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RESEARCH ARTICLE

Shoot clipping and gibberellic acid spray enhances seed quality of coriander (*Coriandrum sativum* L.)

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Abstract

Coriandrum sativum L., also referred to as dhania, is an annual herbaceous plant widely cultivated for its aromatic seeds and tender green leaves. Despite its therapeutic value and widespread cultivation, poor seed quality limits its productivity and commercial potential. A field experiment on coriander cv. Ajmer Coriander-1 was conducted during rabi season (2021–2022) in a randomized complete block design (RCBD) in 3 replications to evaluate the combined effects of 2 shoot clipping regimes (no clipping and clipping) at 45 days after sowing (DAS) and 5 foliar sprays of gibberellic acid (GA_3) at 55 DAS (0, 25, 50, 75 and 100 ppm) on seed quality parameters. Laboratory evaluation of harvested seeds revealed that the combined treatment of shoot clipping with GA_3 at 75 ppm (C_2G_3) significantly enhanced germination (91.00 %), rate of germination (20.07), seedling length (26.37 cm) seedling dry weight (2.53 mg) seed vigour indices (length- 2399.56 and mass- 230.52) while reducing membrane damage as showed by lower electrical conductivity compared to other treatments. These findings suggest that the conjoint application of shoot clipping and GA_3at 75 ppm effectively enhance coriander seed quality and may serve as practical strategy for improving seed performance and overall seed productivity.

Keywords: dhania; electrical conductivity; germination; gibberellic acid; seed vigour

Introduction

Since ancient times, India is known as the "Home of Spices" (1). Spices have special significance in many facets of life, such as in cooking, medicine, economics, culture and religion (2). Coriander, also known as Chinese parsley, dhania, or cilantro, is an annual herbaceous plant that is mostly grown for its tender green leaves and seeds. Coriander has long been used for its health benefits in Ayurveda, traditional Chinese medicine and other folk medicines. It has been applied to diabetic management, anxiety relief, inflammation reduction and digestive problems (3). According to Spices Board of India (4), the provisional export quantity of coriander was 3.72 lakh tonnes in 2023–2024, contributing a value ~Rs. 71864.46 lakh. While there was a slight dip in export quantity from 2022–2023 (4.08 lakh tonnes), the export value increased, indicating higher global demand or better pricing. States like Rajasthan and Gujarat are the major producers of seed spices in India, contributing more than 80 % of total production (5). As per the Ministry of Agriculture and Farmers Welfare (6), India recorded an estimated area of 6.71 lakh ha under coriander cultivation, with a total production of around 8.40 lakh tonnes. This steady production, coupled with strong export performance, highlights India's position as a major player in the global coriander trade. In Himachal Pradesh, it covers an area 32 ha with annual production of 0.065 tonnes and average yields of 492 kg ha^{-1} (7).

Poor seed quality continues to be a major limiting factor in agricultural research, which has up to now mostly concentrated on improving crop yields through genetic modification, better crop management, irrigation and the prudent use of agrochemicals. Good germination, quick emergence and ideal plant stand cause high-quality seed, which adds 15–25 % to total crop productivity (8). When conditions are optimum, research can forecast field emergence and is frequently used to analyse seed quality. Numerous publications have demonstrated a robust relation between field emergence and laboratory germination experiments. Laboratory evaluation of GA_3-treated coriander seeds has been found effective in predicting field emergence and vigour (9). The assessment of seed physiological potential usually performed through germination and vigour tests. According to previous studies vigour tests are renowned for identifying comparatively small differences across the various stages of seed deterioration within a seed lot (10). However, laboratory-based assessment of seed vigour is lacking, particularly on seed quality attributes of coriander.

