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Impact of taurine and citric acid foliar spraying and their combination on a few wheat crop growth and yield aspects Iba 99, a variety of *Triticum aestivum* L

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Abstract

A 2024–2025 winter field experiment in Al-Shafi'iyah examined the effects of foliar spraying with different concentrations of citric acid and taurine, and their interaction, on wheat growth and yield metrics. Two components and three replicates comprised the factorial experiment. The leaves were first treated with citric acid. For the first factor, no spraying was done (C0), and for the second, 1.5 and 3 g/L taurine were administered to the leaves. Statistical study showed that citric acid and taurine treatments affected plant height, spike length, leaf area, spikes per plant, 1000-grain weight, grain yield, straw output, and biological yield. Concerning how the two interact, C2T1 was the best experimental treatment. It significantly outperformed it and noted the highest values for each of the aforementioned characteristics. This leads us to the conclusion that the wheat crop's growth performance and production were clearly impacted by the application of taurine and citric acid.

Keywords: Citric acid, taurine, wheat crop, Iba99, growth, yield

Introduction

Due to its high carbohydrate, protein, and nutritional content, wheat is a crucial field crop and a global staple. Additionally, its resilience to different temperatures makes it a significant crop in Iraqi agriculture, particularly in semi-arid locations (Alagely *et al.*, 2023) [2]. Iraq has focused on developing local wheat varieties that may survive in various climates. Iba is a popular Iraqi crop. The tremendous genetic diversity of this species helps it to boost its productivity and adapt to different agricultural approaches, making it unique. Al-Kaab *et al.* (2016) [6]. Many studies have shown that Iba 99 responds to fertilizer and planting density. Its increased growth and output demonstrate its adaptation and resistance to new settings. This was Al-Hamdani and colleagues (2016) [4]. Citric acid is an important organic acid in plants because it enhances micronutrient availability including zinc, iron, and manganese. Mengel (2002) [31], Güneş *et al.* (2007) [18]. When applied topically to plants, it stimulates nutrient uptake by activating growth and photosynthetic enzymes. Citric acid also boosts photosynthesis and chlorophyll, improving plant physiological efficiency. It helps cells maintain ionic equilibrium and reduces the effects of dehydration and hunger. (Ali, 2024) [5]. Citric acid has also been shown to improve feeding efficiency and lessen the impact of environmental stress on nutrient uptake, both of which have a positive impact on the development of vegetative traits and yield components. (Touhami *et al.*, 2017) [43]. Taurine is considered one of the organosulfur compounds and is a non-protein amino acid widely distributed in nature. It plays multiple vital roles related to regulating physiological processes and resisting stress.

Although its presence in plants is in limited quantities compared to animals, recent studies have indicated the possibility of utilizing it as a growth-stimulating compound when applied externally, especially under conditions of environmental stress. Scientific research indicates that taurine has an important role as an antioxidant, as it works to reduce the accumulation of free radicals and protect cell membranes from oxidative damage, which positively affects the stability of vital processes within the plant (Schaffer *et al.*, 2010) [39]. The results of some studies have shown that foliar spraying with taurine leads to improved vegetative growth characteristics and increased photosynthetic efficiency by maintaining the integrity of chloroplasts and enhancing the activity of enzymes associated with photosynthesis. It also contributes to improving the absorption and translocation of nutrients within the plant, which leads to increased crop productivity, especially in environments with limited resources (Redmond *et al.*, 2016) [36].

This research investigates foliar spraying citric acid and taurine and their interactions, affects several wheat development and yield characteristics (Iba99).

