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Impact of Epsom Salt Concentrations on the Growth and Development of Gladiolus Cultivars

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ABSTRACT

Background. Gladiolus is an important ornamental plant known for its vibrant colors and high demand in the market. Its growth is greatly affected by several factors, among which the most prominent are magnesium and sulfur deficiency. Epsom salt is a rich source of magnesium and sulfur and has the ability to improve the vegetative and reproductive attributes of different gladiolus cultivars. However, its optimum concentrations for improved growth and development need to be identified.

Materials and Methods. This study was conducted at the ornamental nursery, The University of Agriculture, Peshawar, Pakistan, following a randomized complete block design with two factors. Factor A comprised Epsom salt concentrations at 0%, 2%, 4%, and 6%. While, Factor B included gladiolus cultivars, namely White Prosperity, Rosa Supreme, Nova Lux, and Advanced Red. Foliar application of Epsom salt was done when the plants reached three to five true leaf stages.

Results. Among all the concentrations, Epsom salt showed greater chlorophyll content at the rate of 4%, as well as the number of florets, floret diameter, floret fresh weight, floret dry weight, spike length, and vase life. Likewise, the highest number of leaves, leaf area, floret diameter, number of florets, floret fresh and dry weight, as well as vase life, weight, and diameter of daughter cormels were observed in the Advance Red cultivar of gladiolus. Interactive effects revealed that Advance Red, with 4% Epsom salt, achieved maximum floret weight, dry matter, and vase life, while the longest spikes were recorded in White Prosperity.

Conclusion. This study identifies 4% Epsom salt as the optimal concentration for enhancing gladiolus growth and floral quality, with Advanced Red emerging as the most responsive cultivar.

Keywords: corm development, Epsom salt, flowering, gladiolus, magnesium, sulfur

Highlights

- Optimal Epsom salt supplementation enhances photosynthetic efficiency and floral quality

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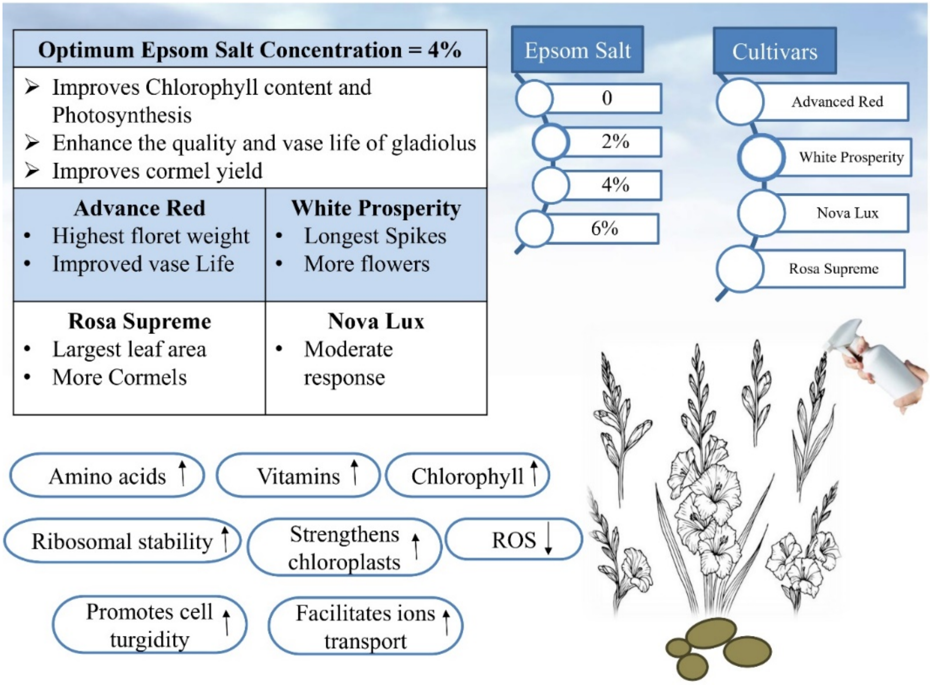
- Genotypic variation drives differential responses to mineral fortification
- Integrated cultivar-nutrient strategy maximizes commercial viability.

GRAPHICAL ABSTRACT



1. INTRODUCTION

Gladiolus (*Gladiolus grandiflorus* L.) is an important ornamental crop known for its beautiful flowers arranged in an acropetal manner on the spike [1]. It is believed to have originated in South Africa. Gladiolus belongs to the family Iridaceae [2]. The flowers of gladiolus are large and vibrant with very eye-catching colors. The gladiolus spike consists of 15-20 florets. The florets start to open from the lowermost floret present on the spike (from the base to the apex). Due to its vibrant colors, large florets, easy cultivation, and varietal variation, this plant has gained widespread recognition in the floriculture industry. Gladiolus is commonly known as "sword lily" because its leaves resemble a sword [3].

