**Evaluation of Primed Coriander Seeds for Phenological, Yield Attributing and Physiological Characteristics**

**ABSTRACT**

This study was conducted over two consecutive years (2021-22 and 2022-23) at Research field, Dept. of Seed Science and Technology, Chauras Campus, H.N.B. Garhwal Central University, Uttarakhand, to assess the impact of various seed priming treatments on coriander's phenological, yield attributing and physiological characteristics. The experiment included priming treatments with Trichoderma viride, vermiwash, silver nanoparticles, concentrated H₂SO₄, and plasma, with unprimed seeds as controls. The germplasm was procured from the bhatwari village of Uttarakashi District in Uttarakhand.

Field trials demonstrated that silver nanoparticle priming significantly enhanced plant height, early flowering, umbel production, and seed yield. Physiological analysis revealed increased chlorophyll and protein content in primed seeds, indicating improved seed quality.

These results suggest that silver nanoparticle priming is the most effective method for enhancing seed performance and yield potential in coriander. This study underscores the significance of advanced priming techniques in sustainable seed enhancement and productivity under diverse environmental conditions.

**Keywords:** Trichoderma viride, Plasma, Vermiwash, Silver Nanoparticles, Seed Priming

**Introduction:**

Seed priming is a pre-sowing treatment that enhances seed performance by improving germination, seedling vigor, and overall plant growth. It involves controlled hydration of seeds, which initiates metabolic processes without allowing radicle emergence (Farooq *et al.,* 2019). This technique has been widely recognized for its ability to improve seed quality, particularly under diverse environmental conditions (Ashraf & Foolad, 2005).

Coriander (Coriandrum sativum L.) is an important spice crop valued for its culinary, medicinal, and aromatic properties. However, its seed germination and early growth are often influenced by environmental stresses and seed quality (Singh *et al.,* 2021). Advanced seed priming techniques have emerged as a promising strategy to enhance seed vigor, accelerate germination, and improve crop yield. Various priming treatments, including biological agents, organic extracts, nanotechnology, and physical treatments, have been explored to improve seed quality and plant performance (Hussain *et al.,* 2020).

Trichoderma viride, a beneficial fungus, enhances plant growth by suppressing soil-borne pathogens and promoting nutrient uptake (Harman *et al*., 2004). Vermiwash, an organic extract from earthworms, is rich in enzymes, plant growth regulators, and beneficial microorganisms that stimulate germination and early seedling development (Rajiv *et al*., 2013). Silver nanoparticles (AgNPs) have shown potential in improving seed germination, seedling vigor, and pathogen resistance due to their antimicrobial properties (Rai & Ingle, 2012). Concentrated sulfuric acid (H₂SO₄) is commonly used for seed scarification, enhancing water absorption and breaking seed dormancy (Baskin & Baskin, 2014). Plasma treatment, an emerging technology in agriculture, modifies the seed coat structure, enhances nutrient uptake, and reduces seed-borne pathogens (Randeniya & de Groot, 2015).

The present study was conducted to evaluate the effects of these seed priming techniques on coriander’s phenological traits, yield-attributing characteristics, and physiological parameters under natural field conditions. By assessing germination, plant growth, chlorophyll content, protein levels, and seed yield, this research aims to identify the most effective priming treatment for improving seed quality and productivity. The findings will contribute to sustainable agricultural practices by integrating innovative priming techniques for enhanced seed performance and yield potential.

**Material and Methods :**

The study was conducted at the research field of the Department of Seed Science and Technology, Chauras Campus, H.N.B. Garhwal Central University, Uttarakhand, following a randomized block design with three replications. The seeds were collected from bhatwari village of Uttarakhand. The treatments included *Trichoderma viride* (24 hours), Vermiwash (6 hours), Silver nanoparticles (24 hours), Concentrated H₂SO₄ (2 minutes), Plasma treatment (6 minutes), and a control (untreated seeds). The experimental field was thoroughly prepared by plowing, harrowing, and leveling, followed by manual removal of weeds and stubbles in the month of November 2021 and 2022. Seeds were sown using a dibbler at a depth of 3 cm with a spacing of 30 × 15 cm. Farmyard manure (FYM) was applied as per standard recommendations, and necessary irrigation and manual weeding were carried out during the crop cycle. Harvesting was performed manually once 90% of the seeds were fully ripened, with separate collection and drying of each plot’s produce before threshing and winnowing.

