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Research Article

Evaluation of the Effect of Different Wavelengths, Nanomaterials, and Synthetic Plant Hormones on the Germination of Onion (*Allium cepa L.*) Seeds

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Abstract | The laboratory study was conducted to investigate the effects of different light wavelengths (including red and far-red light), selected plant hormones, and nanomaterials on the germination of onion *(Allium cepa L.)* seeds. The results revealed that all tested nanomaterials and plant hormones enhanced seed germination to varying degrees, with the stimulatory effect increasing as the concentration increased. Gibberellic acid (GA_3) exhibited the highest stimulatory effect on seed germination compared to kinetin. Similarly, zinc nanoparticles showed a greater positive effect on germination percentage than copper nanoparticles. Regarding light treatments, exposure to white light significantly inhibited seed germination to a level similar to that observed under far-red and blue light treatments. In contrast, the highest germination percentage (88.7%) was recorded under dark conditions, indicating that onion seeds exhibit dark-requiring germination behavior. Moreover, pre-treatment with far-red light before transferring the seeds to darkness affected germination, and the degree of this effect varied depending on the duration of exposure.

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Introduction

The agricultural industry plays a crucial role in driving economic development and ensuring food security for the rapidly growing global population, which currently stands at approximately 7.5 billion people (Berners-Lee *et al.*, 2018; Porter *et al.*, 2014). Since around 90% of food crops are grown from seeds, seeds are considered a vital input for sustainable agricultural productivity and production. Healthy agricultural seeds produce more vigorous and resilient seedlings, contributing to efficient agricultural practices.

In the current scenario, agriculture faces a wide range of challenges, including changing environmental conditions such as salinity, drought, accumulation of heavy metals in soil, and climate change. These factors can adversely affect seed germination, seedling development, and ultimately crop yields (He *et al*., 2018; Yadav *et al*., 2020; Imran *et al*., 2021). Therefore, it is essential to adopt sustainable agricultural practices to protect seeds from pests and insects while maintaining the balance of the agroecosystem.

The use of conventional agrochemicals is not recommended for sustainable seed treatment due to problems related to leaching and hydrolysis of chemical compounds. There is an urgent need for new, safe, and cost-effective technologies based on natural agents and green chemistry approaches to reduce the environmental burden on the soil. Emerging technologies and strategies are continuously being developed to address seed-related challenges. To revolutionize modern agricultural practices, products based on natural compounds, plant growth regulators, and nanomaterials are increasingly being introduced (Neme *et al*., 2021).

Onion (*Allium cepa*), a member of the family Amaryllidaceae, is one of the most important vegetable crops. It occupies a distinguished place in biological research due to its unique structure, root system, cellular organization, and genetic and reproductive characteristics. Biologists consider onion an important model plant for studying seed germination, cell division, and embryonic development (Al-Khatari *et al*., 2023). Onion seeds are small, black, and covered with a hard outer coat (testa). They contain a fully developed embryo and a nutrient-rich endosperm that provides energy during germination. Onion is grown in one season and flowers and produces seeds in the following year.

Onion seeds are classified as negatively photoblastic, meaning that light can inhibit their germination. They require moderate temperatures and suitable moisture to initiate germination and are sensitive to high salinity. Germination can also be affected by the presence of toxic compounds or oxygen deficiency (Tingting *et al*., 2022; Lahhob *et al*., 2025; Tarmooz *et al*., 2025). The present study aims to evaluate the influence of environmental, hormonal, and nanotechnological treatments on onion seed germination. It first investigates the effect of different light wavelengths, applied through colored filters, on both germination percentage and germination rate. Additionally, it analyzes the response of onion seeds to plant growth regulators, particularly gibberellin (GA) and carnitine, with an emphasis on their roles in promoting germination. Furthermore, the study examines the impact of zinc oxide (ZnO) and copper (Cu) nanoparticles on germination percentage seedling vigor and embryonic tissue integrity, while also determining the optimal concentrations that enhance germination efficiency without inducing toxicity.

Materials and Methods

Seeds

Onion (*Allium cepa L.*) seeds were obtained from local markets and from the Agricultural Research Center and Water Resources.

