



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

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## Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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## 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 H<sub>2</sub>SO<sub>4</sub>, 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

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advanced priming techniques in sustainable seed enhancement and productivity under diverse environmental conditions.

**Keywords:** *Trichoderma viride*; plasma; vermiwash; silver nanoparticles; seed priming.

## 1. INTRODUCTION

Seed priming is a pre-sowing technique that enhances seed vigor, uniformity, and overall plant performance. It involves partial hydration of seeds to initiate metabolic activities required for germination, without allowing radicle protrusion (Farooq et al., 2019). This method is especially beneficial for improving germination rates, seedling establishment, and crop productivity under both optimal and stress conditions. Numerous studies have emphasized that seed priming not only improves seed quality but also contributes to enhanced stress tolerance, early seedling vigor, and overall crop yield (Ashraf & Foolad, 2005; Paparella et al., 2015).

Coriander (*Coriandrum sativum* L.), a widely cultivated aromatic and medicinal plant, holds significant economic value due to its culinary, pharmacological, and therapeutic properties. However, coriander seeds are characterized by slow and erratic germination, which often results in poor stand establishment and reduced productivity. Environmental stresses such as low temperature, drought, and salinity further aggravate the situation, making seed quality improvement a priority in coriander cultivation (Singh et al., 2021).

Among biological treatments, *Trichoderma viride*, a filamentous fungus known for its antagonistic action against a broad range of soil-borne pathogens, has shown promising results in promoting seed germination, root growth, and plant vigor. The fungus enhances the rhizosphere by producing growth-promoting substances and facilitating nutrient solubilization (Harman et al., 2004; Mastouri et al., 2010). Studies have reported improved seedling growth and enhanced resistance to biotic stresses in several crops, including coriander, when primed with *Trichoderma* spp. (Contreras-Cornejo et al., 2009).

Vermiwash, an organic liquid derived from earthworm activity, is another sustainable priming agent. It contains enzymes (such as proteases and amylases), vitamins, micronutrients, and plant growth hormones like auxins and cytokinins that play a crucial role in

seed germination and seedling development (Rajiv et al., 2013; Sinha et al., 2010). Vermiwash has been reported to improve seed germination rates, enhance chlorophyll content, and stimulate root development in a variety of crops (Gajalakshmi et al., 2001).

The application of nanotechnology in agriculture has opened new avenues for seed treatment. Silver nanoparticles (AgNPs) have received attention for their antimicrobial, antioxidant, and growth-promoting properties. Nanopriming with AgNPs enhances seed germination, seedling vigor, and plant health by minimizing pathogen infection and improving nutrient uptake (Rai & Ingle, 2012; Mahakham et al., 2016). In coriander, AgNP treatment has shown improved seedling growth and resistance to early-stage infections.

Chemical scarification using concentrated sulfuric acid ( $H_2SO_4$ ) is a traditional method used to overcome hard seed coats and seed dormancy. The acid treatment erodes the seed coat, facilitating rapid water imbibition and uniform germination. Though effective, this method requires precise handling due to its corrosive nature (Baskin & Baskin, 2014; Khan et al., 2009). When used cautiously,  $H_2SO_4$  scarification can significantly improve the germination of coriander seeds, which are known for their hard pericarp.

Plasma treatment is an innovative physical seed priming technique that involves exposing seeds to ionized gas (plasma). This method alters the physicochemical properties of the seed surface, improving water absorption, enzymatic activity, and reducing microbial contamination (Randeniya & de Groot, 2015). Plasma treatment also facilitates better seedling emergence and vigor, making it a promising tool for sustainable agriculture. Recent studies have shown that cold plasma treatment can enhance germination and seedling vigor in a variety of crops, including spices and medicinal herbs (Ling et al., 2015). The current study evaluates the comparative effects of different priming techniques—*Trichoderma viride*, vermiwash, silver nanoparticles, sulfuric acid, and plasma treatment—on the phenological, physiological,

and yield-related parameters of coriander under natural field conditions. Key indicators such as germination rate, seedling length, chlorophyll content, total protein, and final seed yield were assessed.

Findings from similar studies reveal that integrating biological and advanced physical priming agents can significantly boost seed quality and crop productivity (Anwar et al., 2021; Jisha et al., 2013). Chlorophyll content, which is closely linked to photosynthetic efficiency, has been found to increase significantly with both biological and nanopriming treatments. Protein content, a vital physiological marker, also improves under treatments that stimulate enzymatic and hormonal activity during early seed development. The integration of novel and traditional seed priming methods offers a comprehensive strategy for improving coriander seed performance. Among the evaluated treatments, biological agents like *Trichoderma viride* and organic extracts like vermiwash align well with sustainable agricultural practices, while innovations like plasma treatment and AgNPs provide technologically advanced alternatives with rapid and significant effects. This study contributes valuable insights into optimizing coriander seed priming protocols, promoting sustainable cultivation, and improving agricultural productivity under varying environmental conditions.

## 2. MATERIALS 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. A lab experiment was conducted to optimize the superior concentration of various priming agents. On the basis of that experiment, Superior treatments included *Trichoderma viride* (24 hours), Vermiwash (6 hours), Silver nanoparticles 10 ppm (24 hours), Concentrated H<sub>2</sub>SO<sub>4</sub> (2 minutes), Plasma treatment (6 minutes), and a control (untreated seeds) were assessed in the field. 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.

### 2.1 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.

### 2.2 Physiological Studies

#### 2.2.1 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.

#### 2.2.2 Formulas

Chlorophyll 'a' ( $\mu\text{g mg}^{-1}$ ) =  $13.19 A_{664} - 2.57 A_{647}$

Chlorophyll 'b' ( $\mu\text{g mg}^{-1}$ ) =  $22.10 A_{647} - 5.26 A_{664}$

Total Chlorophyll ( $\mu\text{g mg}^{-1}$ ) =  $7.93 A_{664} + 19.53 A_{647}$

#### 2.2.3 Protein estimation

Protein estimation was carried out using the Lowry method (1951), where extracted proteins reacted with the Folin-Ciocalteu 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.

## 2.3 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.

## 3. RESULTS AND DISCUSSION

The present study evaluated the effect of different treatments, including *Trichoderma viride*, vermiwash, silver nanoparticles, concentrated sulfuric acid (H<sub>2</sub>SO<sub>4</sub>), 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.

### 3.1 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.

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

**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	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 <sup>-1</sup> )	Harvest index (%)
<i>Trichoderma viride</i>	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. H <sub>2</sub> SO <sub>4</sub>	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 2. Effect of Seed Priming on the chlorophyll and protein content in Coriander in 2021-22 and 2022-23**

Treatment	Chlorophyll a (mg/100g)	Chlorophyll b (mg/100g)	Total Chlorophyll (mg/100g)	Protein Content (mg/g)
<i>Trichoderma viride</i> (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. H <sub>2</sub> SO <sub>4</sub> (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

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 (H<sub>2</sub>SO<sub>4</sub>) 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.

#### 4. 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.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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