Research Article

Evaluating the Impact of Seed Priming Techniques on Germination and Growth Behavior of *Coleus blumei* Benth

Muhammad Muzamil Ijaz[1,2*], Adnan Younis[1], Abida Parveen[3*], Muhammad Abdul Salam Khan[2], Hooria Mushtaq[1], Ahmad Faiz Akbar[1], Nasir Ahmad Khan[4] and Ahsan Akram[1]

[1]Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan; [2]Directorate of Floriculture (T&R) Punjab, Lahore; [3]Department of Botany, University of Agriculture, Faisalabad, Pakistan; [4]Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan.

Abstract | *Coleus blumei* (Lamiaceae) is an ornamental foliage plant, which is valued for its colorful leaves, low maintenance and easily cultivation. Unfortunately, its commercial sowing and seedling vigor is largely impeded by a major problem: the small size of its seed, which results in poor and erratic germination. The present investigation was conducted to overcome this problem, the use of different priming methods including osmo (PEG), hydro and hormonal seed priming (5% Indole-3-butyric acid IBA and 5% Gibberellic acid GA_3) were tested with a completely randomized design (CRD). The results showed that hormonal priming with 5% GA_3 was superior treatment and positively improved all germination and seedling characteristics. GA_3 priming promoted germination at a faster rate with 50% and 90% germination at 3.5 days and enhanced the final percentage of the seed germination compared to non-primed control (8.5 days), which showed significantly lower germination percentage. It also produced the best vigor index (6.25) and better seedling growth as compared to control which evolved in terms of root length (3.1 cm), shoot length (0.7 cm), fresh weight (2.47 g) and dry weight (1.9 g). These results definitively prove that the GA_3 inducing hormonal priming is a very effective and applicable approach to relieving germination constrains of the small seed-sized *Coleus blumei*, and contribute to more efficient propagation/cultivation.

Received | Jun 14, 2025; **Accepted** | Nov 4, 2025; **Published** | December 26, 2025
***Correspondence** | Muhammad Muzamil Ijaz, Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan; Abida Parveen, Institute of Horticultural Sciences, University of Agriculture, Faisalabad, Pakistan; **Email:** abidadogar4@gmail.com
Citation | Ijaz, M.M., A. Younis, A. Parveen, M.A.S. Khan, H. Mushtaq, A.F. Akbar, N.A. Khan and A. Akram. 2025. Evaluating the impact of seed priming techniques on germination and growth behavior of *Coleus blumei* Benth. *Sarhad Journal of Agriculture,* 41(5): 177-185.
DOI | https://dx.doi.org/10.17582/journal.sja/2025/41.5.177.185
Keywords | Seed priming, *Coleus blumei*, Germination, Growth.

Introduction

The coleus is a species-rich genus of the Lamiaceae, which contains many species and more than 300 named varieties (Rattray & Wyk, 2021). These plants are native to Malaysia and Southeast Asia, they were brought to Europe from Java in 1851 and it has been grown as ornamental plant because of its colorful foliage (Wang *et al*., 2020). A multipurpose annual, Coleus has been used in the ornamental bedding plant industry for years due to its variable leaf features and coloration (Nagpal *et al*., 2008). They prefer moist and well-drained soil and grow to an average height of 0.5-1 m, but in some cases they may become as tall as up to 2 m (Suva *et al*., 2015). Apart from the ornamental role, the genus Coleus includes a large number of plant species having colossal medicinal values and can be easily grown for different economic reasons (Reddymalla *et al*., 2021; Chandora *et al*., 2023). Beginning in the 1800s, early cultivated and hybridized types had much more plain colorations and habits of growth. Some species, like *Coleus ambionicus*, are known for containing medicinal compounds and having antimicrobial activities (Datta, 2023).

Although coleus is one of the most important medicinal and dye yielding crop, lack of quality seeds in local market is a major constraint for its production. One of the major problems confronting growers, particularly in developing countries is that of soil heterogeneity and low quality resulting in poor germination rate, uneven seedling emergence and retarded growth. This suboptimal condition prompts the competition among seedlings for critical resources such as light, water, and nutrients, causing differences in plant biomass and performance (Raj *et al*., 2021). This disparity between sowing and emergence takes its toll in a loss of income. The high quality seeds and F1 hybrids are not only very expensive but also create in built germination problems which are major constraints in the production of these types of seeds (Varier *et al*., 2010).

To overcome these pervasive problems, seed priming has gained an immense role as an efficient and inexpensive pre-sowing physiological technique. This method is considered as an applicable approach to improve seed germination, promote seedling vigor, and increase crop yield, particularly in various and abiotic stress conditions (Abbasi Khalaki *et al*., 2021). Priming is a regulated hydration that consists in soaking seeds in particular solution to drive the metabolic process preceding germination, as the enzymatic activation, metabolic repair and the accumulation of germination-related compounds, up to dry back prior radical protrusion (Paparella *et al*., 2015). To enhance the germination metabolism should subsequently lead to a faster, synchronized and more uniform emergence in subsequent seed sowing (Waqas *et al*., 2019). The advantages are diverse, and include increased seed vigor, tolerance to soil-borne abiotic factors, and the healthier base on which to initiate seedling growth (Ibrahim, 2016; Abid *et al*., 2018). Physiological bolstering caused by priming, mediated through enhanced osmotic adjustment and lowered mechanical impedance to water uptake, can be retained after redrying and can easily be manifested upon rehydration in the soil (Shabbir *et al*., 2014). Different forms of priming, such as hydropriming (soaking the seeds in water), osmopriming (treatment with solutions such as PEG) and hormone priming (application of phytohormones, e.g. GA_3 or IBA), have been successfully used to breakdown dormancy and enhance germination in a variety of horticultural crops.

