± 3.00%. For the harvested rainwater samples, the average germination rate was 89.0 ± 2.58%.

At dose concentration of 1.00 mg L^{-1} the germination rate was 96.7 ± 1.21%, while at 2.00 mg L^{-1} it was 90.8 ± 3.52%. An average decrease of around -12.1% was observed at the 5.00 mg L^{-1} dose. At dose of 5.00 mg L^{-1} the rate value was 78.7 ± 1.10%. The average germination rates were 70.0 ± 1.32% for 10.0 mg L^{-1} exposure, 58.0 ± 2.99% for 25.0 mg L^{-1} dose and 52.0 ± 3.26% for 50.0 mg L^{-1} contamination. Figure 2 illustrates the germination rate relative to the control group based on the response to each dose concentration. At 50 mg L^{-1},

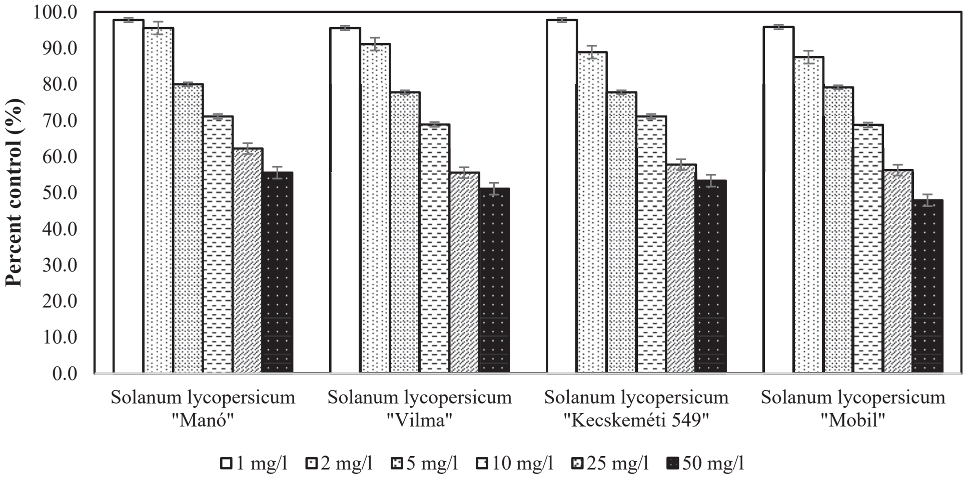

Fig. 2. Comparative analysis of the germination rate of the seeds tested
Mean values ± standard error are presented as a percentage of the corresponding control levels (%)

the germination rate decreased to 55.6% in the case of Manó, 51.1% in the case of Vilma, 53.3% in the case of Kecskeméti 549 and 47.9% in the case of Mobil. On average, the extent of variation at a concentration of 50 mg L^{-1} and 1 mg L^{-1} is $-44.8 \pm 2.35\%$. The decline value was −42.2% for Manó, −44.4% for Vilma, −44.4% for Kecskeméti 549 and −47.9% for Mobil. The analysis into seed germination decline included simulating samples of low and highly contaminated water, indicating that real contamination levels are in the middle. The variation in germination rates between the seeds exposed to the harvested precipitation sample and those at 50 mg L^{-1} were −41.9% for Manó, −47.7% for Vilma, −46.7% for Kecskeméti 549, and −50.0% for Mobil. The average value is $-46.6 \pm 3.43\%$. The average germination ratio for the two samples is 53.4 ± 3.43%, for Manó is 58.1%, for Vilma is 52.3%, for Kecskeméti 549 is 53.3%, for Mobil is 50.0%. The decrease in seed sprouting is due to the presence of asbestos, specifically chrysotile asbestos, which negatively impacts both the internal and external factors involved in germination (Trivedi and Ahmad, 2011). Many other studies have also found a decrease in seed germination under adverse conditions due to partial dehydration of seeds and a significant decrease in the process of respiration. The harmful effects of asbestos on germination may be attributed to protein deformation or an up-regulation of the transcription process, however, the specific mechanism involved is still unclear (McIlrath et al., 1963; Shukla et al., 2006; Trivedi and Ahmad, 2011; Luo et al., 2018).

The rate to the control group in root length resulting from asbestos cement content in the irrigation water differed among all tested *S. lycopersicum* seeds, ranging from 41.1 to 94.3% (Fig. 3). Specifically, for the Manó seeds, the reduction ranged from 47.7% (50.0 mg L^{-1}) to 94.3% (1.00 mg L^{-1}). For Vilma, the percentage of root length in relation to the control group varied between 46.0 and 90.8%. For Kecskeméti 549, this range was 44.3–88.6%, while for Mobil it was 41.1–91.1%. At a concentration of 1.00 mg L^{-1}, the mean value of the root length ratio is 91.2 ± 2.34%, while at 2.00 mg L^{-1} it is 84.4 ± 3.17%. The average ratio is 74.3 ± 4.03% for 5.00 mg L^{-1}, 59.8 ± 4.43% for 10.0 mg L^{-1}, 52.4 ± 4.26% for 25.0 mg L^{-1} and 44.8 ± 2.82%

