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Magnesium Sulfide Nanoparticles of Hordeum vulgare: Green Synthesis and their nano- nutrient impact on seed priming effect, germination, root and shoot length of Brassica nigra and Trigonella foenum-graecum

M. Kezia Elizabeth
GITAM Deemed (To Be) University
Randhi Uma Devi (urandhi@gitam.edu)
GITAM Deemed (To Be) University
Dr. Parameshwar Makam
Uttaranchal University
A Ratnamala
GITAM Deemed (To Be) University

Research Article

Keywords: Green synthesis, magnesium sulphide, nanoparticles, seed priming, germination rate and time, root length, and shoot length.

Posted Date: February 16th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-3933602/v1

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Additional Declarations: No competing interests reported.

Abstract

This work describes the green synthetic process for magnesium sulfide nanoparticles (MgS NPs) using an extract from Hordeum vulgare leaves. An examination of the MgS NPs was performed utilizing X-ray diffraction (XRD), UV-visible spectroscopy, and scanning electron microscopy (SEM) techniques. The MgS NPs generated were spherical and had a high level of purity. They had a band gap of 2.0 eV, a uniform distribution, and an average crystal size of 14 nm. The MgS nanoparticles synthesized exhibited several geometrical morphologies, including spherical, rod-shaped, and bean-shaped structures. The nanoparticles exhibited an average size of 5 nm, with a band gap of precisely 4.85 eV. The efficacy of MgS NPs on *Brassica nigra* and *Trigonella foenum-graecum* for seed priming, germination rate and time, root length, and shoot length has been assessed using different doses. Optimal germination occurs at concentrations of 15mg/100ml and 20mg/100ml, while germination is impeded when the concentration surpasses 30mg/100ml. MgS NPs exhibit a diminutive size and elevated reactivity, which allows them to augment the water absorption and nutrient control capacities of seeds. Consequently, this promotes the germination process and plant growth by decreasing the average duration of germination. Seeds of *Brassica nigra* and *Trigonella foenum-graecum* that had been subjected to treatment with MgS NPs had enhanced average root and shoot lengths, as well as accelerated germination. The results of this study suggest various promising opportunities for investigating the application of environmentally friendly nanotechnology to improve agricultural practices.

1. Introduction

The fascinating and constantly expanding area of nanotechnology allows the creation of extremely microscopic substances (Azzazy et al., 2012; Gul et al., 2024; Kaur, 2024). Applications of nanotechnology have improved impact on electronics (Pyun et al., 2023), therapeutics (Al-Taie and Özcan Bülbül, 2024; Gul et al., 2024), food (Nanda et al., 2024; Wang et al., 2024), sustainable agriculture (Mohammadi et al., 2024), chemical and pharmaceutical industries (Chakraborty et al., 2023; Iqubal et al., 2022), and environmental health (Pamanji et al., 2024; Wang et al., 2024). Innovative nanomaterial synthesis methods have advanced nanoscience and technology throughout the past decade. Top-down or bottom-up methods can regulate nanomaterial dimensions, morphologies, and properties. Advanced materials science and technology research is stressing 'green synthesis' methodologies (Kaur, 2024) to monitor, purify, and restore nanomaterials to improve their ecological sustainability (Alsaiari et al., 2023; Puri et al., 2024). Green metallic nanoparticles are made from bacteria, fungi, and algae (Chormey et al., 2023; El-Sheekh et al., 2022) but for larger quantities preparation, using plant extracts is easier than utilizing microbes. The chemicals are biogenic nanoparticles. Creating reliable, durable, and environmentally friendly synthesis procedures is essential for "green synthesis," which eliminates unwanted or harmful byproducts. To achieve this, appropriate solvent systems and natural resources are needed (Ghosh et al., 2022; Iravani, 2011).

Conventional agriculture relies on pesticides and fertilizers, degrading the environment and polluting natural resources. The global population is anticipated to exceed 9–10 billion by 2050, requiring a 25–

70% increase in food production (Sundararajan et al., 2023). Thus, modern agricultural technology is essential for sustainability and production. Nanofertilizers and nanopesticides can revolutionize agriculture by cleaning up polluted water and soil (Sundararajan et al., 2023) and reducing fertilizer and pesticide use (Wang et al., 2023). Plant establishment in agriculture requires good seed germination and healthy seedlings. A quiescent, fully grown seed imbibes water and the embryonic axis, usually the radicle grows into a root and shoot. Nano-priming improves seed viability in poor environments (Acharya et al., 2019). Nano-priming can preserve seeds, boost germination, synchronize germination, accelerate plant growth, protect crops from abiotic and biotic stress and reduce fertilizer and insecticide use (Afagh et al., 2023; Singh et al., 2023). Figure 1 shows many agricultural uses for nano-priming seeds.

Plant growth and development require magnesium. It is essential to plant chlorophyll and chloroplasts. In contrast, magnesium is essential for plant enzyme activation. Most kinases and phosphorylases require Mg^{2+} to activate. ATP or ADP hydrolysis by magnesium (Mg^{2+}) produces phosphoric acid and energy. It also boosts phosphorylation and ATP production (Ahmed et al., 2023; Chen et al., 2018). Conversely, sulfur-rich soils are known for their agricultural potential. Certain fungal species cannot grow in sulfur-rich soils (Chaudhary et al., 2023; Ren et al., 2022). *Hordeum vulgare*, or barley, is a cereal grain produced in temperate climates worldwide. The first recorded cultivation of this grain was in Eurasia around 10,000 BCE. The global use of *Hordeum vulgare* crop is 70% animal feed and 30% alcohol and food additives. The study of *Hordeum vulgare* hay for algae control in ponds and other freshwater sources is fascinating (Blattner, 2018). *Hordeum vulgare* biofuel research has begun, although with restricted scope. This research examines the effects of seed priming with environmentally friendly *Hordeum vulgare* magnesium sulfide nanoparticles. Agriculture's scarcest macronutrient is magnesium sulfide. As an enzyme cofactor and tissue stabilizer, it is important (Morales-Díaz et al., 2017). The study examined the green synthesis of magnesium sulfide nanoparticles (MgS NPs) using an extract from *Hordeum vulgare* leaves, characterization studies and its impact on *Brassica nigra* and *Trigonella foenum-graecum* towards the *seed priming, germination rate and time, root length, and shoot length*.

