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Nano primming: An emerging technology in medicinal and aromatic crops

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Abstract
The integration of nanoparticles and bio-stimulants in agriculture has emerged as a promising approach for enhancing plant growth, stress tolerance, and overall productivity. This review aims to synthesize the findings of ten research articles, each focusing on the application of nano-priming, an emerging seed technology, and leverages nanoparticles to enhance germination, growth, and stress tolerance in medicinal and aromatic crops. This technique, which involves treating seeds with nanoparticles, offers a sustainable approach to boost crop productivity by modulating plant metabolism, improving nutrient uptake, and enhancing resistance to biotic and abiotic stresses. This abstract will explore the mechanisms of nano-priming, its applications in medicinal and aromatic crops, and future perspectives for sustainable agriculture. This unique combination of Nano primers with growth stimulants address the climate change and resource depletion pose significant challenges to agriculture, impacting crop yields and food security. Medicinal and aromatic crops, vital for pharmaceuticals and perfumery, are also vulnerable to these stresses. Nano-priming, utilizing nanoparticles to enhance seed performance, offers a promising solution for sustainable agriculture. This technique will promise to offer a promising path towards enhanced plant growth, improved stress tolerance, and overall increased agricultural productivity. These studies specifically focused on the synergistic effects of these combined treatments on seed germination, seedling development, drought tolerance, and the synthesis of antioxidants in plants. Evident research indicates that, when used together, NPs and bio stimulants can significantly enhance plant growth and development. Hence, the abstract highlights the potential of combining nanoparticles and bio stimulants to improve plant growth, increase stress tolerance, and enhance overall productivity, offering a promising approach for developing sustainable agricultural practices.

Keywords: Nanoparticles, seed germination, plant growth, stress tolerance, nutrient uptake and sustainable agriculture

Introduction
An inventive seed treatment method called nano-priming is quickly becoming known for its potential to completely transform agriculture, particularly when it comes to aromatic and medicinal crops. This method uses nanoparticles (NPs) to improve germination, stress tolerance, and seed quality, among other aspects of plant growth and development. Research indicates that by adjusting plants' physiological and biochemical reactions to external stressors, such as heavy metal toxicity, nano-priming can increase crop yields (Mazhar *et al*., 2022) [1].
Therefore, using nanoparticles to promote seed germination and overall plant performance, nano-priming is a novel way to boost the growth, development, and stress resilience of aromatic and medicinal crops. Given environmental issues like climate change and resource depletion, this technique has enormous potential to increase the yield and quality of these priceless products.

Here's a breakdown of nano-priming's significance in the context of medicinal and aromatic crops
1. Boosting seed germination and seedling establishment
- **Enhanced Water Uptake:** Nanoparticles can penetrate the seed coat, potentially forming Nano pores and inducing the expression of aquaporin genes, which are

responsible for water uptake, leading to faster and more efficient imbibition, particularly beneficial for aged seeds or seeds with dormancy issues.

- **Optimized Metabolism**: Nano-priming can fine-tune the balance of essential plant hormones like abscisic acid and gibberellins, and regulate levels of reactive oxygen species (ROS) crucial for initiating and regulating metabolic processes that break dormancy and promote germination.
- **Improved Seedling Vigour:** Faster germination and more robust initial growth translate into stronger, healthier seedlings that can establish themselves more effectively in the field, increasing their chances of survival and maximizing yield.

2. Enhancing plant growth and secondary metabolite production

- **Improved Nutrient Acquisition:** Nano-priming with specific nanoparticles (e.g., zinc, iron) can enhance the uptake and utilization of essential nutrients by roots, leading to better plant growth and development.
- **Increased Photosynthesis:** Some nanoparticles can boost chlorophyll synthesis and photosynthetic efficiency, leading to increased biomass production, according to ScienceDirect.com.
- **Modulated Metabolism:** Nano-priming can influence gene expression related to metabolic processes, including the production of valuable secondary metabolites (e.g., flavonoids, anthocyanins, glucosinolates) in medicinal and aromatic plants, potentially boosting the content and efficacy of their active compounds.

3. Enhancing stress resilience

- **Abiotic Stress Tolerance:** Nano-priming can equip plants with increased tolerance to stresses like drought, salinity, and heavy metal contamination by modulating antioxidant systems, improving water use efficiency, and promoting nutrient homeostasis.
- **Biotic Stress Resistance:** Some nanoparticles possess antimicrobial properties or can enhance the plant's natural defence mechanisms against diseases and pathogens, leading to healthier crops and potentially reducing the reliance on chemical pesticides.

Potential concerns and future outlook of Nano priming

While nano-priming shows great promise, it's crucial to address potential concerns related to nanoparticle use in agriculture:

- **Phytotoxicity:** High concentrations or specific types of nanoparticles can be detrimental to plant growth and metabolism. Optimizing nanoparticle types, concentrations, and application methods is crucial to minimize negative effects.
- **Environmental Safety:** Potential accumulation of nanoparticles in the soil and food chain requires thorough investigation and robust regulatory frameworks. Prioritizing sustainable and eco-friendly approaches like green synthesis methods is essential.
- **Scaling Up:** Translating lab-based successes to large-scale field applications requires further research and development to optimize protocols and ensure consistent effectiveness in diverse agricultural settings (Mazhar *et al*., 2022) [1].

Notwithstanding these difficulties, nano-priming has the potential to completely transform the production of aromatic and medicinal crops by giving them the means to flourish in progressively harsher conditions, ultimately promoting sustainable agriculture and satisfying the world's need for food and medicine. Wider use and long-term advantages of this cutting-edge technology will be made possible by additional research concentrating on comprehending the molecular mechanisms at play, investigating novel nanoparticle forms, and resolving safety concerns (Elbanna *et al*., 2024) [2].

Because of its potential to solve issues including drought stress, low soil fertility, and pest management, the use of nanotechnology into agricultural methods has attracted a lot of attention recently. The combined effects of nanomaterials and biostimulants on plant growth, seed priming, and stress resilience have been the subject of numerous investigations. Together with biostimulants like Spirulina sp., selenium, and yeast extract, nanoparticles like copper (CuNPs), titanium dioxide (TiO2NPs), and zinc oxide (ZnONPs) have shown benefits for plants in terms of increased growth, yield, and stress tolerance.

