

Growth responses of *Coriandrum sativum* L. to sewage water irrigation: A pilot case study in the Dhuripara region of Bilaspur

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Abstract

This study evaluates the impact of sewage water irrigation on the growth of coriander (*Coriandrum sativum* L.) cultivated in the Dhuripara region of Bilaspur, India. Field experiments were conducted using municipal sewage water (treatment) and bore well water (control). The growth parameters included plant height, root length, number of leaves and stems, leaf area index (LAI), leaf area ratio (LAR), biomass, and net primary productivity. Sewage irrigation significantly enhanced vegetative parameters, including plant height (55.03 cm in treatment vs. 42.17 cm in control), root length, and leaf production. However, despite an initial boost, the treatment led to a significant reduction in final plant biomass compared to the control. Statistical analysis confirmed that sewage water alters the interrelationships among key growth parameters (such as LAI and LAR). The findings indicate a rapid, growth-promoting effect of sewage nutrients, which is offset by a final decline in total plant mass. The leaves act as the major reservoir for total metal load, while the seeds show a higher sensitivity to Pb and Cr. We caution that while sewage water enhances early vegetative growth, the presence of pollutants in the irrigation source requires urgent toxicological assessment to guarantee the safety and prevent long-term soil contamination.

Keywords: *Coriandrum sativum* L., Irrigation, Sewage water, Growth response, Statistical analysis.

INTRODUCTION

The growing scarcity of freshwater resources, exacerbated by increasing anthropogenic demands, has made the utilization of treated wastewater and raw sewage water for agricultural irrigation an increasingly prevalent practice globally, including in India [1]. This substitution, while pragmatic, introduces a complex duality: sewage water is often rich in beneficial nutrients like nitrogen, phosphorus, and organic matter, which can enhance soil fertility and crop productivity. However, it also carries a heterogeneous mix of anthropogenic contaminants, including heavy metals and organic pollutants, which pose risks to plant health and, critically, food safety [2,3]. Consequently, a comprehensive evaluation of the agroecological implications—specifically, the morphological growth responses and biomass structure of locally grown crops—is essential for assessing the long-term sustainability and safety of this practice.

Previous studies on various crops, such as lettuce, tomato, and napier grass, have yielded mixed results, demonstrating growth enhancement in some cases due to nutrient loading, while others show negative impacts due to cumulative contaminant stress [4,5]. Almas *et al.* (2025) found that untreated wastewater negatively impacted lettuce growth and yield significantly compared to canal water (control) [6].

Studies utilizing hydrothermal and halothermal time models have quantified the interactive effects of temperature and osmotic stress on seed physiology, demonstrating that high osmotic potentials significantly limit crucial processes like germination, as shown in *Cucumis melo* [7] and *Helianthus annuus* [8]. These studies provide a strong mechanistic framework for interpreting the stress responses concerning the high salinity and nutrient load of the sewage water.

Coriandrum sativum L. (Coriander), a highly consumed leafy herb, is a crucial cash crop in the Bilaspur region. Despite its significant economic and dietary role, there is a critical lack of specific, comprehensive research on how coriander grown in the Dhuripara region, which relies heavily on local sewage water for irrigation, responds morphologically and structurally to this water source. This gap leaves local farmers, consumers, and policymakers uninformed regarding the true benefits versus the potential long-term risks specific to this herb and this catchment area.

To address this critical knowledge gap, this study investigates the growth attributes (e.g., plant height, root length, leaf area) and biomass structure (shoot and root dry weights) of *Coriandrum sativum* L. under varying concentrations of sewage water irrigation sourced from the Dhuripara region.

Our primary objective is to quantify the differential morphological and biomass growth responses of *C. sativum* across various sewage water irrigation treatments. We also seek to identify the specific concentration threshold at which the benefits of nutrient enrichment are overcome by the detrimental effects of contaminants.

We hypothesize that moderate sewage water concentration will initially promote growth due to nutrient availability, but higher concentrations will lead to significant morphological and biomass inhibition compared to the control group. The study demonstrates that sewage water irrigation significantly facilitates the bioaccumulation of heavy metals in the edible parts of *C. sativum*.

