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Effects of Biostimulant Applications on the Morphological Characteristics of Coriander and Parsley under Soil Cultivation System

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ABSTRACT

This study evaluated the effects of two biostimulant applications (soil inoculation with *Trichoderma harzianum* and foliar spraying of *Ascophyllum nodosum* seaweed extract) on the morphological characteristics of coriander (*Coriandrum sativum* L.) and parsley (*Petroselinum crispum* Mill.) grown under a soil cultivation system. The experiment was conducted as a factorial arrangement in a randomized complete block design (RCBD) with two factors: *Trichoderma* inoculation (control vs. 500 mg L^{-1} applied twice) and seaweed extract foliar application (control vs. 1 g L^{-1} applied four times). Growth parameters measured included plant length (PL), plant volume (PV), leaf number (LN), plant fresh mass (PFM), plant dry mass (PDM), and dry matter percentage (DM). For coriander, *Trichoderma* application significantly increased PL, PV, LN, PFM, and PDM, while seaweed foliar application significantly improved PV, LN, PFM, and PDM. The interaction between *Trichoderma* and seaweed was significant for LN, PFM, and PDM, with the combined application producing the highest values for these parameters. For parsley, *Trichoderma* application significantly enhanced PL, PV, PFM, and PDM, and also significantly reduced DM. Seaweed foliar application alone significantly increased only PL. The interaction effect was significant only for DM. Principal component analysis (PCA) confirmed that *Trichoderma* and seaweed biostimulants, particularly when applied together, can effectively improve the morphological characteristics and productivity of coriander, while *Trichoderma* alone provides notable benefits for parsley under soil cultivation conditions.

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1. Introduction

Coriander (*Coriandrum sativum* L.) and parsley (*Petroselinum crispum* Mill.) are two of the most widely cultivated and economically important leafy vegetables belonging to the Apiaceae family (Sayed-Ahmad et al. 2017). Coriander and parsley are excellent sources of vitamins (particularly vitamin C, vitamin K, and provitamin A), minerals, dietary fiber, and bioactive phytochemicals such as flavonoids, phenolic acids, and essential oils (Agyare et al. 2017; Chandana et al. 2025). These compounds contribute to their antioxidant, antimicrobial, anti-inflammatory, and diuretic activities, thereby enhancing their importance in human health and nutrition. In recent years, the demand for these fresh herbs has increased substantially due to the growing consumer preference for healthy, natural, and minimally processed foods, as well as the expansion of the global herb and spice market (Ramadan 2023). The production of high-quality leafy vegetables and herbs depends on a multitude of factors, including genetic potential, environmental conditions, and agricultural management practices (Abolghasemi and Saeidi Goraganib 2024; Gruda et al. 2025). Among these, plant nutrition and the application of biologically active substances have received considerable attention as strategies to enhance crop growth, yield, and quality while reducing reliance on synthetic chemical inputs (Rezaei and Erfani Moghadam 2025). In this context, biostimulants have emerged as promising tools for sustainable agriculture. Biostimulants are defined as substances or microorganisms that, when applied to plants or the rhizosphere, stimulate natural processes to enhance nutrient uptake, nutrient efficiency, tolerance to abiotic stress, and crop quality (du Jardin 2015). Unlike traditional fertilizers, biostimulants do not directly supply nutrients in significant amounts; rather, they modulate plant physiological and biochemical processes to promote growth and development (Calvo et al. 2014). The use of biostimulants aligns with the principles of sustainable agriculture and integrated crop management, as they can improve productivity while minimizing environmental impact.

Among the diverse array of biostimulants, *Trichoderma* spp. and seaweed extracts have attracted particular interest from researchers and growers due to their multifaceted beneficial effects on plants. *Trichoderma* is a genus of free-living, avirulent, and opportunistic filamentous fungi that are commonly found in soils and root ecosystems. Certain *Trichoderma* species, such as *T. harzianum*, *T. viride*, *T. asperellum*, and *T. virens*, are well-known as biocontrol agents against a wide range of soilborne plant pathogens, including *Fusarium*, *Rhizoctonia*, *Pythium*, and *Sclerotium* species (Harman et al. 2004). However, in addition to their antagonistic properties, *Trichoderma* spp. are also recognized as plant growth-promoting fungi (PGPF) that can directly stimulate plant growth and development. The mechanisms underlying this growth promotion include the production of plant growth regulators (e.g., auxins, cytokinins, and gibberellins), solubilization of soil nutrients (e.g., phosphorus, potassium, and micronutrients), enhancement of root development and architecture, and induction of systemic resistance against biotic and abiotic stresses (Jiménez Bremont et al. 2026). Furthermore, *Trichoderma* can colonize plant roots and establish beneficial symbiotic associations that improve nutrient uptake and water use efficiency, thereby enhancing plant vigor and productivity (Mondal et al. 2026).

