



RESEARCH ARTICLE

Impact of polymer seed coating and foliar application of micronutrients on quality traits of harvested seeds of radish

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Abstract

To investigate the impact of polymer seed coating treatments and foliar application of micronutrients, on enhancement of seed quality traits in radish, analysis of harvested seeds was done during two consecutive years, 2022 and 2023. Under field conditions, first experiment, comprising nine treatments of seed coating with polymer at 10 mL/kg seed, along with the combination of micronutrients viz., zinc sulphate (ZnSO₄) + copper sulphate (CuSO₄) + boric acid (H₃BO₃) (each at 300 mg/kg of seed) and control. In the second experiment, radish seedlings were transplanted according to treatment in 135 plots measuring 2.4 × 1.2 m, each accommodating sixteen plants at a spacing of 60 × 30 cm. During bolting and at 50 % flowering radish plants were treated with water, ZnSO₄ at 0.5 %, CuSO₄ at 0.5 %, H₃BO₃ at 0.3 % and no spray. The results revealed that the treatment combination, polymer seed coating at 10 mL/kg seed, ZnSO₄ at 300 mg/kg seed, CuSO₄ at 300 mg/kg seed, H₃BO₃ at 300 mg/kg seed and a foliar application of H₃BO₃ at 0.3 % during bolting and 50 % flowering, significantly improved the speed of germination (13.51), germination percentage (92.83 %), seedling length (23.23 cm), seedling dry weight (12.87 mg), SVI-I (2156.55) and SVI-II (1194.32) of the harvested seeds. Hence, the above-mentioned treatment combination may be recommended for enhancing the seed quality traits in radish.

Keywords: micronutrients; polymer seed coating; radish; seed quality attributes

Introduction

Radish (*Raphanus sativus* L.) is a significant root vegetable of family Cruciferae and is cultivated in both tropical and temperate regions globally and is indigenous to Europe and Assam (1). It is predominately a cool-season vegetable crop and sown throughout winter from September to January on the northern plains and is preferred for its tender, fleshy enlarged edible roots, primarily utilised in salad. In addition to its culinary and salad purposes, it also offers numerous medicinal properties such as increasing appetite, preventing constipation, they aid in the treatment of urinary tract infections, piles, liver problems, jaundice and gall bladder problems. This vegetable also treats neurological disorders, sleeplessness and headache (2). Radish is an excellent source of vitamin C and minerals such as calcium, phosphorous, potassium (3). India had produced 3347 thousand metric tons radish roots by cultivating on an area of 209 thousand hectares in 2021 (4). The major radish producing states are West Bengal which has the highest production followed by Haryana, Punjab, Assam and Bihar. In HP, radish is cultivated on 2.09 thousand hectares area and its annual production is 44.74 thousand metric tonnes (4).

The productivity of seed crops of radish is suboptimal, which can be enhanced by improved management practices, particularly with the use of micronutrients. Micronutrients are vital components

for balanced growth and development in plants and are as crucial as macronutrients, however required in smaller quantities. Micronutrients are crucial for germination and seedling development influencing processes such as cell wall development, respiration, photosynthesis and chlorophyll synthesis (5). Among micronutrients, zinc (Zn), boron (B) and copper (Cu), the role of Zn is crucial for growth, plant development and biomass production, as it is necessary for the synthesis of indole acetic acid and facilitates energy production, protein synthesis and growth regulator synthesis (6). Zinc is also essential for pollen development, sexual fertilisation and germination (7). While B is crucial for growth of pollen tube, seed setting, seed formation and primarily facilitates the transport of metabolites from source to sink (8, 9). Copper is essential for several metabolic processes in plants, including the metabolism of cell walls. It also functions as a structural component of regulatory proteins, electron transport during photosynthetic reactions, mitochondrial respiration, the synthesis of plant hormones and as an enzyme cofactor (10, 11).