MATERIALS AND METHODS

Site description and experimental design

The study was conducted in Dhuripara, Bilaspur (22.09°N, 82.15°E) from Nov 2024 to March 2025. To provide high-resolution physiological data for this area, a pilot case study (on-farm) design was utilized, comparing a treatment plot (municipal sewage) to a control plot (borewell water). To ensure high-input conditions typical of the region, both plots (0.0035 ha) received a standard NPK basal dose (64:46:42.8 kg ha⁻¹). *C. sativum* seeds were sown at 20 × 15 cm spacing. The identical basal fertilization was intended to simulate local agronomic practices where sewage water is used as a supplemental rather than a replacement nutrient source.

Sampling and physiological indices

To account for within-plot variance, five plants were randomly harvested per plot at seven intervals (19 to 109 DAS). Growth was quantified via height, root length, and leaf number. Dry biomass (80 °C, 48h) was used to calculate Net Primary Productivity (NPP). Physiological efficiency was determined using standard formulas for Relative Growth Rate (RGR), Net Assimilation Rate (NAR), and Leaf Area Ratio (LAR) per [9], while Leaf Area Index (LAI) was calculated based on the leaf area-to-ground area ratio.

Yield components

Measurements included seeds per inflorescence, 100-seed weight, seed dimensions (length/diameter via screw gauge), and total grain yield (q ha⁻¹).

Heavy metal accumulation

Heavy metal concentrations (Pb, Cd, Ni, Cr, Zn, Fe) were measured in harvested tissues via AAS to evaluate food safety against FAO/WHO standards.

Statistics and risk assessment

Statistical differences between the two environments were assessed using independent t-tests by Microsoft Excel Data Analysis ToolPak ($p < 0.05$ significant; mean ± SD).

Limitation of the study

Due to the logistical constraints of the Dhuripara field site and the nature of municipal wastewater access, a single-plot on-farm design was utilized.

Random subsampling (n=5) was employed at seven distinct intervals (19 to 109 DAS) to capture within-plot variability and the temporal physiological shifts that single-harvest replicated plots might miss. Consequently, these findings are presented as a site-specific pilot case study. The t-tests are the indicators of significant differences between these two specific irrigation environments. While the results provide critical insights into the physiological tipping points and toxicological risks of coriander in this specific region, they should be viewed as a foundational baseline rather than a broad regional generalization.

RESULTS AND DISCUSSION

Post-harvest soil analysis (Table 1) confirmed that sewage water (treatment) acted as a potent nutrient source, significantly increasing concentrations of nitrogen (282.0 kg ha⁻¹), potash (436 kg ha⁻¹), and phosphorus (7.87 kg ha⁻¹) compared to the control. However, the treatment site also showed a 50% increase in electrical conductivity (0.39 mmhos cm⁻¹), indicating an osmotic stress component that influenced later growth stages.

Table 1: Physicochemical characteristics of irrigation sites before and after harvest of coriander

Characteristics	control site Sandy clay	treatment site Sandy clay
Soil texture		
Sand (%)	33	40
Silt (%)	11	13
Clay (%)	30	32
pH	7.25	7.43
Electrical Conductivity (mmhos cm ⁻¹)	0.26	0.39
Organic Carbon (%)	0.75	0.72
Nitrogen (kg ha ⁻¹)	200.5	282.0
Potash (kg ha ⁻¹)	392	436
Phosphorus (kg ha ⁻¹)	6.29	7.87
Sulfur (ppm)	28.75	31.25

Growth dynamics and vegetative parameters

The growth of *Coriandrum sativum* was monitored over 109 days after sowing (DAS). Key findings from Table 2 suggest that treatment plants were significantly taller by 79 DAS (55.03 cm vs. 42.17 cm in control). Root length followed a similar trend, peaking at 12.55 cm in the treatment plot, suggesting that sewage nutrients encouraged extensive root exploration. The treatment group maintained significantly higher leaf numbers during the reproductive phase (64–109 DAS), ending with 28.80 leaves/plant compared to 16.20 in the control ($p < 0.05$). No significant difference was found in the number of stems, suggesting that sewage water primarily drives vertical growth and foliage expansion rather than branching.