**Phenological and Yield Studies**:

Observations recorded in the field included days to 50% flowering, plant height, number of branches per plant, number of umbels per plant, number of umbellets per umbel, number of fruits per umbel and umbellet, seed yield per plant, 1000-seed weight, total seed yield per hectare, biological yield, and harvest index.

**Physiological studies**

**Chlorophyll content**

Physiological studies involved chlorophyll and protein estimation to determine the biochemical effects of priming treatments. Chlorophyll content was assessed using the Arnon method (1949), where pigments were extracted with 80% acetone and measured spectrophotometrically at 664 nm and 647 nm to calculate chlorophyll a, chlorophyll b, and total chlorophyll content.

**Formulas**

Chlorophyll ‘a’ (µg mg-1 ) = 13.19 A664 – 2.57 A647

Chlorophyll ‘b’ (µg mg-1 ) = 22.10 A647 – 5.26 A664

Total Chlorophyll (µg mg-1 ) =7.93 A664 + 19.53 A647

**Protein estimation**

Protein estimation was carried out using the Lowry method (1951), where extracted proteins reacted with the Folin-Ciocalteau reagent, forming a blue-colored complex measured at 660 nm. The protein content in samples was determined using a standard curve generated with Bovine Serum Albumin (BSA). These assessments emphasized on the effectiveness of different priming treatments in enhancing coriander seed quality, growth, and productivity under natural field conditions.

**Statistical analysis :**

The collected data was analyzed using OPSTAT software. Analysis of variance (ANOVA) was performed for phenological, yield, and physiological parameters. Microsoft Excel 2007 was also used.

**Results and Discussions :**

The present study evaluated the effect of different treatments, including Trichoderma viride, vermiwash, silver nanoparticles, concentrated sulfuric acid (H2SO4), plasma treatment, and a control, on various growth, yield, and seed quality parameters. The findings reveal significant differences among the treatments, highlighting the potential of innovative and organic seed enhancement techniques.

**Flowering, Growth and Yield Attributes**

The days to 50% flowering varied significantly among treatments, with the shortest time observed in silver nanoparticle-treated plants (52.27 days), followed by Trichoderma viride (54.325 days), whereas the control exhibited the highest duration (61.06 days). This reduction in flowering duration due to silver nanoparticles could be attributed to their role in enhancing enzymatic activity and nutrient uptake (Shang *et al*., 2019). Plant height was also significantly influenced, with silver nanoparticle treatment (79.24 cm) recording the highest height, indicating its role in improved cell elongation and metabolic activity (Raliya *et al*., 2015).A significant variation was noted in the number of branches per plant, where silver nanoparticle treatment showed the highest number (20.43), followed by Trichoderma viride (18.49). The increased branching in these treatments could be attributed to improved nutrient availability and hormonal balance (Vejan *et al*., 2016). The number of umbels per plant was also significantly higher in silver nanoparticle treatment (76.64), followed by Trichoderma viride (73.25), suggesting enhanced floral initiation and reproductive efficiency.The number of umbellates per umbel, fruits per umbel, and fruits per umbellate showed significant differences. Silver nanoparticles resulted in the highest values for all these parameters, with 8.3 umbellates per umbel, 62.3 fruits per umbel, and 8.835 fruits per umbellate. The enhanced reproductive output in silver nanoparticle and Trichoderma viride-treated plants aligns with previous findings suggesting improved pollen viability and fertilization efficiency under such treatments (Singh *et al.,* 2020).

Seed yield per plant was highest in silver nanoparticle-treated plants (15.54 g), followed by Trichoderma viride (15.00 g), whereas the control recorded the lowest value (12.00 g). This is in accordance with previous studies indicating that bio-stimulants and nanomaterials can enhance seed development by promoting nutrient translocation and photosynthetic efficiency (Raliya *et al*., 2016). Similarly, the highest 1000-seed weight (12.05 g) was recorded under silver nanoparticle treatment, demonstrating their role in enhancing seed vigor and quality.