The cultivar Ajmer Coriander-1 was selected for the present experiment due to its wide adaptability and commercial importance in North Indian coriander growing areas. It is a high yielding variety recommended for cultivation under semi-arid and sub-temperate conditions and widely adopted by farmers for its stable performance (11). Coriander possesses regenerative capacity; therefore, shoot

clipping (i.e., defoliation) at specific stages can influence the seed yield and quality (12,13). On the other side, gibberellic acid (GA_3) is reported to enhance growth, flowering, fruit set, seed yield and quality attributes of coriander (14–16). Recently, previous researchers reported significant increase in seed yield and physiological vigour in coriander following foliar GA_3 application (17). Although individual effects of shoot clipping and gibberellic acid on coriander growth and yield have been studied (18), the combined effects on seed quality of cv. Ajmer Coriander-1 have received limited attention. Therefore, the present study was carried out to evaluate the interactive effects of shoot clipping and GA_3 application on seed quality attributes. Understanding this interaction between shoot clipping and GA_3 application may provide valuable insights for optimising agronomic practices aimed at enhancing seed vigour and productivity of coriander.

Materials and Methods

Site description

The present investigation was conducted during the rabi season of 2021–2022 at the Khaltoo experimental farm of Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, situated in the mid-hill zone of the state at an elevation of 1250 m above mean sea level. The climate of the experimental site is sub-temperate to semi-humid, characterised by cold winters, warm summers and monsoonal rainfall. During the cropping period, the mean temperature ranged from 14.5 °C to 22.9 °C, with minimum and maximum extremes of 2.3 °C in December and 33.2 °C in April, respectively. Rainfall distribution was uneven, with no precipitation recorded from November 2021 to March 2022, while the highest rainfall (82.7 mm) was recorded in February 2022 (Fig. 1). The experimental soil is loam to clay loam in texture with neutral reaction (pH 6.85–7.05).

Experimental details

The field trial was laid out on October 15, 2021 in a factorial randomized complete block design (RCBD) with ten treatments combining shoot clipping and GA_3 spray, replicated thrice (Table 1). Shoot clipping was done at 45 days after sowing (DAS) at 6 inches from ground level to promote lateral branching, while GA_3 was applied as a foliar spray at 55 days after sowing (DAS) at concentrations of 0, 25, 50, 75 and 100 ppm. The require amount of GA_3 was dissolved in distilled water to prepare the desired concentrations and applied uniformly using a knapsack sprayer at a spray volume of approximately 500 L ha^{-1}, during calm weather conditions to ensure uniform distribution of the solution.The seeds of coriander (*cv*. Ajmer Coriander-1) were sown as per the treatments in a plot sized 2 × 2 m with spacing 30 × 10 cm. Healthy, bold and disease-free coriander seeds were accessed from ICAR-National Research Centre on Seed Spices, Ajmer. During field preparation, basal dose of 10 t farmyard manure (FYM) ha^{-1} was incorporated into the soil. The fertiliser dose of 30 kg N, 40 kg P_2O_5 and 20 kg K_2O ha^{-1}, applied proportionally to the plot size, was followed as per the recommendations for coriander cultivation under mid-hill conditions of Himachal Pradesh. At sowing, the entire dosage of potassium (K) and phosphorus (P) as well as half of the nitrogen (N) were applied as a basal dose; the remaining N was top-dressed at 30 DAS. At 25 and 45 DAS, two hand weeding was performed to keep the crop free of weeds. The crop's needs for irrigation were met to keep the soil sufficiently moist during the growth season. Need-based plant protection measures were used to shield the crop from diseases and insect pests. When the seeds achieved physiological maturity and most of the umbels became brown, manual harvesting was followed. For additional seed quality study, the harvested seeds were shade-dried in ambient laboratory conditions for 7–10 days until the seed moisture content reached approximately 8–9 %. Drying was carried out in a well-ventilated room. The dried seeds were stored in airtight polyethylene containers at a temperature of 25 ± 2 °C and relative humidity of 50–60 % until further analysis.