Preparation of gibberellin (GA3) and kinetin solutions

For the preparation of the two hormone solutions, 0.1 g of each hormone was accurately weighed and dissolved separately in 1 ml of ethanol. The volume of each solution was then brought up to 100 ml with distilled water to prepare stock solutions with a concentration of 1000 ppm. From these stock solutions, serial dilutions were prepared to obtain the concentrations required for the experiment, which were 10, 50, 100, and 150 ppm.

Preparation of nanocompounds

In this study, nanocomposites were prepared at certain concentrations depending on the manufacturer concentrations (0.01,0.03,0.05,0.07) mg/ml^{-1} by dissolving the required concentrations with 5 ml of ethanol. The volume is supplemented to 500 ml of deionized water to obtain the above required concentrations.

Seed germination

Using a growth incubator and Petri dishes with a diameter of 9 cm containing two layers of filter paper Whatmann No.1. Before planting, the seeds were sterilized with 10% Hydrochlorite solution for 10 minutes to sterilize, then washed with distilled water to remove the effect of the sterilizer. 25 seeds were placed in each plate and distributed over 3 replicates using the Completely Randomized Designen and then placed in the wooden boxes designed and used by (Al-Ukaili, 1990) open from the top for the purpose of placing the optical filters used in the experiment and with a design that makes the filter firmly fixed on top of the box so that no other rays are allowed to pass through as well as allowing it to be easily replaced.

The seeds were irrigated with 3 ml of distilled water and 3 ml of gibberellin and kinetin for the hormone experiments and were placed in the growth incubator at a temperature of 25 + 2, then the boxes were closed with the optical filters to be studied, and after six days of planting, which is the period required for the germination of Onion seeds, the percentage of germination was calculated using the following equation:

$$\text{Germination rate} = \frac{\text{Number of germinated seeds}}{\text{Total number of seeds}} \times 100$$

Light sources

Germination of seeds in the dark was carried out by placing the dishes containing the seeds inside a closed box so that no light was allowed to penetrate them and placing them in the growth incubator. The light sources used are 4 fluorescent tubes, each tube 20 watts, installed in the ceiling of the incubator with a height of 40 cm.

The light source for the red and far-red effect studies consisted of two 60 Watt incaneescant lamps. Red light was obtained by filtering one type of filter red (0.11 cal/cm2/min). Far-red was obtained by filtering two layers of yellow and purple (0.08 cal/cm2/min).

As for the blue light source, it was obtained by light filter of filtering blue. The optical filters were placed in the place designated for them at the top of each box, according to the conditions of each experiment, after placing the petri dishes containing the seeds prepared for planting.

Statistical analysis

Statistical analysis was done using Statistical package for Social Science (SPSS) version 21.0 (IBM Corporation, Armonk, NY, USAV). The socio-demographic characteristics and general information were presented by percentage, mean and standard deviation.

Results

The seeds were tested to determine whether their germination was light- or dark-dependent. Germination was higher in darkness (85.4%) than in light (29.3%). This indicates that the seeds are negatively photoblastic, where light inhibits germination by affecting the phytochrome system, while darkness provides favorable moisture and physiological conditions, leading to higher germination rates (Figure 1).

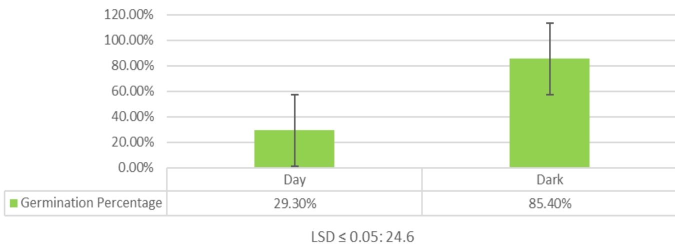

Figure 1: *The germination percentage of onion seeds*

The figures below present the effect of different light wavelengths on the germination of onion seeds, demonstrating distinct inhibitory responses. Germination in darkness reached 88.0%, while exposure to light reduced germination to 26.7%. Treatments with red, far-red, and blue light resulted in inhibition rates of 64.0%, 1.3%, and 24.0%, respectively (Figure 2).