Table 2: Morphological growth parameters of *C. sativum* L. under control (CW) and sewage water (SW) treatment across different growth stages

DAS	Group	Plant Height (cm)	Root Length (cm)	No. of Leaves	No. of Stems
19	CW	4.05 ± 0.09	3.17 ± 0.10*	1.83 ± 0.25*	—
	SW	4.54 ± 0.22*	2.58 ± 0.14	1.53 ± 0.23	—
34	CW	9.02 ± 0.24	4.66 ± 0.19	20.63 ± 1.34	1.00 ± 0.00
	SW	9.96 ± 0.31*	6.06 ± 0.08*	21.40 ± 2.03	1.00 ± 0.00
49	CW	28.17 ± 0.38*	4.81 ± 0.18*	47.33 ± 5.75	3.47 ± 0.80
	SW	25.64 ± 1.98	3.79 ± 0.96	50.40 ± 3.93	4.83 ± 1.37
64	CW	35.64 ± 0.89	9.39 ± 0.64	51.83 ± 3.91	8.83 ± 2.31
	SW	36.13 ± 0.51	10.49 ± 0.36*	60.07 ± 2.37*	8.40 ± 1.10
79	CW	42.17 ± 7.61	9.03 ± 1.80	19.83 ± 1.35	8.73 ± 2.32
	SW	55.03 ± 7.92*	12.55 ± 1.72*	21.73 ± 2.39*	9.40 ± 1.66
94	CW	40.21 ± 0.72	8.36 ± 0.81	9.53 ± 2.55	8.27 ± 1.85
	SW	42.27 ± 0.84*	10.23 ± 0.70*	21.00 ± 0.72*	8.70 ± 2.34
109	CW	37.37 ± 3.51	9.15 ± 1.90	16.20 ± 1.22	8.97 ± 2.68*
	SW	40.71 ± 0.60*	10.86 ± 0.49*	28.80 ± 6.73*	7.00 ± 0.46

*Indicate a statistically significant difference between groups at the same DAS ($p < 0.05$). DAS: Days After Sowing; CW: Control Water; SW: Sewage Water.

Biomass accumulation and partitioning

Total biomass accumulation and partitioning are summarized in Fig. 1.

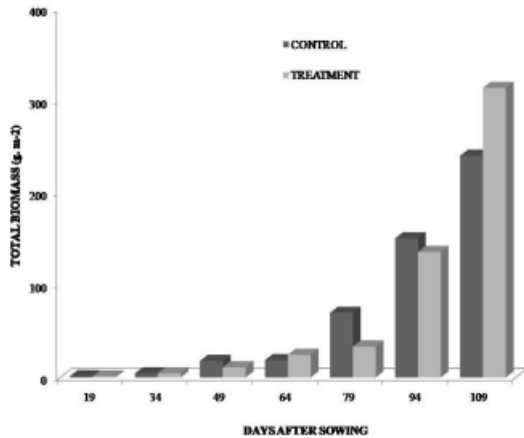


Fig.1: Total biomass of coriander at the control and treatment sites, respectively

Biomass dynamics (Table 3, Fig.1) revealed a significant "reversal" trend. From 49 to 94 DAS, the treatment group accumulated significantly higher total biomass, peaking at 70.17 g m⁻² at 79 DAS (more than double the control). However, by 109 DAS, the control plot achieved a significantly higher final biomass (314.38 g m⁻²) compared to the treatment (240.70 g m⁻²). This suggests that the initial rapid growth in the treatment group did not translate into final dry matter, likely due to salt-induced stress or metabolic exhaustion. The Root/Shoot (R/S) ratio was generally lower in the treatment group during peak growth (0.06 at 79 DAS), indicating a shoot-dominant strategy fueled by easily accessible nutrients.

Table 3: Standing Crop Biomass (g m⁻²) and Root/Shoot ratio of Coriander.

