



RESEARCH COMMUNICATION

Effects of hydroponic nutrient strength and *Trichoderma* strains on morpho-physiological and biochemical traits of mustard microgreens

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Abstract

The present study evaluated the interactive effects of hydroponic nutrient with different strengths and *Trichoderma* strains on morpho-physiological and biochemical traits of mustard (*Brassica juncea* L.) microgreens. Treatments comprised of three nutrient strengths pure water (N₁), half-strength nutrient solution (N₂) and full-strength nutrient solution (N₃) in combination with three *Trichoderma* strains (T₁, T₂, T₃), arranged in a factorial design. Results indicated significant improvements in seed germination, vigour index, seedling height, shoot fresh weight and microgreen yield with increasing nutrient concentration. Across treatments, N₃ recorded the highest mean germination (90.5 %), vigour index (604.02) and fresh weight (75.59 mg shoot⁻¹). *Trichoderma* inoculation further enhanced early growth, with T₂ producing seedlings with best vigour (606.09) and height (7.8 cm). The highest shoot population density (27.77 × 10³ shoots m⁻²) and fresh yield (1.503 kg m⁻²) were observed under N₃. Biochemical attributes also responded significantly; N₃ promoted higher chlorophyll (60.6 mg 100 g⁻¹ FW), carotenoids (17.6 mg 100 g⁻¹ FW) and antioxidant activity (72.5 %), whereas vitamin C was maximised in N₁ (79.5 mg 100 g⁻¹ FW), likely reflecting altered carbon allocation under nutrient-limited conditions. Shoot nitrate content declined with increasing nutrient strength and this response was independent of *Trichoderma* inoculation. Ash content (0.67 %) and dry matter (5.51 %) were also enhanced under N₃. Overall, the integration of nutrient solution (N₃) with *Trichoderma* strain T₂ provided the most consistent improvements in growth, yield and nutritional quality, suggesting a synergistic role of mineral nutrition and microbial inoculants in optimising microgreen production.

Keywords: biochemical quality; growth and yield; hydroponic nutrient strength; mustard microgreens; *Trichoderma* strains

Introduction

Microgreens, the edible seedlings harvested at the cotyledon to first true-leaf stage, have emerged as a fast-cycling, high-value crop with dense phytonutrient profiles and appealing sensory attributes (colour, flavour, texture). They are increasingly regarded as a novel class of superfoods with promising health implications (1). Interest has grown around their potential as “functional foods,” as preharvest factors (species, fertilisation, biofortification, lighting and harvest stage) strongly modulate their morpho-physiology and quality traits (2). Recent reviews highlight microgreen production as a scalable approach for nutrient-rich, fresh produce in controlled environments and urban supply chains (3–7). Within microgreens, Brassicaceae types, including mustard (*Brassica juncea* L.), are notable for rapid growth, high chlorophyll and carotenoid contents, vitamin C, phenolics and glucosinolate-derived isothiocyanates that

underpin their antioxidant capacity (3, 8, 9). These phytochemicals, together with biomass traits (germination, vigour, height) and yield, are commonly used to evaluate both agronomic performance and nutritional quality.

Hydroponics is the predominant microgreen production method; nutrient with its solution strength directly affecting emergence dynamics, seedling vigour, canopy density, pigment accumulation and fresh yield. Controlled trials on Brassica microgreens show that stepping nutrient strength from water to half or full-strength solutions can increase fresh yield and modulate pigments and minerals, though the magnitude and direction are species and genotype dependent (3, 10). Managing nitrate is particularly important for leafy seedlings because fertilisation can elevate tissue nitrate; current risk assessments and EU limits for leafy vegetables motivate strategies that balance growth with nitrate accumulation (11, 12).

Alongside mineral nutrition, beneficial microbes are increasingly used as low-residue inputs to improve crop health and performance in soilless systems. *Trichoderma* spp. are well characterised root symbionts and biofungicides that antagonise pathogens and induce plant growth and stress tolerance via multiple mechanisms, including mycoparasitism, ISR/priming, modulation of phytohormones (e.g., auxin), improved nutrient uptake and enhanced antioxidant status (13–17). These effects can translate into greater seedling vigor, biomass, chlorophyll content and resilience, traits directly measured in microgreen production.