Seaweed extracts are complex mixtures of bioactive compounds derived from various marine macroalgae, including brown algae (*Ascophyllum nodosum*, *Laminaria* spp., *Fucus* spp.), red algae (*Kappaphycus* spp., *Gracilaria* spp.), and green algae (*Ulva* spp.). These extracts are rich in plant growth regulators (auxins, cytokinins, gibberellins, abscisic acid, and ethylene), polysaccharides (alginate, carrageenan, fucoidan, and laminarin), betaines, amino acids, vitamins, and mineral nutrients (Khan et al. 2009; Ertani et al. 2018). The application of seaweed extracts has been reported to stimulate seed germination, root and shoot growth, chlorophyll synthesis, photosynthesis, and flowering, as well as to improve tolerance to abiotic stresses such as drought, salinity, and extreme temperatures (Battacharyya et al. 2015; El Boukhari et al. 2020). These beneficial effects are attributed to the synergistic action of the diverse bioactive compounds present in seaweed extracts, which can modulate endogenous hormone levels, enhance nutrient uptake and assimilation, and activate antioxidant defense systems (Khan et al. 2009). *Trichoderma* primarily influences the rhizosphere and root system, while seaweed extracts are typically applied to the foliage and act on above-ground plant parts. This complementarity suggests that their combined application may produce synergistic or additive effects. Although the individual effects of *Trichoderma* and seaweed extracts on various crops have been extensively documented, there is limited information regarding their combined application, particularly on leafy vegetables and herbs such as coriander and parsley. The interaction between microbial biostimulants and seaweed-based biostimulants may lead to synergistic or additive effects on plant growth and yield, as they act through different but complementary mechanisms. For instance, soil incubation with *Trichoderma* may enhance root development and nutrient solubilization, thereby improving the uptake of nutrients that are essential for the growth-promoting effects of seaweed extracts. Conversely, foliar application of seaweed extracts may provide growth-promoting hormones and stress-protective compounds that could enhance the establishment and efficacy of *Trichoderma* in the rhizosphere. Therefore, investigating the combined application of these biostimulants is of significant interest for developing integrated and sustainable crop management strategies. Therefore, the present study was conducted to evaluate the effects of *Trichoderma* and seaweed biostimulant applications, individually and in combination, on the morphological characteristics of coriander and parsley under a soil cultivation system.

2. Materials and Methods

2.1. Experimental Site and Design

This experiment was conducted during the winter and spring seasons of 2024 in the research greenhouse of the Department of Horticultural Science and Engineering at Arak University (latitude 34°04'48"N, longitude 49°40'38"E, altitude 1700 m). A factorial experiment based on a randomized complete block design (RCBD) with two factors and three replications (blocks) was employed. Each experimental unit consisted of a soil plot (1.0 m × 1.0 m) containing 18 plants established at a uniform spacing. Treatments were applied to whole plots, and the plot was the experimental unit for statistical analysis. Each treatment combination was replicated three times, resulting in a total of 12 plots per plant species. The experimental factors consisted of two *Trichoderma* levels (inoculated soil at a concentration of 500 mg/L and non-inoculated control) and two seaweed-extract levels (foliar application of *Ascophyllum nodosum* extract at a concentration of 1 g/L and distilled-water control). Thus, four treatment combinations were assessed for each plant species: (1) Control (neither *Trichoderma* nor seaweed), (2) foliar application of seaweed extract alone, (3) soil inoculation with *Trichoderma* alone, and (4) combined application of *Trichoderma* and seaweed extract.