Seed yield per hectare (kg/ha) followed the same trend, with silver nanoparticle treatment yielding the highest (896 kg/ha), followed by vermiwash (788.5 kg/ha) and Trichoderma viride (679.5 kg/ha). The biological yield also showed significant variations, with silver nanoparticles leading (2683.425 kg/ha). The higher harvest index (HI) observed in vermiwash (35.365%) suggests improved partitioning efficiency, which is crucial for sustainable agricultural practices (Mosa *et al.,* 2018).The results suggest that silver nanoparticles and Trichoderma viride significantly enhance growth, yield, and quality parameters. Silver nanoparticles emerged as the most effective treatment, followed by Trichoderma viride and vermiwash, indicating their potential for eco-friendly and sustainable seed enhancement strategies. These findings are consistent with previous studies (Shang *et al*., 2019; Singh *et al.,* 2020), reinforcing the need for further research to optimize dosages and explore long-term effects.

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| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Treatment** | **Days to 50 % flowering** | **Plant height (cm)** | **Number of branches per plant** | **Number of umbel per plant** | **Number of umbellate per umbel** | **Number of fruits per umbel** | **Number of fruits per umbellate** | **Seed yield per plant (g)** | **1000 seed weight (g)** | **Seed yield (kg/ha)** | **Biological yield (kg ha-1)** | **Harvest index (%)** |
| *Trichoderma viride*  | 54.325 | 75.2 | 18.49 | 73.25 | 6.38 | 55.5 | 8.33 | 15.00 | 11.23 | 679.5 | 2482.975 | 27.365 |
| Vermiwash  | 56.575 | 70.5 | 17.89 | 65.38 | 6.23 | 53.25 | 7.965 | 14.00 | 10.99 | 788.5 | 2229.515 | 35.365 |
| Silver nanoparticle  | 52.27 | 79.24 | 20.43 | 76.64 | 8.3 | 62.3 | 8.835 | 15.54 | 12.05 | 896 | 2683.425 | 33.395 |
| Conc. H2SO4  | 58.335 | 71.14 | 16.8 | 64.35 | 6.17 | 50.05 | 7.825 | 14.485 | 10.85 | 666 | 2249.95 | 29.595 |
| Plasma treatment  | 55.03 | 72.68 | 17.5 | 67.7 | 6.02 | 53.32 | 8.165 | 14.64 | 11.1 | 735 | 2347.75 | 31.3 |
| Control | 61.06 | 69.35 | 14.86 | 62.25 | 5.8 | 48.4 | 4.23 | 12 | 10.45 | 523 | 2021.35 | 25.865 |
| C.D. (0.05) | 4.63 | 2.11 | 2.84 | 9.02 | 0.38 | 2.89 | 0.43 | 1.97 | 2.00 | 1.18 | 2.84 | 1.42 |
| SE(m) | 1.27 | 0.80 | 1.20 | 3.27 | 0.16 | 2.03 | 0.14 | 0.44 | 0.72 | 0.26 | 1.20 | 1.10 |
| CV (0.05) | 2.39 | 5.36 | 5.5 | 9.42 | 4.18 | 5.48 | 4.49 | 5.05 | 1.21 | 5.75 | 10.30 | 4.52 |

**Table 1: Effect of Seed priming on the phenological and Yield attributing Characteristics in coriander in natural conditions during 2021-22 and 2022-23**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatment** | **Chlorophyll a (mg/100g)** | **Chlorophyll b (mg/100g)** | **Total Chlorophyll (mg/100g)** | **Protein Content (mg/g)** |
| *Trichoderma viride* (24Hrs) | 1.215 | 0.54 | 1.755 | 5.11 |
| Vermiwash (6Hrs) | 1.145 | 0.52 | 1.665 | 4.94 |
| Silver nanoparticle (24 hrs) | 1.34 | 0.595 | 1.935 | 6.05 |
| Conc. H2SO4 (2 min) | 1.08 | 0.485 | 1.565 | 4.67 |
| Plasma treatment (6 min) | 1.135 | 0.53 | 1.665 | 5.08 |
| Control | 1.035 | 0.465 | 1.5 | 4.61 |
| C.D. (0.05) | 0.11 | 0.15 | 0.18 | 1.13 |
| SE(m) | 0.45 | 0.47 | 0.42 | 0.49 |
| CV (0.05) | 1.33 | 1.42 | 1.23 | 2.33 |