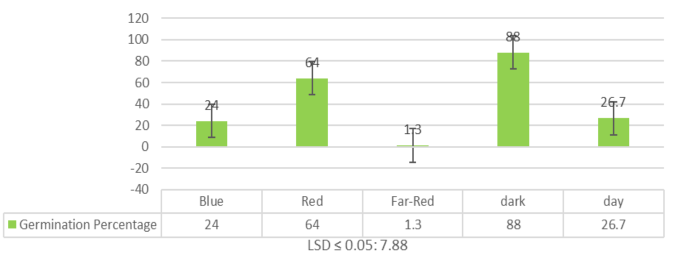

Figure 2: *The effect of wavelengths on the germination percentage of onion seeds.*

The results in Figure 3 indicate that the highest germination percentage was recorded under three consecutive days of darkness, reaching 85%. This suggests that onion seeds exhibit a high germination response in complete darkness, a common characteristic of many light-sensitive seeds, where darkness stimulates the physiological processes required for germination.

The treatment involving one day of FR followed by two days of darkness also resulted in a relatively high germination percentage of 73%, which is close to that of continuous darkness. This indicates that initial exposure to FR light did not irreversibly inhibit germination; rather, the subsequent dark period likely reversed the effect by converting phytochrome back to its inactive Pr form, which promotes germination. In contrast, two days of darkness followed by one day of FR resulted in a lower germination percentage of 60%. This reduction may be attributed to the FR exposure at the end of the sequence, which converted phytochrome to its active Pf form, known to inhibit germination in light-sensitive seeds such as onion.

For the treatment of one day of darkness followed by one day of FR and then one day of darkness, germination decreased to 36%. It is likely that the intermediate FR exposure re-inhibited phytochrome after a brief initial stimulation, and the final dark period was insufficient to fully reverse this effect.

Finally, the treatment with three consecutive days of FR exposure resulted in the lowest germination percentage (4%), confirming that continuous FR light strongly suppresses germination in onion seeds due to the persistence of phytochrome in its active Pfr form, which prevents the initiation of germination processes

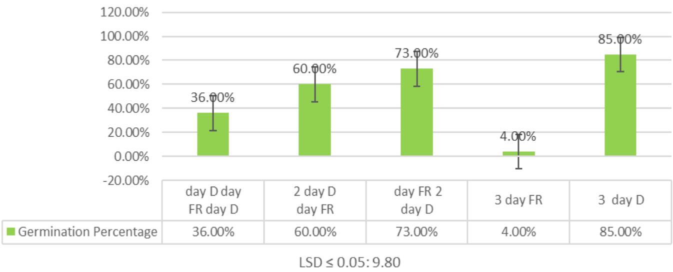

Figure 3: *The effect of far-red light on germination at different exposure periods of onion (Allium cepa) seeds.*

The Table 1 illustrates the interaction between red and far-red light. Onion seeds exposed to far-red light combined with a proportion of red light for 8 minutes, following a sequence of two days of darkness and one day of far-red light, exhibited a germination percentage of 42.0%. When the duration of red light exposure was increased to 10 minutes, germination rose to 50.0%, and further increased to 60.0% when the exposure time to red light reached 60 minutes.
However, when the seeds were subsequently exposed again to far-red light followed by red light for 10 minutes each, under the same sequence of darkness and far-red light exposure, germination decreased to 46.0%. In contrast, when the final exposure was to red light for another 10 minutes, the germination percentage increased to 70.0%. Germination declined again to 40.0% when the duration of far-red light exposure was extended to two days and was completely inhibited after three days of far-red light exposure. The dark treatment recorded the highest germination percentage at 85.0%.