There are about 260 varieties of the gladiolus. The growth and flowering traits vary depending on the specific variety. The commercial propagation of gladiolus is mostly done by asexual or vegetative propagation through corms and cormels to achieve true to type and quick production. Typically, gladiolus corms are planted in winter and flowering starts in spring, depending upon the cultivars and climatic variation. The plant thrives well in tropical and sub-tropical regions. Gladiolus is the eighth most important cut flower in the world. Countries with the most gladiolus production include France, Netherlands, Brazil, USA, Italy, Bulgaria, Australia, and Poland [4]. Akin to these countries, the floriculture sector of Pakistan has recognized the importance of the gladiolus plant because of its unique features. In Pakistan, this crop is cultivated in various regions of Punjab, KPK, Sindh, and Balochistan. Gladiolus is a highly adaptable crop and grows well in different environments [5].

Gladiolus spikes are mostly used for ornamental purposes, specifically in bouquets, decorations, and exhibitions [6]. Plant attributes are slightly affected by the biotic and abiotic factors. Besides these factors, the plant's nutritional requirements are essential to be fulfilled to achieve optimum growth and flower quality of the crop [7].

Magnesium (Mg) and sulfur (S) are two of the most important secondary macronutrients required by the plant. Mg is the central component of the chlorophyll molecule. Plant health is greatly influenced by the availability of magnesium and sulfur. They help in the relocation of nutrients in the plant's body and regulate different enzymes to improve plant growth. Sulfur is known to help plants to activate their defense system against pests and diseases. If these nutrients are deficient in the soil, the growth of the plant remains retarded and shows the signs of chlorosis between the veins, as well as less yield with inferior quality flowers. Thus, it is important to provide the plants with an optimum amount of these nutrients to have high quality gladiolus cut flowers.

Foliar application of Epsom salt is the best way to meet the needs of magnesium and sulfur in plants. Various studies have revealed that it improves the flower quality and quantity, promotes the chlorophyll content, and improves the growth and development of plants, ultimately resulting in higher quality and vase life of the flowers [8]. However, the response of Epsom salt to every cultivar differs because each cultivar has a different ability to absorb and utilize these nutrients. Hence, this study was conducted to find out the optimum concentration of Epsom salt for improved growth and production of various gladiolus cultivars under the agro-climatic conditions of Peshawar, Pakistan.

2. MATERIALS AND METHODS

This study was conducted using a randomized complete block design with two factors. Factor A comprised Epsom salt ($MgSO_4 \cdot 7H_2O$) concentrations (0%, 2%, 4%, and 6%), while Factor B comprised Gladiolus cultivars, namely White Prosperity, Advance Red, Rosa Supreme, and Nova Lux. There were a total of 16 treatment combinations, each replicated thrice, with a total of 48 experimental units. The soil of the experimental field had a silt loam texture and it was prepared thoroughly through ploughing, followed by leveling. Gladiolus corms were sown on March 1, 2024 on ridges, maintaining a 30 cm spacing both within and between rows.

Epsom salt solutions were prepared following the method described by Akhtar et al. [8] by dissolving 20 g, 40 g, and 60 g of Epsom salt in 1L of distilled water to obtain 2%, 4%, and 6% solutions, respectively. Foliar applications of these solutions were carried out twice, first at the three-leaf stage and again at the five-leaf stage of plant development. All cultural practices, including weeding, irrigation, and hoeing were kept constant throughout the experiment.

Soil analysis was done before the experiment as per the method of Estefan et al. [9]. The analysis is shown in Table 1. Soil samples were collected at a depth of 0-30 cm, air-dried, ground, and passed through a 2 mm sieve. The Bouyoucos hydrometer method was used to determine soil texture. Digital pH and EC meter were used to measure soil pH and electrical conductivity (EC) in a 1:2.5 soil-water suspension.

The Kjeldahl digestion method was used to determine the available nitrogen. AB-DTPA extraction procedure was followed for phosphorus and potassium determination. Potassium was determined on a spectrophotometer and phosphorus on a flame photometer. Atomic absorption spectrophotometry (AAS) was used for the estimation of magnesium, while turbidimetric method was used for the estimation of sulfur content. The results indicated that the soil of the research field was deficient in magnesium and sulfur, thus highlighting the need for a prominent magnesium and sulfur source to address the issue.