For example, Elbanna *et al*. (2024) [2] investigated how foliar application of Spirulina sp. and CuNPs affected French basil growth, observing increases in chlorophyll content and growth indices. In pomegranate plants, Abdelmigid *et al*. (2023) [3] examined the combined impacts of TiO2NPs and seed priming, which resulted in improved seedling growth and stress resistance. Likewise, Iqbal *et al*. (2022) [4] investigated the physiological impacts of gamma-aminobutyric acid (GABA) therapy on drought-stricken sweet pepper, demonstrating enhanced growth and stress tolerance.

Furthermore, research by Sardar *et al*. (2023) and Kandileri *et al*. (2021) [5, 6] evaluated the impact of several treatments on early-stage seedling growth and seed germination in species such as Saraca asoca and Swertia chirata, showing notable increases in physiological parameters. Furthermore, studies on the use of ZnONPs (Ajmal *et al*., 2023) [7], iron oxide nanoparticles (Mazhar *et al*., 2022) [1], and selenium priming (Sariñana-Navarrete *et al*., 2024) [8] to different crops highlight the potential of these nanomaterials in agricultural enhancement.

In addition to analyzing the possible uses and ramifications of nanotechnology in contemporary agriculture, this study attempts to provide a thorough examination of these investigations, including an outline of the methodology employed and their findings.

Materials and Methods

In order to assess the effects of copper nanoparticles (CuNPs) and Spirulina sp. on growth metrics like leaf area, biomass, and essential oil content, Elbanna *et al*. (2024) [2] treated French basil plants during the vegetative stage with foliar treatments of both Spirulina sp. and CuNPs, both separately and in combination. The results showed that the combination of CuNPs and Spirulina significantly enhanced plant growth, as seen by a discernible increase in leaf area, biomass, and essential oil content when compared to the control group. Although separate therapy also produced positive outcomes, the combination treatment proved to be the most effective. The observed synergistic effect was attributed to the antioxidant properties of spirulina and the enhanced nutritional absorption of CuNPs, suggesting that this approach could be helpful for promoting the growth of medicinal plants, particularly in controlled environments.

Results and discussion

The produced CuNPs were found to be spherical with a mean diameter of 4.51 nm by TEM analysis (Fig. 1), and their crystalline structure was confirmed by XRD analysis (Fig. 2), which revealed a face-centered cubic phase of copper. The fresh and dry weight of basil was greatly increased by applying 500 mg/L CuNPs; the greatest values were noted at this concentration (Table 1), however growth was inhibited by higher doses. Compared to CuNPs alone, the combination of CuNPs (500 mg/L) and Spirulina extract (1.5 g/L) produced the best growth performance in both seasons. This supports earlier research showing that the combination of biofertilizers and nanofertilizers increases plant growth and the generation of essential oils.

Table 2 and Table 3 summarize the plant height, number of branches, oil yield, and oil percentage, with significant improvements observed in treatments combining CuNPs and Spirulina, especially at 500 mg/L CuNPs and 1.5 g/L Spirulina.

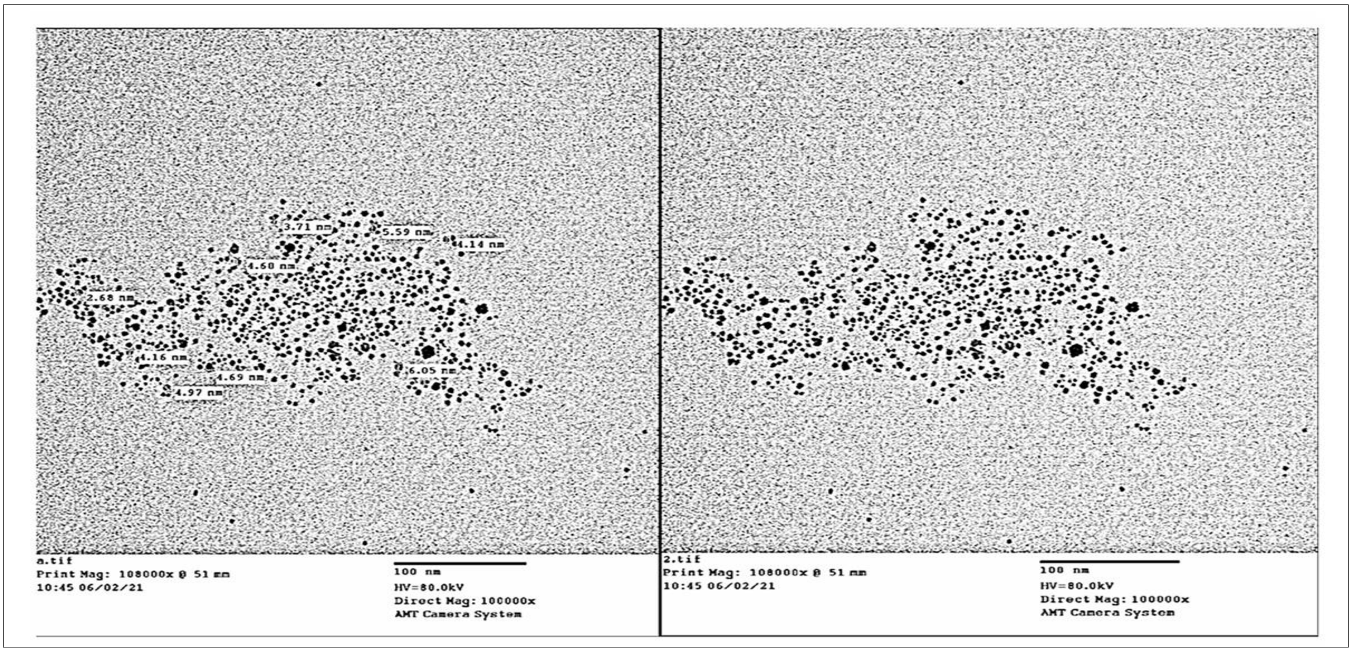


Fig 1: Transmission Electron Microscope (TEM) image of spherical copper nano particles

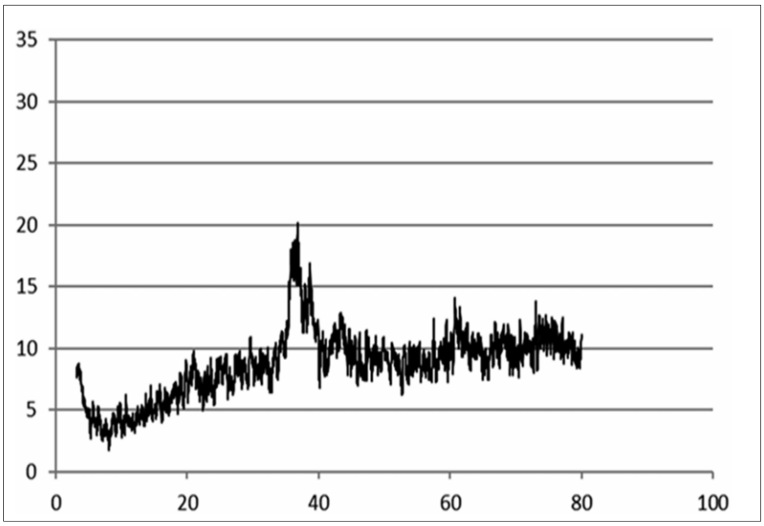


Fig 2: X-Ray diffraction plot

Table 1: Fresh and dry weights of French basil plants, after the treatments foliar spraying