Materials and Methods

In the Al-Shafi'iyah area, which is 14 kilometers west of the Al-Diwaniyah Governorate's center, To test citric acid foliarly, researchers sprayed multiple amounts in 2024–2025 winter growth. (C6H8O7) produced by TTCA Co., Ltd., of Chinese origin, and taurine (Aminoethanesulfonic acid-2 C2H7NO3S) manufactured by Foodchem International, of Chinese origin, and their interplay on a few wheat variety

growth and yield parameters (Iba 99). The experiment was carried out using factorial trials with two factors: citric acid spraying was the first factor. (C0: no spraying, C1: 1.5 g/L, C2: 3 g/L), The second step was taurine spraying (T₀: no spraying, T₁: 0.5 g/L, C2: 1 g/L). The interaction was observed with three replicates per treatment. Tilling, smoothing, and leveling were the methods used to prepare the soil. Then, using the techniques outlined by Page *et al.* (1982) [35] and Black (1965) [9], The physical and chemical parameters were assessed using random samples (Table 1). Each 2-by-3-meter patch was 50 cm apart. After that, each plot had 15 2-meter-long, 20-cm-apart rows. Seeding depth was 6 cm and pace was 100 kg ha⁻¹. The planting fertilizer used was 80 kg ha⁻³ triple superphosphate (46% P₂O₄). Application of 120 kg ha⁻¹ nitrogen fertilizer occurred twice: 15 days post-planting during germination and 45 days thereafter. Urea, 46% nitrogen, was the nitrogen fertilizer. Hoeing and weeding were done as required. Until the season finished, this was vital.

Table 1: shows soil physical and chemical properties at the testing site

Attributes		Value
E.C) ds/m ⁻¹)		4.5
pH		7.1
Available potassium (mg.kg ⁻¹)		95.11
Available phosphor (mg.kg ⁻¹)		3.00
Available nitrogen (mg.kg ⁻¹)		0.09
Soil separators (g.kg ⁻¹)	clay	48.01
	silt	34.34
	sand	16.61

The Studied Traits

Plant Height

After 10 plants in each experimental unit bloomed, we randomly measured their height from soil surface to spike top using a metric ruler.

Leaf area (cm²)

The leaf area was measured after blooming using Liang *et al.*'s (1973) [23] method. Leaf area is calculated by multiplying width by length by 0.75.

Spike Length

The average of 10 randomly selected plants was measured from the base of the spike to the tip of the terminal spike (excluding the terminal spike).

Number of spikes (spike.m⁻²)

At full maturity, each experimental unit randomly collected one square meter from shielded rows depending on spikes.

Weight of 1000 grains (g)

Each experimental unit's sample was weighed after randomly counting 1,000 grains with a seed counter to determine yield per square meter.

Grain yield (tons ha⁻¹)

Manual analysis was performed on every experimental unit's square meter. The grains were weighed after being separated from straw. The weight of 1,000 grains for each treatment was estimated from this. After adding 14%

moisture, it was converted from gm.m⁻² to ton.ha⁻¹.

Biological yield (tons ha⁻¹)

Grain yield was determined from harvested plants. Grams per square meter were converted to tons per hectare for the plant's biomass, which included grains and straw.

Straw yield (tons ha⁻¹)

Grain weight was removed from biomass weight to calculate straw yield.

Results and Discussion

The statistical analysis's findings in Table (2) showed significant differences at the probability level (P≤0.05) in the height of wheat plants as a result of the effect of citric acid and taurine, as well as the interaction between them. The value of the least significant difference (LSD) was 0.05 for citric acid (2.71), for taurine (2.71), and for the interaction (4.69). The results indicate a significant advantage for treatment C2, reaching 93.31 cm, compared to treatments C1 and C0, which recorded values of 88.30 cm and 82.31 cm, respectively. The differences between them exceeded the value of the least significant difference (L.S.D) = 2.71, which indicates a clear effect of citric acid in increasing plant height. The reason for the effect of citric acid in achieving this increase in wheat plant height may be attributed to its role in improving the availability of nutrients, especially micronutrients, by acting as a chelating compound, thus increasing their absorption and translocation within the plant. Many organic chelating compounds, including citric acid, have showed promise in enhancing mineral nutrient absorption (Cunha-Chiamolera *et al.*, 2025; Madhupriya, 2024) [11, 25]. According to Menhas *et al.* (2024) [32] and Mahamud *et al.* (2026) [26], citric acid helps plant cells create energy and regulate their metabolism, which stimulates cell division and elongation. A recent wheat research demonstrated that citric acid as a chelating agent improves nutrient absorption, increasing vegetative growth and plant height (Mishra *et al.*, 2024) [33]. El-Tohamy and El-Greadly (2007) [16] also found that citric acid considerably increased vine growth.

