Effect of Foliar Application of Cysteine and Ferrous Sulfate on the Vegetative Growth and Flowering of Chinese Carnation (*Dianthus chinensis* L.)

Ali Basim Mohammad

Department of Horticulture and Landscape Engineering, College of Agriculture, Tikrit University, Salahuddin, Iraq.

E-mail: ali.b.m019@tu.edu.iq.

Abstract

This study was conducted in the lath house of the Department of Horticulture and Landscape Design, College of Agriculture, Tikrit University, during the 2025–2026 growing season. The research aimed to evaluate the effect of foliar application of Cysteine as the first factor at three levels (C0, C1, C2) and Ferrous Sulfate as the second factor at three levels (F0, F1, F2), as well their interaction on the vegetative and physiological growth characteristics of China Pink (*Dianthus chinensis L.*). The experiment was designed according to a Randomized Complete Block Design (RCBD) as a factorial experiment. The results revealed significant differences among the treatments. Cysteine application showed a pronounced effect on improving growth traits; the C2 treatment was superior, recording the highest values for plant height, number of branches,number of leaves, number of flowers and chlorophyll content (17.24 cm, 10.23 branch . plant-1, 24.11 leaf . plant-1, 12.18 flower . plant-1 and 40.53 SPAD) respectively, whereas the control treatment (C0) recorded the lowest values.. While the application of Ferrous Sulfate significantly enhanced in enhancing these traits. So the F2 treatment produced high values for the same parameters (15.51 cm 8.95 branch . plant-1 , 21.22 leaf .plant -1, 10.27 flower. plant-1, and 37.95 SPAD) respectively. This result reflects the physiological importance of iron in chlorophyll synthesis and the activation of vital processes within the plant. The interaction between the two factors showed significant differences, it was highly prominent. The C2F2 treatment significantly outperformed others, recording the highest values across all traits studied : 18.76 cm for plant height, 12.93 branch . plant^{-1}, 26.33 leaf .plant^{-1}, 14.13 flower .plant^{-1}, and 43.86 SPAD for chlorophyll content

Keywords: Ornamental plants, *Dianthus chinensis L*, Amino acids, Cysteine, Ferrous sulfate.

Introduction

Carnation (*Dianthus caryophyllus* L.) is one of the most economically significant ornamental plants belonging to the family Caryophyllaceae. It is widely cultivated for cut flower production due to its diverse floral colors,

ISSN 2072-3857

aesthetic appeal, and long vase life, in addition to its high commercial value in global markets. It is a perennial herbaceous plant often grown as an annual or semi-perennial crop within commercial flower production systems [1].

The carnation is characterized by an erect, branching growth habit; the plant consists of a main stem that branches into several lateral shoots bearing simple, opposite leaves. The flowers are either solitary or clustered in terminal cymes. Carnations are temperate climate plants, growing optimally within a temperature range of 15–25°C. High or low temperatures negatively impact growth and flowering. Furthermore, it requires adequate lighting, well-drained soil, and proper aeration to ensure ideal growth and high-quality floral production [2].

Balanced plant nutrition is a fundamental factor influencing the growth and productivity of carnations, as the plant requires both macro- and micronutrients to complete various physiological processes. Among these, Iron (Fe) is an essential micronutrient that is incorporated into the structure of numerous enzymes and proteins involved in oxidation-reduction (redox) reactions. It also plays a vital role in chlorophyll synthesis and the electron transport chain during photosynthesis and respiration. Iron deficiency leads to chlorosis (yellowing) and reduced photosynthetic efficiency, which adversely affects vegetative growth and floral yield [2,3].

A common source for supplying plants with iron is Ferrous Sulfate $FeSO_4$, which is characterized by high solubility and rapid absorption, particularly when applied via foliar spraying. This method allows the element to reach the leaves directly and subsequently move within the plant, contributing to the rapid correction of iron deficiency and improving chlorophyll content and photosynthetic efficiency [4].

On the other hand, amino acids play a significant role in stimulating plant growth, acting as building blocks for proteins and enzymes, as well as metabolic regulators that help organize physiological processes. Cysteine is a crucial sulfur-containing amino acid that contributes to the formation of antioxidant compounds such as glutathione, which enhances the plant's ability to resist oxidative stress and improves vegetative growth [1].