Treatment	Fresh weight (g) Season(1)	Fresh weight (g) Season(2)	Dry weight (g) Season(1)	Dry weight (g) Season(2)
Control	71.45 ± 0.5^{1}	92.77 ± 0.7^{7h}	17.91 ± 1.4^{1}	15.67 ± 0.7^{21}
500 mg/L CuNPs	85.12 ± 1.1^{1}	102.66 ± 0.9^{7}	22.94 ± 1.0^{1}	17.09 ± 1.0^{2}
1000 mg/L CuNPs	80.61 ± 0.3^{1}	88.02 ± 1.0^{7}	21.45 ± 1.2^{1}	14.44 ± 1.2^{2}
1500 mg/L CuNPs	73.99 ± 0.1^{h}	64.51 ± 0.8^{7}	20.73 ± 1.0^{1}	14.34 ± 0.9^{2}
500 mg/L CuNPs + 0.5 g/L spirulina	93.41 ± 0.4^{1}	115.69 ± 1.0^{1}	25.86 ± 1.1^{n}	21.95 ± 1.0^{1}
1000 mg/L CuNPs + 0.5 g/L spirulina	86.08 ± 1.0^{1}	100.5 ± 1.5^{9}	23.32 ± 1.1^{de}	14.58 ± 1.3^{2}

1500 mg/L CuNPs + 0.5 g/L spirulina	74.29±0.3^{1}	85.97±1.0^{1}	21.89±1.1^{9}	16.7±1.1^{c}
500 mg/L CuNPs + 1 g/L spirulina	95.85±0.9^{1}	136.69±1.0^{b}	27.17±1.0^{b}	21.98±1.0^{1}
1000 mg/L CuNPs + 1 g/L spirulina	92.19±1.0^{1}	123.56±1.0^{c}	24.16±1.0^{de}	20.38±1.1^{1}
1500 mg/L CuNPs + 1 g/L spirulina	76.97±0.1^{9}	99.06±1.0^{9}	23.15±1.0^{de}	17.2±1.1^{c}
500 mg/L CuNPs + 1.5 g/L spirulina	122.26±1.0^{1}	167.1±1.1^{1}	27.87±1.9^{b}	24.0±1.0^{1}
1000 mg/L CuNPs + 1.5 g/L spirulina	101.66±1.2^{2}	102.1±0.4^{1}	25.09±1.0^{d}	21.23±1.1^{1}
1500 mg/L CuNPs + 1.5 g/L spirulina	92.4±1.0^{1}	100.1±1.0^{1}	24.23±1.1^{de}	20.87±0.9^{2}
LSD	1.39879343	1.67832759	2.00054928	1.7424742

Data are expressed as mean values±standard deviation; LSD refers to the least significant difference test. In each column, the same letter means non-significant difference, while different letters mean significant difference at p≤0.05.

Table 2: Plant height and the number of branches of French basil plant after the treatments foliar spraying in two seasons

Treatment	Plant height (cm) Season(1)	Plant height (cm) Season(2)	Number of branches/plant Season(1)	Number of branches/plant Season(2)
Control	41.40±0.4	35.80±0.4	5.00±1.0	5.76±1.0^{bc}
500 mg/L CuNPs	48.07±1.0^{b}	47.93±1.0^{a}	7.00±1.0^{ab}	6.00±1.0^{bc}
1000 mg/L CuNPs	46.53±0.0^{1d}	44.47±0.0^{1}	5.00±1.0	5.00±1.0
1500 mg/L CuNPs	45.67±1.0	43.30±1.0^{9}	5.00±1.0	5.00±1.0
500 mg/L CuNPs + 0.5 g/L spirulina	48.73±1.0^{c}	48.60±1.0^{ad}	8.00±1.0^{a}	6.00±1.0^{bc}
1000 mg/L CuNPs + 0.5 g/L spirulina	46.33±1.1^{de}	48.17±0.0^{1de}	7.00±1.0^{ab}	6.00±1.0^{bc}
1500 mg/L CuNPs + 0.5 g/L spirulina	46.30±1.0^{de}	43.43±0.0^{19}	6.00±1.0^{bc}	6.00±1.0^{bc}
500 mg/L CuNPs + 1 g/L spirulina	51.03±0.1^{a}	49.07±0.0^{1}	8.00±1.0^{a}	7.00±1.0^{ab}
1000 mg/L CuNPs + 1 g/L spirulina	49.26±1.1	48.60±1.4^{c}	8.00±1.0^{a}	7.00±1.0^{ab}
1500 mg/L CuNPs + 1 g/L spirulina	47.53±1.0	47.27±0.0^{1ab}	7.00±1.0^{ab}	6.00±1.0^{bc}
500 mg/L CuNPs + 1.5 g/L spirulina	51.57±0.0^{1a}	51.90±0.1	9.00±1.5	8.00±1.0
1000 mg/L CuNPs + 1.5 g/L spirulina	51.50±0.1	50.17±0.0^{9}	9.00±1.5	7.00±1.0^{b}
1500 mg/L CuNPs + 1.5 g/L spirulina	47.97±0.1^{c}	49.20±0.2^{c}	8.00±1.0^{ab}	7.00±1.0^{b}
LSD	1.290086696	1.290086696	1.762300627	1.67832759

Data are expressed as mean values±standard deviation; LSD refers to the least significant difference test. In each column, the same letter means non-significant difference, while different letters mean significant difference at p≤0.05.

Table 3: Plant height and the number of branches of French basil plant after the treatments foliar spraying in two seasons.