2. Materials and methods

The chemicals/ reagents used in this study are sodium sulfide hydrate (Na_2S) and magnesium nitrate hexahydrate $Mg(NO_3)_2$ were purchased from Merck chemicals. *Hordeum vulgare*, *Brassica nigra* and *Trigonella foenum-graecum* seeds were purchased from Seed Preservation Laboratory, Rajendranagar, Hyderabad. *Hordeum vulgare* leaves were obtained from seeds sown for 20 to 25 days at Gandhi Institute of Technology and Management (GITAM), Hyderabad campus.

2.1. *Hordeum vulgare* leaf extract

Seeds of *Hordeum vulgare* were planted in GITAM's Hyderabad campus and allowed to grow for 25 days. These leaves were collected and allowed to air-dry at room temperature for twenty-four hours while being covered. After that, the leaves are reduced to a powder form. A solution of plant extract that is 10% (w/v) in water is heated to 80°C and maintained under vigorous stirring for an hour and a half. The components

of this liquid are separated by running the liquid through a centrifuge for five minutes at 3,000 RPM. The supernatant fluid is collected and stored at 40°C for further use as a key raw material in synthesizing the phytocapped MgS NPs.

2.2. Synthesis of MgS NPs

The MgS NPs were synthesized by a chemical reaction using the $Mg(NO_3)_2$ and Na_2S in water. A 1M aqueous solution of $Mg(NO_3)_2$ and a 1M aqueous solution of Na_2S were prepared. 1 mL of 1M aqueous solution of $Mg(NO_3)_2$ was poured into a beaker and heated at 40°C for half an hour. In a different beaker, 50 mL of 1M aqueous solution of Na_2S was heated with a magnetic stirrer at a temperature of 40°C for half an hour. Then, to investigate the precipitation of MgS NPs, 50 ml of 1M aqueous solution of Na_2S was placed in a burette and gradually added to a 1 M aqueous solution of $Mg(NO_3)_2$ while the mixture was continuously stirred for three hours. After adding the 1M aqueous solution of Na_2S to the 1 M aqueous solution of $Mg(NO_3)_2$, a precipitate of MgS NPs was produced. After separating the precipitate from the rest of the mixture, it was washed with distilled water to eliminate any remaining contaminants. The sample was then dried in an oven at 80°C for five hours. The dry sample obtained was ground into a powder with a mortar and pestle, and it yielded a fine MgS NPs powder. The MgS NPs powder was collected and stored for future use and analysis.

2.3. Green synthesis of MgS NPs from *Hordeum vulgare* leaves

The extract from *Hordeum vulgare* leaves was added to 1M aqueous solutions of $Mg(NO_3)_2$ and Na_2S in equal parts to synthesize MgS Nanoparticles. The leaves of the *Hordeum vulgare* plant are combined with 50 ml of 1M aqueous solutions of $Mg(NO_3)_2$ in a beaker and heated for 50 minutes at 40°C temperature. Meanwhile, 50 ml of 1M aqueous solutions of Na_2S is swirled at 40°C on the magnetic stirrer in a separate beaker for 50 minutes. After 3 hours of stirring the *Hordeum vulgare* leaf extract capped to 1M aqueous solutions of $Mg(NO_3)_2$, 50 ml of 1M aqueous solutions of Na_2S is added drop-wise with a burette to obtain the precipitation of *Hordeum vulgare* leaf extract capped MgS NPs. Used a separating funnel and filter paper to isolate the capped MgS NPs from the *Hordeum vulgare* leaf extract. Ethanol and distilled water were used to properly wash the precipitate before drying at 80°C for 5 hours in a hot air oven. After being dried, the sample was then crushed using a mortar and pestle to form a fine powder that was later used in green synthesis to manufacture *Hordeum vulgare* (Barley) capped MgS NPs. UV-Vis, XRD, and SEM were employed to learn more about the size and shape of NPs. *Brassica nigra* (mustard) and *Trigonella foenum-graecum* (Fenugreek) seeds were utilized to test the impact of *Hordeum vulgare* (Barley) capped MgS NPs on germination rate, shoot, and root length. *Brassica nigra* and *Trigonella foenum-graecum* seeds were immersed in distilled water with 20 mg of MgS NPs for durations of 3, 6, and 9 hours. The objective was to assess the shorter soaking times to enhance the germination and longer durations to improve the root length. To investigate the effects of increasing *Hordeum vulgare* capped MgS NP concentrations, NPs were distributed in distilled water at 5, 10, 15, and 20 mg. Planting

Brassica nigra and *Trigonella foenum-graecum* seeds with *Hordeum vulgare* capped MgS NPs and varied concentrations.

2.4. Germination tests for seed priming

The formula for calculating the seed germination rate can be found in Eq. 1. This formula may be used to divide the number of seeds that germinated on the seventh day by the total number of tested seeds. The germination rate, expressed as a percentage, equals D multiplied by E times 100.

$$MGT = \sum(n \times di) / N \quad [1]$$

Where n is the number of newly germinated seeds on an i^{th} day and, di is the number of days, n denotes the number of seeds that have just started to sprout. And the germinability is assessed using the Eq. 2.

$$\% GE = C / E * 100 \quad [2]$$

[Note: observations of germination were carried out on the third and seventh days].

Where GE indicates the germinability, C is the number of seeds that germinated by the third day, and E is the total number of seeds that were investigated throughout this experiment. We ultimately determined the normal germination time by applying the computation shown in Eq. 3.

Mean germination time (MGT) was calculated by using the Equation:

$$MGT = \sum(n \times d) / N \quad [3]$$

Where, n = daily seed germination rate, d = time in days since the test began, and N = total number of seeds that sprouted by the end of the test.

3. Results and Discussions

3.1. Synthesis of MgS NPs

The extract from *Hordeum vulgare* leaves was added to 1M aqueous solution of $Mg(NO_3)_2$ and followed by the Na_2S in equal parts to synthesize *Hordeum vulgare* capped MgS NPs. The precipitate formed has been properly washed with ethanol and distilled water. The wet material was dried at 80°C for 5 hours in a hot air oven and powdered using a mortar and pestle to the fine powder form of *Hordeum vulgare* (Barley) capped MgS NPs (Afsheen et al., 2020; Elizabeth et al., 2022). UV-Vis, XRD, and SEM were employed to learn more about the size and shape of NPs.

3.2. Analysis of MgS NPs

3.2.1. UV-Visible Spectra Analysis

Absorption spectroscopy encompasses the complete range of wavelengths in the visible area of the electromagnetic spectrum, while UV-Visible spectrophotometry (UV-Visible or UV/Vis) specifically focuses on the adjacent ultraviolet region. This technique is commonly used in numerous practical and theoretical applications due to its affordability and simplicity of implementation. The UV-Visible absorption spectra of MgS NPs, obtained from *Hordeum vulgare* leaf extract, were determined using a UV-1800 apparatus operating at room temperature. The spectral response (SPR) of nanoparticles (NP) was measured in the range of 200–800 nm by mixing the NP solution with distilled water (Afsheen et al., 2020; Elizabeth et al., 2022).