Despite the parallel advances in (i) optimising hydroponic nutrient regimes for microgreens and (ii) deploying *Trichoderma* as biocontrol/bio-stimulant in protected cultivation, there is a limited evidence based on their combined effects, particularly on mustard microgreens, across integrated morpho-physiological (germination percentage, vigour index, growth rate, height, stand density and fresh yield) and biochemical endpoints (moisture, nitrate, ash, chlorophylls, carotenoids, vitamin C, antioxidant activity via DPPH). Establishing these relationships can guide input decisions (nutrient strength and *Trichoderma* strain selection) to improve yield-quality trade-offs and reduce nitrate risks in short cycle leafy crops. The present study addresses this gap by factorial testing three hydroponic nutrient strengths and three *Trichoderma* strains in mustard microgreens and quantifying the above trait suite.

Materials and Methods

The experiment entitled “Effects of hydroponic nutrient strength and *Trichoderma* strains on morpho-physiological and biochemical traits of mustard microgreens” was conducted during 2023-24 at the Division of Basic Sciences and Humanities, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar. The study involves three nutrient concentrations (pure water, half strength of hydroponic nutrient solution and full strength of hydroponic nutrient solution) and three *Trichoderma* strains (*Trichoderma viride* smppsap1, *Trichoderma viride* smppsap2 and *Trichoderma viride* smppsap3), which were isolated, purified and characterised in our laboratory. In addition, a control treatment (N1 × T0) without nutrient supplementation and without *Trichoderma* inoculation was used for comparison. Pure cultures of *Trichoderma viride* strains (smppsap1, smppsap2, smppsap3) were grown on PDA for 7-10 days at 25 ± 2 °C and spores were harvested by flooding the plates with sterile distilled water containing 0.01 % Tween-80. The suspension was filtered through sterile cheesecloth and adjusted to 1×10^7 conidia mL⁻¹ using a haemocytometer. For biopriming 100 g of mustard seeds, free from chemical treatments, were soaked in 700 mL spore suspension (1:7 w/v) at 22–25 °C for 6 hr with intermittent agitation, following protocols similar to seed priming studies with PGPR under stress conditions (18). The soaked seeds were incubated on moist sterile filter paper for 18 hr in darkness, shade-dried to original moisture and used for microgreen production.

The experiment was laid out in a factorial completely randomized design (CRD) with three replications. Plastic trays of uniform size (200 sq. inch) were filled with coco peat to a depth of 2.0 cm and lightly moistened prior to sowing. Bioprimed mustard seeds (*Brassica juncea*) were evenly broadcasted over the medium

at a fixed seed density of 20 g per 200-inch², gently pressed to ensure proper contact with growing medium, followed by lightly misting with water. After sowing, the trays were covered with a dark breathable cloth to simulate soil darkness and kept under blackout conditions for 2–3 days (48–72 hr) until most seeds germinated. The surrounding temperature was maintained at 25 ± 2 °C and humidity was kept within 70–80 % by light misting when necessary. Once the hypocotyls emerged and the cotyledons began to unfold, the blackout cover was removed. In the laboratory, the trays were maintained under controlled conditions with artificial fluorescent light (150–200 $\mu\text{mol m}^{-2} \text{s}^{-1}$ PAR) for a 12 hr photoperiod, at a temperature of 25 ± 2 °C and relative humidity of 70–80 %. Irrigation was done twice daily with fine mist spraying to maintain adequate moisture without waterlogging. Crops were allowed to grow until the appearance of the first true leaf, at which stage they were harvested by cutting the stems just above the medium surface using sterilised scissors.

Seed germination percentage was assessed by marking three 1-inch² blocks in each tray and recording the number of germinated and ungerminated seeds. Seedling vigour index was calculated as per Abdul-Baki and Anderson (19). Growth and yield attributes, including seedling height, shoot fresh weight, shoot dry weight, shoot population density and total fresh yield were recorded at the time of harvest. The moisture content of harvested microgreens was determined by oven-drying the samples at 70 °C to a constant weight while chlorophyll and carotenoid contents were determined in 80 % acetone following Arnon (20). Vitamin C was estimated by titration with 2, 6-dichlorophenolindophenol dye using oxalic acid extract, while ash content was determined by dry ashing in a muffle furnace at 500–550 °C until constant weight, both following AOAC methods (21). Antioxidant activity was determined by the DPPH free radical scavenging assay, measuring absorbance decrease at 517 nm, while nitrate content was quantified by the salicylic acid-sulfuric acid colorimetric method at 410 nm against a potassium nitrate standard curve (22, 23).