Table 1: *The effect of the interaction between far-red and red light on the germination percentage of onion seeds.*

Treatments	Germination percentage	Treatments	germination percentage
1day D - 1day FR - 8mint R –1day D	42.0%	1day D -- 1day FR -- 10mint R –10 mint FR –10mint R –1day D	70.0%
1day D - 1day FR – 10 mint R –1day D	50.0%	2day FR—10 mint R—1day D	40.0%
1day D -- 1day FR – 60 mint R –1day D	60.0%	3 day Far—Red	0.0%
1day D -- 1day FR -- 10mint R –10 mint FR -- 1day D	46.0%	3 day Dark	85.0%
LSD ≤ 0.05	5.27		

The data presented in the Table 2 illustrate the effect of copper and zinc nanoparticles on the germination percentage of onion seeds. Results revealed that all tested concentrations of copper nanoparticles significantly enhanced seed germination compared to the control treatment (8.0%). Specifically, a concentration of 0.01 mg ml^{-1} Cu-NPs increased germination to 26.7%, while 0.03 mg ml^{-1} resulted in 40.0%. The highest germination percentage was recorded at 0.07 mg ml^{-1}, reaching 50.0%.

Table 2: *The effect of nanoparticles on the germination percentage of onion seeds.*

	Nano zinc				Nano copper			
Treatments	0.01	0.03	0.05	0.07	0.01	0.03	0.05	0.07
Onion seeds	36.0%	46.7%	60.0%	58.0%	26.7%	40.0%	49.7%	50.0%
Control Far/red	8.0 %	8.0%	8.0%	8.0%	8.0 %	8.0%	8.0%	8.0%
LSD ≤ 0.05	6.79				6.58			

Similarly, zinc nanoparticles exhibited a more pronounced stimulatory effect on germination. At a concentration of 0.01 mg ml^{-1} Zn-NPs, the germination percentage reached 36.0% and further increased to 46.7% at 0.03 mg ml^{-1}. The highest germination percentage was observed at 0.07 mg ml^{-1}, with a value of 58.0%.

Regarding the effects of synthetic plant hormones (kinetin and gibberellic acid, GA_3), all applied concentrations significantly stimulated seed germination relative to the control. Kinetin at 10 ppm increased germination to 26.7%, while 50 ppm induced 50.7%, and the maximum germination was achieved at 200 ppm with 62.7%. Gibberellic acid exhibited a stronger promotive effect compared to kinetin, with germination percentages of 30.7%, 53.3%, and 68.0% at concentrations of 10, 50, and 200 ppm, respectively, compared to 8.0% in the control treatment. Table 3 shows the germination percentage of plant hormones kinetin and gibberellic acid.

These results clearly indicate that both nanoparticles (Cu and Zn) and plant growth regulators (kinetin and GA_3) have significant promotive effects on the germination of onion seeds, with zinc nanoparticles and GA_3 showing the most pronounced stimulation, particularly at higher concentrations.

Discussion

Light is one of the principal environmental factors governing plant physiological processes, as it exerts a direct influence on both seed germination and growth. Differences in light wavelength may either promote or inhibit germination depending on the plant species. In our current study, onion seeds exposed to white light and far-red light exhibited a marked reduction in germination rates, whereas red light induced only slight inhibition in comparison to other treatments. In contrast, seeds achieved their highest germination percentage under dark conditions, indicating that onion seeds may be classified as dark-requiring seeds. This ability to germinate in darkness may be explained by the presence of active phytochrome (Pfr) within dry seeds from the outset, thus enabling germination to commence without prior exposure to light (Liu *et al*., 2022; Santini *et al*., 2023).

Moreover, these seeds may have surpassed their light requirement, or they may harbor adequate levels of active phytochrome capable of functioning under complete darkness (Abdelkader *et al*., 2023). Regarding blue light, the results showed pronounced inhibition of germination under continuous exposure, with germination percentages approximating those observed under white light. This inhibitory effect is attributed to the photoconversion of phytochrome from its active form (Pfr) into its inactive form (Pr) under blue light; prolonged blue light exposure mimics the effect of far-red light (Oka *et al*., 2025). A similar response has been observed in cocklebur seeds, which germinate in darkness.

