Growth response of coastal hibiscus (*Hibiscus tiliaceus*) seedlings to zeolite and glutamine under water stress

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Abstract
Water stress is one of the most prominent environmental factors negatively impacting plant growth and represents a significant challenge in areas with limited water resources. Therefore, this study aimed to explore the impact of water stress on the growth of coastal hibiscus seedlings and the role of zeolite and glutamine in mitigating it. A pot experiment was conducted during the spring season of 2024 according to a split-split-plot design with three replicates. The study included two levels of water stress (50% and 100% of field capacity), adding zeolite (0, 500, and 1000 g pot^{-1}) and spraying with glutamine (0, 150, and 300 mg L^{-1}). The results showed an apparent decrease in the studied traits (percentage increase in plant height, percentage increase in stem diameter, percentage increase in number of leaves, leaf area, percentage of dry matter) in plants stressed by (50% of field capacity) with decreased percentages of (6.33%, 2.80%, 7.10%, 2.68%, and 11.69%), respectively, compared to non-stressed plants. The results also demonstrated the effective role of the studied factors in mitigating the effects of water stress. Both zeolite and glutamine, either individually or in combination, contributed to reducing the resulting damage when applied to plants exposed to water stress at 50% of the field capacity. The results showed that growth rates were higher or similar to those recorded in non-stressed plants, which reinforces the role of these vital factors in improving the ability of plants to withstand water stress conditions.
Keywords amino acids, Malvaceae, natural mineral, field capacity,

Introduction
Hibiscus tiliaceus L. is a shrubby plant belonging to the Malvaceae family [1]. It is an evergreen tree that grows 3–10 m tall and is native to tropical, coastal, and subtropical regions such as the Americas, Australia, Africa, Asia, and all Pacific islands. Its leaves are heart-shaped and spirally arranged on the stem [2]. In addition to its use as an ornamental plant in landscaping, this plant has significant medicinal importance due to its content of a group of active chemical compounds that contribute to exerting antimicrobial effects, enhancing its vital role in both agriculture and public health [3, 4]. The plant's leaves have been used in Indonesian and Malaysian folk medicine to

remove phlegm, cleanse the respiratory system, and treat fever, cough, and bronchitis in Asian and African countries [5].

Water stress is one of the most important obstacles affecting plant growth, as it leads to an increase in the ratio of roots to the vegetative part, an increase in the amount of lignin and cutin, and a decrease in leaf area [6]. It also leads to the closure of stomata, which leads to a decrease in the rate of photosynthesis and an increase in respiration, which reduces the net biosynthesis [7]. This calls for the search for sustainable solutions to mitigate the effects of water stress. Among these solutions, the role of zeolite stone stands out as an effective natural medium in improving soil properties, enhancing its water retention capacity, and enhancing the efficiency of water resource use. Zeolite is a unique natural mineral, consisting of crystalline aluminum silicates with a distinctive oxide structure. These minerals are formed from tetrahedral units, with the oxide bonded to the tetragonal faces of $AlO4$ and $SiO4$, creating unique voids containing channels that play a key role in chemical and water processes. Therefore, studies have shown that adding zeolite to dry and stressed areas improves the physical properties of the soil, increasing its water and nutrient retention, as its water absorption capacity reaches 100% with slow nutrient release [8,9].

Glutamine is one of the essential amino acids in plants and plays a pivotal role in the biosynthetic pathways of proline, which contributes to enhancing plant resistance to water stress by regulating osmotic balance and maintaining plant cell stability. This reinforces the importance of glutamine in supporting the physiological adaptation mechanisms of plants under drought conditions [10], as proline is an important amino acid that acts as an antioxidant, removing reactive oxygen species (ROS), reducing oxidative damage in plants, and protecting cellular components from damage caused by stress [11]. Several studies have indicated the positive effect of adding glutamic acid on photosynthetic activity and leaf function, as assessed by measuring chlorophyll content [12]. This effect is likely attributed to the close relationship between photosynthetic capacity and nitrogen concentration in leaves. Some studies have also shown that glutamic acid contributes to the stimulation of transcription factors that activate genes responsible for protein expression, helping plants survive under abiotic stress conditions [13].

Coastal hibiscus shrubs are newly cultivated and widespread in Iraq. Due to the lack of studies on this plant, this study aims to identify the nature of seedling growth under water stress and to study the effect of adding zeolite and spraying glutamine on vegetative growth characteristics under the same stress conditions.