**Table 2: Effect of Seed Priming on the chlorophyll and protein content in Coriander in 2021-22 and 2022-23**

Physiological assessments confirmed the effectiveness of seed priming in improving photosynthetic efficiency and metabolic activity. Chlorophyll plays a critical role in photosynthesis and plant metabolism, and its content is often indicative of plant vigor and health (Porra *et al.,* 1989). The highest chlorophyll a (1.34 mg/100g), chlorophyll b (0.595 mg/100g), and total chlorophyll (1.935 mg/100g) were recorded in seeds treated with silver nanoparticles for 24 hours. This suggests that silver nanoparticles might enhance chlorophyll synthesis, potentially by influencing plant metabolic pathways, as reported in previous studies (Singh *et al.,* 2018). *Trichoderma viride* (24 hrs) also exhibited enhanced chlorophyll content, with chlorophyll a (1.215 mg/100g), chlorophyll b (0.54 mg/100g), and total chlorophyll (1.755 mg/100g), supporting findings that *Trichoderma* spp. enhance plant growth and biochemical attributes (Shoresh *et al*., 2010).

The control treatment exhibited the lowest chlorophyll a (1.035 mg/100g), chlorophyll b (0.465 mg/100g), and total chlorophyll (1.5 mg/100g), suggesting that untreated seeds had comparatively lower metabolic activity. The plasma treatment (6 min) and vermiwash (6 hrs) treatments showed intermediate results, implying a moderate effect on chlorophyll biosynthesis. Sulfuric acid (H₂SO₄) treatment resulted in the lowest values after control, likely due to its potential phytotoxic effects (Basra *et al.,* 2005). Protein content is an essential determinant of seed quality and vigor. The highest protein content (6.05 mg/g) was observed in silver nanoparticle-treated seeds, aligning with previous studies that report enhanced metabolic activity and stress tolerance associated with nanoparticle application (Rai & Ingle, 2012). *Trichoderma viride* (24 hrs) and plasma treatment (6 min) also showed improved protein content (5.11 mg/g and 5.08 mg/g, respectively), indicating a positive effect on protein synthesis, which is consistent with the role of biostimulants in improving seed physiology (Harman *et al.,* 2004). Vermiwash treatment (4.94 mg/g) also exhibited relatively higher protein content, likely due to the presence of plant growth-promoting substances (Sharma & Garg, 2017). Conversely, sulfuric acid treatment resulted in a reduced protein content (4.67 mg/g), likely due to oxidative stress and protein degradation (Basra *et al.,* 2005). The control treatment had the lowest protein content (4.61 mg/g), reaffirming the benefits of seed priming techniques. The critical difference (C.D. 0.05) values indicate statistically significant variations among treatments. The coefficient of variation (CV) values, ranging from 1.23% (total chlorophyll) to 2.33% (protein content), suggest high experimental precision. The standard error of the mean (SEm) values further support the reliability of the findings.

**Conclusion :**

These findings strongly suggest that seed priming, particularly with silver nanoparticles and *Trichoderma viride*, is an effective strategy for improving coriander growth and yield. The increased photosynthetic efficiency, enhanced nutrient uptake, and better metabolic activity observed under these treatments contribute to improved agronomic performance. Future studies should explore the molecular mechanisms underlying these benefits and assess the long-term economic viability of these treatments for commercial seed production. Silver nanoparticle treatment exhibited the most significant enhancement in chlorophyll content and protein concentration, followed by *Trichoderma viride* and plasma treatment. These findings highlight the potential of these treatments in improving seed quality and metabolic efficiency. Future research should explore the mechanistic basis of these enhancements at a molecular level.