Treatment	Oil (%) Season(1)	Oil (%) Season(2)	Oil yield ml/plant Season(1)	Oil yield ml/plant Season(2)
Control	0.055±0.001^{b}	0.067±0.001	4.202±0.10	6.164±0.11^{1}
500 mg/L CuNPs	0.120±0.010^{a}	0.100±0.001	8.593±0.10	10.953±0.011^{1}
1000 mg/L CuNPs	0.100±0.001^{a}	0.067±0.001	8.394±0.06	9.027±0.011^{1}
1500 mg/L CuNPs	0.093±0.001^{a}	0.060±0.019	8.031±0.01	5.929±0.010^{1}
500 mg/L CuNPs + 0.5 g/L spirulina	0.120±0.010^{a}	0.109±0.001^{d}	11.528±0.1^{1}	12.397±0.010^{1}
1000 mg/L CuNPs + 0.5 g/L spirulina	0.093±0.001^{a}	0.105±0.001^{d}	10.114±0.06^{1}	11.377±0.011^{1}
1500 mg/L CuNPs + 0.5 g/L spirulina	0.110±0.010^{de}	0.100±0.002	8.403±0.10	6.857±0.011^{1}
500 mg/L CuNPs + 1 g/L spirulina	0.173±0.011^{b}	0.123±0.001	15.071±0.0^{1b}	17.595±0.010^{1}
1000 mg/L CuNPs + 1 g/L spirulina	0.099±0.001^{a}	0.120±0.010^{cd}	10.761±0.11^{1}	13.114±0.001^{1}
1500 mg/L CuNPs + 1 g/L spirulina	0.113±0.001^{d}	0.113±0.01^{cd}	10.482±0.19^{1}	10.54±0.11^{1}
500 mg/L CuNPs + 1.5 g/L spirulina	0.380±0.010	0.163±0.011	21.174±0.11	23.689±0.10^{1}
1000 mg/L CuNPs + 1.5 g/L spirulina	0.173±0.011	0.153±0.011	12.209±0.10	18.862±0.11^{1}
1500 mg/L CuNPs + 1.5 g/L spirulina	0.133±0.001	0.140±0.010	13.174±0.001^{1}	13.174±0.001^{1}
LSD	0.012002719	0.01250915	0.17342611	0.14305719

Data are expressed as mean values ± standard deviation; LSD refers to the least significant difference test. In each column, the same letter means non-significant difference, while different letters mean significant difference at p≤0.05.

Abdelmigid *et al.* (2024) [3] examined the effects of using green-synthesized titanium dioxide nanoparticles (TiO2NPs) for pomegranate seed priming on plant vigor, seed germination, and seedling growth in both controlled and field settings. TiO2NP-primed seeds showed better germination rates, increased seedling development, and overall vigor as compared to untreated seeds. The nanoparticles also improved nutrient absorption from the soil. By optimizing nutrient uptake and promoting early-stage growth, the study highlighted the potential of TiO NPs in seed priming, particularly in suboptimal soil conditions. This suggests that their inclusion in seed priming protocols could significantly improve the growth and agronomic profile of pomegranate plants.

Locally produced coffee beans, pomegranate fruits, and titanium dioxide (TiO2) from Across Organics were among the items used in this investigation. Plant extracts made from coffee grounds and pomegranate peels were combined with an aqueous TiO2 solution and heated to biosynthesize TiO2 nanoparticles (TiO2NPs). The TiO2NPs were subsequently examined for seed priming, uptake, and internalization after being described using a variety of methods, such as UV-Vi spectroscopy, TEM, SEM, XRD, and EDX.

Results and Discussion

Changes in colour and UV-Vis spectra (Figure 3) verified the creation of titanium dioxide nanoparticles (TiO2NPs) using coffee extract (CE) and pomegranate peel extract (PPE). Random clusters of irregularly shaped nanoparticles were found by SEM analysis (Figure 3A). TiO2NP uptake in seed embryos was verified by TEM and XRF studies, with TiO2NPs_CE exhibiting greater accumulation (Figure 4 and 5).