Table 1. Experimental Soil Analysis

Soil Characteristics	Values
Sand (%)	17.0
Silt (%)	56.0
Clay (%)	27.0
pH	8.2
EC (ds/m)	0.45
Nitrogen (%)	0.11%
Phosphorous (mg/kg)	4.50
Potassium (mg/kg)	110
Magnesium (%)	0.015%
Sulfur (%)	0.007%

Data was recorded on different parameters to determine the impact of Epsom salt on the growth and development of gladiolus cultivars. The studied parameters included the number of leaves per plant, chlorophyll content (SPAD), leaf area (cm^2), number of florets per spike, floret diameter (cm), fresh and dry weight of florets (g), vase life, spike length (cm), weight (g) and diameter (mm) of daughter corms, and the number of cormels per corm.

The number of leaves and the number of florets were calculated by counting them from randomly selected plants and their average was computed. SPAD-502 chlorophyll meter was used to measure the chlorophyll content from mature and healthy leaves. Leaf area was recorded with the help of a leaf area meter from randomly selected leaves and their average was computed. Likewise, floret diameter was recorded with a Vernier caliper from randomly selected florets from each treatment and replication and the average was recorded. Floret fresh weight was computed by weighing the florets collected from each treatment and replication on a digital scale and the average was computed. These florets were then dried in the oven at 70°C and their dry weight was recorded. Vase life was computed from randomly selected florets of gladiolus cultivars from each treatment and replication. The florets were placed in distilled water at room temperature and the average number of days required to lose their freshness were recorded. Spikes were collected from each treatment and replication. Their length was measured from the base to the top with the help of a measuring tape and the average was computed. After harvesting, the diameter was recorded with the Vernier caliper and the average was computed. Likewise, the number of cormels from each mother corm was counted and the average was computed.

2.1. Statistical Analysis

Statistical analysis was done using two-way Anova performed via Statistix 8.1 software. Each treatment had three replicates. Statistical differences between the means were identified by applying the LSD test at 95% and 99% confidence intervals ($p < 0.05\%$ & $p < 0.01\%$) where needed. R Studio was used for data visualization, including principal component analysis (PCA) and Pearson correlation analysis [10].

3. RESULTS

Overall, Epsom salt concentrations significantly affected growth, flowering, yield, and post-harvest traits of gladiolus cultivars, with several parameters showing significant interaction effects. Moderate Epsom salt levels generally produced better responses across the cultivars, while cultivar-specific differences remained evident. Table 2 reveals that gladiolus cultivars showed a significant difference in terms of the number of leaves. The maximum number of leaves (7.35) was seen in Advance Red cultivar, whereas the minimum number of leaves (6.65) was recorded in Rosa Supreme.

Table 2. Effect of Epsom Salt on No. of Leaves, Chlorophyll Content (SPAD), Leaf Area (cm^2), No. of Florets, Floret Diameter (cm), and Floret Fresh Weight (g) of Gladiolus Cultivars

Epsom Salt Conc. (%)	NoL	CC	LA	NoF	FD	FFW
0 (distilled water)	7	32.17 B	766.96	8.49 B	6.87 B	1.54 B
2	6.8	36.28 B	735.83	8.42 B	7.34 B	1.65 B
4	7.17	44.68 A	774.92	9.68 A	8.74 A	1.93 A
6	6.6	33.17 B	713.24	8.41 B	7.40 B	1.54 B
LSD at ($p \leq 0.01$)	NS	6.78	NS	1.07	0.82	0.15
Gladiolus Cultivars						
White Prosperity	6.97 ab	36.71	781.97 A	9.55 A	7.68 AB	1.63 B
Advance Red	7.35 a	38.44	758.24 A	8.82AB	8.39 A	1.88 A
Rosa Supreme	6.64 b	36.58	841.07 A	8.87 A	7.44 B	1.58 B
Nova Lux	6.65 b	34.54	609.66 B	7.76 B	6.57 C	1.57 B
LSD at ($p \leq 0.05$)	0.69	NS	101.19	1.07	0.82	0.15
Interaction	NS	NS	NS	NS	NS	0.23

Note. NoL= number of leaves, CC= chlorophyll content, LA= leaf area, NoF= number of florets, FD= floret diameter, FFW= floret fresh weight