Accordingly, this study was aimed at investigating various priming methods to improve the poor germination of *C. blumei* because of its small seed size. The results are helpful to fill a significant knowledge-practice gap with an economical approach of achieving more uniform germination and better seedling. This study not only enhances the understanding of seed physiology but also provides practical recommendations to improve propagation and crop production of Coleus in particular, and possibly horticulture under challenging conditions.

Materials and Methods

The seed of *Coleus blumei* used in this study was obtained from Chanan Din Seed Market, Lahore Pakistan and the experiment was conducted at Seed Physiology Lab of Department of Agronomy, University of Agriculture Faisalabad. The experimental design was a CRD with five treatments mentioned in Table 1 and three replications per treatment, each replicate consisting of 26 seeds. The treatments used were unprimed control (T_0), osmopriming with polyethylene glycol solution (T_1), hydropriming with distilled water (T_2), and hormonal priming including 5% indole-3-butyric acid (T_3) and 5% gibberellic acid (T_4). Seeds were soaked in their extracts for 24 h at room temperature for priming as shown in Figure 1. To observe the treatment factor effects, germination data were taken every day. This method was followed according to the protocol described by Rehman *et al*. (2015).

Osmopriming treatment

For osmopriming, 0.1 g PEG in 50 mL of distilled water solution was prepared. Subsequently, 0.1 g of seeds was soaked in the PEG solution for 24 h. The treated seeds were dried in an oven at 30°C for 30–35 minutes, and sowed as shown in Figure 1 (H) (Basra *et al*., 2004).

Table 1: *Following treatment used during study*

Treatment	
T_0	Control (No chemical)
T_1	Osmo priming (using PEG)
T_2	Hydro priming
T_3	Hormonal priming 5% indole-3-butyric acid solution (IBA)
T_4	Hormonal priming 5% gibberellic acid solution (GA_3)

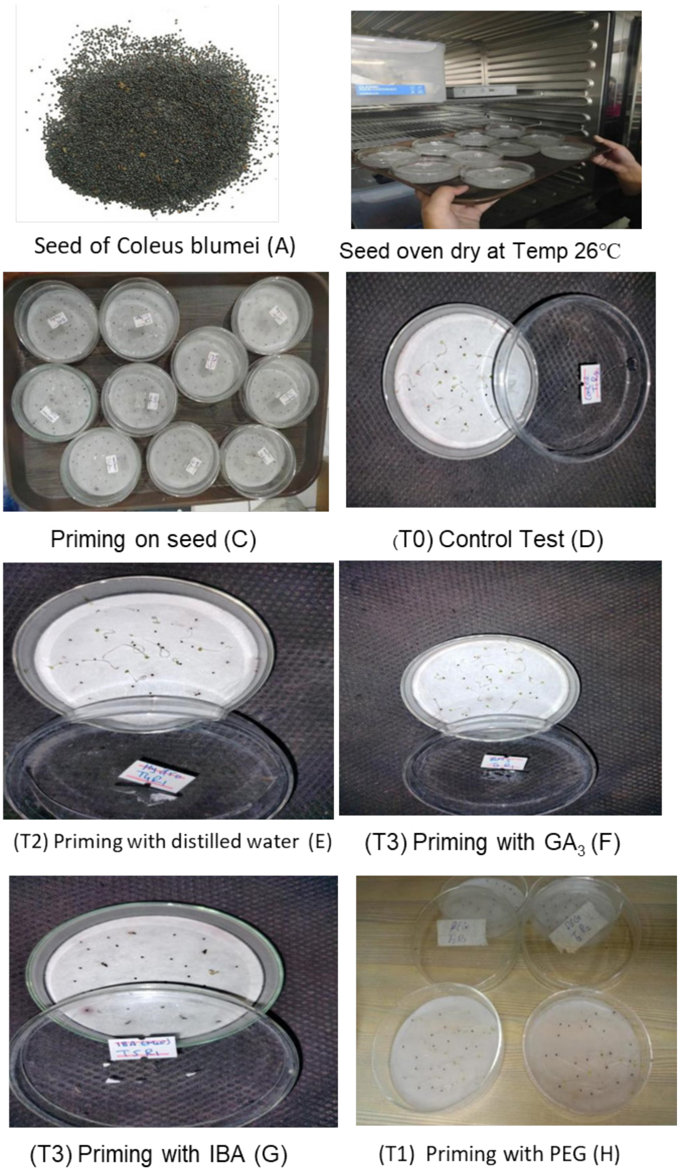

Figure 1: *Methodology for adopting various priming techniques on Coleus blumei seeds*

Hydropriming treatment

Hydropriming was performed as per Takshak and Agrawal (2018). About 0.1 g seeds of *Coleus blumei* were soaked in 50 ml distilled water for 24h at room temperature. After soaking, seeds were dried in an oven at 30°C for 30–35 minutes to arrest the priming treatment as shown Figure 1 (E).