Materials and Methods

The experiment was conducted on 6-month-old coastal hibiscus seedlings, obtained by cuttings, during the period from 15/3/2024 to 15/10/2024 in the green Saran shade of the Horticulture and Landscape Department at the College of Agriculture / University of Kerbala in Al-Hussainiya District/ Kerbala/ Iraq. The study was carried out according to a split-split plot design with three replicates, where the water stress treatment was placed in the main plots, while the secondary plots included the zeolite and glutamine treatments. Each replicate contained 18 treatments resulting from three levels of zeolite (0, 500, and 1000 g pot^{-1}), three concentrations of the amino acid glutamine (0, 150, and 300 mg L^{-1}), and two levels of water stress (50% and 100% of field capacity). The experiment included 54 experimental units, which contained five observations (seedlings), so the number of seedlings used in the study was 270. Zeolite was added to the soil when the seedlings were transferred from the planting bags to pots containing 10 kg of soil. The amino acid glutamine was sprayed six times, two weeks after the transfer, with 15 days between each spray. Water stress was applied one month after the seedlings were transferred. After the experiment was completed, the following vegetative characteristics were taken average increase in plant height (cm), stem diameter (mm), number of leaves (leaf plant^{-1}), as well as leaf area (cm^2 leaf^{-1}) (using the Image J program in Windows 7 operating system) [14], and percentage of dry matter.

Table (1): The effect of zeolite and glutamine on the percentage of increase in the height of coastal hibiscus seedlings under water stress (cm)

Stress level (Field capacity %)	Zeolite level (g pot^{-1})	Glutamine concentration (mg L^{-1})			Stress and Zeolite interaction
		0	150	300	
50	0	68.88	70.88	73.41	75.39
	500	76.68	80.35	82.15	77.84
	1000	80.61	82.28	84.41	79.99
100	0	72.48	74.41	76.08	77.92
	500	82.68	87.18	89.48	84.36
	1000	78.61	91.48	94.61	86.72
L.S.D $_{0.05}$		2.687			1.881
Glutamine averages		72.69	83.09	85.34	Stress averages
L.S.D $_{0.05}$		0.741			
Stress and Glutamine Interaction					
50 %		71.06	79.72	82.44	77.74
100 %		74.32	86.45	88.24	83.00
L.S.D $_{0.05}$		1.802			2.325
Zeolite and Glutamine Interaction					Zeolite averages
0		70.68	72.65	74.75	76.66
500		79.68	83.76	85.81	81.10
1000		79.61	86.88	89.51	83.36
L.S.D $_{0.05}$		1.759			1.166

Results and Discussion

Average increase in seedling height (cm)

Table (1) shows that the percentage of plant height increase in non-stressed plants (100% of field capacity) reached 83.00 cm, while it decreased to 77.74 cm in stressed plants (50% of field capacity), with a decrease of 6.33%. The same table shows that not adding zeolite recorded the lowest average increase in height, amounting to (76.66 cm), while adding (1000 g pot^{-1}) zeolite gave the highest increase, amounting to (83.36 cm), with an increase rate of (8.73%). The results also indicate a significant effect of glutamine, as the treatment (300 mg L^{-1}) had the highest average increase in length, reaching (85.34 cm), with an increase rate of (17.40%), compared to the comparison treatment, which gave the lowest average, reaching (72.69 cm).

It is noted from the same table that the two-way interaction between the studied factors was significant, as the unstressed seedlings with the addition of (1000 g pot^{-1}) of zeolite achieved the highest values for the percentage of increase in plant height, which amounted to (86.72 cm) compared to the interaction treatment between stressed plants at a rate of (50% of the field capacity) without adding zeolite, which gave the lowest value, which amounted to (75.39 cm). It is also noted from the same table that the treatment of plants that were not exposed to stress with spraying (300 mg L^{-1}) of glutamine achieved an average increase of (88.24 cm), while the lowest value was at a concentration of (0 mg L^{-1}) with stressed plants at a rate of (50% of the field capacity) of (71.06 cm). As for the binary interaction between zeolite and glutamine, the zeolite treatment at the level of (1000 g pot^{-1}) and glutamine at a concentration of (300 mg L^{-1}) achieved the highest average of (89.51 cm) compared to the comparison treatment, which recorded an average of (70.68 cm).

As for the triple interaction of the studied factors, it was found that the interaction of the field capacity value (100%) with the level (1000 g pot^{-1}) of zeolite and the concentration (300 mg L^{-1}) of glutamine achieved the highest significant increase in this trait with an average of (94.61 cm), while the lowest increase in plant height was in the treatment (50% of the field capacity value) with the level (0 g pot^{-1}) of zeolite and the concentration (0 mg L^{-1}) of glutamine, which reached (68.88 cm).