Table 1. Treatment details of the experiment

Treatment legend	Treatment details
C_1G_1	25 ppm GA_3 + no clipping
C_1G_2	50 ppm GA_3 + no clipping
C_1G_3	75 ppm GA_3 + no clipping
C_1G_4	100 ppm GA_3 + no clipping
C_1G_5 (Control)	No GA_3 + no clipping
C_2G_1	25 ppm GA_3 + clipping
C_2G_2	50 ppm GA_3 + clipping
C_2G_3	75 ppm GA_3 + clipping
C_2G_4	100 ppm GA_3 + clipping
C_2G_5	No GA_3 + clipping

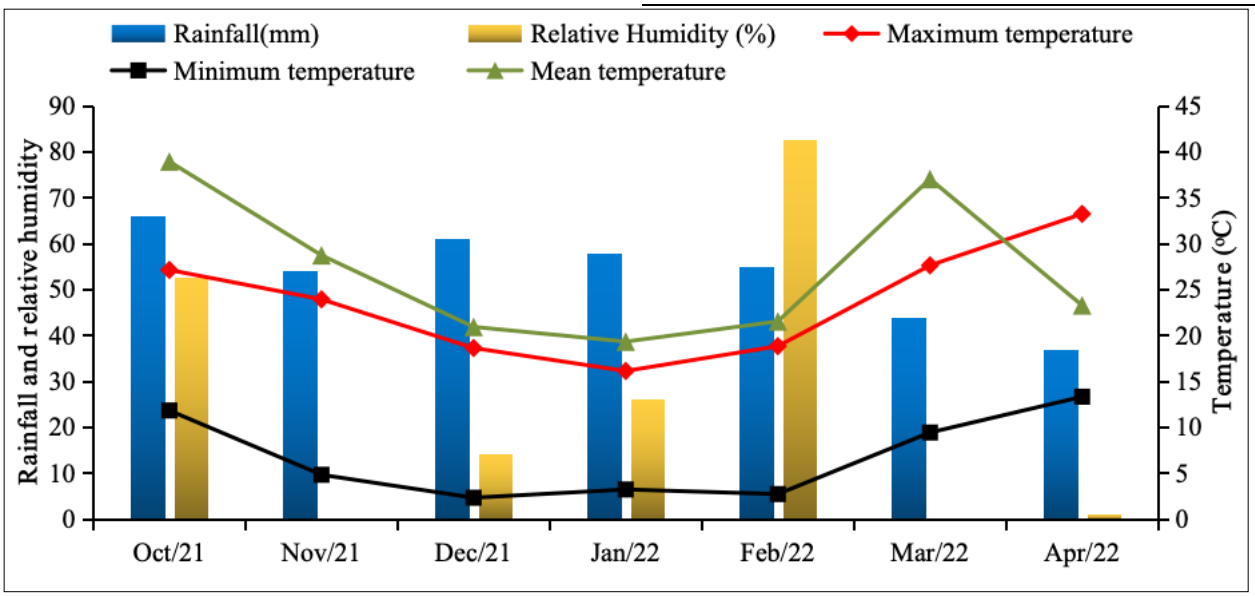


Fig. 1. Meteorological observations during the experimental period.

Seed quality assessment

Treatment-wise harvested coriander seeds were brought to the laboratory of Department of Seed Science and Technology of Dr Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh and analysed for various quality attributes including germination and its rate, seedling length and dry weight, seed vigour index I (length-basis) and II (Mass-basis) and electrical conductivity as per standard protocols. Germination was recorded on the 21st day after sowing as per International Seed Testing Association (ISTA) guidelines tested using 100 seeds per treatment in 3 replications, employing the paper roll method in a seed germinator at 25±5 ℃ and 80 % relative humidity under continuous light, with first and final counts at 7 and 21 days, respectively and germination percentage calculated according to ISTA (19). Speed of germination was determined by daily counting of emerging seedlings and the germination index was computed as described by Maguire (20). Seedling length and dry weight were measured at the final count. Seedling length was measured from the tip of the primary leaf to the tip of the primary root in ten randomly selected seedlings, while seedling dry weight was recorded after oven-drying these seedlings at 60°C for 48 hr and cooling in a desiccator. Seed vigour indices were calculated following Abdul-Baki and Anderson (13), with SVI-length as the product of germination percentage and mean seedling length and SVI-mass as the product of germination percentage and seedling dry weight. Electrical conductivity was assessed separately using soaked seed samples prior to germination testing and analysed using digital conductivity meter (Model: Eutech CON 700, Eutech Instruments, Singapore); 50 seeds per replication immersed in 250mL distilled water for 24 hr at room temperature, with the conductivity of the leachate measured after subtracting that of distilled water (µ Scm^{-1}). The general view of experimental field at the vegetative and peak flowering stage is presented in Fig. 2.