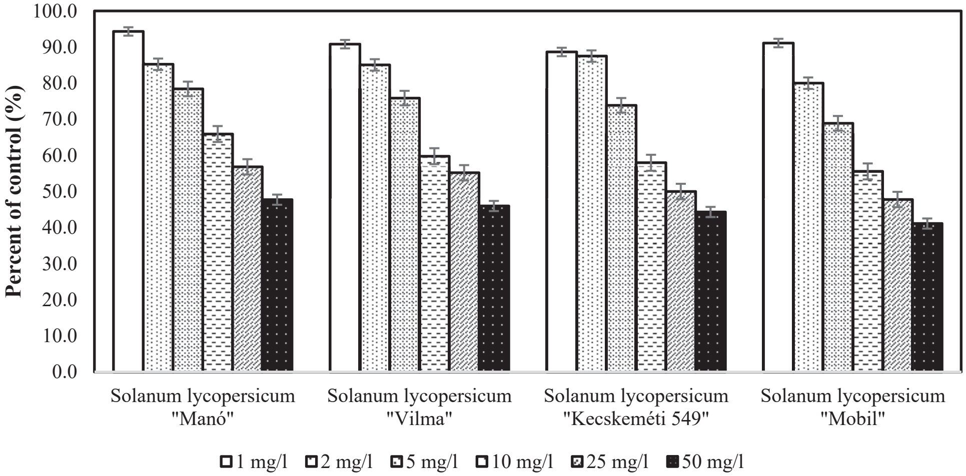

Fig. 3. Comparative examination of the length of the roots that were analyzed
Mean values ± standard error are presented as a percentage of the corresponding control levels (%)

for 50.0 mg L^{-1}. On average, the extent of variation at a concentration of 50 mg L^{-1} and 1 mg L^{-1} is −46.4 ± 2.57%. The variation in root length rates between the seeds exposed to the harvested precipitation sample and those at 50 mg L^{-1} were −48.1% for Manó, −51.2% for Vilma, −52.4% for Kecskeméti 549, and −57.0% for Mobil. The average deviation is −52.2 ± 3.66%. The average ratio for the two samples is 47.8 ± 3.66%, for Manó is 51.9%, for Vilma is 48.8%, for Kecskeméti 549 is 47.6%, for Mobil is 43.0%. According to Trivedi and Ahmad (2011), asbestos can lead to varying degrees of reduction in root length. Additionally, it was reported that chrysotile asbestos contamination in soil creates a challenging environment for plant growth and productivity due to imbalanced nutrient conditions (O'dell and Claassen, 2006).

The height of the shoot has also changed significantly. The total height spectrum of the tested samples varied between 47.6 and 98.8% (Fig. 4). For the Manó seeds, the reduction ranged from 53.7% (50.0 mg L^{-1}) to 98.8% (1.00 mg L^{-1}). For Vilma, the percentage of height of the shoot in relation to the control group varied between 51.9 and 98.8%. For Kecskeméti 549, this range was 48.2–96.4%, while for Mobil it was 47.6–95.1%. At a concentration of 1.00 mg L^{-1}, the mean value of the height of the shoot ratio is 97.3 ± 1.82%, while at 2.00 mg L^{-1} it is 88.4 ± 3.44%. The average ratio is 79.0 ± 4.13% for 5.00 mg L^{-1}, 68.6 ± 5.11% for 10.0 mg L^{-1}, 60.4 ± 5.27% for 25.0 mg L^{-1} and 50.3 ± 2.92% for 50.0 mg L^{-1}. On average, the extent of variation at a concentration of 50 mg L^{-1} and 1 mg L^{-1} is −46.9 ± 1.32%. The variation in height of the shoot rates between the seeds exposed to the harvested precipitation sample and those at 50 mg L^{-1} were −44.3% for Manó, −45.5% for Vilma, −47.4% for Kecskeméti 549, and −48.7% for Mobil. The average deviation is −46.5 ± 1.95%. The average ratio for the two samples is 53.5 ± 1.95%, for Manó is 55.7%, for Vilma is 54.5%, for Kecskeméti 549 is 52.6%, for Mobil is 51.3%.