Average increase in primary stem diameter (mm)

Table (2) shows significant differences in the stem diameter of coastal hibiscus seedlings as a result of the study factors. Plants that were not exposed to stress (100% of the field capacity) recorded an average increase in the primary stem diameter of 5.558 mm, while stressed plants (50% of the field capacity) recorded the lowest average increase of 5.402 mm with a decrease rate of 2.80%. Also, the zeolite treatment at the level (1000 g pot^{-1}) achieved the highest average of (5.677 mm), while it was noted that not adding zeolite led to recording the lowest average of (5.267 mm) with an increase rate of (7.78%). As for the glutamine treatment, spraying the concentration (300 mg L^{-1}) gave the highest average increase in stem diameter of (6.047 mm) with an increase rate of (27.09%), compared to the control treatment, which recorded the lowest average of (4.758 mm).

The results also showed that the two-way interaction between the studied factors was significant, as the best average increase in seedling stem diameter was achieved when the treatment of non-stressed plants was interacted with the zeolite treatment at a level of (1000 g pot^{-1}) which gave (5.761 mm) compared to the treatment of stressed plants with a level of (0 g pot^{-1}) zeolite which gave an average increase of (5.222 mm) (Table 2). The same table also shows that the treatment of non-stressed plants with a concentration of (300 mg L^{-1}) glutamine gave the highest stem diameter of (6.112 mm), while the lowest diameter was achieved in the water stress treatment (50% of field capacity) with a concentration of (0 mg L^{-1}), which reached (4.710 mm).

The data of the same table showed that the interaction between zeolite and glutamine had a significant effect on the stem diameter trait, as the interaction treatment between zeolite at a level of (1000 g pot^{-1}) and glutamine at a concentration of (300 mg L^{-1}) achieved the highest average of (6.148 mm) compared to the comparison treatment, which gave the lowest average of (4.616 mm).

From the results of the triple interaction of the studied factors, a significant difference was observed in the stem diameter trait. The triple interaction treatment between water stress, zeolite and glutamine recorded the highest average of (6.251 mm) when treating non-stressed plants from the field capacity with the level (1000 g pot^{-1}) of zeolite and the concentration (300 mg L^{-1}) of glutamine, while the lowest average was achieved when plants exposed to stress were not treated with zeolite and glutamine, as it reached (4.599 mm).

Table (2): Effect of zeolite and glutamine on the average increase in the diameter of the main stem (mm) of coastal hibiscus seedlings under water stress

Stress level (Field capacity %)	**Zeolite level (g pot^{-1})**	**Glutamine concentration (mg L^{-1})**			**Stress and Zeolite interaction**
		0	**150**	**300**	
50	0	4.599	4.661	4.871	5.222
	500	5.083	5.591	5.866	5.388
	1000	5.985	5.913	6.045	5.594
100	0	4.634	4.981	4.802	5.312
	500	5.312	5.911	6.050	5.603
	1000	5.989	6.096	6.251	5.761
L.S.D $_{0.05}$		0.202			0.123
Glutamine averages		4.758	5.635	6.047	
L.S.D $_{0.05}$		0.060			
Stress and Glutamine Interaction					Stress averages
50 %		4.710	5.514	5.981	5.402
100 %		4.806	5.757	6.112	5.558
L.S.D $_{0.05}$		0.097			0.121

Zeolite and Glutamine Interaction				Zeolite averages
0	4.616	4.731	4.926	5.267
500	5.197	5.751	5.958	5.496
1000	5.987	6.004	6.148	5.677
L.S.D $_{0.05}$	0.140			0.093

Average increase in the number of leaves (leaves plant^{-1})

It is clear from Table (3) that the water stress treatment (50% of the field capacity) caused a significant decrease in the average increase in the number of leaves in the plant, with a decrease rate of (7.10%), as the non-stressed plants (100% of the field capacity) gave an average of (33.77 leaves plant^{-1}), while the average decreased to (31.37 leaves plant^{-1}) in the stressed plants. As for the zeolite treatment, it led to a significant increase in the above trait, as the seedlings treated at the level (1000 g pot^{-1}) achieved the highest average number of leaves, which amounted to (34.80 leaves plant^{-1}) and an increase rate of (18.16%), while the treatment without addition achieved (29.45 leaves plant^{-1}). The results also indicated the effect of glutamine, as the treatment with a concentration of (300 mg L^{-1}) was superior and gave the highest average, which amounted to (35.07 leaves plant^{-1}) and an increase rate of (19.04%) compared to the comparison treatment, which recorded the lowest average, which amounted to (29.46 leaves plant^{-1}).