Statistical analysis

The experimental data was statistically analysed using a factorial RCBD design using OP STAT Software. The overall significance of treatment differences (main and interactive effects) on the measured seed quality parameters was assessed using the '*F*' test and the treatment means have been compared using the critical difference (C.D.) at 5 % level of significance. Also, the statistical summary table showing *F*-values and *p*-values for each variable is shown in Table 2.

Results and Discussion

Seed germination

Seed germination was significantly influenced by shoot clipping. Averaged over GA_3 spray, maximum (83.15 %) seed germination was recorded in C_2 (clipping) whereas the minimum (77.05 %) was observed in C_1 (no clipping) (Table 3). Analysis of data further revealed a highly significant effect of GA_3 application on this trait. When averaged over shoot clipping treatments, maximum (86.50 %) seed germination was recorded in G_3 (75 ppm) while, treatment G_5 (no GA_3) resulted in minimum (71.12 %) seed germination. The laboratory results showing variation in seed germination percentage are shown in Fig. 3.

The interaction effect of shoot clipping and GA_3 spray also revealed significant differences on seed germination. This indicates that the response of seed germination varied depending on the combination of clipping and GA_3 treatments. Maximum (91.00 %) seed germination was recorded in C_2G_3 (shoot clipping + GA_3 spray at 75 ppm), whereas, minimum (69.25 %) was recorded in C_1G_5 (no clipping + no GA_3 spray) (Table 1). The possible reason for higher seed germination in C_2G_3 might be due to increased rate of photosynthesis and translocation of nutrients and photosynthates production, that led to increase in seed size, which ultimately gave rise to bolder and healthier seed, more seed filling and higher deposition of stored reserve food material in the seed resulted in enhanced seed germination. Increased germination percentage might also be attributed to the induction of synthesis of α-amylase, protease and other hydrolytic enzymes by the applied gibberellic acid. Gibberellic acid also appears to induce the activity of

Table 2. Two-way analysis of variance (ANOVA) showing *F*-values with corresponding *p*-values for the effects of cutting (C), gibberellic acid (GA_3) and their interaction on the seed germination and seedling growth parameters

Variable	C	GA_3	C × GA_3
Seed germination (%)	262.659 (<0.001)	192.768 (<0.001)	5.056 (0.003)
Speed of germination	40.230 (<0.001)	42.628 (<0.001)	2.766 (0.045)
Seedling length (cm)	704.495 (<0.001)	490.377 (<0.001)	6.236 (<0.001)
Seedling dry weight (mg)	6.635 (0.015)	188.346 (<0.001)	15.306 (<0.001)
Seedling vigour index-I (length)	723.640 (<0.001)	490.389 (<0.001)	6.944 (<0.001)
Seedling vigour index-II (mass)	161.741 (<0.001)	355.658 (<0.001)	19.139 (<0.001)
Electrical conductivity (µS cm^{-1})	90.818 (<0.001)	118.056 (<0.001)	17.635 (<0.001)

Values represent *F*-statistics with corresponding *p*-values in parentheses.