The study revealed that MgS NPs exhibited absorption spectra ranging from 200 to 800 nm. The band gap was discovered by tracing an arc originating from the origin. The MgS NPs under consideration have a linear nature, rendering them suitable as direct band materials. The MgS NPs were discovered to possess a highly desirable semiconducting band gap of 2.0 electron volts (eV). The presence of a distinct band gap emission in the metal sulfide nanoparticles indicates their exceptional level of crystallinity. The existence of nanoparticle materials is indicated by the blue shift in the band gap, which is caused by the quantum confinement effect and the confinement of excitons. The findings are consistent with previous studies. Figure 2 illustrates the correlation between absorbance and wavelength using a graph. The greater band gap signifies that NPs are absorbing a bigger amount of light. The emergence of NPs can be evidenced by a rise in the band gap magnitude, which arises from the confinement of electrons and holes inside a limited spatial region. Due to their higher capacity for absorbing visible light, NPs have the potential to accelerate the process of germination.

3.2.2. XRD Analysis

X-ray diffraction (XRD) is widely used for analyzing nanoparticles due to its ability to interact with electrons in the inner shell of an atom. We utilize the FX Gieger Series RAD-B equipment from Rigaku (Japan) for X-ray diffraction analysis. The powder samples are positioned on a conventional glass sample holder and subjected to acceleration at 15 kV within a chamber housing an X-ray generator. The data were evaluated using software designed for X-ray diffraction measurements and JCPDS cards. The XRD pattern of MgS NPs obtained from Hordeum vulgare leaves extract (Fig. 2) displayed diffraction peaks at 35.04, 50.1, and 60.2, which corresponded to different crystal planes. The positions of these peaks exhibit a strong correlation with the literature that has been previously reported (Xie and McCourt, 2008). The X-ray diffraction results indicate a spherical structure composed of many crystals with a monoclinic arrangement. Based on the chart, most of the particles exhibited an orientation within the range of (50) to (60) planes.

The typical crystal size was determined using Debye-Scherrer's Eq. (1).

$D = 0.98*\lambda / \beta \cos \theta$ [1]

The size of the crystallite is represented by the symbol D, the broadening of the diffraction line is represented by the symbol β, and the wavelength of X-rays is represented by the symbol λ, which has a specific value of 1.5406. The formula provided produces an average size of 14 nm for MgS NPs, aligning

with the data presented in the reference (West, 2022). The diffraction pattern provides evidence that the generated MgSNPs possess a crystalline structure as shown in Fig. 3. Generally, the germination and growth rate are influenced by the characteristics and dimensions of nanoparticles, and it is believed that the crystalline nature could enhance the germination and growth rate.

3.2.3. SEM morphological studies

Scanning electron microscopy (SEM) can analyze milligram quantities of material to ascertain particle dimensions, morphology, and surface characteristics. In SEM, a narrow electron beam scans the cleaned and positioned sample in a parallel pattern. The signals produced by electrons interacting with a sample are shown on cathode ray tubes (Weiss and Moser, 2015). The SEM-JSM-5910 was used to analyze the micro-surface structures and morphology of the produced MgS NPs. The SEM captures high-resolution images that depict the spatial variability of the properties within the area. At a voltage of 15 kV, various magnifications and scale bar sizes were employed to examine the sample of MgS NPs. The morphology was examined at several magnifications, including 5000x with a 5 µm scale bar, 10,000x with a 1 µm scale bar, 20,000x with a 1 µm scale bar, 2500x with a 10 µm scale bar, 60,000x with a 0.2 µm scale bar, and 40,000x with a 0.5 µm scale bar, at different locations. As shown in Fig. 4 (a), the observations from the SEM images reveal that the majority of the MgS NPs transform into spherical clusters when they assemble (Bujňáková et al., 2017). The SEM images occasionally revealed particles with a size as tiny as 10 nm, suggesting a size range between 10 and 50 nm. The literature (Mukhopadhyay, 2014) states that the SEM images in Fig. 4(b) reveal the presence of MgS NPs in many forms, such as spherical, rod-like, bean-like, and other irregular shapes. Particles often exhibit uniform size and dispersion. *Hordeum vulgare* capped MgS NPs possess a small size and high reactivity, which could potentially enable them to enhance the water absorption and nutrient regulation capabilities of seeds. This, in turn, facilitates both the germination process and the growth of plants.

With these studies, the *Hordeum vulgare* capped MgS NPs have been further studied for their efficacy on *Brassica nigra* and *Trigonella foenum-graecum* for seed priming, germination rate and time, root length, and shoot length has been assessed using different doses.

3.3. Applications of *Hordeum vulgare* capped MgS NPs

3.3.1. Effect on seed priming

Germination is one of the most critical phases in guaranteeing moisture affirmation, and if done correctly, it can also help speed up the process of plant growth, which can be beneficial. Due to their extremely small size, nanoparticles may allow water and other nutrients to penetrate seeds without harming their core composition. Plants can take up more nutrients with less runoff when using nanoparticles as fertilizer (Moorthy et al., 2015). This is because nanoparticles have a greater release rate and a larger surface area than larger particles. As a result, the plant could be able to make better use of the nutrients it receives. The rate of germination as well as the growth of *Brassica nigra* and *Trigonella foenum-graecum* seeds were analyzed and compared to those of control centers while the seeds were grown in the

presence of varying concentrations of MgS NPs that were synthesized from the extract of *Hordeum vulgare* leaves as shown Fig. 5.

3.3.2. Germination tests

Germination tests determine the overall viability of a seed lot. Germination and seed vigour are reliable indicators of a crop's performance in the field. The seeds should take two days to take up moisture and four days to form a root and a leaf, although the germination rate might vary greatly depending on the variety (Dahal and Bradford, 1990). The production of nanoparticles, their characterization, and their application to seeds and crops boost germination rates and alter plant psychology, ultimately leading to increased agricultural production. MgS NPs were extracted from *Hordeum vulgare* leaves using solutions that contained 5 milligrams of metal sulfide NPs in 100 mL of distilled water, as well as 10 milligrams, 15 milligrams, 20 milligrams, and 30 milligrams of each type of synthesized NP. As shown in Fig. 6, on Petri dishes with varying amounts of metal sulfide solutions, *Brassica nigra* and *Trigonella foenum-graecum* seedlings were planted and allowed to germinate. In solutions of metal sulfide nanoparticles, various aspects of germination, including rate, root and shoot length, and mean time to germination, were investigated.