Additionally, amino acids contribute to enhancing nutrient uptake, activating enzymatic systems, and regulating hormonal balance within the plant. This positively reflects on increasing photosynthetic efficiency and improving both vegetative growth and flowering [5,6].

Recent studies indicate that combining amino acids with mineral elements, such as ferrous sulfate, results in a synergistic effect. The objective of this study is to investigate the synergistic effects of combining amino acids with mineral elements—specifically ferrous sulfate—on the growth, physiological processes, and flowering quality of ornamental plants, with a focus on carnations. The study aims to determine how this combination enhances nutrient uptake efficiency, boosts photosynthetic activity, and optimizes hormonal regulation to improve overall vegetative development and reproductive performance.

Material and Methods

This experiment was conducted in the lath house of the Department of Horticulture and Landscape Design, College of Agriculture, Tikrit University, during the 2025–2026 growing season. The study aimed to evaluate the effects of foliar application of Cysteine and Ferrous Sulfate on several vegetative growth , flowering and physiological characteristics of Carnation (*Dianthus caryophyllus*).

Carnation seedlings were planted in plastic pots (25–30 cm in diameter) filled with a mixture of loamy soil and peat moss (1:1 v/v). The seedlings were uniform in size and age, healthy, and possessed a well-developed root system. All necessary agricultural practices, including irrigation and plant care, were performed according to the plants' requirements throughout the duration of the experiment.

The experiment included two factors; the first factor involved foliar application of cysteine at three levels: (C0) without spraying (control treatment), (C1) at a concentration of 50 mg . L^{-1}, and (C2) at a concentration of 100 mg . L^{-1}. As for the second factor, it was the foliar application of ferrous sulfate at three levels: (F0) without spraying, (F1) at a concentration of 100 mg. L^{-1}, and (F2) at a concentration of 200 mg . L^{-1}. Spray solutions were prepared using distilled water with the addition of a surfactant at a rate of (0.1%), and the spraying process was carried out using a manual sprayer until full wetness of the leaves during the early morning hours.

Spray solutions were prepared using distilled water with the addition of a surfactant (wetting agent) at a concentration of 0.1%. Foliar application was carried out using a manual sprayer until the leaves reached full wetness during the early morning hours. Treatments commenced two weeks after transplanting and were repeated three times at 15-day intervals.

The experiment was implemented using a Randomized Complete Block Design (RCBD) as a (3* 3) factorial experiment, consisting of 9 interaction treatments with three replicates. Each experimental unit contained 3 plants, making a total of 81 plants.

At the end of the experiment, several vegetative and physiological traits were measured, including relative

ISSN 2072-3857

chlorophyll content (SPAD) using a SPAD meter on recently matured leaves, plant height (cm), and number of branches (branch. plant $^{-1}$), number of leaves (leaf plant^{-1}), and number of flowers (flower. plant^{-1}). Data were statistically analyzed using the SAS (2012) software, and means were compared using the Least Significant Difference (LSD) test at a probability level of 0.05.

Results and Discussion

Plant Height

The results presented in Table (1) there are significant differences among the treatments. The foliar application of Cysteine at the highest level (C2) produced the highest average plant height of 17.24 cm, whereas the control treatment which recorded the lowest value.

Similarly, the Ferrous Sulfate treatment at the highest concentration (F2) showed a remarkable superiority in vegetative growth traits, with an average plant height of 15.51 cm. Regarding the interaction between the two factors, the C2F2 treatment recorded the highest plant height, reaching 18.76 cm.

Table (1): Effect of foliar application of Cysteine and Ferrous Sulfate on the plant height of *Dianthus chinensis L.*.

Cysteine Means	Ferrous Sulfate ($mg \cdot L^{-1}$)			Cysteine ($mg \cdot L^{-1}$)
	(F2)	(F1)	(F0)	
11.10^{c}	12.26^{g}	11.76^{g}	9.26^{h}	C0
14.53^{b}	15.50^{d}	14.53^{e}	13.56^{f}	C1
17.24^{a}	18.76^{a}	16.86^{b}	16.10^{c}	C2
	15.51^{a}	14.38^{b}	12.97^{c}	Mean effect of ($FeSO_4$)

"Means of each factor or their interactions followed by different letters indicate significant differences at the $P \leq 0.05$probability level according to Duncan's Multiple Range Test (DMRT).