2.2 Plant Material and Cultivation

Seeds of coriander (*Coriandrum sativum* L.) and parsley (*Petroselinum crispum* Mill.) were obtained from Sina Bazr Alvand Company and sown at a depth of 5 cm in seedling trays. A 1:1 mixture of cocopeat and perlite was used as the growing substrate. At the three-leaf stage, the seedlings were carefully removed from the trays and transferred to soil plots with sandy loam soil (pH 7.15, organic matter 2.27%, EC 0.5 dS/m) and sufficient natural light. Before planting, base fertilizer consisting of 40 kg N/ha (as urea), 52 kg P_2O_5/ha (as superphosphate), and 65 kg K_2O/ha (as potassium sulfate) was thoroughly mixed with the soil. Depending on the plant growth stage, modified Hoagland solution was used for supplementary nutrition. The greenhouse temperature was maintained at 25–30 °C during the day and 20–25 °C at night. Pests and diseases were controlled optimally throughout the growing season.

2.3. Treatment Application

The commercial seaweed extract (*Ascophyllum nodosum* extract; Algea AS, Kristiansund, Norway), supplied by Baharan Company (Isfahan, Iran), was used without further modification. The seaweed extract solution was prepared at a concentration of 1 g L^{-1}. Foliar applications were performed at 7-day intervals, with a total of four applications before harvest. The solution was uniformly sprayed onto both the upper and lower surfaces of the leaves using a handheld sprayer until runoff. The *Trichoderma* treatment consisted of Trichorun P, a commercial biofertilizer containing *Trichoderma harzianum* (10^7 propagules g^{-1}), supplied by Biorun Company (Karaj, Iran). Soil inoculation was performed at a concentration of 500 mg L^{-1}, with two applications: one at the time of plant transfer to soil and another at the mid-cultivation stage.

2.4. Morphological growth parameters

At the end of the experimental period, six plants were randomly selected from each plot for morphological measurements. Each of the six plants was measured individually for plant length, shoot volume, number of leaves, shoot fresh mass, shoot dry mass, and dry matter percentage. The mean of the six plants was then calculated and used as the value of that experimental unit for statistical analysis. Plant length was measured from the soil surface to the tip of the longest leaf, using a graduated metal ruler. Shoot fresh mass was determined using a digital balance with a precision of 0.001 g. The volumes of fresh shoots were determined using the water displacement method with a 100 mL graduated cylinder (precision: ±1 mL). To determine dry weight, plant tissues were dried at 65°C for 72 hours until constant weight was reached. Dry matter percentage was calculated using the following formula: Dry matter (%) = (Dry weight / Fresh weight) × 100.

2.5. Statistical Analysis

Data were analyzed using Minitab 17 software. Data normality and variance homogeneity were checked prior to analysis. The experiment was arranged as a 2×2 factorial in a randomized complete block design (RCBD) with three replications (blocks). Within each experimental unit (treatment × block combination), six plants were measured individually, and their mean was used as the value of that experimental unit for statistical analysis. Significant differences among treatment means ($p < 0.05$) as identified by ANOVA were further separated using Tukey's HSD test. Principal Component Analysis (PCA) was conducted using Origin Pro 2024 on standardized data.

3. Results

3.1. Main Effects of *Trichoderma* and Seaweed treatments on Growth Parameters of Coriander

The main effects of *Trichoderma* and seaweed treatments on coriander growth parameters are presented in Table 1. *Trichoderma* application significantly (P ≤ 0.05) increased plant length (+12.7%), plant volume (+34.9%), leaf number (+24.0%), plant fresh mass (+48.2%), and plant dry mass (+39.3%) compared to the control. However, dry matter percentage was not significantly affected by *Trichoderma* application. Foliar application of seaweed significantly increased plant volume (+28.7%), leaf number (+24.4%), plant fresh mass (+38.2%), and plant dry mass (+34.5%) compared to the control. Plant length was not significantly affected by seaweed foliar application (36.6 cm vs. 35.4 cm), nor was dry matter percentage (10.8% vs. 11.2%).

Table 1. Main effects of *Trichoderma* and Seaweed treatments on growth parameters of Coriander.