Table 2: Effects of Citric Acid and Taurine Applications and Interactions on Wheat Plant Height

Citric acid	Taurine			Mean
	T ₀	T ₁	T ₂	
C0	82.33	83.32	81.30	82.31
C1	88.30	89.31	87.29	88.3
C2	93.31	94.29	92.34	93.31
Mean	87.98	88.97	86.97	
L.S.D 0.05	H=2.71	M=2.71	H*M= 4.69	

Table (3) shows that citric acid significantly affected wheat plant leaf area parameters (P≤0.05), whereas taurine had a minor effect. The LSD values for citric acid and taurine show a strong interaction. (4.66) and for the interaction (8.07), which indicates the existence of the differences recorded between the treatments. In the experimental results, treatment C2 recorded the highest average leaf area of 49.00 cm², significantly surpassing treatments C1 and C0, which recorded values of 43.22 cm² and 36.33 cm², respectively. The significant differences between these

treatments exceeded the LSD (least significant difference) of 4.66, indicating the positive effect of citric acid on enhancing the leaf area of wheat plants. The chelating action of citric acid, which increases the availability of nutrients, particularly micronutrients, and improves their absorption and transport within the plant, may account for this impact. (Cunha-Chiamolera *et al.*, 2025) ^[11]. Additionally, as a part of the tricarboxylic acid cycle, citric acid is intimately related to the fundamental metabolic functions of the plant. This increases leaf growth by boosting the synthesis of ATP, which is required for essential functions including cell division and elongation. (Aydemir, 2025) ^[7]. Increased structural efficiency was a result of this. Improvements in chlorophyll synthesis led to photosynthesis, which is consistent with the results of Mishra *et al.* (2024) ^[33] in wheat.

In terms of taurine, treatment T₁² recorded the greatest leaf area value of 43.33 cm², while treatments T₀ and T₂ recorded values of 42.89 cm² and 42.33 cm², respectively, according to Table (3). Nevertheless, despite a positive effect, the differences between them were less than the LSD (least significant difference) value (LSD = 4.66), suggesting that the taurine effect did not approach statistical significance. This can be explained by the fact that taurine acts as an antioxidant and osmotic regulator, contributing to cell membrane stability and reducing oxidative stress, thus improving the efficiency of physiological processes without a significant increase in leaf area (Nawaz *et al.*, 2024) ^[34]. Furthermore, the relative decrease at the high concentration in treatment T₂ may be attributed to dose-related effects leading to equilibrium. Metabolic.

As for the interaction, the treatment C2T₁ recorded the highest leaf area value at (50.00) cm². However, the differences between it and treatments C2T₀ and C2T₂ were less than the LSD (Least Significant Difference) value (LSD = 8.07), indicating no significant differences between them. On the other hand, the differences between treatments C2T₁, which recorded the highest value, and C0T₁, which recorded the lowest value, were much greater than the L.S.D value, indicating a significant interaction effect. This interaction can be explained by a synergistic effect, as citric acid improves nutrient absorption, while taurine enhances their utilization efficiency within the plant by reducing oxidative stress. This is reflected in improved physiological performance and increased leaf growth in wheat (Zaghloul *et al.*, 2024) ^[45]. This indicates that improved mineral nutrition is the decisive factor in increasing leaf area, while taurine acts as a cofactor that enhances the physiological response within certain limits. This also confirms the importance of The synergy between nutritional factors and biostimulants in improving vegetative growth characteristics is in line with modern trends in the use of biostimulants to improve crop productivity (Sun *et al.*, 2024) ^[40].