Micronutrients can be supplied to plants via soil application, foliar spray, or seed treatment. While the necessary number of micronutrients can be supplied through various techniques, foliar sprays have proven to be more effective (12) and advantageous for the quick absorption of nutrients (13). Foliar application of micronutrients is more beneficial than soil

application, as the rates for foliar application are far less than soil application and same results could be attained easily as well as the crop immediately reacts to the nutrient applied (14). Foliar application is 6 to 20 times more effective than soil application (15). It is extensively shown that the micronutrients applied through foliar application during active growth phases enhance plant growth and hence increase in production and qualitative characteristics across many crops (16). Polymer coating is a sophisticated procedure that involves the application of the precise quantity of active chemicals combined with a liquid polymer directly on to the seed surface ensuring that the shape of seed remains unobscured, with a total weight gain of seed up to 1–2 % (17). The polymer may have facilitated the formation of appropriate and uniform coating around the seed coat. The application of polymer coating facilitates the sowing process by ensuring the smooth flow of seeds. The incorporation of colourants helps in visual assessment of placement precision and improves the aesthetic appeal, marketability and customer preference of seeds. To evaluate the impact of polymer seed coating treatments, along with foliar application of micronutrients, on seed quality parameters of harvested seeds of radish, this study was conducted.

Materials and Methods

An experiment was conducted in the Department of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh, India during the year 2022 and 2023. The experiment design was a completely randomised design (factorial).

Chemicals

Zinc sulphate (ZnSO_4), copper sulphate (CuSO_4) and boric acid (H_3BO_3).

Seed source

Seeds of radish (cv. Japanese White) were obtained from the Department of Seed Science and Technology, Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh.

Description of cultivar

The experimental material used for the present investigation was radish cv. Japanese White. The roots of Japanese White are cylindrical, 22–25 cm in length and 5 cm in diameter. The skin of root is snow-white, flesh-crisp, solid and mildly flavoured. It is suitable for growing during October–December in the plains and July–September in hills. Average yield of roots is 190–250 q/ha. The seed yield ranges between 9–10 q/ha (UHF, 2020).

Polymer source

The polymer used in the present study was Little's Polykote procured from Little's Oriental Balm and Pharmaceuticals Ltd. 85, Galaxy Road, Ayanambakkam, Chennai. The nutrients present in the polymer are of natural sources such as N, P, K, amino acids and growth hormones. It is eco-friendly, biodegradable and microplastic-free polymer.

Procedure for polymer coating of seeds

The cleaned seeds were coated with polymer after diluting with double distilled water manually, subsequently the seeds were air dried to bring back to original moisture content and then used for sowing.

The seeds of radish var. Japanese White from the field trial were harvested and evaluated for various parameters. Under field conditions, the first experiment comprising nine treatments of seed coating with polymer, micronutrients and their combinations, i.e., T₁- Control, T₂- Polymer seed coating at 10 mL/kg seed, T₃- Polymer seed coating at 10 mL/kg seed + ZnSO_4 at 300 mg/kg seed, T₄- Polymer seed coating at 10 mL/kg seed + CuSO_4 at 300 mg/kg seed, T₅- Polymer seed coating at 10 mL/kg seed + H_3BO_3 at 300 mg/kg seed, T₆- Polymer seed coating at 10 mL/kg seed + ZnSO_4 at 300 mg/kg seed + CuSO_4 at 300 mg/kg seed, T₇- Polymer seed coating at 10 mL/kg seed + ZnSO_4 at 300 mg/kg seed + H_3BO_3 at 300 mg/kg seed, T₈- Polymer seed coating at 10 mL/kg seed + CuSO_4 at 300 mg/kg seed + H_3BO_3 at 300 mg/kg seed, T₉- Polymer seed coating at 10 mL/kg seed + ZnSO_4 at 300 mg/kg seed + CuSO_4 at 300 mg/kg seed + H_3BO_3 at 300 mg/kg seed (Table 1). In second experiment, radish seedlings (treatment wise) were transplanted in 135 plots of size 2.4 × 1.2 m accommodated sixteen plants at as spacing of 60 × 30 cm. At bolting and 50 % flowering radish plants were sprayed with N₁- no spray, N₂- water spray, N₃- ZnSO_4 (0.5 %), N₄- CuSO_4 (0.5 %) and N₅- H_3BO_3 (0.3 %) (Table 1). Observations on different parameters including speed of germination, seed germination (%), seedling length (cm), seedling dry weight (mg) and seed vigour indices were performed as per the standard procedures.