Our study further revealed that far-red light suppresses onion seed germination, yet this inhibition may be reversed by exposure to red light or darkness, indicating the pivotal role of phytochrome in controlling the germination process, where the pigment remains in its active form (Pfr) until germination is initiated. Earlier work on dark-requiring Nemophila seeds has demonstrated the photo reversibility of phytochrome, Weller *et al*. (2000) highlighted that red, far-red, and blue light are the most effective spectral components influencing seed germination, and these wavelengths also contribute to other physiological functions in the plant. Phytochrome A functions optimally in the wavelength range of 600–690 nm but becomes inactive at wavelengths exceeding 700 nm, whereas phytochrome B remains active; hence, phytochrome A plays a critical role in the early phases of germination. Studies suggest that wavelengths near 660 nm are ideal for stimulating early germination, as demonstrated in Arabidopsis seeds (Li *et al*., 2023).

At the hormonal level, we found that treating onion seeds with gibberellic acid (GA_3) and kinetin under

Table 3: *The effect of plant hormones on the germination percentage of onion seeds.*

	Gibberellin (GA3)				Kinetin			
Treatments	10	50	100	200	10	50	100	200
Onion seeds	30.7%	53.3%	57.0%	68.0%	26.7%	50.7%	53.3%	62.7%
Control Far/Red	8.0 %	8.0%	8.0%	8.0%	8.0 %	8.0%	8.0%	8.0%
LSD ≤ 0.05	7.60				6.98			

far-red light exposure enhanced germination. This effect may be due to these hormones acting similarly to red light by activating phytochrome B, thereby promoting germination. Earlier studies, such as El-Rasafi (2025), showed that gibberellic acid addition stimulates germination of dark-requiring seeds, such as Phacelia and Nemophila, even under far-red exposure. Ogawa *et al.* (2003) also demonstrated that increasing the concentration of gibberellic acid or soaking seeds in it improves both germination percentage and speed, and that GA can overcome inhibitory light effects. Conversely, prolonged exposure to far-red light inhibits germination by suppressing phytochrome receptor activity, leading to decreased levels of gibberellins (GA) and elevated levels of abscisic acid (ABA), thereby disrupting the hormonal balance required to initiate germination (Al-Ukaili, 1990).

In our current investigation, we additionally employed zinc and copper nanocompounds, which exhibited a notable enhancement of germination rates in onion seeds compared to non-nanoparticle treatments.

This improvement in germination can be attributed to the ability of nanoparticles to enhance seed coat permeability to water and gases, activate hydrolytic enzymes that degrade stored reserves, facilitate the transport of micronutrients into seed tissues, induce mild reactive oxygen species that trigger metabolic cascades, and modulate hormonal balance by promoting gibberellin synthesis or reducing abscisic acid levels during the early germination phase. These findings align with recent studies reporting the stimulatory effects of metal nanoparticles, particularly zinc and copper, on seed germination and early seedling growth across various species (Ali *et al.* 2020; Feizi *et al.*, 2013).

Conclusions

The red light and far-red light represent key environmental factors that directly and indirectly affect the seed germination process by activating the phytochrome system, modulating hormonal pathways, and enhancing the seeds' physiological activity. Recent studies confirm that exploiting these wavelengths can be an effective tool for improving germination rates and seedling quality in many plant species, opening up prospects for agricultural applications and advanced germination techniques to enhance agricultural production.

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Novelty Statement

This study provides new insights into how light wavelengths, plant hormones, and nanomaterials collectively influence the germination physiology of *Allium cepa L.* seeds. By integrating hormonal and nanotechnological treatments with photobiological responses, the research identifies previously unreported interactions that clarify the dark-requiring germination behavior of onion seeds and determine optimal stimulatory conditions that enhance germination efficiency.

Author's Contribution

Fatima Hamed Ismail and Majid Hanoon Sharhan: The author conducted the experimental work, performed data collection and analysis, and prepared the manuscript. The study design, interpretation of results, and final revision of the manuscript were completed under the supervision and guidance of the academic advisors.

Generative AI and AI-assisted technology statement.
Generative AI tools were used exclusively to improve the clarity and language quality of the manuscript. No AI tools were involved in generating, analyzing, or interpreting the research data. The author is fully responsible for the scientific content and conclusions.

Conflict of interest
The author declares no conflicts of interest related to the research, authorship, or publication of this article.

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