Hormonal priming treatment

Seeds were subjected to hormonal treatment with indole-3-butyric acid (IBA) and gibberellic acid (GA_3) at 5% concentration each. GA_3 was directly dissolved into distilled water, but IBA was first dissolved in a small volume of ethanol and then diluted to the desired concentration with distilled water. Seeds were soaked in each hormonal solution for 24 h and then dried under controlled temperature conditions as shown in Figure 1 (F and G) (Jisha *et al.*, 2013).

Germination parameters

Germination components were determined according to the standard methods. Days to first germination was counted as the interval between sowing and appearance of first radicle. Percentage of Water Content (WoC) was calculated by formula of (FW – WU)/FW × 100%, which represents the weight loss during the drying process (%) following the equation described by Cornejo *et al.* (2015). Mean Germination Time (MGT) was calculated as per the formula given by Rehman *et al.* (2015), MGT = $\Sigma(n \times D)/\Sigma n$ n is the number of seeds germinated on day D, the percentage of final germination was determined by dividing MGT by N (final number of seeds tested). Germination energy (%) was determined as the percentage of seeds germinated at 4–5 days after commencement with respect to the total number of seeds applied (Basra *et al.*, 2005). The germination index (GI) was calculated according to the formula proposed by AOSA along with a vigor index which was obtained multiplying the percentage of germinated seeds with total length of seedlings (Abdul-Baki and Anderson, 1973).

Morphological parameters

The measurements of seedlings (randomly selected) were recorded at 20-30 days after transplanting. Root and shoot length were measured with a measuring tape from 10 seedlings per replication. Seedling fresh weights were weighed with the aid of an electric balance. For dry weights, seedlings were microwaved at 70°C for 24 h and weighed.

Results

Germination attributes

The germination characters of *Coleus blumei* seeds were significantly enhanced by all the seed priming treatments in contrast to the unprimed control (T_0). The number of days required for the first emergence was significantly reduced by all priming treatments, and the hormonal treatment (T_4) with GA_3 was found to be most effective, initiating germination in as quickly as 3.5 days (Figure 2). Hydropriming (T_2, 3.6 days) was followed by IBA priming (T_3, 3.87 days), and osmopriming with PEG seed treatment (T_1, 3.97 days), whereas the slowest initiation were found in control T_0 at five days.

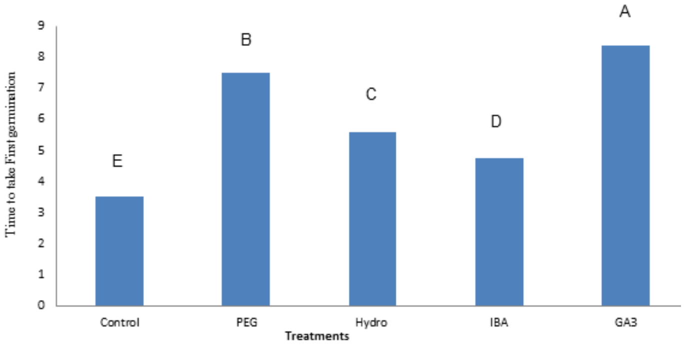

Figure 2: *Effect of seed priming technique on time to take first germination (days). T_0 = control, T_1 = osmopriming, T_2 = Hydro priming T_3 = IBA 5% solution, T_4 = GA_3 5% solution. Means sharing the same case letter did not differ significantly at $P \leq 0.05$.*

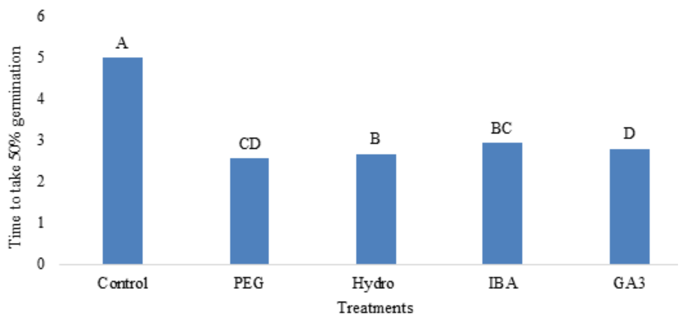

Figure 3: *Effect of seed priming technique on time to take 50% germination (days) T_0 = control, T_1 = osmopriming, T_2 = Hydro priming T_3 = IBA 5% solution, T_4 = GA_3 5% solution. Means sharing the same case letter did not differ significantly at $P \leq 0.05$.*

The same trend was reflected in time to 50% germination (T_4) with GA_3 priming (6.25 days) taking relatively the shortest time compared to other treated seeds and control treatment that gain 7.25 days (Figure 3). The Mean Germination Time (MGT) was also the shortest in GA_3 treatment (3.5 days), confirming its effects for stimulates a rapid and uniform germination, while longest MGT recorded from control treatment (5 days) (Figure 4). Hormonal priming with GA_3 in general imparted the highest beneficial influence on all germination parameters.