Number of Branches

The results presented in Table (2) indicate that a significant superiority among the study treatments, as the cysteine foliar application treatment at level (C2) produced the highest average number of branches, reaching 10.23 branches plant^{-1}, whereas the control treatment which recorded the lowest value.

Similarly, the ferrous sulfate foliar application treatment at level (F2) showed a notable superiority in vegetative growth traits, where the

average number of branches reached 8.95 branches plant^{-1}.
Regarding the interaction effect between the two factors, the (C2F2) treatment recorded the highest value for the number of branches, reaching 12.93 branches plant^{-1}.

Table (2): Effect of Cysteine and Ferrous Sulfate foliar application on the number of branches of China Pink (*Dianthus chinensis*).

Cysteine Means	Ferrous Sulfate (mg·L^{-1})			Cysteine (mg·L^{-1})
	(F2)	(F1)	(F0)	
5.09 ^{c}	5.95 ^{f}	5.33 ^{g}	4.00^{h}	C0
7.27 ^{b}	7.96 ^{c}	7.24 ^{d}	6.60 ^{e}	C1
10.23 ^{a}	12.93 ^{a}	9.40 ^{b}	8.37 ^{c}	C2
	8.95 ^{a}	7.32 ^{b}	6.32 ^{c}	Ferrous Sulfate Means

"Means of each factor or their interactions followed by different letters indicate significant differences at the $P \leq 0.05$probability level according to Duncan's Multiple Range Test (DMRT).

Number of Leaves

The data presented in Table (3) clearly indicate significant differences among the experimental treatments. Foliar application of cysteine at level (C2) resulted in the highest mean number of leaves, reaching 24.11 leaves plant^{-1}, compared with the control treatment, which recorded the lowest value of 14.28 leaves plant^{-1}.
Similarly, foliar spraying with ferrous sulfate at level (F2) showed a clear superiority in vegetative growth traits, with a mean leaf number of 21.22 leaves plant^{-1}, compared with the treatment that recorded the lowest value of 17.38 leaves plant^{-1}.
Regarding the interaction effect between the two factors, the treatment combination (C2F2) produced the highest number of leaves, reaching 26.33 leaves plant^{-1}.

ISSN 2072-3857

Table (3): Effect of foliar application of cysteine and ferrous sulfate on the number of leaves of Chinese carnation (Dianthus chinensis L.) plants.

Cysteine Means	Ferrous Sulfate ($mg \cdot L^{-1}$) (F2)	(F1)	(F0)	Cysteine ($mg \cdot L^{-1}$)
14.28 c	17.13 f	14.83 g	10.90 h	C0
19.32 b	20.20 c	19.36 d	18.40 e	C1
24.11 a	26.33 a	23.13 b	22.86 b	C2
	21.22 a	19.11 b	17.38 c	Mean effect of ($FeSO_4$)

"Means of each factor or their interactions followed by different letters indicate significant differences at the $P \leq 0.05$probability level according to Duncan's Multiple Range Test (DMRT).

Number of Flowers

As shown in Table (4) significant significant differences among the study treatments, as the cysteine foliar application treatment at level (C2) produced the highest average number of flowers, reaching 12.18 flowers $plant^{-1}$, whereas the control treatment recorded the lowest value of 5.78 flowers $plant^{-1}$.

Similarly, the ferrous sulfate foliar application treatment at level (F2) showed a notable superiority in vegetative growth traits, where the average number of flowers reached 10.27 flowers $plant^{-1}$, whereas the treatment that gave the lowest value of 7.73 flowers $plant^{-1}$.

As for the interaction effect between the two factors, the (C2F2) treatment recorded the highest value for the number of flowers, yielding the highest value of 14.13 flowers $plant^{-1}$.

ISSN 2072-3857

Table (4): Effect of Cysteine and Ferrous Sulfate foliar application on the number of flowers of China Pink (*Dianthus chinensis L.*).