Epsom salt treatments significantly affected the chlorophyll content levels (Table 2). Plants treated with 4% Epsom salt exhibited maximum chlorophyll content (44.68 SPAD), with the second-highest value at 2% concentration (36.28 SPAD). However, the lowest value (32.17 SPAD) was recorded from the control. Leaf area showed considerable variation between cultivars (Table 2). The leaf area of Rosa Supreme (841.07 cm²) was maximum and statistically similar to White Prosperity (781.97 cm²) and Advance Red (758.24 cm²). The smallest leaf area (609.66 cm²) was that of Nova Lux. Different cultivars and Epsom salt concentrations significantly influenced the number of florets per spike (Table 2). Among all the cultivars, White Prosperity produced the maximum number of florets (9.55), at par with Rosa Supreme (8.87) and Advance Red (8.82) and significantly superior to Nova Lux (7.76). Among the Epsom salt treatments, the highest number of florets per spike (9.68) was recorded with 4% application, followed by 0% (8.49), 2% (8.42), and 6% (8.41), with the latter three being statistically similar.

Floret diameter was also significantly affected by the interaction between the respective cultivar and Epsom salt concentration (Table 2). Advance Red produced the largest floret diameter (8.39 cm), which was statistically at par with White Prosperity (7.68 cm), whereas Nova Lux had the smallest (6.57 cm) diameter. The maximum floret diameter among Epsom salt treatments was observed in the 4% concentration group (8.47 cm), followed by 6% (7.40 cm), while the control had the lowest (6.87 cm) diameter.

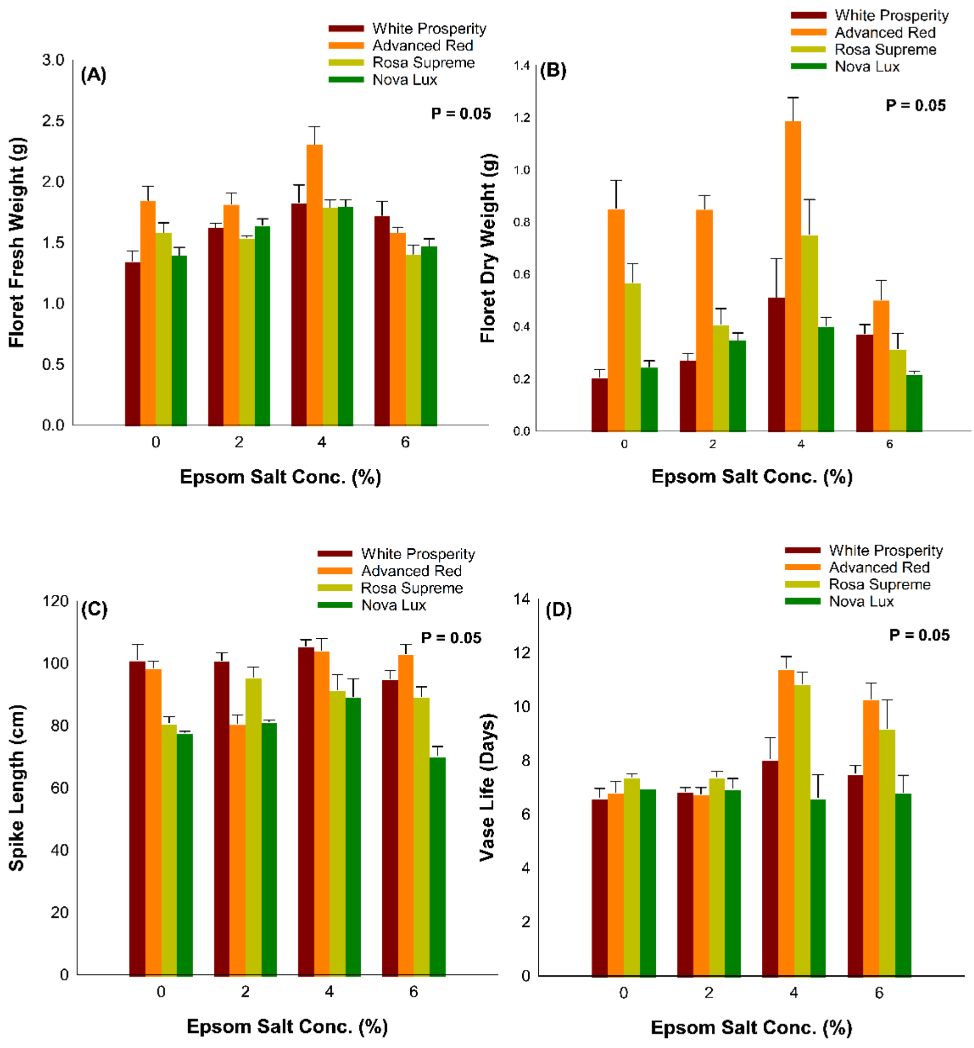


Figure 1. Floret Fresh Weight (A), Floret Dry weight (B), Spike Length (C), and Vase Life (D) of Gladiolus Cultivars as Affected by Epsom salt Application