Table 3: Impact of Citric Acid and Taurine Spraying on Wheat Leaf Area (cm² Alone and Together)

Citric acid	Taurine			Mean
	T ₀	T ₁	T ₂	
C0	36.33	36.00	36.67	36.33
C1	43.33	44.00	42.33	43.22
C2	49.00	50.00	48.00	49.00
Mean	42.89	43.33	42.33	
L.S.D 0.05	H=4.66	M=4.66	H*M= 8.07	

The statistical analysis's findings in Table (4) show that wheat spike length was significantly affected by citric acid levels, while taurine did not show an independent significant effect. The interaction between the two factors also did not have a significant effect according to the Least Significant Difference (L.S.D) test. The difference between the mean citric acid levels exceeded the L.S.D value of 0.53, particularly between C2 and the other treatments, indicating a real effect of improved mineral nutrition. On the other hand, the results indicate no significant effect of taurine or the interaction, as the differences between their means remained below the significance level (P≤0.05) defined by the L.S.D values. Furthermore, neither the taurine nor the interaction treatments showed statistically significant differences, as the calculated differences were lower than the calculated L.S.D values (L.S.D = 0.53 for taurine and L.S.D = 0.93 for the interaction). This suggests. The absence of a significant effect of these factors can be explained by the significant superiority of citric acid in light of its physiological role as an intermediate organic acid in the Krebs cycle, Plants absorb minerals better due to its chelating agent. Citric acid increases the solubility of elements such as iron, zinc, and manganese and improves their translocation through plant tissues, which positively impacts photosynthetic efficiency by increasing chlorophyll content and activating photosynthetic enzymes, most notably ribulose-1,5-bisphosphate carboxylase/oxygenase (Rellán-Álvarez *et al.*, 2010; Aydemir, 2025) ^[37, 7]. This study confirmed previous findings that organic acids, particularly citric acid, improved wheat's vegetative development and morphology. Kaya *et al.* (2020) showed that the addition of citric acid promoted growth and productivity by increasing photosynthetic efficiency and micronutrient uptake. In wheat, citric acid improved growth-related aspects connected to decreased oxidative stress and greater nutrient availability (Aydemir, 2025) ^[7]. However, taurine increased little without being statistically different. Taurine readings rose somewhat, but not significantly. This can be explained within the framework of biostimulants, as taurine acts as a physiological regulator that contributes to modifying the plant's biological response without being a direct source of nutrients. Studies indicate that amino acid-like compounds enhance stress tolerance by regulating osmotic balance and stimulating antioxidant systems, in addition to their effect on hormonal signaling pathways such as auxins and cytokinins (Rouphael and Colla, 2020) ^[38]. However, the effectiveness of these compounds remains conditional on the plant's nutritional status, being more pronounced under conditions of stress or nutrient deficiency, which may explain the limited effect of taurine in this study. The results of the insignificant effect of taurine are consistent with a number of studies that have shown that the effect of amino acids or biostimulants is limited or insignificant when sufficient mineral nutrition is available. The study by Sun *et al.* (2024) ^[40] The effect of amino acids in wheat is more pronounced under stress conditions, while their effect is less pronounced under ideal conditions. The researcher also pointed out that biostimulants operate within limited response ranges, and their effectiveness depends on the plant's nutritional balance, which explains why the effect of taurine did not reach a statistically significant level in this study.

As for non-significance in the interaction between citric acid and taurine, this can be explained by the concept of physiological response saturation. Improving mineral nutrition led to a high level of physiological efficiency, which reduced the possibility of demonstrating a significant additional effect from the biostimulant. In other words, citric acid acted as the primary growth promoter, while taurine's role was limited to physiological modification within statistically insignificant limits. This supports Colla *et al.* (2014)'s ^[10] finding that biostimulants' effects are synergistic and nutritionally dependent. The lengthier spikes may be caused by citric acid activating photosynthesis and other mechanisms that boost nutritional availability. Enzymatic activity divides and lengthens spike meristematic tissues, improving the antioxidant system and hormone balance. Since mineral nutrition is strongly related to biological processes that regulate development, this physiological mechanism may explain the obvious growth. According to contemporary sustainable agriculture research, biostimulants complement dietary and environmental variables and increase nutrient efficiency to boost crop yields. The findings show that managing mineral nutrition is the first step to enhancing wheat growth features, with integrated biostimulant strategies possible. (Rouphael and Colla, 2020) ^[38].

Table 4: demonstrates how citric acid, taurine, and their interactions affect wheat spike length in centimeters.