Speed of germination: Seed germination was recorded by counting the number of seedlings emerged each day up to final count of seedling emergence and rate of germination (18).

Speed of germination =

$$\frac{\text{Number of normal seedlings}}{\text{Days to first count}} + \dots + \frac{\text{Number of normal seedlings}}{\text{Days to final count}} \quad (\text{Eq.1})$$

Seed germination percentage: It was worked out by putting 100 seeds each in four replications by following between paper method were incubated in seed germinator maintained at 20 °C (19). The final count of germination was made on 10th day.

Germination (%) =

$$\frac{\text{Total Number of normal seedlings}}{\text{Number of seeds sown}} \times 100 \quad (\text{Eq.2})$$

Seedling length: For measuring the seedling length, 10 normal seedlings were selected at random from each treatment combination. The length of seedling was evaluated by measuring the total length of each seedling from the tip of the apex leaf to the tip of primary root with the help of a scale and expressed as mean value in centimeter (cm).

Seedling dry weight: To determine dry weight of seedling, 10 seedlings were wrapped in butter paper pockets and placed in an oven at 80 °C for 48 hr. Then, dry weight of seedlings was measured and the average value was reported in milligrams (mg).

Seedling vigour index-I and II: It was calculated as per the formula suggested by previous researchers (20).

Table 1. Effect of polymer seed coating treatments and foliar application of micronutrients on speed of germination of harvested seeds (Pooled)

	2022-23					Mean
	N ₁	N ₂	N ₃	N ₄	N ₅	
T ₁	10.05	10.07	10.41	10.26	10.57	10.27 ^h
T ₂	10.13	10.13	11.58	10.44	11.77	10.81 ^g
T ₃	11.14	11.14	12.26	11.62	12.44	11.72 ^e
T ₄	10.45	10.45	11.80	10.53	11.84	11.01 ^f
T ₅	11.22	11.21	12.44	11.78	12.67	11.86 ^d
T ₆	11.34	11.34	12.55	11.38	12.83	11.89 ^d
T ₇	12.04	12.03	13.12	12.28	13.16	12.52 ^b
T ₈	11.47	11.47	12.66	11.72	13.04	12.07 ^c
T ₉	12.12	12.13	13.32	12.63	13.51	12.74 ^a
Mean	11.11 ^d	11.11 ^d	12.24 ^b	11.40 ^c	12.43 ^a	
Source of variation						
						CD_{0.05}
						Df
						F_{cal}
						P_{tab}
Seed coating treatments (T)						0.15
Foliar application of micronutrients (N)						0.11
Seed coating treatments × Foliar application of micronutrients (T × N)						0.34
Year (Y)						0.07
Year × Seed coating treatments						NS
Year × Foliar application of micronutrients (Y × N)						NS
Year × Seed coating treatments × Foliar application of micronutrients						NS

CD_{0.05}: critical difference at the 5 % probability level; NS: non-significant; Df: degrees of freedom; F_{cal}: calculated F-value; T: seed coating treatments; N: foliar application of micronutrients; Y: year.

Seedling vigour index - I =

$$\text{Germination (\%)} \times \text{Seedling length (cm)} \quad (\text{Eq.3})$$

Seedling vigour index - II =

$$\text{Germination (\%)} \times \text{Seedling dry weight (mg)} \quad (\text{Eq.4})$$

Statistical analysis

The collected data was then entered into MS-Excel for averaging and other calculations. Two-way analysis (ANOVA) was performed using OPSTAT software, with significance tested at $p=0.05$ and CD values provided in Table 1–6.