Microbial analysis was conducted as supportive assessments to verify *Trichoderma* establishment and biocontrol relevance, complementing the primary evaluation of growth, yield and biochemical quality traits. For microbial analysis, samples of harvested microgreens were subjected to serial dilution and plating. Bacterial counts were made on nutrient agar plates and fungal counts on potato dextrose agar (PDA) using the pour plate technique (24). Plates were incubated at 28 ± 2 °C for 48–72 hr and results were expressed as CFU mL⁻¹. The data were analysed using a two-way analysis of variance (ANOVA) under a completely randomized factorial design (nutrient strength × *Trichoderma* strain), following the procedures described (25).

Results and Discussion

Seed germination and seedling growth

Seed germination and vigour index of mustard microgreens were significantly influenced by nutrient strength, *Trichoderma* strains and their interactions (Table 1). Among treatments, full-strength nutrient solution (N3) recorded the highest germination (90.5 %) and vigour index (604.02), while pure water (N1) showed the lowest. Similarly, among the *Trichoderma* strains, Strain-2 (T2) enhanced germination (87.4 %) and vigour index (606.09), indicating its superior plant growth-promoting effect compared to

Table 1. Effect of nutrient strength and biopriming with *Trichoderma viride* strains on seed germination and seedling growth of mustard microgreens

Treatment	Seed germination (%)	Seedling vigour index-I	Days to 1 st true leaf stage	Seedling height (cm)
Main effect of hydroponic nutrient (N)				
Pure water (N1)	80.3	554.96	14.6	6.8
Half-strength nutrient (N2)	87.8	584.54	13.3	7.5
Full-strength nutrient (N3)	90.5	604.02	13.0	8.1
C.D. ($p \leq 0.05$)	1.02	22.50	0.63	0.11
Trichoderma strains biopriming (T)				
<i>Trichoderma viride</i> strains 1 (T1)	85.8	564.94	14.3	7.4
<i>Trichoderma viride</i> strains 1 (T2)	87.4	606.09	13.0	7.8
<i>Trichoderma viride</i> strains 1 (T3)	85.3	572.48	13.6	7.6
C.D. ($p \leq 0.05$)	1.02	22.50	0.63	0.11
Interaction effects of hydroponic nutrient and <i>Trichoderma</i> strains (N × T)				
N1 × T1	78.5	541.17	15	6.8
N1 × T2	80.5	571.13	14	6.9
N1 × T3	81.9	552.58	15	6.9
N2 × T1	89.6	583.74	14	7.4
N2 × T2	89.2	623.03	13	8.2
N2 × T3	84.5	546.84	13	8.0
N3 × T1	89.5	569.91	14	8.0
N3 × T2	92.5	624.12	12	8.5
N3 × T3	89.5	618.04	13	8.0
C.D. ($p \leq 0.05$)	1.76	38.98	0.90	0.19

other strains. This improvement may be attributed to *Trichoderma*-mediated phytohormone production, nutrient solubilisation and better root system development, which enhance early seedling establishment (12, 26).

The time to reach the first true leaf stage was significantly reduced with nutrient enrichment, especially under N3 and *Trichoderma* strain 2 (T2), which required only 12–13 days (Table 1). Concurrently, seedling height increased significantly under N3, with the maximum height of 8.5 cm recorded in T2 × N3. Faster leaf initiation and taller seedlings in nutrient-supplemented and *Trichoderma*-inoculated treatments can be explained by improved nitrogen availability and *Trichoderma*-induced auxin-like activity (27).

Yield and yield attributes

Shoot fresh weight and dry matter content were also significantly improved (Table 2). N3 consistently supported higher biomass accumulation, with T2 × N3 yielding 76.53 mg shoot⁻¹ fresh weight and 5.45 % dry matter. Similar findings were reported (28), who reported that optimised nutrient strength coupled with biostimulant inoculation enhances assimilate accumulation and biomass partitioning in leafy vegetables.

Shoot population density and microgreen yield followed the same trend (Table 2). The maximum shoot density (28.01×10^3 shoot m⁻²) and fresh yield (1.511 kg m⁻²) were recorded in T2 × N3, while pure water (N1) showed the lowest values. These results indicate that both nutrient availability and *Trichoderma* synergistically enhance plant stand and productivity. Enhanced yield performance under hydroponics with biostimulant amendments has also been reported in microgreens and lettuce (3, 29).