From the same table, it is noted that the two-way interaction between the studied factors was significant and that the best seedlings in terms of the increase in the number of leaves were when the treatment of unstressed plants was interacted with the treatment (1000 g pot^{-1}) zeolite, which gave the highest values in the studied trait, reaching (36.51 leaves plant^{-1}), while the interaction treatment between (50% of the field capacity) with the level (0 g pot^{-1}) zeolite recorded a low value with an average of (28.98 leaves plant^{-1}). It is also noted from the same table that the treatment of unstressed plants with a concentration of (300 mg L^{-1}) glutamine was superior, with an average of (35.33 leaves plant^{-1}) in the above trait, while the plants that were treated with a ratio of (50% of the field capacity) with a concentration of (0 mg L^{-1}) glutamine gave an average of (28.00 leaves plant^{-1}). The same table also indicates that the two-way interaction between zeolite and glutamine led to the presence of significant effects, as the zeolite treatment at the level (1000 g pot^{-1}) with the glutamine treatment at a concentration of (300 mg L^{-1}) achieved the highest average number of leaves, amounting to (37.37 leaves plant^{-1}) compared to the comparison treatment, which gave a low percentage increase in the number of leaves, amounting to (26.88 leaves plant^{-1}).

As for the triple interaction of the studied factors, it was shown that the interaction treatment of non-stressed plants with the level (1000 g pot^{-1}) of zeolite and the concentration (300 mg L^{-1}) of glutamine gave a significant increase in this trait with an average of (39.53 leaves plant^{-1}) compared to the treatment (50% of the field capacity value) with the level (0 g pot^{-1}) of zeolite and the concentration (0 mg L^{-1}) of glutamine, which gave an average of (25.60 leaves plant^{-1}) (Table 3).

Table (3): The effect of zeolite and glutamine on the average increase in the number of leaves (leaf plant^{-1}) for coastal hibiscus seedlings under water stress

Stress level (Field capacity %)	Zeolite level (g pot^{-1})	Glutamine concentration (mg L^{-1})			Stress and Zeolite interaction
		0	150	300	
50	0	25.60	28.80	29.60	28.98
	500	27.87	31.57	34.47	32.03
	1000	33.47	35.73	35.20	33.09
100	0	28.17	32.00	32.60	29.92
	500	32.60	35.20	37.40	34.89
	1000	29.00	37.47	39.53	36.51
L.S.D $_{0.05}$		3.057			1.840
Glutamine averages		29.46	33.18	35.07	Stress averages
L.S.D $_{0.05}$		1.197			
Stress and Glutamine Interaction					
50 %		28.00	31.30	34.80	31.37
100 %		30.92	35.07	35.33	33.77
L.S.D $_{0.05}$		1.700			1.920
Zeolite and Glutamine Interaction					Zeolite averages
0		26.88	30.40	31.10	29.45
500		30.23	33.38	35.93	33.46
1000		31.23	36.60	37.37	34.80
L.S.D $_{0.05}$		2.154			1.344

Leaf area (cm^2)

The results of Table (4) confirm the presence of significant differences in leaf area of coastal hibiscus seedlings, as the average leaf area of unstressed plants reached 46.95 cm^2, while it decreased to 45.69 cm^2 in stressed plants, and the percentage of decrease was 2.68%. The same table also shows the superiority of the zeolite treatment at the level of (1000 g pot^{-1}), as it recorded the highest average of (49.31 cm^2) with an increase rate of (14.09%) compared to the comparison treatment, which gave the lowest average of (43.22 cm^2). As for glutamine, the results showed that the treatment (300 mg L^{-1}) recorded the highest average leaf area of (50.64 cm^2) with an increase rate of (20.42%), while the comparison recorded the lowest leaf area of (42.05 cm^2).