Results and Discussion

Speed of germination

The pooled data presented in Table 1 exhibited significant influences of polymer seed coating and micronutrients application on speed of germination individually and in combination. The results showed that among seed coating treatments, highest speed of germination (12.74) was noticed in the seed lot obtained from the plants of radish grown from seeds coated with polymer at 10 mL/kg seed + ZnSO₄ at 300 mg/kg seed + CuSO₄ at 300 mg/kg seed + H₃BO₃ at 300 mg/kg seed. Significantly minimum speed of germination (10.27) was observed in control (no treatment). Among the micronutrients application, seeds extracted from radish plants sprayed with H₃BO₃ (0.3 %) at bolting and 50 % flowering recorded the maximum speed of germination (12.43) and it was lowest (11.11) in no spray and water spray. The interaction effects T₉N₅ i.e., seeds coated with polymer at 10 mL/kg seed + ZnSO₄ at 300 mg/kg seed + CuSO₄ at 300 mg/kg seed + H₃BO₃ at 300 mg/kg seed and spraying then with 0.3 % H₃BO₃, resulted in rapid speed of germination (13.51) which was statistically at par with T₉N₃. Whereas, the minimum speed of germination (10.05) was observed in interaction, T₁N₁ i.e., control. Faster seed germination often indicates higher-quality, more resilient and vigorous seeds. Therefore, when compared to alternative treatments, the treatment combination may have been essential in enhancing the quality of the radish seed. This could be

because the polymer is hydrophilic, which could have accelerated the rate of imbibition; additionally, the presence of critical micronutrients could have accelerated cell activation, resulting in increased activity in mitochondria and the genesis of high-energy compounds and essential biomolecules that were accessible in the initial stages of germination because imbibition damage was minimised by controlling the absorption of water. Similar results were observed in pigeonpea, French bean and green gram (21–23).

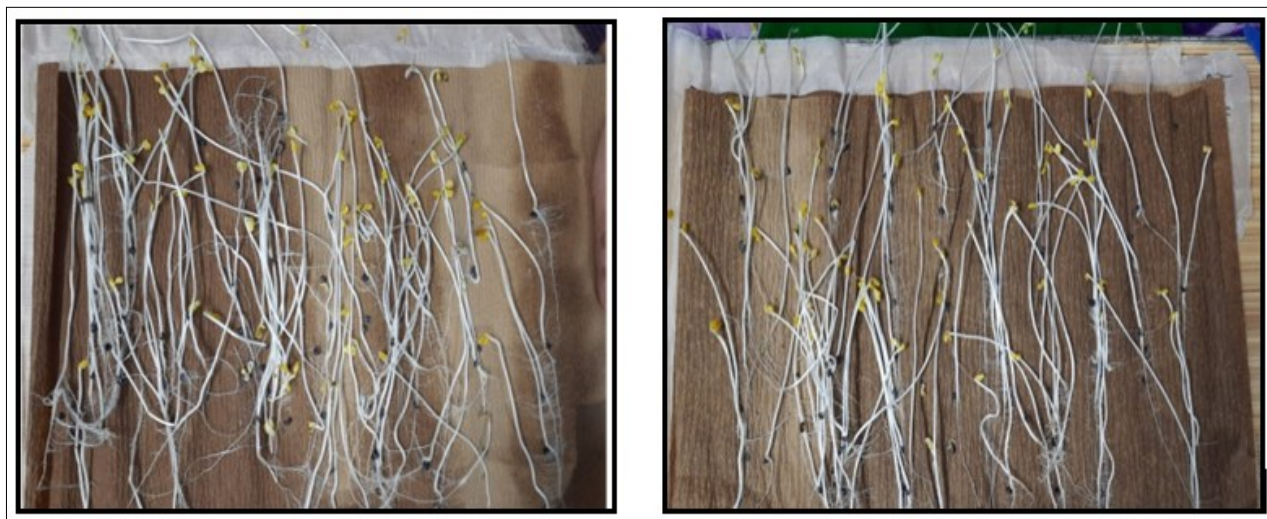
Germination percentage (%)