To determine whether nanoparticles affect the germination of seeds, 15 seeds of each type of NPs suspension were grown in 12 Petri dishes at varying concentrations i.e., “control, 5 mg/100 ml, 10 mg/100 ml, 15 mg/100 ml, 20 mg/100 ml, 30 mg/100 ml”, along with a control for both types of seeds (*Brassica nigra* and *Trigonella foenum-graecum*). The total number of seeds that were planted in the petri dish is denoted by D, and the number of sprouts that emerged after one week is denoted by E. After repeating the procedure three times, we wrote down all our observations and conclusions. After seven days, the length of each plant's root system and the shoot was measured in centimeters. This was done for each nanoparticle concentration. Throughout the entire counting operation, every reading, including the total number of seeds that germinated, was meticulously documented daily.

3.3.3. The effect on the percentage of germination rate

A different percentage of germination occurs when MgS nanoparticle suspensions are used instead of the control treatment. The effects of *Hordeum vulgare* leaf extract on the germination rate of *Brassica nigra* and *Trigonella foenum-graecum* seeds, as well as the control treatment, are depicted in Figs. 5 and 6, respectively. The germination rate is the proportion of seeds that germinate to the total number of seeds planted. The maximum germination rates were obtained with concentrations of 15 mg/100 ml and 20 mg/100 ml. The increased germinability at 30 mg/100 ml does not translate to an increased germination rate. It shows that a larger dose at the beginning of germination can halt the germination process. High germination rates can be achieved with low doses of nanoparticle suspension (5 mg/100 ml and 10 mg/100 ml) for *Trigonella foenum-graecum* seeds, but for *Brassica nigra* seeds, much higher concentrations are needed. The germination rate is highest for double steric and lowest for single steric (Farahani et al., 2011). MgS NPs were shown to have a high germination rate (in percentage terms) for both types of seeds. At 20 mg/100 ml, germination of *Trigonella foenum-graecum* seeds was 100%, while

at 15 mg/100 ml, germination of *Brassica nigra* seeds was 86%. The germination rates of both plants are reduced by 30 mg/100 ml. In every case, the high-concentration suspension of 30 mg/100 ml nanoparticles had a much higher germination rate than the control treatment. The germination rate was significantly reduced in all cases compared to the nanoparticle dispersion at a 30 mg/100 ml dosage. The results are summarized in Table 1.

Table 1
Germinability and Germination rate

Seeds	% of Germinability (3rd Day)	% of Germination rate (7th Day)
Trigonella foenum-graecum seeds		
Control	73.3	100
5mg/100ml	86.6	100
10mg/100ml	86.6	100
15mg/100ml	93.3	100
20mg/100ml	86.6	100
30mg/100ml	73.3	100
Brassica nigra seeds		
Control	66.6	100
5mg/100ml	60	100
10mg/100ml	66.6	100
15mg/100ml	86.6	100
20mg/100ml	80	100
30mg/100ml	73.3	100

3.3.4. Effect of *Hordeum vulgare* capped MgS NPs on root length

The root length of *Brassica nigra* and *Trigonella foenum-graecum* seeds increased when they were grown in a suspension of metal sulfide nanoparticles in comparison to control seeds, except for the 30 mg/100 ml concentration of NPs for *Trigonella foenum-graecum* seeds, which showed a significantly reduced root length, as shown in Fig. 8. At dosages of “10mg/100ml, 15mg/100ml, and 20mg/100ml”, the root length of both varieties of seeds rises. The best concentrations for maximum size were “10mg/100ml” for *Brassica nigra* seeds and “15mg/100ml” for *Trigonella foenum-graecum*. A dose-dependent effect is suggested here since higher concentrated dosages of nanoparticles result in a considerable reduction in

root length. Because NPs at higher concentrations are more reactive and toxic, they have the potential to inhibit and suppress the development process, which can result in shorter roots (Sevik and Guney, 2013).

Because the metal sulfides NPs have made it possible for the plant to absorb water and light in a manner that is superior to that necessary for growth, the root length has risen. Roots that are both healthy and long require a suspension of NPs that is precisely calibrated to the appropriate concentration. We found that the maximum root length for *Trigonella foenum-graecum* was 2.0 cm and 3.1 cm for MgS NPs synthesized using a green synthesis method. We also found that the maximum length for *Brassica nigra* seeds was 0.3 cm and 0.9 cm for MgS NPs. These values are significantly greater than those observed for seeds that were given a control treatment. MgS NP solutions of 10 mg/100 ml and 15 mg/100 ml were shown to produce the maximum root length in *Brassica nigra* and *Trigonella foenum-graecum* seeds, respectively (Finch-Savage et al., 2004). However, even at doses as high as “20mg/100ml”, there is a noticeable reduction in the root length. At greater dosages (such as “20mg/100ml and 30mg/100ml”), both seeds' root length is shorter than initially. According to the study's findings, utilizing nanoparticle dispersion can result in a significant increase in root length, even when the nanoparticle concentration is kept relatively low.

3.3.5. Effect of metal sulfide NPs on shoot length

Metal sulfide nanoparticle suspensions of varying concentrations were similarly found to promote shoot length (Subedi and Ma, 2004). Shoot length is more significant in all concentrations compared to the control treatment, but the effects vary widely (Fig. 7, and Fig. 8). Root and shoot growths are the most characteristic biological processes in plant life. These serve as a good indicator for the compatibility of a plant growth with varying environmental conditions. In a 7-day study, *Trigonella foenum-graecum* grew to a maximum of 3.5 cm in length when grown in a suspension of MgS NPs, but only 2.0 cm and 1.9 cm when grown in solutions of 20 mg/100 ml and 30 mg/100 ml, respectively. At 15 mg per 100 ml, the maximum length of *Brassica nigra* seeds was 2.5 cm; at lower doses, the seeds were shorter. Therefore, we can deduce that a 15 mg/100 ml concentration of MgS NP is optimal for producing longer shoots. This analysis confirms that MgS NPs accelerated the rate of germination.