Quality attributes

Moisture content remained unaffected by treatments (Table 3), reflecting the intrinsic high-water content of microgreens (> 94 %) as water accumulation in microgreens is tightly regulated to maintain cellular turgor and physiological balance, whereas other traits, such as growth and biochemical composition, are more responsive to nutrient and microbial inputs. However, ash content was significantly influenced, with N3 and *Trichoderma* strains enhancing mineral accumulation. The increase in ash content indicates improved nutrient assimilation under enriched hydroponic conditions, in line with previous findings in brassica microgreens (30).

Table 2. Effect of nutrient strength and biopriming with *Trichoderma viride* strains on yield attributes and yield of mustard microgreens

Treatment	Shoot fresh weight (mg shoot ⁻¹)	Shoot dry matter (%)	Shoot population density ($\times 10^3$ shoot m ⁻²)	Microgreen fresh yield (kg m ⁻²)
Main effect of hydroponic nutrient (N)				
Pure water (N1)	67.24	4.85	24.15	1.400
Half-strength nutrient (N2)	71.11	4.96	26.96	1.499
Full-strength nutrient (N3)	75.54	5.51	27.77	1.503
C.D. ($p \leq 0.05$)	1.06	0.04	6.08	0.037
Trichoderma strains biopriming (T)				
<i>Trichoderma viride</i> strains 1 (T1)	69.13	5.03	25.90	1.465
<i>Trichoderma viride</i> strains 1 (T2)	73.26	5.09	26.90	1.471
<i>Trichoderma viride</i> strains 1 (T3)	71.54	5.18	26.08	1.467
C.D. ($p \leq 0.05$)	1.06	0.04	6.08	0.037
Interaction effects of hydroponic nutrient and <i>Trichoderma</i> strains (N × T)				
N1 × T1	62.67	4.75	22.75	1.394
N1 × T2	70.60	4.85	25.68	1.404
N1 × T3	68.47	4.95	24.03	1.403
N2 × T1	70.23	4.91	27.22	1.496
N2 × T2	72.67	4.97	27.01	1.497
N2 × T3	70.43	5.01	26.65	1.505
N3 × T1	74.50	5.43	27.72	1.505
N3 × T2	76.53	5.45	28.01	1.511
N3 × T3	75.59	5.65	27.56	1.495
C.D. ($p \leq 0.05$)	1.83	0.07	10.53	0.064

Table 3. Effect of nutrient strength and biopriming with *Trichoderma viride* strains on quality of mustard microgreens

Treatment	Moisture content (%)	Ash content (%)	Total chlorophyll (mg 100 ⁻¹ g FW)	Total carotenoid (mg 100 ⁻¹ g FW)
Main effect of hydroponic nutrient (N)				
Pure water (N1)	94.6	0.54	52.9	14.3
Half-strength nutrient (N2)	94.8	0.60	58.1	15.8
Full-strength nutrient (N3)	94.6	0.67	60.6	17.6
C.D. ($p \leq 0.05$)	NS	0.031	0.56	0.45
<i>Trichoderma</i> strains biopriming (T)				
<i>Trichoderma viride</i> strains 1 (T1)	94.2	0.58	57.0	16.0
<i>Trichoderma viride</i> strains 1 (T2)	94.8	0.60	57.7	16.1
<i>Trichoderma viride</i> strains 1 (T3)	95.1	0.63	56.9	15.6
C.D. ($p \leq 0.05$)	NS	0.031	0.56	0.45
Interaction effects of hydroponic nutrient and <i>Trichoderma</i> strains (N × T)				
N1 × T1	93.8	0.52	52.8	13.6
N1 × T2	95.0	0.55	54.0	15.1
N1 × T3	95.0	0.56	51.9	14.2
N2 × T1	94.8	0.58	58.7	16.7
N2 × T2	94.7	0.59	56.5	14.6
N2 × T3	95.0	0.65	59.0	16.1
N3 × T1	94.0	0.65	59.5	17.7
N3 × T2	94.6	0.67	62.7	18.7
N3 × T3	95.3	0.69	59.8	16.6
C.D. ($p \leq 0.05$)	NS	0.059	0.98	0.78

Total chlorophyll and carotenoid concentration were significantly improved with N3 and *Trichoderma* inoculation (Table 3). The maximum chlorophyll (62.7 mg 100 g⁻¹ FW) and carotenoid content (18.7 mg 100 g⁻¹ FW) were observed in T2 × N3. Higher pigment accumulation under these treatments indicates enhanced photosynthetic efficiency and antioxidant potential. Reports suggest that *Trichoderma* can stimulate chlorophyll biosynthesis via improved nutrient uptake and modulation of plant metabolism (14).