The pooled data pertaining to germination percentage is presented in Table 2. The results conclude that among different seed coating treatments, seeds coated with polymer at 10 mL/kg seed + ZnSO₄ at 300 mg/kg seed + CuSO₄ at 300 mg/kg seed + H₃BO₃ at 300 mg/kg seed recorded significantly maximum germination percentage (89.46 %) and minimum germination percentage (79.70 %) was recorded in control. Among foliar applications of micronutrients, germination percentage (87.33 %) was significantly maximum in seeds of radish plants sprayed with H₃BO₃ (0.3 %) at bolting and 50 % flowering. Germination percentage (81.76 %) was lowest in no spray and water spray. Seed germination is an important aspect in determining the physiological quality of seeds because it indicates the potential of seeds to produce normal and healthy seedlings in the field as well as laboratory conditions. The interaction effects (T₉N₅) revealed that seeds harvested from radish plants grown by using seeds coated with polymer at 10 mL/kg seed + ZnSO₄ at 300 mg/kg seed + CuSO₄ at 300 mg/kg seed + H₃BO₃ at 300 mg/kg seed and receiving a foliar spray treatment of 0.3 % H₃BO₃ resulted in higher seed germination (92.83 %). It was statistically at par with T₉N₃, T₉N₄ and T₇N₅. However, the significantly lowest germination percentage (78.44 %) was recorded in T₁N₁ i.e., control which did not receive any coating or foliar application (Fig. 1.). The enhancement of germination resulting from the combined application of polymer and micronutrients likely occurred because the polymer facilitated the formation of proper and uniform layer around the seed coat, thereby creating a micro environment conducive to seed germination and secondly, the presence of micronutrients within the polymer may have enabled their entry into the seed via uniform imbibition, stimulating metabolic activity

Table 2. Effect of polymer seed coating treatments and foliar application of micronutrients on germination (%)^{*} of harvested seeds (Pooled)

	2022-23					Mean
	N ₁	N ₂	N ₃	N ₄	N ₅	
T ₁	78.44 (8.91)	78.45 (8.91)	80.70 (9.04)	78.50 (8.92)	82.43 (9.13)	79.70 (8.98) ⁱ
T ₂	79.25 (8.96)	79.25 (8.96)	81.74 (9.10)	79.17 (8.95)	83.51 (9.19)	80.58 (9.03) ^h
T ₃	81.30 (9.07)	81.31 (9.07)	84.55 (9.25)	82.23 (9.12)	86.33 (9.34)	83.14 (9.17) ^f
T ₄	79.51 (8.97)	79.51 (8.97)	82.55 (9.14)	79.63 (8.98)	84.37 (9.24)	81.11 (9.06) ^g
T ₅	82.49 (9.14)	82.49 (9.14)	83.44 (9.19)	80.73 (9.04)	87.34 (9.40)	83.30 (9.18) ^e
T ₆	84.42 (9.24)	84.43 (9.24)	85.46 (9.30)	84.22 (9.23)	88.44 (9.46)	85.39 (9.29) ^c
T ₇	83.52 (9.19)	83.51 (9.19)	91.40 (9.61)	89.36 (9.51)	91.41 (9.61)	87.84 (9.42) ^b
T ₈	81.35 (9.07)	81.35 (9.07)	87.56 (9.41)	86.23 (9.34)	89.33 (9.50)	85.17 (9.28) ^d
T ₉	85.57 (9.30)	85.57 (9.30)	92.72 (9.68)	90.60 (9.57)	92.83 (9.69)	89.46 (9.51) ^a
Mean	81.76 (9.10) ^d	81.76 (9.10) ^d	85.57 (9.30) ^b	83.41 (9.18) ^c	87.33 (9.40) ^a	
Source of variation						
Seed coating treatments (T)						CD_{0.05}
Foliar application of micronutrients (N)						df
Seed coating treatments × Foliar application of micronutrients (T × N)						F_{cal}
Year (Y)						P_{tab}
Year × Seed coating treatments						0.06
Year × Foliar application of micronutrients (Y × N)						8
Year × Seed coating treatments × Foliar application of micronutrients						75.930
						0.00000
						0.04
						4
						74.606
						0.00000
						0.13
						32
						2.605
						0.00004
						0.03
						1
						53.420
						0.00000
						NS
						8
						0.139
						0.99733
						NS
						4
						0.019
						0.99928
						NS
						32
						0.043
						1.00000