The same table shows a significant two-way interaction between water stress and zeolite, as the results showed that the treatment of plants that were not exposed to stress with the treatment (1000 g pot^{-1}) zeolite gave the highest average of (49.77 cm^2) compared to the control treatment, which gave the lowest average of (42.61 cm^2), while the two-way interaction treatment between water stress and glutamine gave significant differences in this trait, as spraying glutamine at a concentration of (300 mg L^{-1}) under the conditions of non-stressed plants recorded the highest average leaf area of (51.54 cm^2), while the lowest average was recorded in the absence of glutamine with stressed plants at a rate of (50% of the field capacity), which gave an average of (41.77 cm^2). The same table indicates that the interaction between zeolite and glutamine has a significant effect on the leaf area trait, as it was shown that the highest average leaf area was achieved in the treatment (1000 g pot^{-1}) of zeolite with a concentration of (300 mg L^{-1}) of glutamine, which reached (55.48 cm^2), compared to the treatment (0 g pot^{-1}) of zeolite with a concentration of (0 mg L^{-1}) of glutamine, which gave an average of (40.45 cm^2).

The same table showed the triple interaction between water stress, zeolite and glutamine, as the highest average leaf area (56.06 cm^2) was recorded when treating non-stressed plants with the level (1000 g pot^{-1}) of zeolite and the concentration (300 mg L^{-1}) of glutamine, while the lowest average was recorded in the comparison treatment (water stress at 50% of the field capacity with (0 g pot^{-1}) zeolite and (0 mg L^{-1}) glutamine) reaching (40.18 cm^2).

Table (4): The effect of zeolite and glutamine on leaf area (cm2) of coastal hibiscus seedlings under water stress

Stress level (Field capacity %)	**Zeolite level (g pot^{-1})**	**Glutamine concentration (mg L^{-1})**			**Stress and Zeolite interaction**
		0	**150**	**300**	
50	0	40.18	42.37	42.75	42.61
	500	42.97	44.86	48.87	45.62
	1000	44.69	49.63	54.91	48.85
100	0	40.71	42.65	43.66	43.82
	500	44.76	46.56	49.59	47.26
	1000	45.98	52.57	56.06	49.77
L.S.D $_{0.05}$		2.379			1.279
Glutamine averages		42.05	46.27	50.64	Stress averages
L.S.D $_{0.05}$		0.922			
Stress and Glutamine Interaction					
50 %		41.77	45.57	49.74	45.69
100 %		42.34	46.97	51.54	46.95
L.S.D $_{0.05}$		1.067			0.263
Zeolite and Glutamine Interaction					Zeolite averages
0		40.45	42.51	43.21	43.22
500		43.87	45.71	49.23	46.44
1000		45.34	51.10	55.48	49.31
L.S.D $_{0.05}$		1.742			1.103

Percentage of dry matter in leaves (%)

The results showed significant effects of the study factors on the percentage of dry matter in the leaves of coastal hibiscus seedlings, as the unstressed plants (100% of the field capacity) excelled and gave the highest percentage of dry matter amounting to (30.475%), while it decreased in stressed plants (50% of the field capacity) to (26.910%) with a decrease rate of (11.69%) (Table 5). The highest average for the above trait was also achieved, which amounted to (29.346%) at the level (1000 g pot^{-1}) of zeolite with an increase rate of (4.36%) compared to the lowest average of (28.119%) when zeolite was not added. As for glutamine, the concentration (300 mg L^{-1}) achieved the highest average of (29.698%) with an increase rate of (6.88%) compared to the concentration (0 mg L^{-1}), which gave the lowest average of (27.785%) (Table 5).

It is noted from the same table that the two-way interaction between water stress and zeolite was significant, as the plants that were not exposed to stress with the level (1000 g pot^{-1}) of zeolite gave the highest percentage of dry matter, reaching (30.919%) compared to the stressed plants with the level (0 g pot^{-1}) of zeolite, which gave the lowest percentage, reaching (26.358%). Also, the treatment of the unstressed plants with the glutamine treatment at a concentration of (300 mg L^{-1}) achieved the highest percentage of dry matter, reaching (31.488%), compared to the stressed plants with (0 mg L^{-1}) glutamine, which gave the lowest average, reaching (26.043%). The interaction treatment between zeolite and glutamine also achieved a significant effect, as the level (1000 g pot^{-1}) of zeolite with the concentration (300 mg L^{-1}) of glutamine gave the highest percentage of dry matter, reaching (30.212%), compared to the comparison treatment, which gave the lowest percentage, reaching (26.890%).

It is also noted that the triple interaction between water stress, zeolite and glutamine was significant in the above trait, as the highest average percentage of dry matter was in the interaction treatment between non-stressed plants with (1000 g pot^{-1}) zeolite and (300 mg L^{-1}) glutamine, reaching (32.142%), while the treatment of stressed plants with (0 g pot^{-1} zeolite and 0 mg L^{-1} glutamine) recorded the lowest percentage, reaching (25.130%) (Table 5).