Vitamin C and antioxidant activity were significantly affected by nutrient concentration, *Trichoderma* inoculation and their interaction (Table 4). Antioxidant activity increased with nutrient enrichment, reaching a maximum under full-strength nutrients (72.50 %), while higher vitamin C content was recorded under pure water (79.5 mg 100 g⁻¹ FW). The highest Vitamin C (80.4 mg 100 g⁻¹ FW) and antioxidant activity (73.5 %) were observed in N1 × T2 and N3 × T2 respectively, consistent with earlier reports (31).

Interestingly, shoot nitrate content (Table 4) showed a decreasing trend with increasing nutrient strength, where the lowest nitrate accumulation (555.38 mg 100 g⁻¹ DW) was recorded in T2 × N3. The reduction in nitrate accumulation observed under

Trichoderma treatments may be associated with improved nitrogen assimilation (32).

Microbial and biocontrol parameters

Nutrient strength and *Trichoderma* biopriming markedly influenced microbial dynamics and disease suppression in mustard microgreens (Table 5). Rhizosphere microbial load increased from 1.1×10^6 CFU g⁻¹ FW in the control to 7.1×10^6 CFU g⁻¹ FW under N3 × T3, while seedling surface microbial load showed a parallel rise. Enhanced microbial proliferation under nutrient-enriched and inoculated treatments indicates a favourable rhizosphere environment that supports both indigenous and introduced microbes (33).

Trichoderma recovery and colonisation efficiency improved substantially with nutrient strength, peaking at 9.8×10^5 CFU g⁻¹ FW and 78.9 % under N3 × T3. This reflects the synergistic effect of adequate nutrition and microbial competence in root colonisation, which is critical for growth promotion and plant defense (13). Strain 3 exhibited superior rhizosphere adaptability and higher colonisation efficiency as compared to the other strains. However, strain 2 was found to be best for plant growth, yield and biochemical traits.

Table 4. Effect of nutrient strength and biopriming with *Trichoderma viride* strains on quality of mustard microgreens

Treatment	Vitamin C (mg 100 g ⁻¹ FW)	Antioxidant activity (%)	Shoot nitrate content ($\times 10^1$ mg 100 ⁻¹ g DW)
Main effect of hydroponic nutrient (N)			
Pure water (N1)	79.5	64.48	61.61
Half-strength nutrient (N2)	75.1	67.70	59.73
Full-strength nutrient (N3)	72.8	72.50	56.47
C.D. ($p \leq 0.05$)	0.55	1.06	1.76
<i>Trichoderma</i> strains biopriming (T)			
<i>Trichoderma viride</i> strains 1 (T1)	74.6	67.52	59.74
<i>Trichoderma viride</i> strains 1 (T2)	76.2	69.10	59.73
<i>Trichoderma viride</i> strains 1 (T3)	76.5	68.05	58.34
C.D. ($p \leq 0.05$)	0.55	1.06	1.76
Interaction effects of hydroponic nutrient and <i>Trichoderma</i> strains (N × T)			
N1 × T1	79.3	64.65	62.24
N1 × T2	80.4	65.30	63.53
N1 × T3	78.9	63.50	59.05
N2 × T1	73.2	66.31	59.74
N2 × T2	76.5	68.51	60.11
N2 × T3	75.6	68.26	59.34
N3 × T1	71.3	71.60	57.25
N3 × T2	71.9	73.50	55.54
N3 × T3	75.1	72.40	56.62
C.D. ($p \leq 0.05$)	0.95	1.76	3.05

Table 5. Effect of nutrient strength and biopriming with *Trichoderma viride* strains on microbial and biocontrol parameters of mustard microgreens