Table 3. Impact of shoot clipping and gibberellic acid spray on the seed germination, rate of germination and seedling length at 21 days after germination

Treatments	Seed Germination (%)			Speed of germination			Seedling length (cm)		
	C_1	C_2	Mean B	C_1	C_2	Mean B	C_1	C_2	Mean B
G_1	75.00	81.25	78.12	17.91	19.21	18.56	20.59	23.56	22.07
G_2	79.00	84.50	81.75	18.38	19.41	18.90	22.36	24.36	23.36
G_3	82.00	91.00	86.50	18.61	20.07	19.34	24.54	26.37	25.45
G_4	80.00	86.00	83.00	18.47	19.99	19.23	23.40	25.67	24.52
G_5	69.25	73.00	71.12	16.36	16.36	16.36	19.30	21.23	20.27
Mean A	77.05	83.15		17.95	19.01		22.04	24.23	
Factors	$CD_{0.05}$								
Cutting	0.77			0.34			0.17		
GA_3	1.22			0.54			0.27		
Cutting×GA_3	1.72			0.77			0.38		

C_1: No Clipping; C_2: clipping; G_1:25 ppm GA_3; G_2: 50 ppm GA_3; G_3: 75 ppm GA_3; G_4: 100 ppm GA_3 and G_5: No GA_3.



Fig. 2. A general view of the experimental field showing the vegetative and flowering stage of coriander.



Fig. 3. Laboratory results showing variation in seed germination percentage owing to the treatments.

gluconeogenic enzymes during early stages of seed germination (14). Similar enzymatic enhancement by GA_3 has also been reported in other crops like cauliflower (21, 22), supporting its broad role in improving seed vigour. These results are near those reported previously (23) in onion and in coriander (24), which showed that application of GA_3 at 75 ppm led to increased seedling germination.

Speed of germination

Speed of germination was significantly influenced by shoot clipping and GA_3 spray (Table 3). Averaged over GA_3 spray, maximum (19.01) speed of germination was recorded in C_2 (clipping) whereas, minimum (17.95) was observed in C_1 (no clipping). When averaged overshoot clipping treatments, maximum (19.34) speed of germination was recorded in treatment G_3 (75 ppm) that was statistically at par with G_2 (50 ppm) and G_4 (100 ppm), whereas the minimum (16.36) speed of germination was found in G_5 (no GA_3).

The interaction effect of shoot clipping and GA_3 spray on speed of germination was also significant (Table 1) indicating that the rate of germination varied depending on the combination of clipping and GA_3 treatments, thereby influencing the overall physiological performance of the seeds. Maximum (20.07) speed of germination was recorded in C_2G_3 (shoot clipping + GA_3 spray at 75 ppm) that was statistically at par with C_2G_2 (shoot clipping + GA_3 spray at 50 ppm) and C_2G_4 (shoot clipping + GA_3 spray at 100 ppm), whereas, minimum (16.36) speed of germination was recorded in C_1G_5 (no clipping + no GA_3 spray) and C_2G_5 (shoot clipping + no GA_3 spray). Present results might be due to bolder and healthier seed, enhanced physiological activities like photosynthesis and translocation of nutrients and photosynthates (25). This might be due to better translocation of photosynthates diversified toward source to newly developed sink, which could be supported by heavier build-up of food reserves in the developing seeds in the physiologically active plant due to spraying of gibberellic acid. Similar findings have been reported by previous researchers, in coriander and in fenugreek (10, 24, 26). These results also corroborate with the findings of earlier reports in coriander (17, 24).

Seedling length

The laboratory results showing seedling length among different treatments are shown in Fig. 4. Seedling length was significantly influenced by shoot clipping and GA_3 spray (Table 3). Averaged over GA_3 spray, maximum (24.23 cm) seedling length was recorded in C_2 (clipping), whereas minimum (22.04 cm) seedling length was observed in C_1 (no clipping). When averaged overshoot clipping, maximum (25.45 cm) seedling length was recorded in G_3 (75 ppm), whereas minimum (20.27 cm) seedling length was observed in G_5 (no GA_3). Similarly, the interactive effects of shoot clipping and GA_3 spray on seedling length was also significant suggesting that the combined treatments enhanced seedling growth and vigour through improved physiological activity. Maximum (26.37 cm) seedling length was recorded in C_2G_3 (clipping + GA_3 application at 75 ppm), whereas minimum (19.30 cm) seedling length was observed in C_1G_5 (no clipping + no GA_3 spray). Maximum seedling length in C_2G_3 may be attributed to the production of larger and physiologically bolder and healthier seeds which ensured better nutrient availability during seed germination, thereby promoting enhanced root and shoot growth that ultimately increased the root and shoot growth. Similar findings have been reported previously in coriander (16,17, 25).