Treatment	PL (cm)	PV (cm^3)	LN	PFM (g)	PDM (g)	DM (%)
Control	33.8 b	31.8 b	26.3 b	24.9 b	2.8 b	11.3 a
Trichoderma	38.1 a	42.9 a	32.6 a	36.9 a	3.9 a	10.9 a
Pr > F	0.004	0.000	0.001	< 0/0001	< 0/0001	0.141
Significant	Yes	Yes	Yes	Yes	Yes	No
Control	35.4 a	32.7 b	26.2 b	25.9 b	2.9 b	11.2 a
Seaweed	36.6 a	42.1 a	32.6 a	35.8 a	3.9 a	10.8 a
Pr > F	0.401	0.002	0.001	< 0/0001	< 0/0001	0.183
Significant	No	Yes	Yes	Yes	Yes	No

Within columns and for each treatment, means with the same letters do not differ at the 0.05 significance level. Plant length (PL), Plant volume (PV), Leaf number (LN),Plant fresh mass (PFM), Plant dry mass (PDM), Dry matter (DM).

3.2. Interaction Effects of *Trichoderma* and Seaweed treatments on Growth Parameters of Coriander

The interaction effects of *Trichoderma* and seaweed treatments on coriander growth parameters are shown in Table 2. The interaction was significant for leaf number, plant fresh mass, and plant dry mass, but not for plant length, plant volume, or dry matter percentage. The highest values for leaf number (38.0), plant fresh mass (44.9 g), and plant dry mass (4.7 g) were observed in the combined application of *Trichoderma* + Seaweed, which were significantly higher than all other treatments. The control treatment generally produced the lowest values for these parameters. For plant length and plant volume, although the interaction was not significant, the highest numerical values were also recorded in the *Trichoderma* + Seaweed treatment (37.7 cm and 49.7 cm^3, respectively).

Table 2. Interaction effects of *Trichoderma* and Seaweed treatments on growth parameters of Coriander.

Trichoderma	Seaweed	PL (cm)	PV (cm^3)	LN	PFM (g)	PDM (g)	DM (%)
Control	Control	32.3 b	29.2 b	25.3 b	23.1 c	2.6 b	11.5 a
	Seaweed	35.4 ab	34.4 b	27.2 b	26.8 bc	2.9 b	11.1 a
Trichoderma	Control	38.5 a	36.1 b	27.1 b	28.9 b	3.2 b	11.1 a
	Seaweed	37.7 a	49.7 a	38.0 a	44.9 a	4.7 a	10.6 a
Pr > F		0.166	0.138	0.011	0.002	0.005	0.919
Significant		No	No	Yes	Yes	Yes	No

Within columns and for each treatment, means with the same letters do not differ at the 0.05 significance level. Plant length (PL), Plant volume (PV), Leaf number (LN), Plant fresh mass (PFM), Plant dry mass (PDM), Dry matter (DM).

3.3. Main Effects of *Trichoderma* and Seaweed treatments on Growth Parameters of Parsley

The main effects of *Trichoderma* and seaweed treatments on parsley growth parameters are presented in Table 3. *Trichoderma* application significantly increased plant length (+13.0%), plant volume (+34.0%), plant fresh mass (+33.8%), and plant dry mass (+25.5%), while significantly decreasing dry matter percentage

(−8.0%) compared to the control. Leaf number was not significantly affected by *Trichoderma* application. Foliar application of seaweed significantly increased only plant length (+6.1%) compared to the control. Other parameters, including plant volume, leaf number, plant fresh mass, plant dry mass and dry matter percentage, were not significantly affected by seaweed foliar application.

Table 3. Main effects of *Trichoderma* and Seaweed treatments on growth parameters of Parsley.

Treatment	PL (cm)	PV (cm^3)	LN	PFM (g)	PDM (g)	DM (%)
Control	40.9 b	47.4 b	32.1 a	38.2 b	4.7 b	12.5 a
Trichoderma	46.2 a	63.5 a	34.1 a	51.1 a	5.9 a	11.5 b
Pr > F	0.000	0.000	0.064	0.001	0.011	0.005
Significant	Yes	Yes	No	Yes	Yes	Yes
Control	42.3 b	53.9 a	33.0 a	43.9 a	5.2 a	12.1 a
Seaweed	44.9 a	56.8 a	33.3 a	45.4 a	5.3a	11.9 a
Pr > F	0.044	0.485	0.809	0.684	0.748	0.473
Significant	Yes	No	No	No	No	No

Within columns and for each treatment, means with the same letters do not differ at the 0.05 significance level. Plant length (PL), Plant volume (PV), Leaf number (LN), Plant fresh mass (PFM), Plant dry mass (PDM), Dry matter (DM).