DAS	Parameter	Control (Bore Well Water) Mean ± SD	Treatment (Sewage Water) Mean ± SD	Statistical Significance (p < 0.05)
19	Total Biomass	1.15 ± 0.06 ^A	1.36 ± 0.16 ^B	SW>CW
	R/S Ratio	0.07 ± 0.02 ^A	0.05 ± 0.01 ^B	CW>SW
49	Total Biomass	11.08 ± 1.58 ^A	17.97 ± 1.64 ^B	SW>CW
	R/S Ratio	0.12 ± 0.01 ^A	0.11 ± 0.02 ^B	CW>SW
64	Total Biomass	24.66 ± 3.72 ^A	18.80 ± 6.59 ^B	CW>SW
	R/S Ratio	0.18 ± 0.04 ^A	0.15 ± 0.04 ^B	CW>SW
79	Total Biomass	33.53 ± 4.38 ^A	70.17 ± 12.43 ^B	SW>CW
	R/S Ratio	0.14 ± 0.06 ^A	0.06 ± 0.02 ^B	CW>SW
94	Total Biomass	136.31 ± 3.70 ^A	150.97 ± 4.93 ^B	SW>CW
	R/S Ratio	0.10 ± 0.00 ^A	0.09 ± 0.00 ^A	NS
109	Total Biomass	314.38 ± 21.48 ^A	240.70 ± 73.66 ^B	CW>SW
	R/S Ratio	0.06 ± 0.02 ^B	0.08 ± 0.01 ^A	SW>CW

Notes: Means followed by different superscript letters (A, B) within the same row are significantly different (p < 0.05) based on the Independent Samples t-test. NS = Not Statistically Significant.

Table 4: Net Primary Productivity (g m⁻² day⁻¹) of Coriander

Days after Sowing (DAS)	Parameter	Control (Bore Well Water)	Treatment (Sewage Water)	Statistical Outcome (p < 0.05)
49	NPP _{Total}	0.58 ^A	0.90 ^B	SW>CW
	NPP _{Below}	0.20 ^A	0.11 ^B	CW>SW
64	NPP _{Total}	1.46 ^A	0.06 ^B	CW>>SW
	NPP _{Below}	1.58 ^A	3.42 ^B	SW>>CW
79	NPP _{Total}	1.00 ^A	0.11 ^B	CW>>SW
	NPP _{Below}	6.48 ^A	5.39 ^B	CW>SW
94	NPP _{Total}	13.76 ^A	5.98 ^B	CW>>SW
	NPP _{Above}	11.43 ^A	5.67 ^B	CW>>SW

Statistical significance (p < 0.05) is indicated by superscripts.

Net primary productivity (NPP) and growth analysis

Physiological efficiency was assessed via NPP (Table 4) and growth indices (Table 5). The treatment plot recorded its highest NPP at 79 DAS (3.42 g m⁻² day⁻¹), but the control plot dominated the final stage (109 DAS) with a superior rate of 13.76 g m⁻² day⁻¹. Comparing physiological efficiency (RGR & NAR), it can be inferred that while the treatment group showed higher early Relative Growth Rate (RGR), the Net Assimilation Rate (NAR)—a measure of photosynthetic efficiency—collapsed in the treatment group toward maturity.

The Canopy Development (LAI & LAR) factors suggest that the treatment group developed a massive Leaf Area Index (LAI), peaking at 31.545 (vs. 9.351 in control) at 64 DAS. However, this dense canopy likely led to severe self-shading, explaining the subsequent decline in NAR and final biomass conversion efficiency.

A detailed comparison of mean values for key vegetative parameters, along with statistical significance markers, is presented and illustrated by Fig. 2a-d.

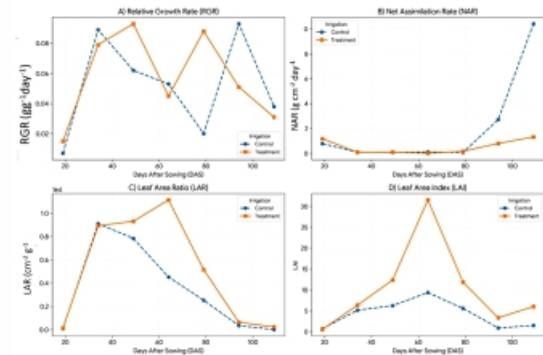


Fig. 2: Trends of a) RGR, b) NAR, c) LAR, and d) LAI over 109 Days After Sowing (DAS), comparing the control (Bore Well Water) and treatment (Sewage Water) sites for Coriander.