Table (5): The effect of zeolite and glutamine on the percentage of dry matter (%) of coastal hibiscus leaves under water stress

Stress level (Field capacity %)	Zeolite level (g pot^{-1})	Glutamine concentration (mg L^{-1})			Stress and Zeolite interaction
		0	150	300	
50	0	25.130	25.885	27.113	26.358
	500	26.081	26.329	27.924	26.597
	1000	27.616	27.827	28.282	27.773
100	0	28.649	29.869	30.064	29.880
	500	30.079	30.550	30.601	30.627
	1000	30.912	31.412	32.142	30.919
L.S.D $_{0.05}$		0.777			0.438
Glutamine averages		27.785	28.594	29.698	Stress averages
L.S.D $_{0.05}$		0.3026			
Stress and Glutamine Interaction					
50 %		26.043	26.778	27.908	26.910
100 %		29.528	30.410	31.488	30.475
L.S.D $_{0.05}$		0.382			0.347
Zeolite and Glutamine Interaction					Zeolite averages
0		26.890	27.877	28.589	28.119
500		28.204	28.341	29.237	28.612
1000		29.264	29.619	30.212	29.346
L.S.D $_{0.05}$		0.559			0.352

Tables (from 1 to 5) showed a significant decrease in the studied vegetative traits (average increase in seedling height, average increase in primary stem diameter, number of leaves, leaf area, and percentage of dry matter in leaves) of coastal hibiscus when seedlings were exposed to water stress at 50% of field capacity. This decline can be attributed to the adverse effect of water stress, which reduces cell expansion and causes a decrease and disruption of vital physiological processes, leading to deterioration of cell membranes and proteins, and a decrease in carbohydrate accumulation and dry matter percentage. Stress also leads to the formation of free radicals that cause the breakdown of chlorophyll, the green pigment responsible for photosynthesis, causing plant tissue death [15, 16]. Water stress can induce oxidative stress in plants by increasing reactive oxygen species (ROS) such as free oxygen O_2, hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH), resulting from incomplete reduction with oxygen. Since water is essential for photosynthesis and carbon dioxide (CO_2) uptake, its deficiency leads to a decline in the production of photosynthetic products, which is reflected in a decrease in the accumulation of carbohydrates and proteins in plant tissues, resulting in a reduction in plant height, leaf number, and leaf area [17, 18].

The study results also demonstrate the role of zeolite in enhancing the traits studied in Tables (from 1 to 5). Zeolite plays a key role in improving plant vegetative characteristics by increasing stem growth and thickness, and enhancing leaf number and area, even under water-stress conditions. This is due to the natural ability of zeolite to retain water and nutrients in the soil, which enhances their uptake by the roots and facilitates photosynthesis. Furthermore, zeolite reduces nutrient loss, improving the growth environment and increasing water availability to the plant [19, 20]. Zeolite also helps improve soil structure and aeration, facilitating the absorption of essential water and nutrients, and mitigating the impact of water stress on plant physiological processes, such as photosynthesis. As a result of these effects, plant dry matter accumulation increases and vegetative growth is significantly improved [21].

The results in Tables (from 1 to 5) also showed that glutamine spraying resulted in a significant increase in all studied traits. This is attributed to its effective role in improving leaf growth, as glutamine is an important amino acid in the synthesis of chlorophyll, proteins, and enzymes necessary for photosynthesis and promoting plant tissue formation [22]. Glutamine acts as a significant source of nitrogen, positively affecting amino acid metabolism and stimulating the accumulation of nitrogen-rich amino acids. This enhances plant physiological processes such as cell division, increased leaf growth, thickening of plant tissue, and improved nutrient uptake, leading to improved vegetative growth and increased dry matter and leaf area. Glutamine also contributes to mitigating the effects of water stress, supporting the overall growth of coastal hibiscus [23, 24].

The results showed a clear negative effect of water stress on the vegetative traits of coastal hibiscus seedlings. A significant decrease in all studied traits was observed in plants exposed to this stress. However, treating the seedlings by adding 1,000 grams of zeolite to each pot and spraying glutamine at a concentration of 300 mg L^{-1} significantly mitigated the negative effects of water stress. This treatment achieved a significant increase in all vegetative traits, and in some cases, outperformed the performance of plants not exposed to stress. Interaction treatments have also proven highly effective in improving plant health and enhancing their resistance to water stress, indicating their potential for use in combating various types of stress due to their distinct properties in supporting plant growth and improving plant performance under harsh environmental conditions.

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