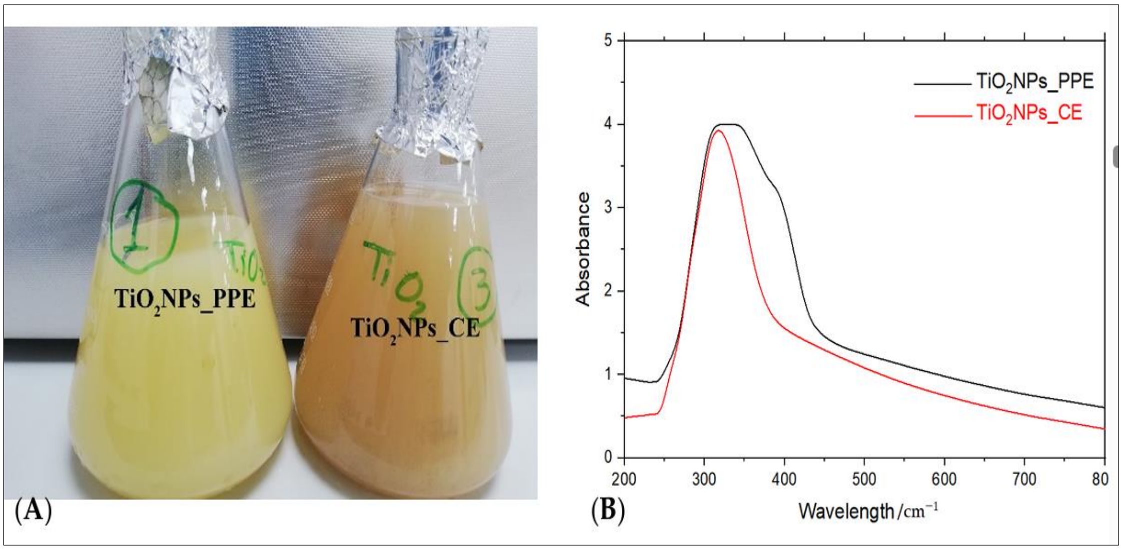
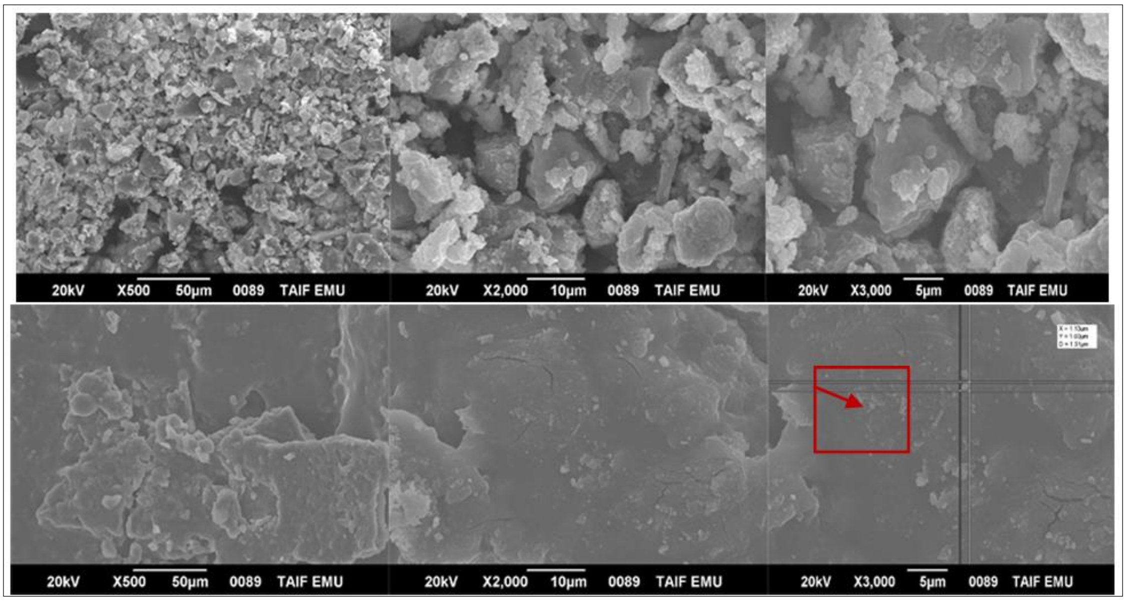
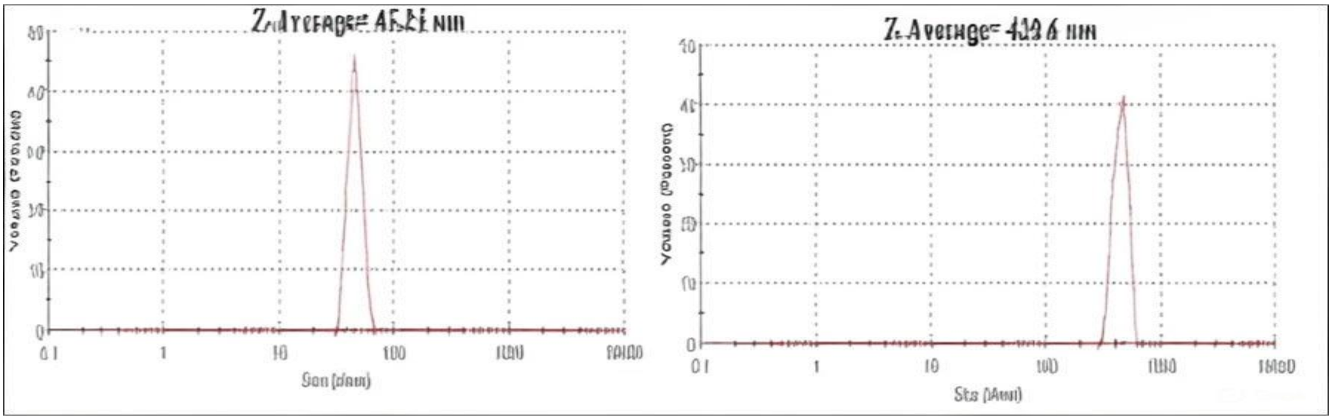


Fig 2: Green synthesis of titanium dioxide nanoparticles using pomegranate peel extract (PPE), and coffee ground extract (CE).



2 (A): Change in colour of the reaction to cloudy yellow and brown after − the production of nanoparticles.



2 (B): UV−Visible spectral analysis of green-synthesized titanium dioxide nanoparticles TiO2NPs_PPE and TiO2NPs_CE.