The above figure illustrates the physiological shift between irrigation groups. Early growth in the treatment group was characterised by rapid mass gain (RGR) and efficient nutrient assimilation (NAR), supported by a resource allocation strategy favoring rapid leaf expansion (LAR) and high canopy density (LAI, peaking at 64 DAS). However, this early advantage was not sustained; while the control maintained steady growth, the treatment group experienced a sharp decline in NAR and RGR toward maturity (109 DAS). This suggests that the dense canopy induced by sewage water eventually led to severe self-shading and physiological stress, compromising late-stage photosynthetic efficiency.

Table 5: Comparative growth analysis of crop under bore well (CW) and sewage water (SW) treatments

Parameter	treatment	19DAS	34 DAS	49 DAS	64 DAS	79 DAS	94 DAS	109 DAS
RGR	CW	0.007 ^A	0.089 ^B	0.062 ^A	0.053 ^A	0.020 ^B	0.093 ^B	0.038 ^A
(g g ⁻¹ day ⁻¹)	SW	0.015 ^B	0.079 ^A	0.093 ^B	0.045 ^A	0.088 ^A	0.051 ^A	0.031 ^A
NAR	CW	0.79 ^A	0.10 ^A	0.08 ^A	0.12 ^A	0.08 ^A	27.20 ^A	10.42 ^B
x 10 ⁻⁴ g cm ⁻² day ⁻¹)	SW	1.18 ^B	0.09 ^A	0.10 ^A	0.01 ^B	0.17 ^B	8.00 ^B	1.32 ^A
LAR	CW	93.38 ^A	9107.82 ^A	7837.19 ^B	4524.13 ^B	2527.48 ^A	344.02 ^A	17.09 ^B
(cm ² g ⁻¹)	SW	136.90 ^B	8922.63 ^A	9306.63 ^A	11143.25 ^A	5154.80 ^B	634.64 ^B	235.17 ^A
LAI	CW	0.667 ^A	5.141 ^A	6.219 ^A	9.351 ^B	5.567 ^B	0.869 ^B	1.471 ^B
	SW	0.519 ^B	6.329 ^B	12.370 ^B	31.545 ^A	11.835 ^A	3.313 ^A	5.999 ^A

Note: Values followed by different superscript letters (A, B) within the same column for each parameter indicate significant differences at $p < 0.05$.

Yield and seed quality

Despite the final biomass deficit, the treatment group outperformed the control in grain yield (Table 6, Fig. 3). Seed yield was 26% higher in the treatment group (16.29 q ha⁻¹) compared to the control (12.90 q ha⁻¹) ($p = 0.0031$). Sewage-irrigated seeds were significantly longer (0.71 cm) and wider (0.52 cm) than control seeds. Although the 100-seed weight did not differ significantly, the increased seed dimensions and count per inflorescence (18.53 vs. 11.99) drove the overall yield advantage.

Table 6: Comparative analysis of yield and seed quality parameters

Parameter	control (Bore Well Water) (mean ± SD)	treatment (Sewage Water) (mean ± SD)	T-test Outcome (p<0.05)
Number of inflorescence Per plant	11.21 ± 1.77	11.09 ± 2.03	NS(p = 0.9231)
Seeds per inflorescence	11.99 ± 1.72	18.53 ± 6.26	NS(p = 0.0543)
Weight of 100 seeds (g)	7.13 ± 0.84	6.63 ± 1.06	NS(p = 0.4324)
Seed's length (cm)	0.64 ± 0.04	0.71 ± 0.03	SW>CW(p = 0.0140)
Seed's diameter (cm)	0.43 ± 0.02	0.52 ± 0.03	SW>CW(p = 0.0005)
Seed yield (q ha ⁻¹)	12.90 ± 1.02	16.29 ± 1.50	TW>CW(p = 0.0031)

The analysis of yield and seed quality parameters provides a mixed, but ultimately positive, assessment of municipal sewage water utilizations.