3.3.6. Mean Germination Time Analysis

The mean germination time (MGT) for *Trigonella foenum-graecum* at 15 mg/100 ml and 20 mg/100 ml is reduced to 1.4 days, however, it is increased to 1.9 days for control seeds. The MGT for *Brassica nigra* is reduced to 1.3 days, whereas it is increased to 1.6 days for control. The results of MGT using 15 mg/500 ml of MgS NPs were 1.2 and 1.3 for *Brassica nigra* and *Trigonella foenum-graecum* seeds, respectively. The MGT concentrations of *Brassica nigra* and *Trigonella foenum-graecum* seeds are presented in Table 1. MGT can be sped up to 1.2 days for *Trigonella foenum-graecum* seeds and 1.1 days for *Brassica nigra* seeds when low amounts of MgS NPs are present, such as 10 mg/100 ml. Low concentrations lowered the minimum germinability threshold (MGT), and the number of germinating seeds increased regardless of the rate at which they were growing (Albrecht and McCarthy, 2006;

Okagami and Kawai, 1977). At high concentrations, for example, 30 mg/100 ml, the germination time recorded was substantial, nearly 2 days for *Trigonella foenum-graecum* seeds; utilizing only a sufficient number of NPs can assist reduce this time. The germination and growth rates of seeds change depending on how long they soak in a solution containing nanoparticles of metal sulfide. Germination tests were conducted after 3, 6, and 9 hours of immersion. There is no effect on root or shoot length, although germination and viability are greatly improved by a three-hour soak. The germination rate and viability of seeds soaked for 9 hours were reduced, but the resulting root growth was far more impressive than that of seeds soaked for only 3 or 6 hours. While soaking for 6 hours does not appear to have much of an effect on any germination test, soaking for 9 hours decreases the germination rate but increases root length. Soaking for three hours promotes germination and nine hours promotes root growth. When compared to utilizing a suspension, the MgS NPs isolated from *Hordeum vulgare* have excellent germinability. However, the germination rate is low regardless of the length of time the seeds are soaked. A three-hour soak lengthens both the roots and the shoots. Therefore, optimal concentrations of MgS NPs must be used to improve germination rates and agricultural output.

4. Conclusion

The leaf extract of *Hordeum vulgare* was subjected to chemical precipitation, leading to the formation of *Hordeum vulgare* capped MgS NPs. These nanoparticles were further analyzed using UV spectroscopy, XRD, and SEM. The spherical *Hordeum vulgare* capped MgS NPs produced exhibited exceptional purity, with a band gap of 2.0 eV, a homogeneous distribution, and an average crystalline size of 14 nm. The MgS NPs produced were found in many geometrical forms, such as spherical, rod-shaped, and bean-shaped structures. The nanoparticles had an average size of 5 nanometers, and their band gap was 4.85 electron volts. Germination is most favorable at concentrations of 15mg/100ml and 20mg/100ml, but it is hindered when the concentration exceeds 30mg/100ml. *Hordeum vulgare* capped MgS NPs possess a small size and high reactivity, enabling them to enhance the water absorption and nutrient regulation capabilities of seeds. This, in turn, facilitated both the germination process and the growth of plants and a reduction in the average germination period. The germination and growth rate are influenced by the characteristics and dimensions of nanoparticles. Seeds of *Brassica nigra* and *Trigonella foenum-graecum* that had undergone treatment with MgS NPs exhibited greater average root and shoot lengths, as well as faster germination. The findings of this study indicate several compelling prospects for exploring the utilization of eco-friendly nanotechnology in enhancing agricultural methods.

Declarations

Author Contribution

MKE: Methodology, Investigation, Formal Analysis. RUD: Conceptualization, Writing original draft, and Supervision. MP: Data curation, Writing - Review & Editing. AR: Software and Resources.

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Figures

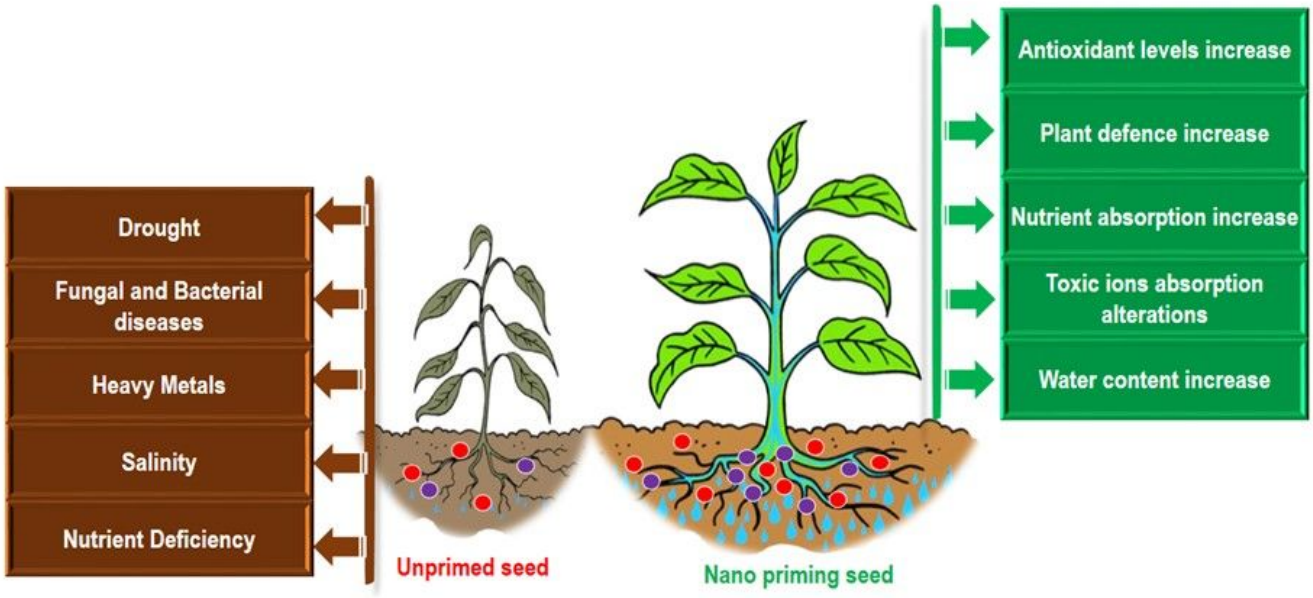


Figure 1

Advantages of nano-priming seeds.