Cysteine Means	Ferrous Sulfate ($mg \cdot L^{-1}$)			Cysteine ($mg \cdot L^{-1}$)
	(F2)	(F1)	(F0)	
5.78 c	6.90 g	5.83 h	4.63 i	C0
8.88 b	9.80 d	9.03 e	7.83 f	C1
12.18 a	14.13 a	11.70 b	10.73 c	C2
	10.27 a	8.85 b	7.73 c	Mean effect of ($FeSO_4$)

"Means of each factor or their interactions followed by different letters indicate significant differences at the $P \leq 0.05$probability level according to Duncan's Multiple Range Test (DMRT).

5- Chlorophyll Content (SPAD)

An examination of the results in Table (5) reveals that significant superiority among the study treatments, as the cysteine foliar application treatment at level (C2) produced the highest average leaf chlorophyll content of 40.53 SPAD, whereas the control treatment recorded the lowest value of 30.54 SPAD. Similarly, the ferrous sulfate foliar application treatment at level (F2) showed a notable superiority in vegetative growth traits, where the average chlorophyll content reached 37.95 SPAD whereas the treatment that yielded the lowest value. As for the interaction effect between the two factors, the (C2F2) treatment recorded the highest value for chlorophyll content, yielding the highest value of 43.86 SPAD.

Table (5): Effect of Cysteine and Ferrous Sulfate foliar application on leaf chlorophyll content (SPAD) of China Pink (*Dianthus chinensis L.*).

Cysteine Means	Ferrous Sulfate ($mg \cdot L^{-1}$)			Cysteine ($mg \cdot L^{-1}$)
	(F2)	(F1)	(F0)	
30.54 c	32.96 g	30.43 h	28.23 i	C0
35.93 b	37.03 d	36.06 e	34.70 f	C1
40.53 a	43.86 a	39.16 b	38.56 c	C2
	37.95 a	35.22 b	33.83 c	Mean effect of ($FeSO_4$)

ISSN 2072-3857

"Means of each factor or their interactions followed by different letters indicate significant differences at the $P \leq 0.05$probability level according to Duncan's Multiple Range Test (DMRT).

Discussion

The obtained results demonstrate that the foliar application of cysteine and ferrous sulfate, whether individually or in combination, led to a significant improvement in the vegetative and physiological growth characteristics of the carnation plant. This can be explained by the vital roles these two factors play in the metabolic processes within the plant. These findings are consistent with those reported by [2,7], who indicated that amino acids act as bio-stimulants that contribute to enhancing growth and development by regulating physiological processes and metabolism within the plant, which is positively reflected in the vegetative traits.

The notable superiority of cysteine treatments, particularly at the high level (C2), in increasing plant height, branch number, and leaf number is attributed to its role as a sulfur-containing amino acid. It enters the structure of many proteins and enzymes and serves as a precursor for the synthesis of vital compounds such as glutathione, which contributes to protecting plant cells from oxidative stress and stimulating cell division and elongation. These results agree with [2] regarding the biological role of sulfur-containing amino acids in the formation of antioxidants within the plant. Furthermore, cysteine may enhance nutrient uptake efficiency and regulate hormonal activity, especially auxins, which positively affects vegetative growth and the formation of branches and leaves, consistent with the findings of [8,9], which indicated that amino acids improve nutrient absorption and regulate hormonal growth.

Regarding the effect of ferrous sulfate, it was evident in improving chlorophyll content (SPAD) and its subsequent impact on other traits. This is attributed to the essential role of iron in chlorophyll synthesis and its integration into the structure of cytochromes and ferredoxin, which are key components in the electron transport chain during photosynthesis and respiration. These results are in line with [10,11] who stated that iron is an essential element in chlorophyll formation and the activation of enzymatic systems associated with photosynthesis. Additionally, iron contributes to activating several enzymes related to carbohydrate and protein metabolism, leading to increased energy production (ATP) and stimulating vegetative growth, which also aligns with recent studies confirming iron's role in enhancing plant growth.

The increase in the number of flowers may be due to the improved nutritional status of the plant resulting from the availability of amino acids and

ISSN 2072-3857

micronutrients, which led to a better balance between vegetative and floral growth, as well as increased synthesis and translocation of carbohydrates to the floral buds. These results are consistent with [12,13], who mentioned that amino acids improve photosynthetic efficiency and increase chlorophyll content, which is positively reflected in flowering.