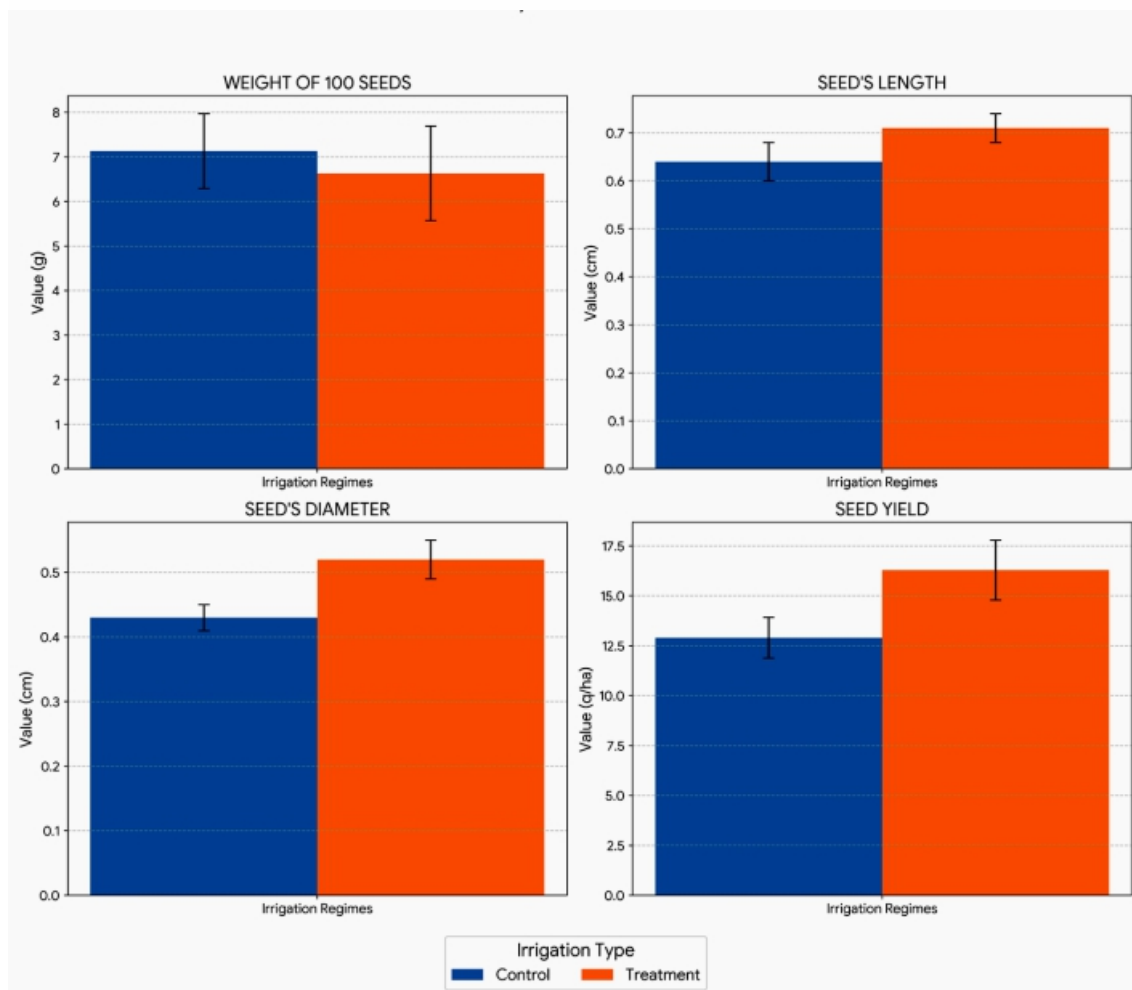


Fig. 3: Comparative yield components of coriander under two irrigation regimes: control (borewell water) and treatment (sewage water).

Heavy metal accumulation and toxicological assessment

The integration of heavy metal analysis (Table 7) provides a critical assessment of the food safety implications of sewage irrigation. Municipal sewage water significantly increased the bioaccumulation of both essential micronutrients and toxic non-essential trace elements across all plant tissues. Leaves and roots acted as the primary sinks for heavy metals. Under treatment conditions, Fe exhibited the highest absolute increase in leaves, rising by 91% (2.362 to 4.512 ppm). Notably, toxic elements Cd and Ni, which were non-detectable or below detection limits (BDL) in the control group, became quantifiable in treated leaf tissues at 0.005 ppm and 0.234 ppm, respectively. Pb concentrations in leaves nearly doubled, reaching 0.150 ppm. This accumulation in foliage is likely driven by the high transpiration rates characteristic of coriander, facilitating the xylem-mediated transport of metals from the root system.