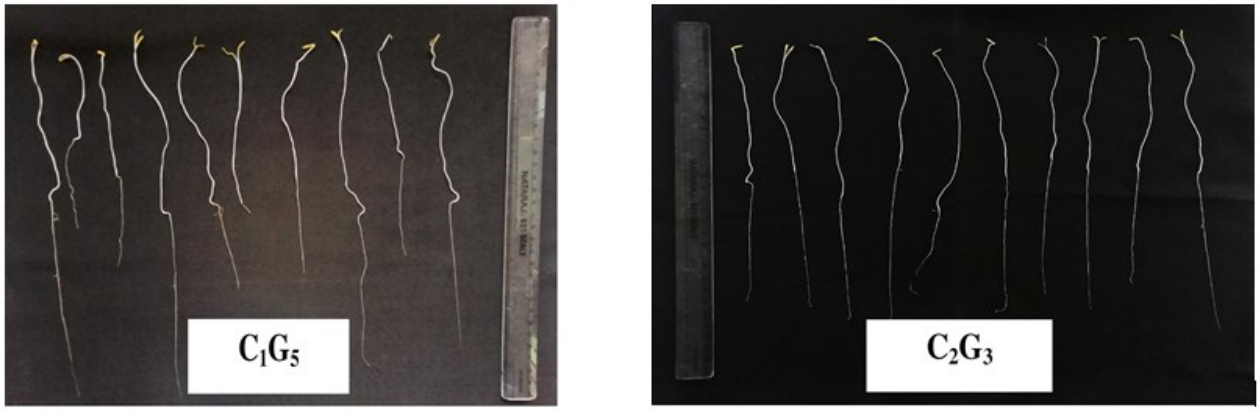


Fig. 4. Laboratory results showing variation in seedling length owing to the treatments.

Seedling dry weight

Data recorded on seedling dry weight clearly showed that this trait has been significantly influenced by shoot clipping, GA_3 application and their interactions (Table 4) indicating that the combined treatments influenced biomass accumulation and overall seedling vigour. Averaged over GA_3 spray, maximum (2.26 mg) seedling dry weight was recorded in C_2 (clipping), whereas minimum (2.23 mg) seedling dry weight was observed in C_1 (no clipping). Averaged overshoot clipping, maximum (2.46 mg) seedling dry weight was recorded in treatment G_3 (75ppm), whereas minimum (2.02 mg) seedling dry weight was observed in G_5 (no GA_3). On the other side, maximum (2.53 mg) seedling dry weight was reported in C_2G_3 (shoot clipping + GA_3 spray at 75 ppm). However, minimum (2.00 mg) seedling dry weight was recorded in C_1G_5 (no clipping + no GA_3 spray). This was perhaps due to the reason that seeds obtained from C_2G_3, having higher accumulation of dry matter that ultimately resulted in higher seedling dry weight. Also, this improvement could also be associated with enhanced physiological activities such as photosynthesis and efficient translocation of nutrients and photosynthates (27). Similar findings have been reported earlier in spinach (28) and in coriander (17, 25).