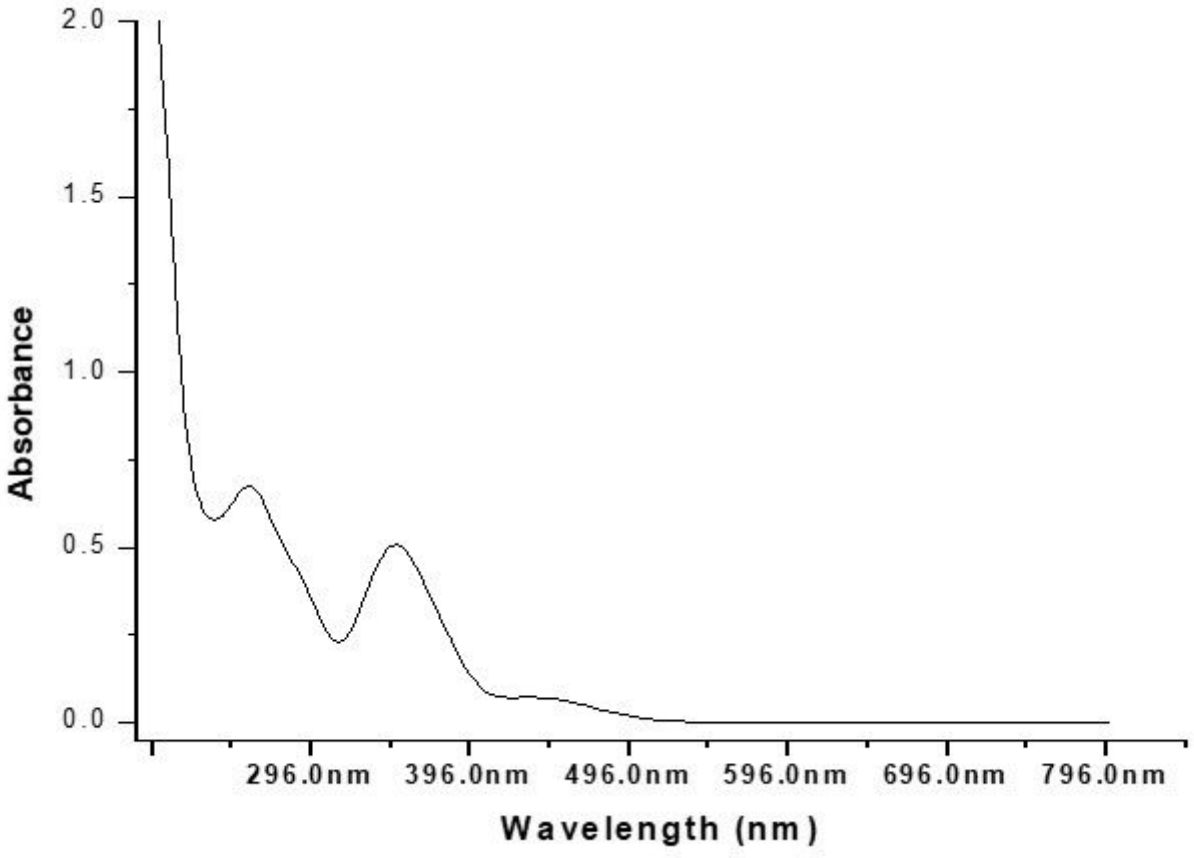


Figure 2

UV-Vis spectraof *Hordeumvulgare* capped MgS NPs.

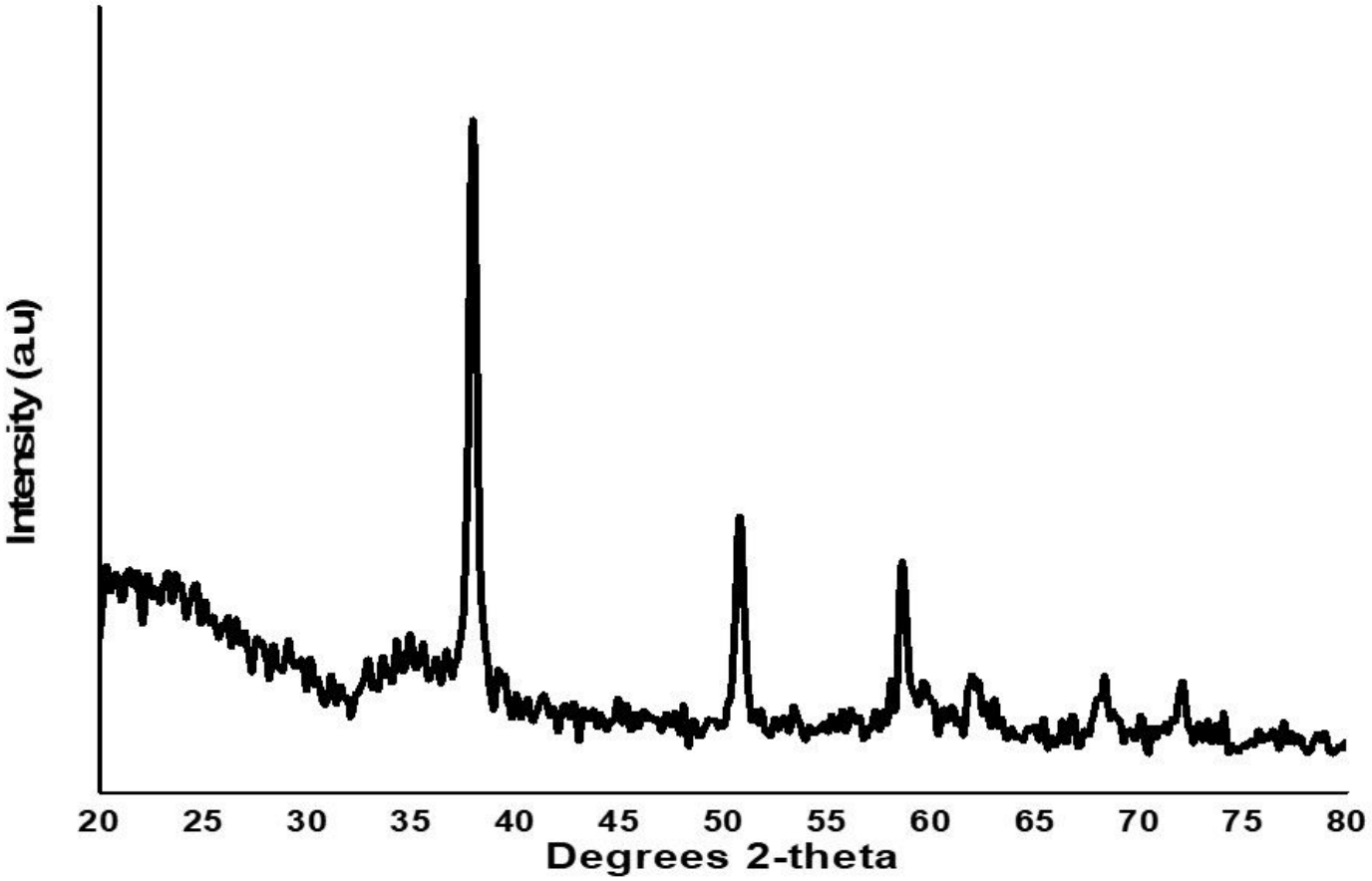
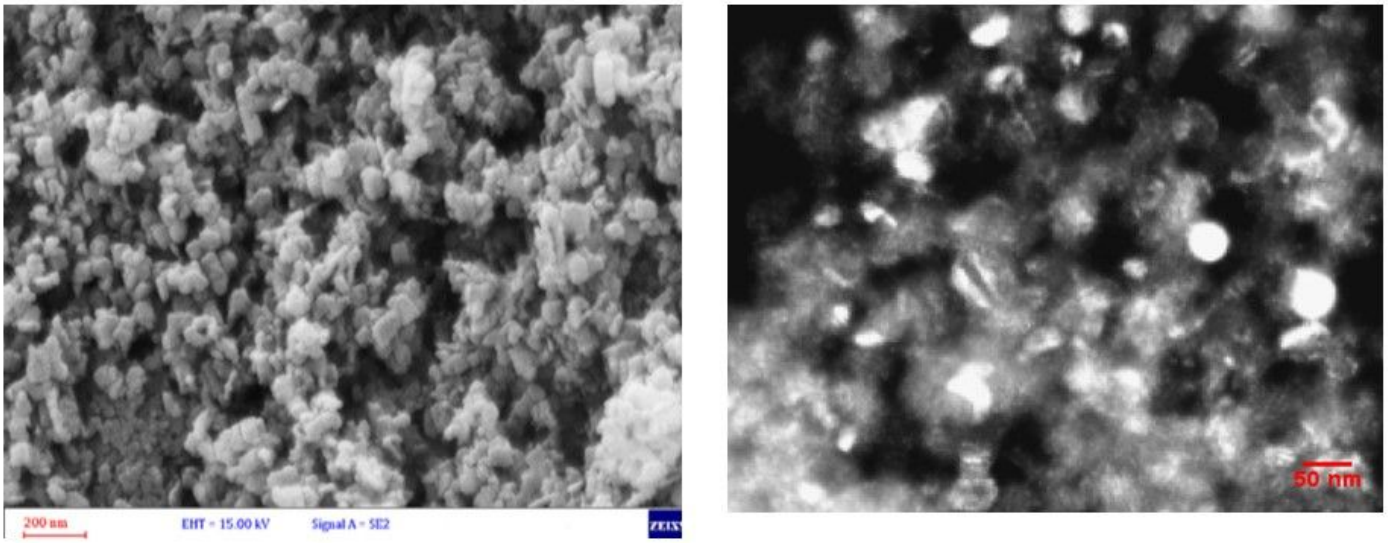