Citric acid	Taurine			Mean
	T ₀	T ₁	T ₂	
C0	8.16	8.26	8.06	8.16
C1	9.00	9.10	8.90	9.00
C2	9.76	9.90	9.63	9.76
Mean	8.97	9.08	8.86	
L.S.D 0.05	H=0.53	M=0.53	H*M=0.93	

A statistical study demonstrates that citric acid, taurine, and their combination greatly reduce wheat spikes (Table 5). ($P \leq 0.05$). The control treatment C0 generated 3.23 spikes per plant, whereas level C2 produced 4.50 spikes per plant, demonstrating that increasing citric acid concentrations enhanced spike quantity. Analysis of least significant differences showed big disparities ($LSD = 0.46$). The Krebs cycle's efficiency may be enhanced by citric acid's biostimulant properties, thus providing the energy necessary for cell division and the differentiation of meristematic tissues into spike primordia. The acid also lowers the soil pH in the area surrounding the roots, increasing the availability of micronutrients and phosphorus necessary for flowering. (El-Afify *et al.*, 2022) ^[13].

As for taurine, the results in Table (4) indicate a significant response ($P \leq 0.05$), with level T₁ significantly outperforming other levels by recording a value of (3.97) spikes/plant⁻¹ compared to the other two levels, with a significant difference exceeding the value of the least significant difference ($L.S.D=0.46$). It is observed that increasing the taurine concentration to level T₂ resulted in a decrease in the average to (3.80) spikes/plant⁻¹, which indicates that the optimal response occurs at intermediate concentrations. The effect of taurine at level T₁ may be attributed to its nature as an osmotic regulator and antioxidant that protects cell membranes from environmental stresses, thus prolonging

the functional efficiency of the leaves and consequently increasing the flow of metabolic products towards the developing spikes (Habib *et al.*, 2025) ^[19]. This suggests that sulfur-containing amino acids may boost photosynthetic efficiency and output, as Zayed *et al.* (2020) ^[46] suggested. As for the effect of the interaction, According to statistical analysis, Table 4 demonstrates substantial differences. ($P \leq 0.05$) in the interaction between the two study variables, with the least significant difference being 0.81. The interaction combination C2T₁ achieved the highest value for the number of spikes, reaching (4.63) spikes/plant⁻¹, thus significantly surpassing the treatment C0T₀, which recorded the lowest value (3.23) spikes/plant⁻¹. Perhaps the reason for this significant superiority of the aforementioned interaction is attributed to a state of physiological synergy, where citric acid contributed to improving mineral absorption and providing carbon structures, while taurine worked to improve the physiological state of the plant and stress resistance, which together led to maximizing the number of spikes produced. This is consistent with the principle of integration between growth-regulating biostimulants (Kandil *et al.*, 2021) ^[21].

Table 5: Impact of taurine and citric acid spraying, as well as their combination, on wheat's spike number (spike.plant⁻¹)

Citric acid	Taurine			Mean
	T ₀	T ₁	T ₂	
C0	3.23	3.26	3.20	3.23
C1	3.93	4.03	3.83	3.93
C2	4.50	4.63	4.36	4.50
Mean	3.88	3.97	3.80	
L.S.D 0.05	H=0.46	M=0.46	H*M=0.81	

The results in Table (6) show significant differences ($P \leq 0.05$) between citric acid and taurine, and their interaction, on the 1000-grain weight trait in wheat. These differences exceeded the LSD value, which is set at a probability level of (0.05). The results showed a significant advantage with the addition of citric acid, as treatment C2 recorded the highest average weight of (39.12) g, compared to the control treatment (C0), which recorded a value of (33.77) g. This result, which exceeded the LSD value of (1.43), may be attributed to the role of citric acid as one of the essential organic acids involved in the Krebs cycle. This helps plant cells produce energy in the form of ATP and support metabolic processes, which in turn influences the final grain size and filling process efficiency. Organic acids enhance wheat spike dry matter and nutrient absorption, supporting this notion (El-Afry *et al.*, 2018) ^[14].