CD_{0.05}: critical difference at the 5% probability level; NS: non-significant; Df: degrees of freedom; F_{cal}: calculated F-value; T: seed coating treatments; N: foliar application of micronutrients; Y: year. *Figures in the parenthesis are square root transformed values.

**Fig. 1.** Comparison between germination (%) of harvested seed T₉N₅ and T₁N₁.

through activation of dehydrogenase and the release of additional enzymes necessary for germination. Micronutrients are essential for the biosynthesis of indole acetic acid, a growth regulator crucial for normal cell enlargement. Furthermore, they are the constituents of amino acids, which are the building blocks for proteins and enzymes that facilitate proper germination and enhance seed vigour. Similar, results were observed by previous researchers in black gram (24).

Seedling length (cm)

The pooled data presented in Table 3 represents the seedling length of harvested seeds. The results conclude that among different seed coating treatments, seed lot collected from radish plants successfully raised by sowing the seeds coated with polymer at 10 mL/kg seed + ZnSO₄ at 300 mg/kg seed + CuSO₄ at

300 mg/kg seed + H₃BO₃ at 300 mg/kg seed produced a significantly longest seedlings (22.28 cm), whereas, shortest seedlings (19.46 cm) were produced from the control. Among application of micronutrients, the seeds obtained from the plants foliar sprayed with H₃BO₃ (0.3 %) at bolting and 50 % flowering resulted in significantly longest seedlings (21.92 cm). However, the seedlings produced from control seed lot were reported to be of smallest size (20.42 cm). Present analysis revealed that the seedling length was significantly affected by the interaction effect of seed coating treatments and foliar application of micronutrients. Longest seedlings (23.23 cm) in the seed lot (T₉N₅) obtained from the plants of radish raised by using the seedlings produced by germinating the seeds coated with polymer at 10 mL/kg seed + ZnSO₄ at 300 mg/kg seed + CuSO₄ at 300 mg/kg seed + H₃BO₃ at 300 mg/kg seed and spraying of radish plants with a

Table 3. Effect of polymer seed coating treatments and foliar application of micronutrients on seedling length (cm) of harvested seeds (Pooled)

	2022-23					Mean	
	N ₁	N ₂	N ₃	N ₄	N ₅		
T ₁	18.82	18.84	19.94	19.02	20.67	19.46 ^c	
T ₂	19.23	19.25	21.04	20.04	21.19	20.15 ^d	
T ₃	20.92	20.91	21.94	21.87	22.62	21.65 ^b	
T ₄	19.84	19.86	21.21	20.12	19.98	20.20 ^d	
T ₅	21.10	21.10	22.14	21.16	22.80	21.66 ^b	
T ₆	19.97	19.99	22.25	21.01	22.05	21.05 ^c	
T ₇	21.67	21.68	22.77	21.93	22.75	22.16 ^a	
T ₈	20.27	20.27	21.27	21.19	21.98	21.00 ^f	
T ₉	22.00	22.07	22.99	21.12	23.23	22.28 ^a	
Mean	20.42 ^d	20.44 ^d	21.73 ^b	20.83 ^c	21.92 ^a		
Source of variation				CD_{0.05}	df	F_{Cal}	P_{tab}
Seed coating treatments (T)				0.27	8	99.836	0.00000
Foliar application of micronutrients (N)				0.20	4	96.399	0.00000
Seed coating treatments × Foliar application of micronutrients (T × N)				0.61	32	3.228	0.00000
Year (Y)				0.13	1	222.917	0.00000
Year × Seed coating treatments				NS	8	0.870	0.54334
Year × Foliar application of micronutrients (Y × N)				NS	4	0.239	0.91607
Year × Seed coating treatments × Foliar application of micronutrients				NS	32	0.456	0.99489