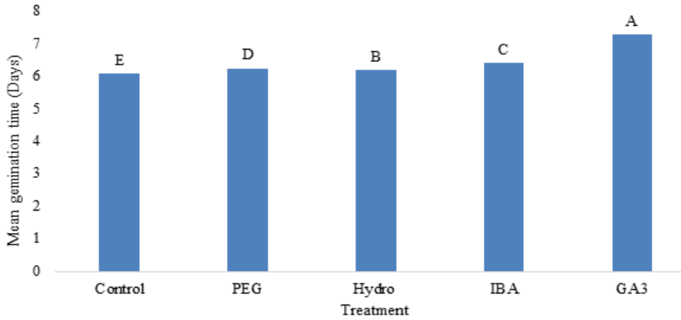

Figure 4: *Effect of seed priming technique on mean germination time (days). T_0 = control, T_1 = osmopriming, T_2 = Hydro priming T_3 = IBA 5% solution, T_4 = GA_3 5% solution. Means sharing the same case letter did not differ significantly at $P \leq 0.05$.*

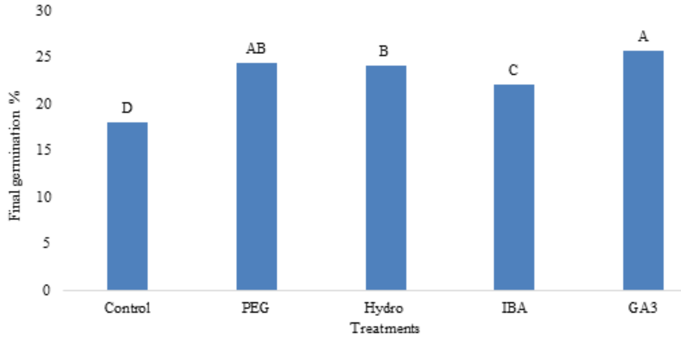

Figure 5: *Effect of seed priming technique on final germination % T_0 = control, T_1 = osmopriming, T_2 = Hydro priming T_3 = IBA 5% solution, T_4 = GA_3 5% solution. Means sharing the same case letter did not differ significantly at $P \leq 0.05$.*

The ultimate germination percentage (GP) of seed was significantly affected by various priming treatments, and the highest GP value of 90% was obtained with T_4 (GA_3 primed), which was statistically different from other treatments described in Figure 5. The lowest germination rates were obtained on seeds without treatment and those under the hydropriming condition (T_0, 40.75% and T_2, 60%) with small difference between them. Intermediate results were recorded with osmopriming by PEG (T_1) and hormonal priming IBA (T_3) which were not statistically different. The germination energy results showed a similar tendency, the highest being related to the GA_3 priming (T_4) 70%), which also differed significantly from control (4.42%) as well as other priming treatments (Figure 6). Hydropriming (T_2, 8.75%) and osmopriming (T_1, 3.75%) were non-significant with each other. The priming treatments showed significant positive influence on germination index, where GA_3 priming (T_4) again rated as the most rapid in initiation period with an onset at 3.5 days after sowing suing it followed by hydropriming (T_2, 3.26 days), IBA priming (T_3, 2.56 days) and osmopriming (T_1, 3.9 days) (Figure 7). The vigor index results also supported data on GA_3 priming and T_4 presented the highest values which were significantly greater as compared to other treatments (Figure 8). In all parameters, control (T_0) had the lowest performance, and hydropriming (T_2) and IBA priming (T_3) presented statistically similar values, with reasonable results.

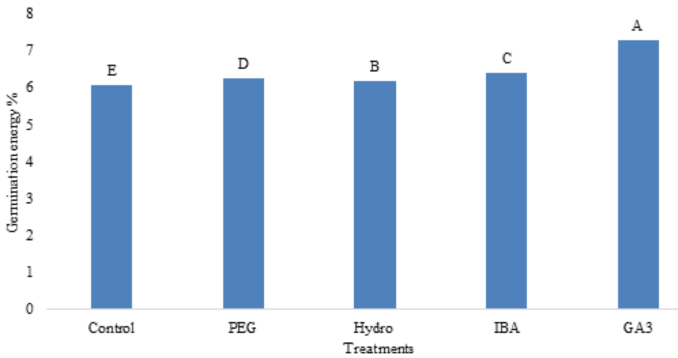

Figure 6: *Effect of seed priming techniques germination energy % T_0 = control, T_1 = osmopriming, T_2 = Hydro priming T_3 = IBA 5% solution, T_4 = GA_3 5% solution. Means sharing the same case letter did not differ significantly at $P \leq 0.05$.*