While absolute concentrations in seeds were generally lower than in leaves, the relative percentage increases were more pronounced for highly toxic elements. Pb showed a critical increase of 468%, rising from 0.019 ppm in the control to 0.108 ppm in the treatment group. Similarly, Cr and Cd in seeds increased by 300% and significant detection levels, respectively. Zn, an essential micronutrient, also rose significantly by 56% (1.081 to 1.687 ppm).

Table 7: Comparative heavy metal concentration (ppm) in coriander tissues

Heavy Metal	Group	Leaf	Seed
Fe	control	2.362 ± 0.01	1.073 ± 0.00
	treatment	4.512 ± 0.11	1.341 ± 0.05
Cd	control	ND	ND
	treatment	0.005 ± 0.00	0.003 ± 0.00
Ni	control	BDL	BDL
	treatment	0.234 ± 0.01	0.047 ± 0.00
Pb	control	0.078 ± 0.00	0.019 ± 0.00
	treatment	0.150 ± 0.02	0.108 ± 0.01
Cr	control	0.010 ± 0.00	0.006 ± 0.00
	treatment	0.026 ± 0.00	0.024 ± 0.00

ND=Not Detected; BDL=Below Detection Limit.

Correlation analysis

Table 8: Correlation matrix between various growth attributes

	LAR		NAR		RGR		Biomass		Net PP		LAI	
	control	treatment	control	treatment	control	treatment	control	treatment	control	treatment	control	treatment
LAR	1.00	1.00	-	-	-	-	-	-	-	-	-	-
NAR	-0.93	-0.54	1.00	1.00	-	-	-	-	-	-	-	-
RGR	0.26	0.48	-0.47	-0.09	1.00	1.00	-	-	-	-	-	-
Biomass	-0.62	-0.56	0.62	0.98	-0.12	0.02	1.00	1.00	-	-	-	-
Net PP	-0.64	-0.55	0.52	0.97	0.07	0.05	0.95	1.00	1.00	1.00	-	-
LAI	0.33	0.95	-0.29	-0.89	0.03	0.14	-0.24	-0.51	-0.23	-0.53	1.00	1.00

The correlation matrix (Table 8) highlights a fundamental shift in the plant's resource allocation strategy under sewage water irrigation. While the methodology remains consistent, the biological implications of these correlations explain the divergence between early growth and final maturity. In the treatment group, a near-perfect positive correlation was observed between NAR and Biomass (0.98) and between NAR and NPP (0.97). This demonstrates that under high-nutrient loads, biomass accumulation is almost exclusively dependent on the efficiency of the photosynthetic machinery rather than just the size of the plant. Under sewage irrigation, the correlation between LAI and LAR increased dramatically to 0.95 (compared to 0.33 in the control). This indicates that the plant shifted toward an aggressive leaf-production strategy (high LAR) to utilise the abundant nitrogen, suggesting a "Luxury Consumption" Trade-off. Critically, the negative correlation between LAI and NAR became significantly more pronounced in the treatment group (-0.89) compared to the control (-0.29). The negative correlation between LAI and NAR (-0.89) is the primary evidence for the final biomass decline: while the sewage water induced a massive canopy (high LAI), this excessive growth triggered severe self-shading, which effectively neutralized the photosynthetic efficiency (NAR) of the lower leaves. The statistical evidence suggests that municipal sewage water acts as a double-edged sword. Initially, the high nutrient load facilitates a rapid increase in leaf area and biomass.

However, the strengthened negative correlation between canopy size (LAI) and efficiency (NAR) implies that the plant reaches a physiological "tipping point." Beyond this point, the cost of maintaining a dense, salt-stressed canopy exceeds the carbon gain, resulting in the observed reduction in final total biomass despite higher initial productivity.