CD_{0.05}: critical difference at the 5 % probability level; NS: non-significant; Df: degrees of freedom; F_{cal}: calculated *F*-value; T: seed coating treatments; N: foliar application of micronutrients; Y: year.

solution of 0.3 % H₃BO₃ which was longest and statistically at par with T₇N₃, T₉N₃, T₃N₅, T₅N₅ and T₇N₅, may be as a result of bold and better quality seeds which upon germination resulted in quite healthy and vigorous seedlings possessing well distinguishable root and shoot apical meristems. Whereas the seed lot of control plants i.e., T₁N₁ when subjected to germination under laboratory conditions resulted in shortest seedlings (18.82 cm) (Fig. 2). The enhanced shoot and root length may result from seed polymerisation with micronutrients, which elevates germination potential and seedling growth. This, in turn, could augment the metabolic activity of indole acetic acid and auxin (25) through micronutrients and their translocation, facilitating early germination, cell division and cell elongation, thereby increasing root and shoot length of the seedlings (26).

Seedling dry weight (mg)

The pooled data presented in Table 4 revealed that among different seed coating treatments, seeds of radish plants which were raised by using seed lot coated with polymer at 10 mL/kg

seed + ZnSO₄ at 300 mg/kg seed + CuSO₄ at 300 mg/kg seed + H₃BO₃ at 300 mg/kg seed when germinated resulted in the good quality seedlings which upon drying exhibited highest value (12.36 mg) for their dry weight. Whereas the dry weight of seedlings was observed to be minimum (10.25 mg) in the seed lot obtained from control plants. Among the foliar application of micronutrients, the dry weight of seedlings was maximum (11.63 mg) for the seedlings which were obtained by the seeds of radish plants sprayed with 0.3 % H₃BO₃ at bolting and 50 % flowering to germinate in the laboratory conditions. However, the minimum value (10.97 mg) was recorded in no spray and water spray. The interaction effects (T₉N₅) of radish plants grown from the seeds subjected to coating treatment of polymer at 10 mL/kg seed + ZnSO₄ at 300 mg/kg seed + CuSO₄ at 300 mg/kg seed + H₃BO₃ at 300 mg/kg seed and spraying of the plants with 0.3 % H₃BO₃ resulted in the production of seedlings exhibiting highest seedling dry weight (12.87 mg) which was statistically at par with T₉N₃, T₇N₄, T₉N₄ and T₇N₅. On the other hand, lowest value (10.04 mg) for seedling dry weight was measured in no spray and water spray lot (T₁N₁, T₁N₂). The increase

Table 4. Effect of polymer seed coating treatments and foliar application of micronutrients on seedling dry weight (mg) of harvested seeds (Pooled)

	2022-23					Mean		
	N ₁	N ₂	N ₃	N ₄	N ₅			
T ₁	10.04	10.04	10.39	10.30	10.50	10.25 ^f		
T ₂	10.17	10.18	10.47	10.39	10.62	10.36 ^f		
T ₃	11.37	11.38	11.35	11.12	11.61	11.36 ^d		
T ₄	10.62	10.62	10.72	10.33	10.79	10.62 ^e		
T ₅	11.51	11.51	11.60	11.45	11.78	11.57 ^c		
T ₆	10.70	10.70	11.72	11.72	11.89	11.35 ^d		
T ₇	11.71	11.70	12.26	12.64	12.60	12.18 ^b		
T ₈	10.81	10.81	11.94	11.82	12.00	11.48 ^c		
T ₉	11.78	11.79	12.76	12.59	12.87	12.36 ^a		
Mean	10.97 ^d	10.97 ^d	11.47 ^b	11.37 ^c	11.63 ^a			
					CD _{0.05}	df	F _{Cal}	P _{tab}
Seed coating treatments (T)					0.14	8	233.322	0.00000
Foliar application of micronutrients (N)					0.10	4	68.290	0.00000
Seed coating treatments × Foliar application of micronutrients (T × N)					0.30	32	5.969	0.00000
Year (Y)					0.06	1	14.374	0.00020
Year × Seed coating treatments					NS	8	0.076	0.99971
Year × Foliar application of micronutrients (Y × N)					NS	4	0.389	0.81624
Year × Seed coating treatments × Foliar application of micronutrients					NS	32	0.160	1.00000