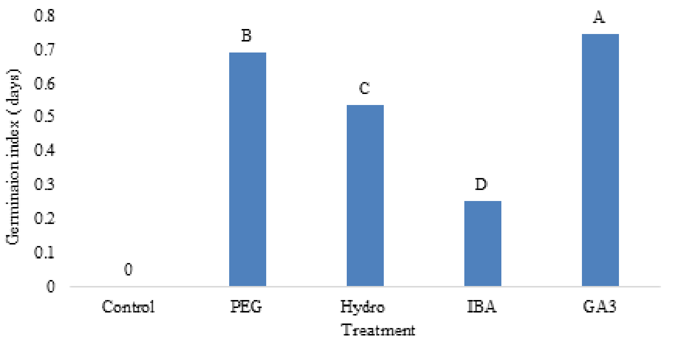

Figure 7: *Effect of seed priming techniques germination index (days) T_0 = control, T_1 = osmopriming, T_2 = Hydro priming T_3 = IBA 5% solution, T_4 = GA_3 5% solution. Means sharing the same case letter did not differ significantly at $P \leq 0.05$.*

Morphological attributes

The findings of the effects on macro development and germination characteristics of *Coleus blumei* by different priming treatments are in Table 2. The maximum root length of 3.1 cm was obtained with GA_3 priming (T_4) and there were significant differences recorded between treatments in terms of root development. The length of roots was 2.1 cm and 2.4 cm in hydropriming (T_2) and PEG priming (T_1), which were intermediately between the positive control and negative control, however planted with no primed seeds (T_0) led to developing short roots. Whereas shoot elongation responded differently among treatments. Control (T_0) had the highest shoot length (0.9 cm) may be as a result of etiolated growth due to lower germination vigor. Considering primed seeds, the most significant shoot length was obtained by IBA application (T_3), followed by PEG (T_1) and GA_3-treated seeds (T_4) with 0.7, 0.6 and 0.5 cm, respectively; however, hydropriming-seeds (T_2) showed the lowest values being only of 0.1 cm under greenhouse conditions.

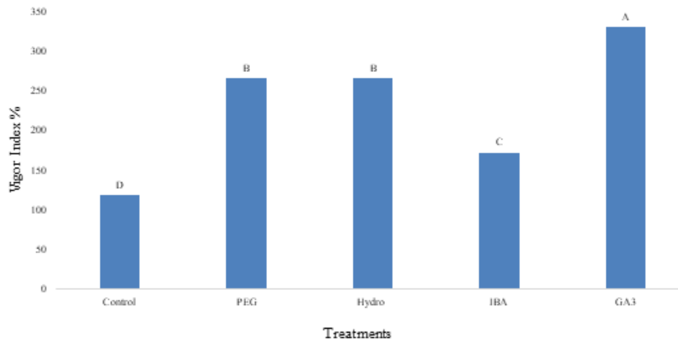

Figure 8: *Effect of seed priming techniques vigor index (days) T_0 = control, T_1 = osmopriming, T_2 = Hydro priming T_3 = IBA 5% solution, T_4 = GA_3 5% solution. Means sharing the same case letter did not differ significantly at $P \leq 0.05$.*

Table 2: *Impact of seed priming techniques on morphological characteristics of coleus blumei*

Treat-ments	Shoot length (cm)	Root length (cm)	Seedling fresh weight (g)	Seed-ling dry weight (g)	Germi-nation %
T_0	0.9 ± 0.02c	1.64 ± 0.09c	1.3 ± 0.02d	0.3 ± 0.17b	67.01 ± 1.44c
T_1	0.6 ± 0.37b	2.4 ± 0.08b	1.2 g ± 0.25a	1.16 ± 0.03a	90.85 ± 0.94ab
T_2	0.1 ± 0.05a	2.1 ± 0.23b	2.03 ± 0.067b	0.4 ± 0.04a	88.54 ± 1.44ab
T_3	0.7 ± 0.05b	1.62 ± 0.07c	1.96 ± 0.09c	0.2 ± 0.03b	92.46 ± 2.72
T_4	0.5 ± 0.09a	3.1 ± 0.12a	2.47 ± 0.20a	1.9 ± 0.53a	95.38 ± 5.01a

Means sharing the same case letter, for a parameter did not differ significantly at $P \leq 0.05$.

Priming treatments had a significant effect on biomass accumulation. T_4 (GA_3-primed seeds) produced the most vigorous seedlings, being 2.47 g fresh weight and 1.9 g dry weight with strong growth vigour and more biomass accumulation into seeds. PEG priming (T_1) similarly affected dry matter accumulation (1.2 g), although to a lower extent than GA_3. In contrast, IBA (T_3), hydropriming (T_2) and T_0 resulted in significantly lower dry weight where inhibitory effects of the metabolic activity and growth were overcome as evidenced by the lowest plant compositional measurements that were 0.2 g, 0.4 g and 0.3 g respectively.

The germination of seeds was significantly improved by all priming treatments. GA_3 priming (T4) was found to be most effective and recorded 95.38 % germination in 3.5 days only. IBA priming (T3) was also effective, 92.46 % germination in 3.56 days while it was minimally higher than PEG and hydropriming treatment which achieved 90.85 % germination in 3.9 days (T1), and 88.54 % after 3.26 days of soaking the seeds with distilled water (T2). For this control (T0), germination was partial and delayed reaching 67.01 % over the observation time. These results indicate that hormonal priming, especially with GA_3, induces enhanced germination synchrony and seedling establishment and early growth of Coleus blumei.