**References :-**

1. Arnon, D. I. (1949). **Copper enzymes in isolated chloroplasts: Polyphenoloxidase in *Beta vulgaris.*** Plant Physiology, 24(1), 1-15. <https://doi.org/10.1104/pp.24.1.1>
2. Ashraf, M., & Foolad, M. R. (2005). Pre-sowing seed treatment—a shotgun approach to improve germination, plant growth, and crop yield under saline and non-saline conditions. *Advances in Agronomy, 88*, 223-271.
3. Baskin, C. C., & Baskin, J. M. (2014). *Seeds: Ecology, biogeography, and evolution of dormancy and germination*. Academic Press.
4. Basra, S. M. A., Farooq, M., Tabassum, R., & Ahmad, N. (2005). Physiological and biochemical aspects of seed vigor enhancement treatments in fine rice (*Oryza sativa* L.). *Seed Science and Technology*, 33(3), 623-628.
5. Farooq, M., Wahid, A., Basra, S. M. A., & Siddique, K. H. M. (2019). Improving drought tolerance in wheat by exogenous application of proline and glycinebetaine. *Journal of Agronomy and Crop Science, 195*(3), 235-246.
6. Harman, G. E., Howell, C. R., Viterbo, A., Chet, I., & Lorito, M. (2004). Trichoderma species—Opportunistic, avirulent plant symbionts. *Nature Reviews Microbiology*, 2(1), 43-56.
7. Hussain, S., Khan, F., Cao, W., He, L., Ahmed, M., & Li, Y. (2020). Seed priming: An effective strategy to improve crop stress tolerance. *International Journal of Molecular Sciences, 21*(2), 556.
8. Lowry, O. H., Rosebrough, N. J., Farr, A. L., & Randall, R. J. (1951). **Protein measurement with the Folin phenol reagent.** Journal of Biological Chemistry, 193(1), 265-275. [https://doi.org/10.1016/S0021-9258(19)52451-6](https://doi.org/10.1016/S0021-9258%2819%2952451-6)
9. Mosa, W. F., Abd El-Maksoud, H. K., & Ali, M. M. (2018). Effect of bio-stimulants on growth and productivity of wheat under different nitrogen levels. Journal of Agronomy, 17(3), 140-149.
10. Porra, R. J., Thompson, W. A., & Kriedemann, P. E. (1989). Determination of accurate extinction coefficients and simultaneous equations for assaying chlorophylls a and b extracted with four different solvents. Biochimica et Biophysica Acta (BBA)-Bioenergetics, 975(3), 384-394.
11. Rai, M., & Ingle, A. P. (2012). Role of nanotechnology in agriculture with special reference to management of insect pests. *Applied Microbiology and Biotechnology*, 94(2), 287-293.
12. Rajiv, P., Rajeshwari, S., & Venckatesh, R. (2013). Vermiwash: A liquid biofertilizer and biopesticide—a review. *International Journal of Engineering Science and Technology, 5*(2), 899-902.
13. Raliya, R., Tarafdar, J. C., & Biswas, P. (2016). Enhancing the mobilization of essential nutrients in agricultural soil using nanomaterials. Environmental Science & Technology, 50(3), 1185-1192.
14. Randeniya, L. K., & de Groot, G. J. (2015). Non-thermal plasma treatment of agricultural seeds for enhanced germination, early growth, and disease control. *Plasma Processes and Polymers, 12*(7), 608-623.
15. Shang, Y., Hasan, M., & Ahammed, G. J. (2019). Physiological and biochemical roles of nanoparticles in plants: An insight into nanoparticle-plant interactions. Plant Physiology and Biochemistry, 139, 47-56.
16. Sharma, K., & Garg, V. K. (2017). Vermicomposting: A sustainable approach to waste management and land reclamation. *Springer.*
17. Singh, A., Kumar, D., & Kundu, A. (2020). Nanotechnology in agriculture: Advances and future prospects. Nanomaterials and Agriculture, 10(2), 1-15.
18. Singh, A., Kumari, P., & Verma, P. K. (2021). Effect of seed priming on seed quality and germination parameters of coriander (*Coriandrum sativum* L.). *Journal of Medicinal and Aromatic Plant Sciences, 43*(1), 15-22.
19. Vejan, P., Abdullah, R., Khadiran, T., Ismail, S., & Nasrulhaq, B. (2016). Role of biofertilizers in sustainable agriculture: A review. Molecules, 21(5), 581.
20. Sheoran OP, Tonk DS, Kaushik LS, Hasija RC, Pannu RS. 1998. Statistical software package for Agricultural Research Workers. Recent Advances in information theory, Statistics and Computer Applications by D.S. Hooda and R.C. Hasija. Department of Mathematics Statistics, CCS HAU, Hisar. pp 139-143.