CD_{0.05}: critical difference at the 5 % probability level; NS: non-significant; Df: degrees of freedom; F_{cal}: calculated *F*-value; T: seed coating treatments; N: foliar application of micronutrients; Y: year.

Table 6. Effect of polymer seed coating treatments and foliar application of micronutrients on seedling vigour index-II (mass) of harvested seeds (Pooled)

	2022-23					Mean
	N ₁	N ₂	N ₃	N ₄	N ₅	
T ₁	787.17	787.26	838.92	808.59	865.11	817.41 ^g
T ₂	806.02	806.81	855.50	822.16	886.91	835.48 ^f
T ₃	924.78	924.89	959.71	914.02	1001.94	945.07 ^d
T ₄	844.02	844.02	885.33	823.07	910.43	861.37 ^e
T ₅	949.10	949.09	967.56	924.30	1029.38	963.89 ^c
T ₆	902.90	903.02	1001.65	985.49	1051.57	968.93 ^c
T ₇	977.54	977.18	1120.68	1129.46	1151.84	1071.34 ^b
T ₈	879.48	879.44	1045.09	1018.99	1071.96	978.99 ^c
T ₉	1001.71	1008.83	1183.26	1140.82	1194.32	1105.79 ^a
Mean	896.97 ^d	897.84 ^d	984.19 ^b	951.88 ^c	1018.16 ^a	
	CD _{0.05}					
Seed coating treatments (T)	13.31					8
Foliar application of micronutrients (N)	9.92					4
Seed coating treatments × Foliar application of micronutrients (T × N)	29.76					32
Year (Y)	6.28					1
Year × Seed coating treatments	NS					8
Year × Foliar application of micronutrients (Y × N)	NS					4
Year × Seed coating treatments × Foliar application of micronutrients	NS					32
	F _{cal}					P _{tab}
Seed coating treatments (T)	433.834					0.00000
Foliar application of micronutrients (N)	224.459					0.00000
Seed coating treatments × Foliar application of micronutrients (T × N)	11.150					0.00000
Year (Y)	93.092					0.00000
Year × Seed coating treatments	0.242					0.98239
Year × Foliar application of micronutrients (Y × N)	0.643					0.63245
Year × Seed coating treatments × Foliar application of micronutrients	0.161					1.00000

CD_{0.05}: critical difference at the 5 % probability level; NS: non-significant; Df: degrees of freedom; F_{cal}: calculated *F*-value; T: seed coating treatments; N: foliar application of micronutrients; Y: year.

Conclusion

This investigation presents data to formulate an effective strategy for increasing radish production. Polymer coating (at 10 mL/kg) of radish seeds along with zinc sulphate (ZnSO₄) + copper sulphate (CuSO₄) + boric acid (H₃BO₃) (each at 300 mg/kg of seeds) with foliar application of H₃BO₃ at 0.3 % sprayed at bolting and 50 % flowering resulted in significant increase in speed of germination, germination percentage, seedling length, seedling dry weight, seedling vigour index-I and II compared to other treatments and control. Hence, the seed producing organisations can use this technology for supplying the micronutrients to the seed which helps in better germination with high vigour. Therefore, this treatment combination can be recommended for quality seed production in radish after multi-location trials and demonstrations.

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Authors' contributions

RJ carried out the laboratory experiment collected and analysed the data participated in sequence alignment and drafted the manuscript. AKT developed the research framework. AC and DT participated in the design of the study and performed the statistical analyses. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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