Discussion

The widespread constraint of uneven seedling establishment on account of low germination levels is one that limits horticultural production systems globally, more so for species with small seeds like *Coleus blumei*. The present analysis reveals that a range of seed pre-treatments alleviates this problem, with GA_3-priming being particularly beneficial for many physiological and morphological traits. Hormonal priming, especially with GA_3 performed better in reducing time to first germination (3.5 days) and 50% germination (6.25 days), which is in supported with findings of previous studies in salvia and other ornamental crops where priming agents greatly increased synchrony and uniformity of germination (Raj *et al*., 2021; Salam *et al*., 2022).

The physiological basis for these enhancements may involve changes in complex biochemical processes that are initiated by priming. As noted by Nciizah *et al*. (2020), pivotal metabolites of catalyze essentially all the key metabolic pathways including dormancy release, germination inhibitors metabolism and hydrolytic enzymes mobilizing the reserves. The results suggest that the biochemical changes mediated by them could be involved in the enhanced cell division and enlargement events during seed germination of seeds (Pangestuti *et al*., 2021), which may finally result into increase in GER% (70% at GA_3 treatment) and vigor index. The most remarkable increase in final germination percentage (90%, GA_3 treatment) was of great significance, demonstrating the superiority of hormonal priming to overcome the inherent physiological constraints imposed by small seed size.

The stimulation of the antioxidant system seems to be key in the priming effectiveness. The elevated levels of glutathione and ascorbate described by Al-Badri *et al*. (2021) provide a mechanistic basis for observed enhanced germination speed and uniformity, especially due to diminished lipid peroxidation activities which usually hinder cellular membrane integrity during germination. This antioxidant stimulation may be particularly important in marginal conditions, given that higher levels of stress tolerance were seen when primed seed lots of sorghum and sunflower were tested.

At molecular level, the plant defense response implies a modulation of genes coding for water transport, cell wall remodeling and energy metabolism in priming treated plants. The fast imbibition of primed seeds indicates changes in aquaporin modulation and membrane permeability, leading to higher water absorption during the critical early stages of germination. In addition, the activity of enzymes such as α-amylase, protease and lipase is increased during priming leading to degradation of stored reserves necessary for energy and construction blocks in embryonic development (Bewley *et al*., 2013).

The better plant morphology characters after priming treatments, specifically the increased root (3.1 cm) and dry weight up to 2.47 g fresh weight might be governed through the various physiological strategies regulated by JAR1 activity (Supplementary Figures S6 and S7). The increased seed water therapies and earlier imbibition involved are perhaps likely to help in the more rapid cessation of germination lag phase Ali *et al*., 2019. Furthermore, the higher increase in seedling dry weight (1.9 g per GA_3 treatment) also indicates that priming stimulates mobilization of stored reserves and more efficient biomass partitioning as reported by Alam *et al*., 2023 for cucumber and other species. The particularly increased root growth in GA_3-treated seeds points to the importance of auxin-mediated responses that are required for the development of a strong root system, enabling efficient nutrient and water acquisition.

The differential treatment responses of parameters indicate the need for applications based on testing of suitable priming approaches in relation to crop-specific requirement or environment. Although GA_3 priming displayed the highest positive influence on most of tested traits, the intermediate performance of osmopriming with PEG and hormonal priming with IBA underlines that a context-specific use might be desirable in specific production systems and limitations. This is consistent with Thakur *et al*. (2023) focus on taking into account seed age, genetic diversity and the desired growth conditions when choosing and optimizing priming protocols.

Conclusions and Recommendations

The findings confirm the usefulness of seed priming, especially that with GA_3 in the alleviation of germination imposed limitations in cultivation of *Coleus blumei*. Results reveal that priming technologies have the potential to significantly improve synchrony of germination, seedling vigor and early growth performance and could be considered as an effective option for increasing efficiency in nursery production. Further investigations are required to clarify the molecular mechanisms of these improvements, to optimize priming strategies for different environments and production systems, and also whether synergistic effects can be obtained by combining priming treatments. It would also be of great interest to evaluate the impact of priming on long-term plant development, flowering behaviour and final crop quality for commercial use. Cost-effective and practical priming methods for mass propagation in nurseries are still the subject of a promising works.

Acknowledgements

The authors are grateful to University of Agriculture Faisalabad and Directorate of Floriculture (T&R) Lahore, Pakistan for their invaluable support and contributions to this research experiment.

Novelty Statement

The findings reveal that GA_3-induced hormonal priming is a critically effective physiological intervention for *Coleus blumei*, directly countering the poor and erratic germination caused by its small seed size. This approach represents a novel strategy to enhance germination uniformity and vigor, thereby facilitating more efficient and reliable commercial production.

Author's Contribution

Muhammad Muzamil Ijaz and Hooria Mushtaq: Performed the experiment and collected data.
Abida Parveen and Muhammad Abdul Salam Khan: Helped in data collection and manuscript write-up.
Adnan Younis and Nasir A. Khan: Data analysis and proofreading.
Ahmad Faiz Akbar and Ahsan Akram: Helped in relevant literature and format setting.

Generative AI or AI assisted technology statement
No generative AI or AI-assisted technologies were used in the creation or preparation of this manuscript.

Conflict of interest
The authors have declared no conflict of interest.