3.4. Interaction Effects of *Trichoderma* and Seaweed treatments on Growth Parameters of Parsley

The interaction effects of *Trichoderma* and seaweed treatments on parsley growth parameters are shown in Table 4. The interaction was significant only for dry matter percentage. For all other parameters, including plant length, plant volume, leaf number, plant fresh mass, and plant dry mass, the interaction was not significant. For dry matter percentage, the highest value (13.0%) was observed in the control treatment, while the lowest value (11.2%) was recorded in the *Trichoderma* only treatment. The *Trichoderma* + Seaweed treatment resulted in a dry matter percentage of 11.9%, which was not significantly different from the control or the seaweed only treatment (11.9%).

Table 4. Interaction effects of *Trichoderma* and Seaweed treatments on growth parameters of Parsley.

Trichoderma	Seaweed	PL (cm)	PV (cm^3)	LN	PFM (g)	PDM (g)	DM (%)
Control	Control	39.0 b	46.2 b	31.2 a	37.2 b	4.8 a	13.0 a
	Seaweed	42.9 ab	48.5 b	33.1 a	39.2 ab	4.6 a	11.9 ab
Trichoderma	Control	45.6 a	61.7 ab	34.8 a	50.6 ab	5.7 a	11.2 b
	Seaweed	46.8 a	65.3 a	33.4 a	51.5 a	6.1 a	11.9 ab
Pr > F		0.273	0.880	0.109	0.896	0.542	0.006
Significant		No	No	No	No	No	Yes

Within columns and for each treatment, means with the same letters do not differ at the 0.05 significance level. Plant length (PL), Plant volume (PV), Leaf number (LN), Plant fresh mass (PFM), Plant dry mass (PDM), Dry matter (DM).

3.5. Principal Component Analysis

Principal component analysis (PCA) was performed separately for coriander and parsley (Figure 1). For coriander, the first two principal components (PC1 and PC2) explained 89.61% and 9.94% of the total variance, respectively, cumulatively accounting for 99.55% of the variation in the data (Figure 1, left). PC1 was strongly and positively associated with plant volume, plant fresh mass, plant dry mass, leaf number, and plant length, while it was strongly negatively associated with dry matter percentage. This indicates that PC1 primarily represents the overall vegetative growth and biomass accumulation dimension, with high PC1 scores corresponding to plants with greater size, higher biomass, and lower dry matter concentration. PC2 was mainly influenced by plant length and, to a lesser extent, by leaf number and plant dry mass. The score plot for coriander clearly separated the four treatment combinations along PC1. The control and seaweed-treatments were located on the negative side of PC1, indicating lower overall growth performance, with the control treatment showing the lowest PC1 score and the highest DW% (as indicated by its position in the upper-left quadrant). In contrast, the *Trichoderma* and *Trichoderma* + Seaweed treatments were positioned on the positive side of PC1, reflecting superior growth performance. Notably, the *Trichoderma* + Seaweed treatment occupied the most extreme positive position along PC1, confirming that the combined application of both biostimulants produced the greatest overall improvement in coriander growth parameters, including plant volume, leaf number, fresh mass, and dry mass. The foliar application of seaweed treatment was intermediate between the control and *Trichoderma* treatments, consistent with the significant but less pronounced effects of seaweed application observed in the univariate analysis. The negative loading of DW% on PC1 further supports the finding that biostimulant-treated plants, particularly those receiving the combined treatment, exhibited greater biomass accumulation with a relatively lower dry matter percentage, likely due to enhanced water uptake and cell expansion.