Seed vigour index-I

The data recorded on seed vigour index-I (length) are embodied in Table 4, which clearly showed that this character has been significantly influenced by shoot clipping, GA_3 spray and their interactions indicating that the combined treatments influenced seedling growth and germination potential, thereby improving overall seed vigour. Averaged over GA_3 spray, maximum (2025.41) seed vigour index-I was observed in C_2 (clipping), whereas, minimum (1706.34) was recorded in C_1 (no clipping). Averaged overshoot clipping, maximum (2205.96) seed vigour index-I was recorded in treatment G_3 (75 ppm), whereas, minimum (1443.29) was observed in G_5 (no GA_3). Again, maximum (2399.56) seed vigour index-I was observed in C_2G_3 (shoot clipping + GA_3 spray at 75 ppm), whereas, minimum (1336.92) was recorded in C_1G_5 (no clipping + no GA_3 spray). In the present study, higher value of seed vigour index- I (on length-basis) in C_2G_3, might be due to higher percentage of bolder seeds coupled with the higher test weight of seeds and due to increased translocation and assimilation of photosynthates from source to the sink (seeds). Also, improvement in vigour index might be attributed to improved germination that was due to stimulation of enzymatic activities and good seedling growth caused by improved mobilisation of food reserves. The results are in accordance with the previous findings in coriander, which reported a significant increase in vigour index of chilli with the application of gibberellic acid (23, 29).

Seed vigour index-II

Data pertaining to the effect of treatments on seed vigour index-II are shown in Table 4 that clearly depicted that this trait has been significantly influenced shoot clipping, GA_3 spray and their interactions indicating that the combined treatments influenced seedling dry matter accumulation and overall seed physiological vigour. Averaged over GA_3 spray, maximum (189.05) seed vigour index-II was recorded in C_2 (clipping) whereas, minimum (172.48) was observed in C_1 (no clipping). Averaged overshoot clipping, maximum (213.05) seed vigour index-II was recorded in G_3 (75 ppm), whereas, minimum (143.48) was observed in G_5 (no GA_3). Again, maximum (230.52) seed vigour index-II was observed in C_2G_3 (shoot clipping + GA_3 spray at 75 ppm), whereas, minimum (138.81) was recorded in C_1G_5 (no clipping + no GA_3 spray). Maximum value of seed vigour index II (on mass-basis) might be as a resultant of highest germination percentage, which was due to stimulation of enzyme

Table 4. Impact of shoot clipping and gibberellic acid spray on electrical conductivity, seed vigour indices and seedling dry weight at 21 days after germination

Treatments	Seedling dry weight (mg)			Seed vigour index-I (Length)			Seed vigour index- II (Mass)			Electrical conductivity (μScm^{-1})		
	C_1	C_2	Mean B	C_1	C_2	Mean B	C_1	C_2	Mean B	C_1	C_2	Mean B
G_1	2.10	2.11	2.10	1544.01	1914.44	1729.22	157.17	171.45	164.31	202.80	174.21	188.50
G_2	2.33	2.20	2.26	1766.13	2058.14	1912.13	184.14	185.90	185.02	197.44	174.93	186.18
G_3	2.38	2.53	2.46	2012.36	2399.56	2205.96	198.58	230.52	213.05	174.67	156.79	165.73
G_4	2.33	2.43	2.38	1872.30	2205.26	2038.78	186.71	209.23	197.97	176.06	162.62	169.34
G_5	2.00	2.03	2.02	1336.92	1549.67	1443.29	138.81	148.15	143.48	328.97	228.99	278.99
Mean A	2.23	2.26		1706.34	2025.41		172.48	189.05		215.99	179.51	
Factors	$CD_{0.05}$											
Cutting	0.02			2.67						5.55		
GA_3	0.04			4.23						8.78		
Cutting×GA_3	0.05			5.98						12.42		

C_1: No Clipping; C_2: clipping; G_1:25 ppm GA_3; G_2: 50 ppm GA_3; G_3: 75 ppm GA_3; G_4: 100 ppm GA_3 and G_5: No GA_3.

activities and good seedling growth caused by improved food reserves mobilisation. These results are in conformity with those reported previously in coriander (13, 25, 30).