References

Abdul-Baki, A.B. and J.D. Anderson. 1973. Vigor determination in soybean seed by multiple criteria. Crop Sci., 13: 630-633. https://doi.org/10.2135/cropsci1973.0011183X001300060013x

Abbasi, K.M., M. Moameri, B.A. Lajayer and T. Astatkie. 2021. Influence of nano-priming on seed germination and plant growth of forage and medicinal plants. Plant Growth Regulat., 93:13-28. https://doi.org/10.1007/s10725-020-00670-9

Abid, M., S. Ali, L.K. Qi, R. Zahoor, Z. Tian, D. Jiang, J.L. Snider and T. Dai. 2018. Physiological and biochemical changes during drought and recovery periods at tillering and jointing stages in wheat (*Triticum aestivum* L.). Scient. Repor., 8: 4615. https://doi.org/10.1038/s41598-018-21441-7

Alam, A.U., H. Ullah, S.K. Himanshu, R. Tisarum,

S. Cha-um and A. Datta. 2023. Seed priming enhances germination and morphological, physio-biochemical, and yield traits of cucumber under water-deficit stress. J. Soil Sci. Plant Nutrit., 23: 3961-3978. https://doi.org/10.1007/s42729-023-01314-3

Al-Badri, M.K.K., A.A.H. Rasheed and S.A.H. Ahmed. 2021. Effect of the seed priming and duration on the seed germination and seedling vigor of sunflower crop. Plant Arch., 21:1122-1127. https://doi.org/10.51470/PLANTARCHIVES.2021.v21.S1.175

Ali, M., S. Hayat, H. Ahmad, M.I. Ghani, B. Amin, M.J. Atif and Z. Cheng. 2019. Priming of (*Solanum melongena* L.) seeds enhances germination, alters antioxidant enzymes, modulates and improves early seedling growth indicating aqueous garlic extract as seed-priming bio-stimulant for eggplant production. Appl. Sci., 9: 22-33. https://doi.org/10.3390/app9112203

Basra, S.M.A., M. Farooq, R. Tabassum. 2004. Physiological and biochemical aspects of seed vigor enhancement treatments in fine rice (*Oryza sativa* L.). *Seed Sci. Techno.*, 32(3): 783-788. https://doi.org/10.15258/sst.2005.33.3.09

Basra, S.M.A., M. Farooq and R. Tabassum. 2005. Physiological and biochemical aspects of seed vigor enhancement treatments in fine rice (*Oryza sativa* L.). Seed Sci. Technol., 33: 623-628. https://doi.org/10.15258/sst.2005.33.3.09

Bewley, J.D. and M. Black. 2013. Seeds: Physiology of development and germination. Springer Science & Business Media

Chandora, R., S. Paul, R.C. Kanishka, P. Kumar, B. Singh, P. Kumar, A. Sharma, A. Kumar, D. Singh, N. Negi and S. Lata. 2023. Ecological survey, population assessment and habitat distribution modelling for conserving Fritillaria Roylei. A critically endangered himalayan medicinal herb. South Afric. J. Bot., 160: 75-87. https://doi.org/10.1016/j.sajb.2023.06.057

Cornejo, F., P.J. Caceres, C. Martínez-Villaluenga, C.M. Rosell and Frias, J. 2015. Effects of germination on the nutritive value and bioactive compounds of brown rice breads. Food Chem., 173: 298-304.

Datta, S.K. 2023. Role of Mutation Breeding In Floriculture Industry. https://doi.org/10.1007/978-981-99-5675-3

Ibrahim, E.A. 2016. Seed priming to alleviate salinity stress in germinating seeds. J. Plant Physiol., 192: 38-46. https://doi.org/10.1016/j.jplph.2015.12.011

Jakobsson, A. and O. Eriksson. 2000. A comparative study of seed number, seed size, seedling size and recruitment in grassland plants. Oikos., 88: 494-502. https://doi.org/10.1034/j.1600-0706.2000.880304.x

Jisha, K.C., K. Vijayakumari, J.T. Puthur. 2013. Seed priming for abiotic stress tolerance: an overview. Acta Physio. Plant., 35(5): 1381-1396. https://doi.org/10.1007/s11738-012-1186-5

Kadir, M., M. Ashan and S.S. yamsia. 2023. Improvement of vigor and early growth of two composite maize varieties through seed priming treatment. J. Agric., 2: 54-60. https://doi.org/10.47709/joa.v2i01.2389

Nagpal, A., B. Singh, S. Sharma, G. Rani and G.S. Virk. 2008. Coleus spp.: Micropropagation and in vitro production of secondary metabolites. Med. Aromat. Plant Sci. Biotechnol., 2:1-7.

Nagpal, A., B. Singh, S. Sharma, G. Rani and G.S. Virk. 2008. Coleus spp.: Micropropagation and in vitro production of secondary metabolites. Med. Aromat. Plant Sci. Biotechnol., 2: 1-7.