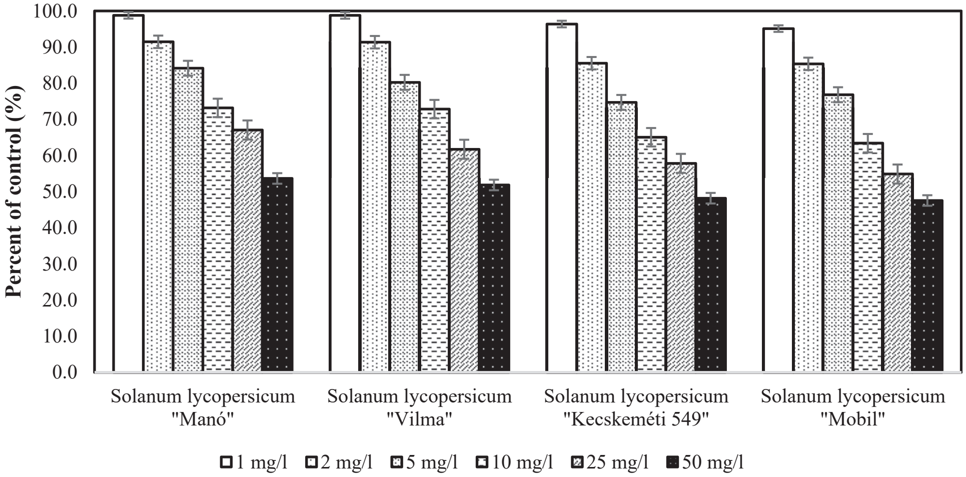

Fig. 4. Comparative examination of the height of the shoot that were analyzed
Mean values ± standard error are presented as a percentage of the corresponding control levels (%)

DISCUSSION

The health impacts of asbestos on humans, specifically chrysotile asbestos, are widely understood now. However, there is a significant lack of attention given to the potential ecological effects of this substance, especially concerning its impact on plant life including agricultural crops (NIPHEP, 1989; Trivedi and Ahmad, 2011). Research has demonstrated that higher concentrations of asbestos in water environments can have negative consequences for aquatic plant species (Schreier and Timmenga, 1986). Trivedi and Ahmad (2011) previously indicated that water and soil contaminated with asbestos result in toxicity that hinders germination, affects seed germination ability, as well as quality characteristics. In their study using potting soil, they utilized soil samples tainted with different types of asbestos fibres while keeping the main properties of the soil consistent (organic carbon, nitrogen, phosphorus potassium, electrical conductivity, pH). This is an important factor considering O'Dell's and Claassen (2006)'s suggestion that chrysotile asbestos-contaminated soil creates a challenging environment for plant growth by disturbing nutrient availability. The crops studied included common wheat, green peas, and white mustard. Their experiments showed diminishing seed germination percentages with increased contamination levels. These negative responses were measured through shoot height reduction, reduction in root length, biomass decrease, chlorophyll content, and decreased plant protein content, resulting from toxic effects induced by asbestos exposure. The reduction in shoot height observed under elevated dose conditions aligns with the findings of Trivedi and Ahmad (2011), Trivedi and Ahmad (2013), Kumar and Maiti (2015), Saleem et al. (2022), Pérez-Labrada et al. (2024) who reported growth inhibition in response to environmental toxin stress, accompanied by hormonal imbalances and disruptions in nutrient absorption. Such dose-dependent inhibitory effects correspond with the broader research in plant toxicology by Hafeez et al. (2023), which demonstrates that increased toxin doses adversely affect plant physiological and metabolic processes.

CONCLUSIONS

The germination rate decreased by −44.0 ± 4.32% on average for the four types of *S. lycopersicum* seeds tested. Manó by −40.0%, Vilma by −44.0%, Kecskeméti 549 by −42.0% and Mobil also by −50.0%. The mean rate of change relative to the control group was −39.5 ± 5.99% in the germination rate. The mean rate of change per 1 mg L^{-1} shows a factor of −0.790 ± 0.120%/mg L^{-1} excluding variance. The mean rate of change relative to the control group was −43.5 ± 3.90%. The mean rate of change per 1 mg L^{-1} shows a factor of −0.869 ± 0.078%/mg L^{-1} excluding variance. The mean rate of change relative to the control group was −31.7 ± 3.41%. The mean rate of change per 1 mg L^{-1} shows a factor of −0.634 ± 0.068%/mg L^{-1} excluding variance. In summary, the research focused on examining how four different types of *S. lycopersicum* respond to varying levels of asbestos-cement contamination during germination and growth. The findings suggest that the presence of chrysotile asbestos significantly lowers seed germination rates, with a noticeable decline as contamination levels rise. Furthermore, it was observed that higher contamination leads to delayed germination and final rates dropping below 50.0%. Moreover, all tested varieties displayed considerable reductions in both root length and shoot height, signalling negative impacts on overall plant growth.

The results are consistent with prior studies that have shown the harmful effects of asbestos, particularly chrysotile asbestos, on seed germination and plant growth. This study highlights the importance of considering the ecological impact and potential effects on agricultural crops when assessing water environments contaminated with asbestos. The observed decrease in seed germination, root length, and shoot height indicates that chrysotile asbestos negatively affects both internal and external factors essential for plant development. This study emphasizes the necessity for further research in this area. The data presented here, including the concentration-dependent reduction in germination rates and changes in root and shoot parameters, enhance our understanding of the ecological consequences of asbestos contamination. Ultimately, this research adds to a growing body of evidence highlighting not only its well-documented health impacts on humans, but also emphasizing its environmental risks.

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