Figure 3

XRD pattern of *Hordeum vulgare* capped MgS NPs.



(a) **(b)**

Figure 4

SEM images of *Hordeum vulgare* capped MgS NPs (a) spherical clusters (b)in different forms.

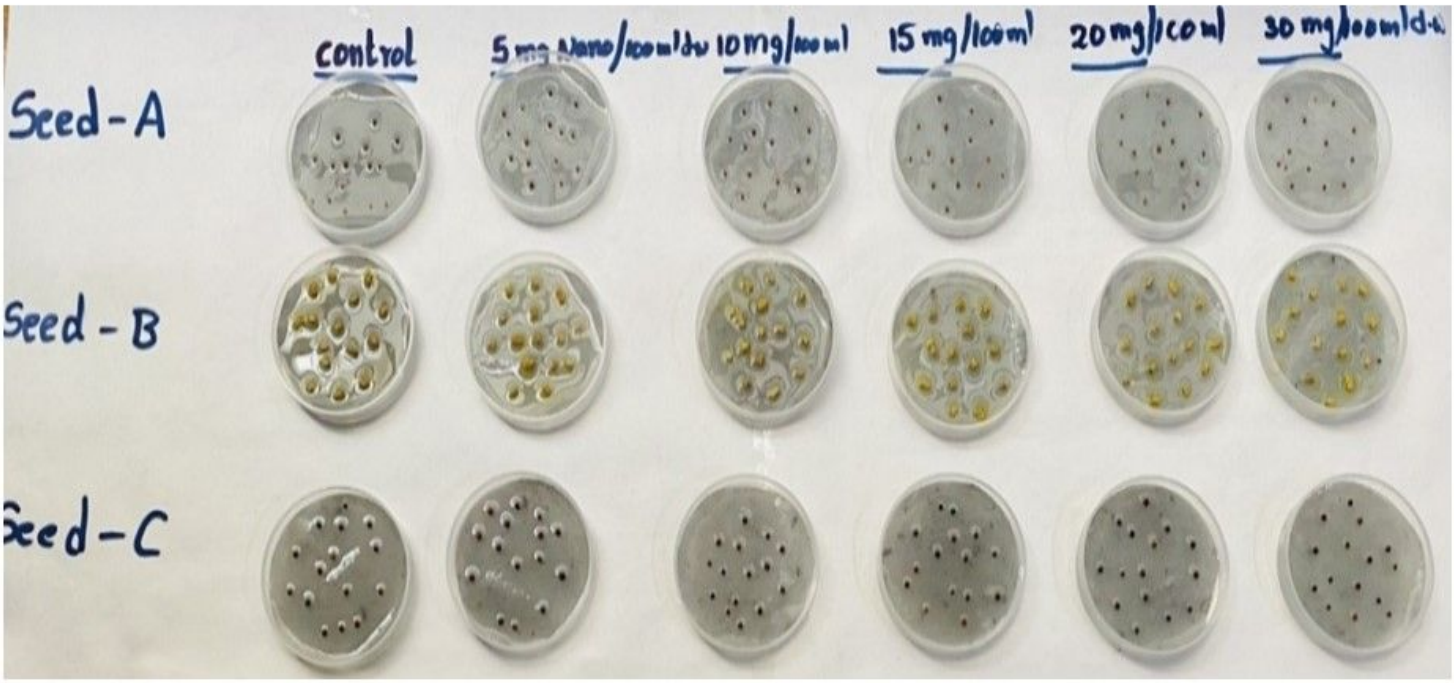


Figure 5

Seed germination studies of *Hordeum vulgare*capped MgS NPs. Seed (**a**) *Trigonella foenum-graecum*(**b**) *Brassica nigra*(**c**) Control