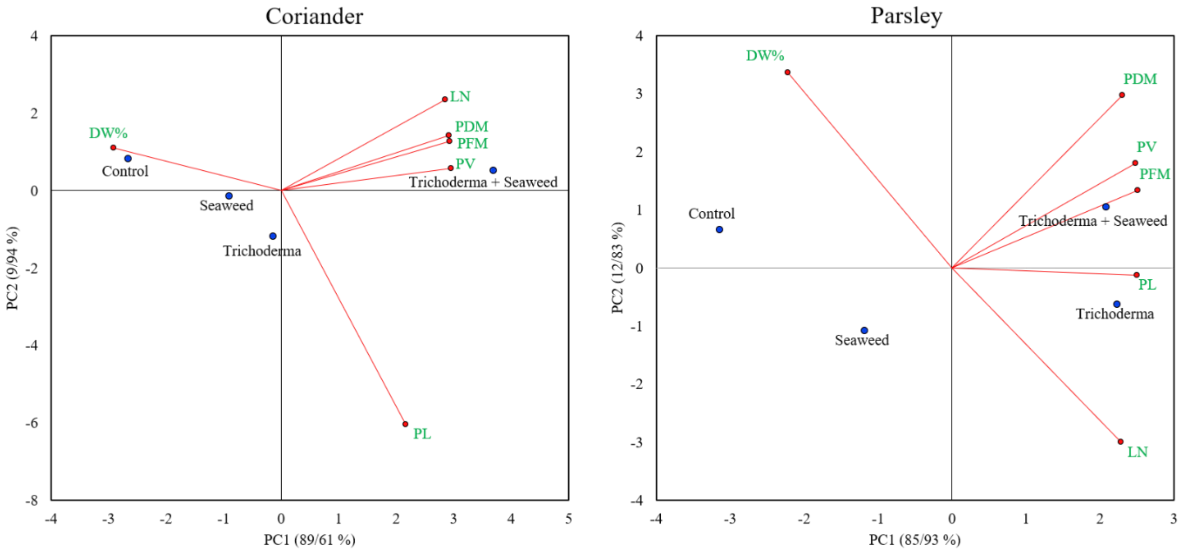

Figure 1. Biplot of principal component analysis (PCA) based on the studied traits in coriander and parsley plants. Plant length (PL), Plant volume (PV), Leaf number (LN), Plant fresh mass (PFM), Plant dry mass (PDM) and Dry matter percentage (DW%). Green vectors represent the studied traits, and their direction and length reflect their loading on the principal components (PC1 and PC2).

For parsley, PC1 and PC2 explained 85.93% and 12.83% of the total variance, respectively, cumulatively accounting for 98.76% of the variation (Figure 1, right). PC1 was strongly and positively loaded by plant fresh mass, plant length, plant volume, plant dry mass, and leaf number, while it was negatively loaded by dry matter percentage. Similar to coriander, PC1 for parsley represents a general growth and biomass accumulation axis. PC2 was primarily influenced by dry matter percentage, plant dry mass, and leaf number. The score plot for parsley revealed a clear separation of treatments along PC1. The control and foliar application of seaweed treatments were located on the negative side of PC1. The *Trichoderma* and *Trichoderma* + Seaweed treatments were positioned on the positive side of PC1, with the combined treatment showing the highest PC1 score. This indicates that *Trichoderma* application, either alone or in combination with seaweed, was the primary driver of improved growth in parsley, enhancing plant length, volume, fresh mass, dry mass, and leaf number. The foliar application of seaweed treatment, in contrast, did not substantially improve overall growth compared to the control, which is consistent with the univariate results showing that seaweed application significantly increased only plant length in parsley. The position of the control treatment in the upper-left quadrant, associated with higher DW%, indicates that untreated parsley plants had higher dry matter concentration but lower overall biomass, while biostimulant-treated plants exhibited greater biomass accumulation with lower dry matter percentage, similar to the pattern observed in coriander.