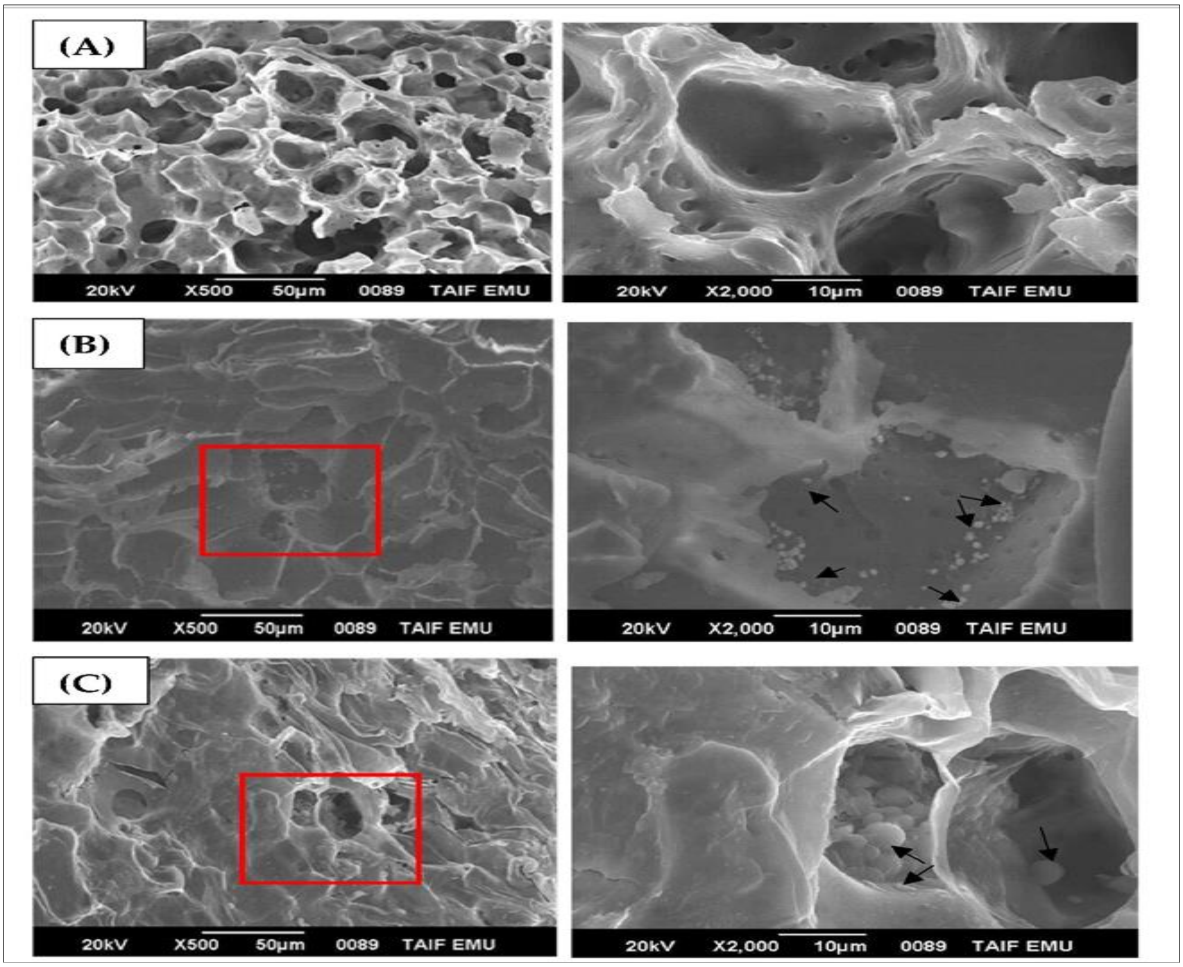


Fig 3: SEM micrographs of primed P. granatum seeds at different magnifications. (A) Hydro primed seeds; (B) TiO2NPs_ PPE-primed seeds; and (C) TiO2NPs_CE-primed seeds (red box and arrows show the adsorbed nanoparticles on seed coat surface)

Iqbal *et al*. (2024) [4] evaluated the impact of gamma-aminobutyric acid (GABA) on photosynthetic activity, water consumption efficiency, and antioxidant enzyme activities. The researchers treated drought-stressed sweet pepper plants by preparing the soil and sprinkling GABA on the leaves. The results showed that, particularly in drought conditions, GABA treatment significantly raised photosynthetic activity, water use efficiency, and antioxidant enzyme levels as compared to the control group. Better growth and higher yields were the outcome of this. The results of the study show that GABA is a helpful biostimulant that increases plant tolerance, maintains cellular homeostasis, and encourages growth and yield in water-limited conditions, all of which assist sweet peppers resist drought stress. Materials and methods Two Capsicum annuum L. types, Mercury and Scope F1, were used in field trials at Qurtuba University in Peshawar, Pakistan. The plants were planted in clay containers with a 3:1 sand-loam soil mixture and composted manure. To evaluate the physiological response, plants were exposed to three different levels of water stress (control, moderate, and severe) and treated with different concentrations of GABA (0, 2, and 4 mM). Samples were taken for examination at 80% maturity. Numerous agronomic, biochemical, and physiological characteristics, such as photosynthetic pigments, soluble sugars, and antioxidant enzyme activities, were examined in soil and plant samples.

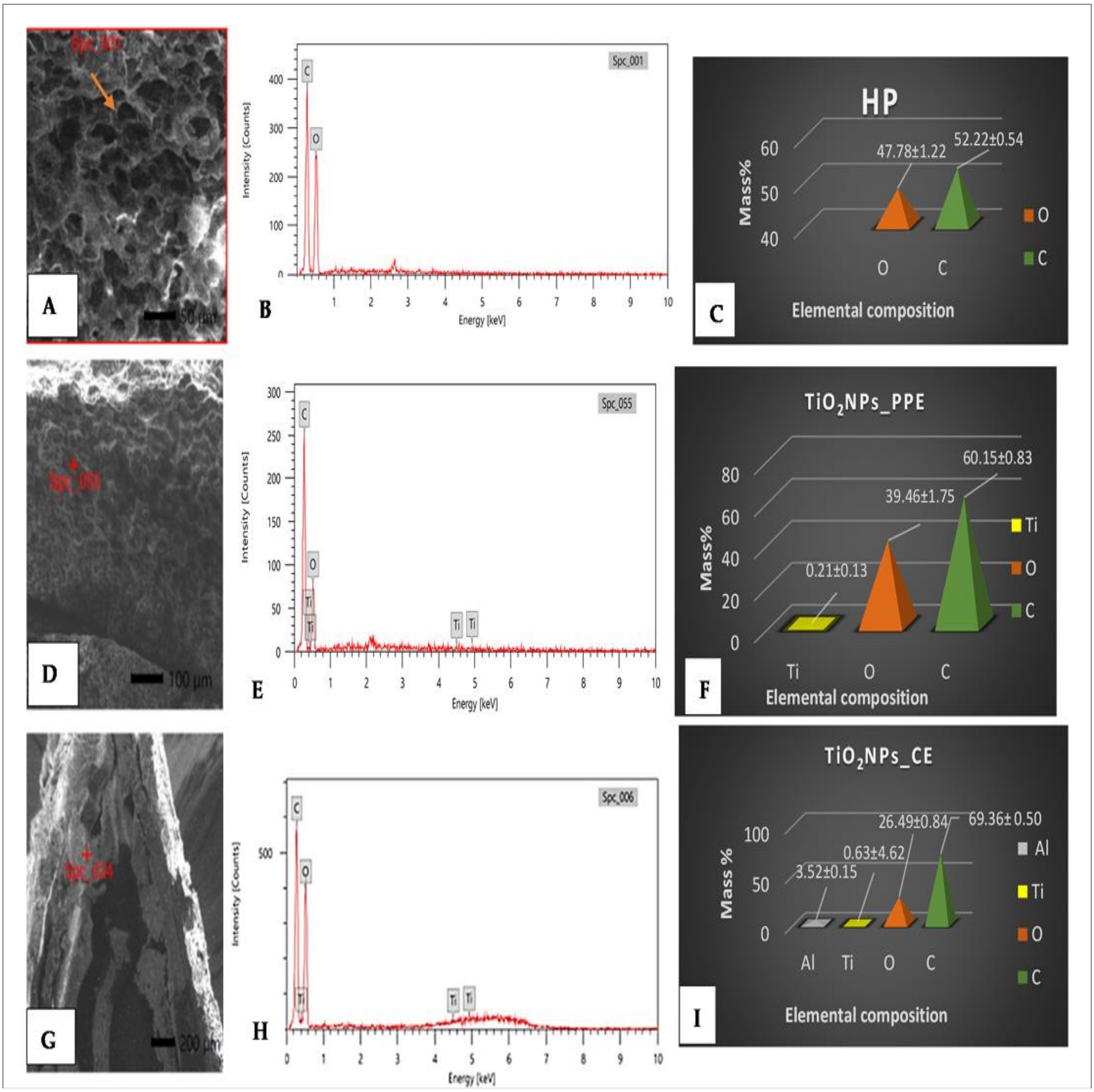


Fig 4: SEM-EDX study of P. granatum hydro-primed seeds (A–C). On the surface of the seed coat, panels (D–F) demonstrate the adsorption of TiO2NPs_PPE and (G, H) demonstrate the adsorption of TiO2NPs_CE and their EDX detection. The element peaks (C, O, and Ti) and their mass percentage are displayed in EDX spectra. The ROI of the seed surface is depicted in the SEM pictures. The amount of adsorbed C, O, and Ti elements (C, F, and I) is represented by mean mass percentages from the sample duplicates used in the study, or mean (%) ± SE.