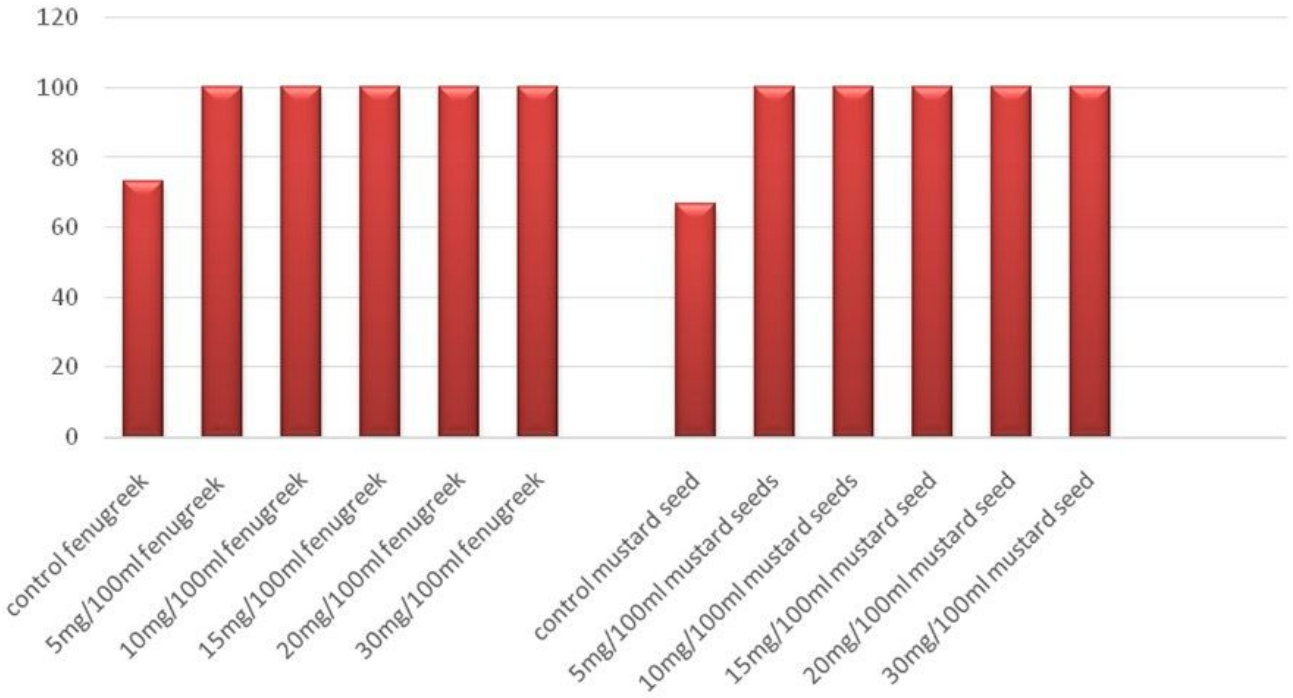


Figure 6

% Germination rate of *Hordeum vulgare*capped MgS NPs.

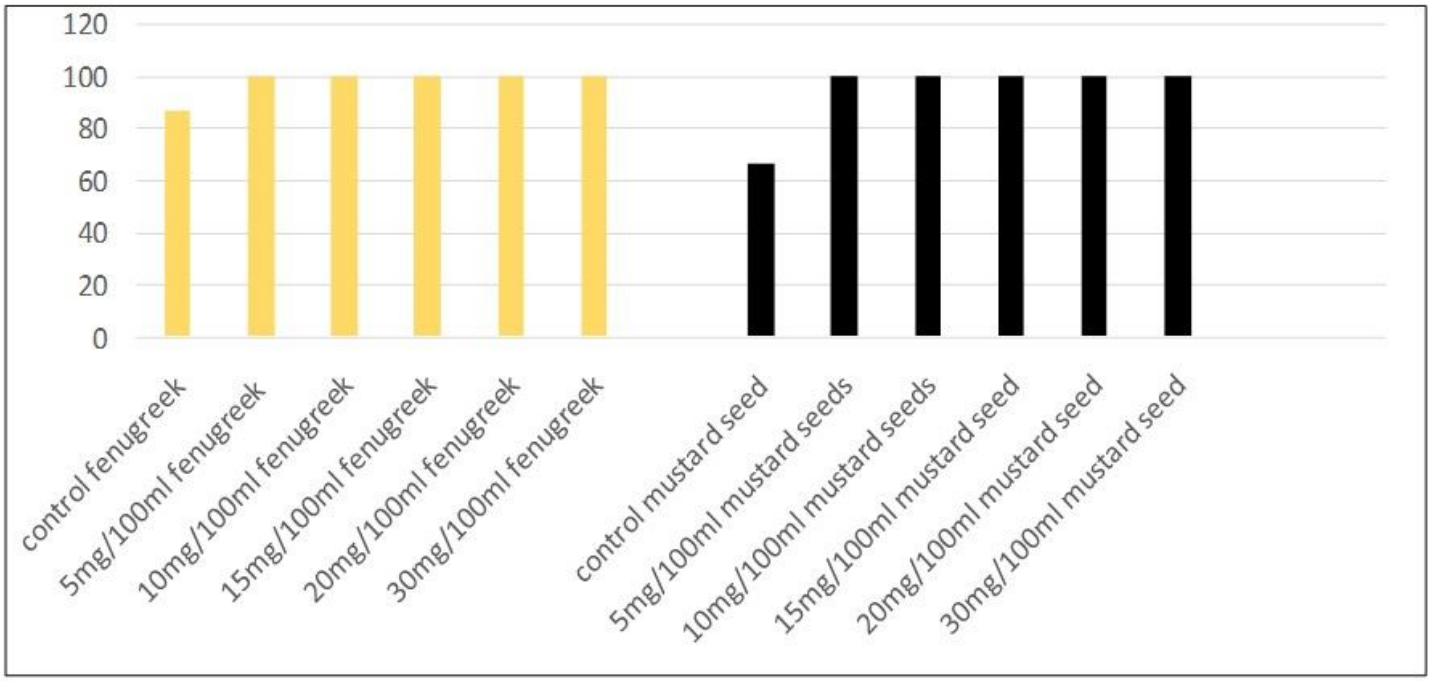


Figure 7

Effect of *Hordeum vulgare* capped MgS NPs on % of germination rate in *Trigonella foenum-graecum* and *Brassica nigra* and control.



Figure 8

Shoot and root developed in Hordeum vulgare capped MgS NPs treated seeds