Nciizah, A.D., M.C. Rapetsoa, I.I. Wakindiki and M.G. Zerizghy. 2020. Micronutrient seed priming improves maize (*Zea mays*) early seedling growth in a micronutrient deficient soil. Heliyon., 6: 8-15. https://doi.org/10.1016/j.heliyon.2020.e04766

Pangestuti, R., E. Sulistyaningsih, B. Kurniasih and R.H. Murti. 2021. Improving seed germination and seedling growth of true seed shallot using plant growth regulator seed priming. Earth Environ. Sci., 883: 12-24. https://doi.org/10.1088/1755-1315/883/1/012024

Paparella, S., S.S. Araujo, G. Rossi, M.A.L.A.K.A. Wijayasinghe, D. Carbonera and A. Balestrazzi. 2015. Seed priming: state of the art and new perspectives. Plant Cell Repor., 34: 1281-1293 https://doi.org/10.1007/s00299-015-1784-y.

Raj, M., S. Gupta, V. Chamola, A. Elhence, T. Garg, M. Atiquzzaman and D. Niyato. 2021. A survey on the role of internet of things for adopting and promoting agriculture 4.0. J. Network Comput. App., 187: 103107. https://doi.org/10.1016/j.jnca.2021.103107

Rattray, R.D and B.E. Van WyK. 2021. The botanical, chemical and ethnobotanical diversity

of southern African Lamiaceae. Molecul., 26: 3712. https://doi.org/10.3390/molecules26123712
Reddymalla, N.R., S. Pureti and V.C. Kolluru. 2021. Cultivation and Utilization of Coleus Species. Medicinal Plants: Domestication, Biotechnol. Region. Import., 28: 229-251. https://doi.org/10.1007/978-3-030-74779-4_7
Rehman, A., M. Farooq, R. Ahmad and S. Basra. 2015. Seed priming with zinc improves the germination and early seedling growth of wheat. Seed Sci. Technol., 43: 262-268. https://doi.org/10.15258/sst.2015.43.2.15
Saha, D., P. Choyal, U.N. Mishra, P. Dey, B. Bose, M. Prathibha, N.K. Gupta, B.K. Mehta, P. Kumar, S. Pandey and J. Chauhan. 2022. Drought stress responses and inducing tolerance by seed priming approach in plants. Plant Stress., 4: 41-66. https://doi.org/10.1016/j.stress.2022.100066
Salam, A., M.S. Afridi, M.A. Javed,A. Saleem, A. Hafeez, A.R. Khan, M. Zeeshan, B. Ali, W. Azhar, Sumaira and Z. Ulhassan. 2022. Nano-priming against abiotic stress: A way forward towards sustainable agriculture. Sustain., 14: 14-88. https://doi.org/10.3390/su142214880
Sarabandi, M., R.K. Singh, S. Kalantari, M. Shokrpour, R. Naresh and S. Rafiee. 2024. Unveiling machine learning's impact on in vitro callogenesis optimization in *Crocus sativus* L. South Afric. J. Bot., 168: 1-8. https://doi.org/10.1016/j.sajb.2024.02.053
Shabbir, I., M. Ayub, M. Tahir, M. Bilal, A. Tanveer, M. Hussain and Afzal. 2014. Impact of priming techniques on emergence and seedling growth of sesame (*Sesamum Indicum* L.) Genotypes. Sci. Agric., 1: 92-96. https://doi.org/10.15192/PSCP.SA.2014.1.3.9296
Steel, R.G.D and J.H. Torrie. 1997. Principle and procedure of statistics: A boimetrical aproach, 3rd Ed. McGraw Hill Book Co., New York.
Suva, M.A., A.M. Patel and N. Sharma. 2015. Coleus species: *Solenostemon scutellarioides*. Inventi Rapid: Planta Acti., 2: 1-5.
Takshak, S. and S.B. Agrawal. 2018. Interactive effects of supplemental ultraviolet-B radiation and indole-3-acetic acid on *Coleus forskohlii.* alterations in morphological, physiological, and biochemical characteristics and essential oil content. Ecotoxicol. Environ., Saf., 147: 313-326. https://doi.org/10.1016/j.ecoenv.2017.08.059
Thakur, V., D. Mal, S.K. Gharde and D. Durlabh. 2023. Effect of Different Seed Priming Treatments on Seed Germination and Seedling Vigor of Okra. J. Food Chemic. Nanotechnol., 9: 271-276. https://doi.org/10.17756/jfcn.2023-s1-035
Varier, A., A.K. Vari and M. Dadlani. 2010. The subcellular basis of seed priming. Curr. Sci., 450-456.
Wang, P., L. Jiang and R. Han. 2020. Biosynthesis of zinc oxide nanoparticles and their application for antimicrobial treatment of burn wound infections. Mater. Res. Expr., 7: 095010. https://doi.org/10.1088/2053-1591/abb150
Waqas, M., N.E. Korres, M.D. Khan, A.S. Nizami, F. Deeba, I. Ali and H. Hussain. 2019. Advances in the concept and methods of seed priming. Priming and pretreatment of seeds and seedlings: Implication in plant stress tolerance and enhancing productivity in crop plants, spriger, Singapore, 11-41. https://doi.org/10.1007/978-981-13-8625-1_2
Xia, J., X. Hao, T. Wang, H. Li, X. Shi, Y. Liu and H. Luo. 2023. Seed priming with gibberellin regulates the germination of cotton seeds under low-temperature conditions. J. Plant Growth Regulat., 42: 319-334. https://doi.org/10.1007/s00344-021-10549-2