Results and Discussion

The development and physiological characteristics of Capsicum annuum L., such as root and shoot characteristics, chlorophyll content, and antioxidant activity, were markedly improved by the application of GABA foliar spray during drought stress (Fig 6A–6c). Under 50% field capacity drought stress, 2 mM GABA was the most effective concentration, whereas under 30% drought stress, 4 mM GABA worked better. Additionally, the study found a strong favorable link between proline, soluble sugars, antioxidant enzymes, and chlorophyll concentration (Table 4, Table 5). These results show that GABA can improve the physiological responses and biochemical contents of plants, there by mitigating drought stress.

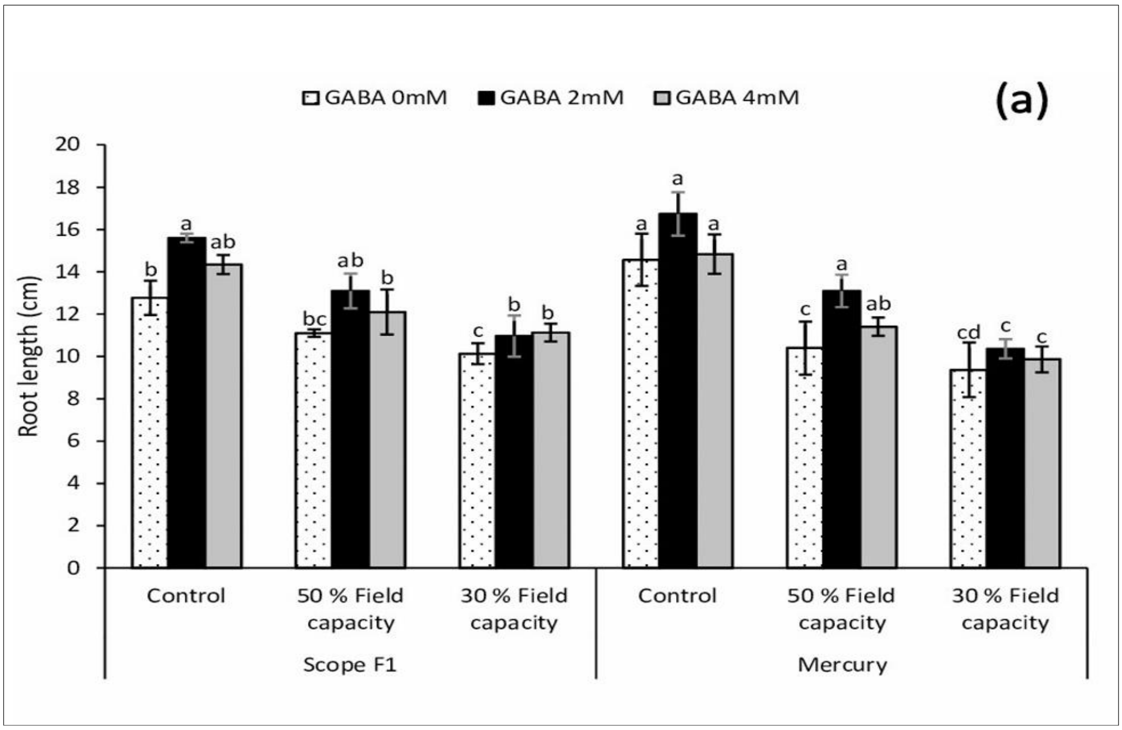
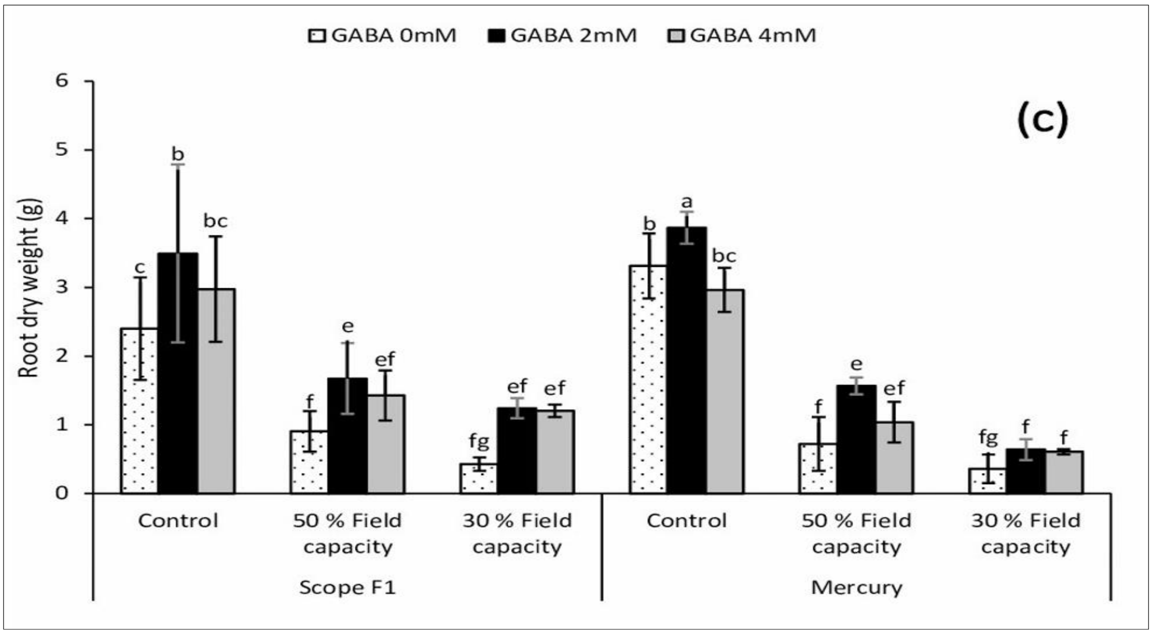


Fig 5: effect of varying levels of exogenously applied GABA on root length

(A) Root fresh weight



(B) Relative water content

In order to determine the effects of hydraulic, mechanical, and chemical priming (with potassium nitrate) on the germination and early growth of Sarasa asoca seeds, Kandileri *et al*. (2024) examined the germination rates, seedling vigor, and total establishment. The results showed that germination rates and seedling vigor were significantly enhanced by both chemical and mechanical priming, particularly when potassium nitrate was used. Potassium nitrate-treated seeds produced stronger seedlings and germination more quickly than hydro-priming or untreated controls. The study highlighted the importance of optimizing seed priming techniques, especially for medicinal and reforestation species like Sarasa asoca, and discovered that potassium nitrate is an effective treatment to enhance seedling growth, which is crucial for successful forestry operations.