As for the interaction effect, the superiority of the (C2F2) treatment across all studied traits indicates a synergistic effect between cysteine and ferrous sulfate. Cysteine worked on enhancing protein synthesis and regulating vital processes, while iron contributed to raising the efficiency of photosynthesis and enzymatic processes, leading to functional integration within the plant that manifested as improved vegetative growth and increased flowering capacity. These results agree with [8,14]. regarding the integrative effect of bio stimulants and micronutrients in enhancing plant growth and productivity.

Conclusion

The results of the study showed that the foliar application of cysteine and ferrous sulfate led to a significant improvement in the vegetative and physiological growth characteristics of the carnation plant. The high levels of Both treatments C2 and F2outperformed in achieving the highest values for most studied traits, particularly chlorophyll content and vegetative growth characteristics. Additionally, the interaction between them demonstrated a positive synergistic effect, with the (C2F2) treatment recording the best results. This indicates that the combination of cysteine and ferrous sulfate at high levels is an effective treatment for enhancing plant growth and improving its biological efficiency.

References

1. **Sun, W., Shahrajabian, M.H., Kuang, Y. &Wang, N. (2024).** Amino acids, bio stimulants, and protein hydrolysates in agricultural sciences. *Plants, 13*(2), 210.
2. **Hernández, L. E., Fernández-García, N., Carvajal, M., & Martínez-Ballesta, M. C. (2024).** Plant nutrition challenges for sustainable agriculture. *Plants.*
3. **Riaz, M., Kamran, M., Fang, Y., Wang, Q., Cao, H., Yang, G.&Deng, L. (2021).** Iron deficiency in plants: Impacts and management strategies. *Journal of Plant Nutrition, 44*(8), 1231–1249.
4. **Fernández,V., &Ebert, G. (2021).** Foliar iron fertilization: A critical review. *Journal of Plant Nutrition and Soil Science, 184*(1), 1–15.
5. **Atero-Calvo, S., Martínez, J., López, R., García, M., &Pérez, L. (2025).** Physiological efficacy of amino acid-based bio stimulants on plant growth and photosynthesis. *Frontiers in Plant Science.*
6. **Bryant, R. B., Edwards, J. T., Smith, D. R., Johnson, K. L., &Williams, P. A. (2025).** Amino acids as fertilizer for agronomic crops. *Agronomy Journal.*

ISSN 2072-3857

7. **Henderson, B. C. R., da Silva, J. A. T., Khan, M. I. R., &Gupta, R. (2025).** Foliar application of amino acids as plant biostimulants: A review. *Plants, 14*(5), 789.
8. **Ebaid, M., El-Hawary, N., Elshazly, M., &Hassan, A. (2025).** Impact of foliar application of amino acids on growth and yield of plants. *PeerJ, 13*, e19802.
9. **Lisboa, L.A.M., *et al*. (2025).** Effect of amino acids in nutrient solutions on plant development and nitrogen metabolism. *Brazilian Journal of Science, 4*(2), 45–55.
10. **Briat, J.F., Dubos, C. & Gaymard, F. (2020).** Iron nutrition, biomass production, and plant product quality. *Trends in Plant Science, 25*(7), 673–689.
11. **Kobayashi, T. & Nishizawa, N.K. (2020).** Iron uptake, translocation, and regulation in higher plants. *Annual Review of Plant Biology, 71*, 589–620.
12. **Deveikytė, J., Kadžiulienė, Ž., Liaudanskienė, I., & Krištaponis, A. (2025).** Amino acids as bio stimulants: Effects on plant growth and quality. *Agriculture, 15*(14), 1496.
13. **Li, T., Zhang, Y., Wang, X., Liu, H.,&Chen, F. (2024).** Integrated physiological and transcriptomic analysis of amino acid fertilizers on plant growth. *Journal of King Saud University – Science, 36*(1), 102756.
14. **Heidarzadeh, A., Moradi, P., Souri, M. K., & Tavallali, V. (2025).** Role of amino acids in plant growth, development, and stress responses. *Plant Cell, Tissue and Organ Culture.*

ISSN 2072-3857