Treatment T₁ reacted best to taurine, with (37.00) g. Taurine's biostimulant function boosts photosynthetic processes and cell membrane integrity, making it easier to move photosynthetic products from leaves to grains during important development stages. Similar to our results, Maleki *et al.* (2022) ^[27] observed that amino acids and their derivatives, such as taurine, increase grass plant production and nitrogen utilization efficiency.

As for the interaction between citric acid and taurine, the C2T₁ treatment recorded the highest grain weight of (39.67) g. This interaction indicates a state of physiological synergy, as citric acid improves the availability of elements in the soil and root zone, while taurine improves the internal

biological processes of the plant, which led to maximizing the grain weight characteristic (Yakhin *et al.*, 2017) ^[44]. These results are consistent with modern scientific trends that confirm that mixing biostimulants and organic acids gives results that surpass the use of each of them individually (Khan *et al.*, 2019) ^[22].

Table 6: Impact of taurine and citric acid spraying, as well as their interaction, on the weight of 1000 grains (g) of wheat

Citric acid	Taurine			Mean
	T ₀	T ₁	T ₂	
C0	33.67	34.18	33.46	33.77
C1	36.66	37.17	36.47	36.76
C2	39.00	39.67	38.70	39.12
Mean	36.44	37.00	36.21	
L.S.D 0.05	H=1.43	M=1.43	H*M=2.48	

Table 7 indicates substantial ($P \leq 0.05$) variations in grain yield due to citric acid, taurine, or both. The treatment average difference was substantially bigger than the L.S.D. values of (0.41) for each component and (0.71) for the interaction. Treatment C2 produced the maximum grain yield, exceeding the L.S.D value of 0.41 for factors, with an average of 4.41 tons ha⁻³ compared to 3.15 tons ha⁻¹ for the control treatment. As a chelating agent, citric acid may improve zinc and iron absorption and bioavailability., which are necessary for the synthesis of chlorophyll. Liu *et al.*, (2023) ^[24] Organic acids contribute to regulating osmotic pressure and improving the plant's water balance, which is reflected in an increase in the number of spikes and grain weight (Tariq *et al.*, 2023) ^[42]. This was also indicated by Hussain *et al.* (2022) ^[20] in their study on cereal crops, where they found that citric acid stimulates antioxidant enzymes, thus extending the lifespan of the scientific leaf. The treatment with the highest yield, 3.91 tons ha⁻¹, was the one with taurine (T₁). This amino acid, which includes sulfur, enhances plant defenses and stabilizes metabolic processes, perhaps explaining this effect. This extends grain storage and leaf photosynthesis. This is from Zhang *et al.* (2023) ^[47]. Maleki *et al.* (2022) ^[27] found that amino acid biostimulants boost photosynthetic efficiency and yield components in various plant conditions, and our findings agree. The interaction resulted in the maximum grain output (4.55 tons ha⁻¹) in treatment (C2T₁). This interaction shows a physiological synergy: taurine optimizes yield by improving internal plant processes and regulating element and metabolic product translocation to the ears, while citric acid increases soil and root zone nutrient availability. Khan *et al.* (2019) ^[22] and Yakhin *et al.* (2017) ^[44] found that organic acids and biostimulants work better together than separately.

Table 7: Impact of taurine and citric acid spraying, as well as their interaction, on wheat grain yield ton.ha⁻¹

Citric acid	Taurine			Mean
	T ₀	T ₁	T ₂	
C0	3.15	3.25	3.05	3.15
C1	3.85	3.95	3.75	3.85
C2	4.41	4.55	4.28	4.41
Mean	3.80	3.91	3.69	
L.S.D 0.05	H=0.41	M=0.41	H*M=0.71	

Table (8) shows that citrus acid boosts straw output statistically. (tons/ha⁻¹). In comparison to the control treatment C0, which recorded a value of (3.85) tons/ha⁻¹, the C2 concentration recorded the greatest average yield of (5.15) tons/ha⁻¹. Citric acid's contribution to enhancing photosynthetic efficiency and boosting carbohydrate synthesis is probably responsible for this rise, which exceeds the L.S.D. (least significant difference) value of 0.45. Plant biomass rises as it gets higher and branches out. Chelating agent citric acid promotes mineral absorption, which is essential for vegetative development. Hussain and colleagues' 2022 investigation. Our findings match Tariq *et al.* (2023)'s ^[42] finding that organic acids improve wheat harvest biochemistry and physiology.