4. Discussion

The findings of this study indicate that biostimulant applications, specifically *Trichoderma* soil inoculation and seaweed extract foliar spraying, significantly enhanced the morphological characteristics of coriander and parsley under soil cultivation conditions. The positive effects of *Trichoderma* on plant growth parameters are consistent with previous studies reporting that *Trichoderma spp.* can enhance plant growth through various mechanisms, including increased nutrient uptake, production of plant growth-promoting substances, and induction of systemic resistance (Mehetre and Mukherjee 2015; Asghar et al. 2024). In coriander, *Trichoderma* application significantly increased plant length, volume, leaf number, fresh mass, and dry mass, indicating a comprehensive growth-promoting effect. Similar results were observed in parsley, where *Trichoderma* significantly improved plant length, volume, fresh mass, and dry mass (Barroso et al. 2019;

Staropoli et al. 2021). Seaweed extracts are known to contain various bioactive compounds, including cytokinins, auxins, abscisic acid, gibberellins, and betaines, which can stimulate plant growth and development (Ali et al. 2021; Mughunth et al. 2024). In this study, seaweed foliar application significantly improved plant volume, leaf number, fresh mass, and dry mass in coriander, but only plant length in parsley. The differential response between the two species may be attributed to species-specific sensitivity to the bioactive compounds present in the seaweed extract or differences in uptake and translocation efficiency.

The interaction between *Trichoderma* and seaweed was significant for leaf number, fresh mass, and dry mass in coriander, with the combined application producing the highest values. This suggests a synergistic effect between the two biostimulants, potentially due to complementary mechanisms of action. *Trichoderma* may enhance root development and nutrient uptake, while foliar application of seaweed extract may provide growth-promoting hormones and improve stress tolerance, together leading to improved growth and productivity (Mughunth et al. 2024; Jiménez Bremont et al. 2026). In parsley, however, the interaction was only significant for dry matter percentage, indicating that the combined application did not provide additional benefits over individual applications for most growth parameters. The reduction in dry matter percentage in parsley with *Trichoderma* application, and in the *Trichoderma* + Seaweed treatment compared to the control, suggests that biostimulant application may lead to increased water content in plant tissues. This could be due to enhanced water uptake and cell expansion, which is consistent with the observed increases in plant fresh mass and volume. However, the lack of significant effects on dry matter percentage in coriander indicates that the increase in dry mass was proportional to the increase in fresh mass, maintaining a stable dry matter percentage.

The PCA results provide a comprehensive and integrated view of the effects of *Trichoderma* and seaweed biostimulants on the morphological characteristics of coriander and parsley, corroborating and extending the findings of the univariate analyses. The clear separation of treatments along PC1 in both species demonstrates that biostimulant application, particularly *Trichoderma* alone or in combination with seaweed, was the dominant factor influencing overall plant growth and biomass accumulation. The strong positive loadings of most growth parameters on PC1 indicate that these parameters were highly correlated and responded coordinately to biostimulant treatments, reflecting a general enhancement of vegetative growth and productivity. The negative association between DW% and the other growth parameters on PC1 in both species suggests that biostimulant-treated plants tended to accumulate fresh biomass with a relatively lower dry matter concentration. This pattern is consistent with the observed increases in plant fresh mass and volume, which may result from enhanced water uptake, cell expansion, and tissue hydration following biostimulant application. Similar findings have been reported in other studies, where biostimulant treatments increased fresh biomass and water content while reducing dry matter percentage (Consentino et al. 2026). The reduction in dry matter percentage may also reflect a shift in biomass allocation toward less dense tissues, such as leaves and stems, which are the economically important parts of coriander and parsley.

Conclusions

The present study demonstrates that *Trichoderma* and seaweed biostimulants can effectively enhance the morphological characteristics of coriander and parsley under soil cultivation systems. For coriander, both *Trichoderma* and seaweed applications significantly improved most growth parameters, and their combined application showed synergistic effects on leaf number, plant fresh mass, and plant dry mass. For parsley, *Trichoderma* application provided the most consistent benefits, significantly improving plant length, volume, fresh mass, and dry mass, while seaweed application alone only improved plant length. The interaction between the two biostimulants was significant only for dry matter percentage in parsley. Principal component analysis confirmed these findings, with the combined application of Trichoderma + Seaweed producing the greatest overall improvement in coriander, while Trichoderma alone was the primary driver of growth enhancement in parsley. Based on these findings, it is recommended that *Trichoderma* and seaweed biostimulants be used, either individually or in combination, to improve the growth and productivity of coriander and parsley under soil cultivation conditions. However, further studies are needed to elucidate the underlying mechanisms of the observed synergistic effects and to optimize application rates and timing for different plant species and environmental conditions.

Data Availability Statement: The authors declare that data supporting the findings of this study are available in the article. If raw data files are required, they are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

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