Treatment	Rhizosphere microbial load (CFU g ⁻¹ FW)	Seedling surface microbial load (CFU g ⁻¹ seedling)	<i>Trichoderma</i> recovery (CFU g ⁻¹ FW)	Colonisation (%)	Disease incidence (% seedling rot)
Main effect of hydroponic nutrient (N)					
Pure water (N1)	3.17 × 10 ⁶	7.13 × 10 ⁵	7.93 × 10 ⁴	47.4	16.8
Half-strength nutrient (N2)	5.13 × 10 ⁶	1.24 × 10 ⁶	3.60 × 10 ⁵	62.6	11.4
Full-strength nutrient (N3)	6.63 × 10 ⁶	1.87 × 10 ⁶	7.73 × 10 ⁵	74.9	8.6
<i>Trichoderma</i> strains biopriming (T)					
<i>Trichoderma viride</i> strains 1 (T1)	4.53 × 10 ⁶	1.13 × 10 ⁶	3.50 × 10 ⁵	57.5	13.6
<i>Trichoderma viride</i> strains 1 (T2)	4.97 × 10 ⁶	1.29 × 10 ⁶	3.90 × 10 ⁵	61.7	12.2
<i>Trichoderma viride</i> strains 1 (T3)	5.43 × 10 ⁶	1.40 × 10 ⁶	4.93 × 10 ⁵	65.6	11.1
Interaction effects of hydroponic nutrient and <i>Trichoderma</i> strains (N × T)					
N1 × T1	2.8 × 10 ⁶	6.5 × 10 ⁵	6.0 × 10 ⁴	42.3	18.7
N1 × T2	3.2 × 10 ⁶	7.1 × 10 ⁵	8.2 × 10 ⁴	48.6	16.5
N1 × T3	3.5 × 10 ⁶	7.8 × 10 ⁵	9.6 × 10 ⁴	51.2	15.3
N2 × T1	4.6 × 10 ⁶	1.1 × 10 ⁶	2.8 × 10 ⁵	58.7	12.6
N2 × T2	5.1 × 10 ⁶	1.25 × 10 ⁶	3.6 × 10 ⁵	62.4	11.4
N2 × T3	5.7 × 10 ⁶	1.38 × 10 ⁶	4.4 × 10 ⁵	66.8	10.2
N3 × T1	6.2 × 10 ⁶	1.70 × 10 ⁶	6.1 × 10 ⁵	71.5	9.4
N3 × T2	6.6 × 10 ⁶	1.85 × 10 ⁶	7.3 × 10 ⁵	74.2	8.6
N3 × T3	7.1 × 10 ⁶	2.05 × 10 ⁶	9.8 × 10 ⁵	78.9	7.8
N1 × T0	1.1 × 10 ⁶	2.5 × 10 ⁵	1.2 × 10 ⁴	15.4	28.6

Disease incidence (seedling rot) declined sharply from 28.6 % in the control to 7.8 % in N3 × T3, demonstrating the strong biocontrol potential of *Trichoderma*. The reduction can be attributed to pathogen suppression through competition, mycoparasitism and induced systemic resistance, further reinforced by optimal plant nutrition (14, 34).

Overall, results demonstrate that ½- to full-strength hydroponic nutrient solution in combination with *Trichoderma*, particularly strain 2 for growth and quality enhancement and strain 3 for microbial colonisation and disease suppression, significantly improved seedling performance, yield, biochemical composition and food safety of mustard microgreens. This integrated approach not only enhanced chlorophyll, carotenoids, vitamin C and antioxidant activity while reducing nitrate accumulation, but also maximized rhizosphere microbial load, *Trichoderma* recovery and protection against seedling rot. These findings underscore the value of combining optimised nutrient regimes with beneficial microbes in hydroponic systems for sustainable production of high-quality, nutrient-dense microgreens.

Conclusion

The study concludes with the remarks that half to full strength hydroponic nutrient solution in combination with *Trichoderma* significantly improved the mustard microgreen performance. It is worth mentioning that strain-2 excelled in enhancing microgreens growth, yield and biochemical traits including chlorophyll, carotenoid and vitamin C content, antioxidant activity, rhizosphere microbial load, *Trichoderma* recovery and protection against seedling rot besides reducing the nitrate accumulation.

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Authors' contributions

FAK and ZMD conceptualised and designed the research study. UWK and IM were primarily responsible for conducting the experimental trials under controlled conditions. MM contributed to the design and interpretation of the microbial aspects of the study, while SA and SH helped in carrying out the biochemical analyses of the microgreens in the laboratory. SAM was responsible for statistical analysis and interpretation of the data. All authors read and approved the final version of manuscript.

Compliance with ethical standards

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

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT (OpenAI) to assist in drafting and refining portions of the manuscript. After using this tool, the authors thoroughly reviewed, revised and edited the content to ensure accuracy and appropriateness and they take full responsibility for the final content of the publication.

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