The treatment (T₁) improved taurine effect by 4.63 ton/ha⁻¹. Taurine, a biostimulant, regulates ionic homeostasis to stabilize metabolism and protect cells from environmental threats (Ahmed *et al.*, 2024). Maleki *et al.* (2022) ^[27] found that taurine boosts plant resilience and vegetative growth, increasing dry matter production. Interaction-wise, C2T₁ hay production peaked at 5.28 tons ha⁻¹. This victory shows physiological equilibrium, as citric acid increased energy and soil nutrient availability while taurine helped internal absorption and tissue development. Modern science shows that organic acids and amino biostimulants boost the plant's efficacy. (Zulfikar *et al.*, 2021) ^[48].

Table 8: Impact of taurine and citric acid spraying, as well as their interaction, on wheat straw production ton.ha⁻¹

Citric acid	Taurine			Mean
	T ₀	T ₁	T ₂	
C0	3.85	3.95	3.75	3.85
C1	4.58	4.68	4.48	4.58
C2	5.15	5.28	5.01	5.15
Mean	4.52	4.63	4.41	
L.S.D 0.05	H=0.45	M=0.45	H*M=0.78	

The statistical analysis in Table (9) demonstrates major implications. ($P \leq 0.05$) of both citric acid and taurine and their interaction on the biological yield of wheat. Data shows that citric acid levels steadily enhanced average yields. C2 outperformed C0, the control treatment, with 8.86 ton.ha⁻¹. As an organic acid, citric acid is crucial to the Krebs cycle, which enhances photosynthetic efficiency and creates energy for cell division and plant tissue growth. Citric acid increases total dry matter via chelating and helping plants absorb and transport micronutrients. Tahjib-Ul-Arif *et al.* (2019) ^[41]. Mallick *et al.* (2021) ^[30] found that organic acids modulate osmotic potential to improve wheat crop vegetative growth.

The statistical analysis table above shows that taurine treatment, notably T₁, generated 7.85 ton.ha⁻¹ more. Taurine protects cell membranes from oxidative damage, extends leaf lifetime, and enhances light absorption and growth regulation. In 2022, El-Metwally and colleagues. Malekzadeh (2015) ^[28] found that amino acids improve nitrogen absorption, increasing wheat dry matter yield. At T₂, there was a little reduction, suggesting physiological nitrogen saturation.

Additionally, binary interaction peaked at 9.13 ton.ha⁻¹ during treatment C2T₁. Citric acid supplies energy and carbon frameworks, while taurine protects the structural system; their synergy gives them dominance. The L.S.D. value of the interference (1.49) confirms that the differences between the interference treatments are significant and real differences resulting from the effectiveness of the materials used (Tahjib-Ul-Arif *et al.*, 2019; Mallick *et al.*, 2021) ^[41, 30].

Table 9: Impact of taurine and citric acid spraying, as well as their interaction, on wheat's biological yield ton.ha⁻¹

Citric acid	Taurine			Mean
	T ₀	T ₁	T ₂	
C0	6.30	6.50	6.10	6.30
C1	7.73	7.93	7.53	7.73
C2	8.86	9.13	8.60	8.86
Mean	7.63	7.85	7.41	
L.S.D 0.05	H=0.86	M=0.86	H*M=1.49	

Conclusion

1. Foliar spraying with citric acid at the mentioned levels resulted in a significant and clear increase in most growth and yield characteristics, especially at the C2 level, confirming its effectiveness in enhancing photosynthetic efficiency and energy production within the plant.
2. Taurine demonstrated high efficacy as a biostimulant and antioxidant, particularly in treatment T₁, as it contributed to protecting cell membranes and extending the functional lifespan of leaves, which positively impacted dry matter accumulation.
3. The dual interaction between citric acid and taurine, especially in treatment (C2T₁), achieved the best performance for the studied variety in most growth and yield characteristics, indicating a synergistic effect combining energy provision and physiological protection.

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