Material and Methods

15 pre-sowing treatments and a control were used in the experimental investigation, which was carried out in the central forest nursery greenhouse at Uttar Banga Krishi Vishwavidyalaya in West Bengal, India, between May 2018 and May 2020. It was reproduced three times using a randomized block design. To evaluate their effects on seed germination and seedling growth, the seeds were subjected to mechanical treatments such as rubbing with sandpaper, as well as soaking in different concentrations of salicylic acid, thiourea, and hot or regular water. With data collected at

intervals up to a year, the study examined the seedling Vigor index, shoot and root lengths, and other growth metrics.

Results and Discussion

The study showed that the best methods for improving Sarasa asoca germination, seedling vigor, and growth characteristics were mechanical treatment (T_5), hot water treatment (T_6), and chemical treatments with thiourea (T_{13}–T_{15}). By promoting moisture and air penetration, these treatments enhanced germination by softening seed coatings and promoting embryo growth (Table 4). However, because of oxygen deprivation and embryo damage, prolonged soaking times in water—especially at higher temperatures—led to decreased germination. The best results were obtained with 200 ppm of thiourea (T_{14}) and 120 ppm of salicylic acid (T_2), which increased seedling development by encouraging meristematic activity and nutrient uptake.

Table 4: Effects of pre-sowing treatments on various germination attributes for Ashoka seeds.

Treatment	IG	%GC	GE	GI	GR	GV	MDG	PV	MGT
T_1	21.5^{bcd}	64.9^{d}	79.8^{de}	22.9^{cd}	24.5^{e}	50.1^{c}	9.9^{ab}	2.1^{bc}	4.0^{a}
	15.7^{bc}								
T_2	19.3^{def}	66.5^{cd}	80.9^{cde}	34.7^{a}	29.6^{def}	52.5^{c}	8.4^{abc}	2.3^{ab}	5.0^{a}
	14.7^{cd}								
T_3	19.0^{def}	61.7^{de}	80.9^{cde}	22.0^{cd}	26.8^{def}	46.4^{c}	7.1^{abc}	1.8^{ef}	3.5^{a}
	13.0^{de}								
T_4	18.5^{ef}	65.8^{cd}	78.5^{e}	19.3^{de}	26.9^{def}	56.4^{bc}	9.3^{ab}	2.6^{a}	3.3^{ab}
	14.3^{cd}								
T_5	17.8^{ef}	86.1^{a}	93.3^{ab}	26.8^{bc}	24.7^{ef}	67.8^{a}	7.1^{abc}	2.1^{bcd}	4.1^{a}
	11.8^{e}								
T_6	16.8^{f}	84.7^{a}	95.0^{a}	27.2^{bc}	26.8^{def}	63.3^{ab}	5.7^{c}	1.6^{f}	4.1^{a}
	17.2^{ab}								
T_7	19.7^{def}	64.3^{d}	85.7^{bcde}	19.3^{de}	28.7^{abcd}	50.0^{c}	8.4^{abc}	2.3^{ab}	3.6^{a}
	17.7^{ab}								
T_8	19.3^{def}	76.8^{b}	88.6^{abc}	25.8^{bc}	29.7^{abc}	55.9^{bc}	6.6^{bc}	1.9^{de}	4.1^{a}
	16.1^{bc}								
T_9	20.5^{bc}	67.8^{cd}	86.4^{bcd}	27.2^{bc}	27.9^{abcd}	50.1^{c}	5.2^{c}	1.1^{h}	3.8^{a}
	17.8^{ab}								
T_{10}	22.3^{ab}	19.7^{f}	38.5^{f}	9.7^{f}	29.0^{abcd}	16.7^{e}	5.1^{bc}	1.6^{f}	1.6^{c}
	18.1^{ab}								
T_{11}	23.8^{a}	17.6^{f}	32.6^{f}	14.5^{ef}	30.5^{ab}	14.0^{f}	5.1^{bc}	1.4^{bh}	2.0^{bc}
	18.7^{a}								
T_{12}	23.0^{ab}	21.5^{f}	47.5^{f}	11.8^{f}	28.2^{abcd}	29.0^{d}	8.6^{abc}	2.2^{bc}	2.0^{bc}
	17.7^{ab}								
T_{13}	18.7^{def}	66.1^{cd}	89.9^{ab}	19.1^{de}	28.9^{abcd}	50.8^{c}	7.5^{abc}	2.0^{de}	3.8^{a}
	17.3^{ab}								
T_{14}	18.8^{def}	73.3^{bc}	89.6^{ab}	19.1^{de}	32.1^{a}	55.5^{bc}	10.3^{a}	2.0^{bcde}	4.0^{a}
	17.5^{ab}								
T_{15}	19.8^{def}	81.5^{ab}	89.9^{ab}	30.4^{ab}	27.4^{cde}	50.9^{c}	9.6^{ab}	2.6^{a}	3.8^{a}
	9.38^{f}								
T_{16}	26.5^{a}	55.9^{e}	80.6^{de}	26.2^{bc}	25.8^{def}	46.4^{c}	7.6^{abc}	1.8^{def}	3.3^{a}
	15.7^{bc}								
Statistic	**IG**	**%GC**	**GE**	**GI**	**GR**	**GV**	**MDG**	**PV**	**MGT**
SE_m	1.6	4.0	3.8	2.7	81.4	25.0	11.2	0.14	0.69
SE^d	1.1	2.8	2.7	1.9	71.0	13.5	41.7	0.10	0.49
HSD	3.6	8.2	7.8	5.6	2.9	10.2	13.4	0.29	1.42

Different letters (a, b, c, d, e, f, g, h) within each treatment value indicate significant differences at $p<0.05$. Means with the same letter are not significantly different.**T** — Treatment **IG** — Initiation of germination **G%** — Germination percentage **GC** — Germination capacity **GE** — Germination energy **GI** — Germination index **GR** — Germination rate **GV** — Germination value **MDG** — Mean daily germination **PV** — Peak value of germination **MGT** — Mean germination time

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