Electrical conductivity

The data presented on electrical conductivity are appended in Table 4 that clearly revealed that this trait has been significantly influenced by shoot clipping and GA_3 spray as well as by their interaction suggesting that the combined treatments influenced membrane integrity and the degree of solute leakage from seeds. Averaged over GA_3 spray, minimum (179.51 µS cm^{-1}) electrical conductivity was recorded in C_1 (clipping), whereas maximum (215.99 µS cm^{-1}) was observed in C_2 (clipping). Averaged overshoot clipping, minimum (165.73 µS cm^{-1}) electrical conductivity was observed in G_3 (75 ppm), whereas maximum (278.99 µS cm^{-1}) was recorded in G_5 (no GA_3). Minimum (156.79 µS cm^{-1}) electrical conductivity was observed in C_2G_3 (shoot clipping + GA_3spray at 75 ppm), while maximum (328.97 µS cm^{-1}) was recorded in C_1G_5 (no clipping + no GA_3 spray).

Electrical conductivity is a reliable indicator of seed vigour, as higher values reflect greater electrolyte leakage due to reduced membrane integrity. The conjoint application of shoot clipping and GA_3spray may have strengthened membrane stability, thereby minimised electrolyte leakage. Improved nutrient availability and enhanced physiological activity under this treatment likely contributed to better membrane integrity and reduced solute efflux. The lower electrical conductivity values observed under combined clipping and GA_3 treatments indicate improved membrane stability and reduced solute leakage from seeds. Membrane integrity is a critical determinant of seed vigour and is closely associated with field emergence potential (31,32). Therefore, the improved seed quality parameters observed in the present study may translate into enhanced field establishment and early crop stand uniformity in coriander. Consequently, lower electrical conductivity values under C_2G_3 indicate higher seed vigour.These results also corroborate to the findings of previous studies in coriander (23, 25, 8).

Further, the enhancement in seed quality attributes under GA_3 treatments may be due to the physiological role of gibberellins in regulating metabolic processes linked with seed development and germination. Gibberellic acid is well known to stimulate the synthesis of hydrolytic enzymes, particularly alpha amylase, which catalyzes the breakdown of stored starch into soluble sugars, thereby promoting the mobilisation of food reserves for embryo growth and seedling development. This improved mobilisation of assimilates might have enhanced better seed filling, higher germination percentages and seed vigour. Also, GA_3 enhanced cell elongation and cell divisions which may have contributed to improving plant growth and reproductive efficiency (33). The treatment combination (Shoot clipping at 45 DAS+ GA_3 spray at 75 ppm at 55 DAS) better performance may be due to the optimal hormonal balance, that enhanced metabolic activity and assimilate partitioning toward seed development, whereas higher concentration i.e., 100 ppm may lead to hormonal imbalance and excessive vegetative growth, thereby reducing the efficiency of assimilate utilisation for seed formation. Similar results have been reported previously regarding the role of GA_3 in enzyme induction, reserve mobilisation and improvement in seed vigour (34,35).

Conclusion

Based on experimental results, it was observed that shoot clipping along with application of gibberellic acid significantly improved the quality attributes of Ajmer Coriander-1. Increased germination percentage, seedling length, dry weight and vigour indices under combined treatments indicate improved physiological efficiency and better assimilate partitioning during seed development. The reduced electrical conductivity values further suggest improved membrane integrity and seed storability. These findings (Shoot clipping at 45 DAS + GA_3 spray at 75 ppm at 55 DAS) highlights that integrating appropriate canopy management practices with gibberellic acid (GA_3) application can serve as an effective strategy for enhancing seed quality attributes in Ajmer Coriander-1. Future research should focus on validating these results under multi-location field conditions and evaluating long-term storage behaviour and field establishment performance of the produced seeds. Additionally, molecular and biochemical investigations may help elucidate the underlying mechanisms responsible for improved seed vigour.

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Authors' contributions

N and MK conceived the research idea. RV and SD^1 developed the theory and performed the computations. N, MK, CK, NC and S verified the analytical methods. NKB, AKT and AS participated in the study design and performed the statistical analysis. N, MK, SD^1, SD^2 and VS drafted and revised the manuscript. All authors reviewed and approved the final manuscript [SD^1- Suddhasuchi Das; SD^2- Sovan Debnath].

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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