Sewage Water as a Growth Stimulant

The significant enhancement of height, leaf count, and root length in the treatment group during early vegetative stages (up to 79 DAS) aligns with the "fertiliser effect" of wastewater. These findings are supported by Anwar *et al.* (2016), who observed similar growth in coriander, and Tak *et al.* (2013), who linked high nitrogen content to vegetative promotion [10,11]. The aggressive early investment in canopy structure (LAI) and biomass is consistent with studies on leafy vegetables by Gent (2017) and as well as the rapid accumulation observed in wastewater-grown aquatic plants [12,13].

Resource Partitioning and the Canopy-Efficiency Trade-Off

A core contradiction emerged as the control group achieved significantly higher final Total Biomass (314.38 g m⁻²) than the treatment (240.70 g m⁻²). Based on our results (EC and statistical correlation), we provide a probable mechanism for this decline. The treatment's excessive LAI (31.54) might have triggered severe self-shading. This led to a collapse in NAR during the reproductive stage, making the control canopy eight times more efficient than the treatment toward harvest.

This trade-off between leaf area and assimilation is documented by Shipley (2002) and –[14,15]. Furthermore, Alghobar and Suresha (2016) suggested that wastewater can introduce salts or metals that induce physiological stress [16]. The 50% increase in soil EC likely forced the plant to reallocate energy from carbon fixation to cell maintenance and osmotic adjustment, a response often linked to reactive oxygen species (ROS) [17]. Direct physiological assays would be required to confirm the precise metabolic pathways of the observed biomass decline.

Despite lower total biomass, the treatment group achieved a 26% higher seed yield (16.29 q ha⁻¹). This paradox suggests that while wastewater peaked early and failed to sustain high NPP at maturity [18], it successfully drove nutrient translocation to the reproductive sinks. The resulting larger, plumper seeds mirror findings by Khan *et al.* (2003) regarding improved seed quality in wastewater-irrigated methi and spinach [19]. While total productivity may require dilution to be sustained [20], the nutrient availability in municipal sewage effectively boosted the economic harvest index.

Food Safety Implications

The emergence of Cd and Ni exclusively in the treatment group serves as a chemical marker for sewage-borne contamination. The WHO/FAO permissible limit for Pb in spices is 0.3 ppm, and in our case, the treatment site crop, it reached 0.108 ppm. It is significantly higher than the control (0.019 ppm) but still safe by current standards. However, the bioaccumulative nature of these elements presents a long-term risk. Chronic consumption of coriander irrigated with raw sewage could lead to soil-to-crop transfer levels that eventually exceed safety standards, posing risks such as nephrotoxicity and neurodevelopmental delays [21]. These findings emphasise that while municipal sewage water effectively boosts production, it must be subject to strict monitoring or pre-treatment to ensure it meets public health safety standards.

CONCLUSION

This study demonstrates that municipal sewage water acts as a "double-edged sword" for *Coriandrum sativum* L. growth. While its nutrient-rich profile significantly enhanced early vegetative parameters—including plant height (55.03 cm vs. 42.17 cm) and leaf number—these gains were ultimately offset by a reduction in final total biomass. Based on the statistical results and growth responses, this decline may be attributed to secondary osmotic stress and elevated soil salinity (EC), which likely impaired photosynthetic efficiency during the maturity phase.

Furthermore, the significant accumulation of heavy metals (notably Pb and Zn) in both leaves and seeds poses a critical trade-off between yield and food safety. While wastewater reuse offers a viable irrigation alternative in water-scarce regions, the risk of contaminant bioaccumulation in edible tissues necessitates mandatory pre-treatment and rigorous monitoring.

Future research should prioritise long-term soil health and the establishment of safe consumption thresholds to mitigate public health risks.

Author Contributions

All authors contributed equally to this article. Nidhi Tiwari: Data curation, formal analysis, investigation, methodology, writing—original draft. Uttara Tiwari: Conceptualisation, Supervision and monitoring. Ashish Tiwari: Data curation, formal analysis, Writing—Review and Editing.

Declarations

Conflicts of Interest

The authors report there are no competing interests to declare.

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Data availability

The data collected, generated and analysed for this investigation are included in this article.

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