Fresh weight of florets was significantly influenced by the interaction between the respective cultivar and the Epsom salt level (Table 2). The highest floret fresh weight (2.30 g) was recorded in Advance Red treated with 4% Epsom salt, while the lowest (1.34 g) was observed in White Prosperity under control conditions (Fig. 1A). Across cultivars, the highest average floret fresh weight was found in Advance Red (1.88 g) and the lowest in Nova Lux (1.57 g). Among Epsom salt treatments, 4% produced the maximum fresh weight (1.93 g), while the control recorded the minimum (1.54 g). Similar trends were observed for floret dry weight (Table 3). The highest dry weight (1.19 g) was found in Advance Red treated with 4% Epsom salt, while the lowest (0.20 g) was recorded in White Prosperity under control conditions (Fig. 1B).

Table 3. Effect of Epsom Salt on Florets Dry Weight (g), Spike Length (cm), Vase life (Days), No. of cormels, Weight of Daughter Corms, and Diameter of Daughter Corms of Gladiolus Cultivars

Epsom Salt Conc. (%)	FDW	SL	VL	NOC	WDC	DDC
0 (distilled water)	0.46B	89.65B	6.96B	4.85	14.57 B	48.86
2	0.47B	89.66B	7.00B	5.24	16.98 AB	47.32
4	0.71A	97.68A	9.25A	5.08	16.37 AB	45.49
6	0.35B	89.53B	8.46A	5.83	18.62 A	50.26
LSD at ($p \leq 0.01$)	0.14	6.28	0.90	NS	2.56	NS
Gladiolus Cultivars						
White Prosperity	0.34C	100.71A	7.27B	4.91 BC	13.65 B	36.93 C
Advance Red	0.84A	96.68A	8.83A	5.83 AB	19.38 A	56.03 A
Rosa Supreme	0.51B	89.42B	8.71A	7.24 A	18.23 A	52.22 AB
Nova Lux	0.30C	79.74C	6.85B	3.83 C	15.28 B	46.28 B
LSD at ($p \leq 0.01$)	0.14	6.28	0.90	1.43	2.56	7.73
Interaction	0.21	12.57	1.80	NS	NS	NS

Note. FDW = Floret dry weight, SL = Spike length, VL = Vase life, NOC = No. of cormels, WDC = Weight of daughter corms, DDC = Diameter of daughter corms

Spike length was also significantly influenced by the interaction between the respective cultivar and the Epsom salt concentration (Table 3). The longest spikes (105.5 cm) were recorded in White Prosperity treated with 4% Epsom salt, while the shortest (70.4 cm) were observed in Nova Lux treated with 6% Epsom salt (Fig. 1C). Vase life was significantly affected as well (Table 3). The longest vase life (11.43 days) was recorded in Advance Red under 4% Epsom salt treatment, while the shortest (6.63 days) was observed in White Prosperity under control conditions (Fig. 1D). Similarly, the number of cormels per corm differed significantly among the cultivars (Table 3). Rosa Supreme produced the highest number (7.24), statistically similar to Advance Red (5.83), while Nova Lux produced the lowest (3.83).

The weight of the daughter corm was significantly influenced by the interaction between the respective cultivar and the Epsom salt level. The maximum weight was observed in Advance Red (19.38 g), followed by Rosa Supreme (18.23 g). Whereas, the minimum weight was exhibited in White Prosperity (13.65 g). The 6%

Epsom salt treatment produced the highest corm with a weight of 18.62 g, at par with 2% Epsom salt treatment, having a corm weight of 16.98 g. The lowest corm weight (14.57 g) was observed in the control. The diameter of the daughter corms varied significantly among the cultivars. The maximum diameter (56.03 mm) was produced in Advance Red, followed by Rosa Supreme (52.22 mm), while the minimum diameter (36.93 mm) was recorded in White Prosperity.

3.1. Principal Component Analysis

PCA and correlation analysis were used to understand the relationship between vegetative growth, flower characteristics, and corm development under Epsom salt application in gladiolus (Fig. 2). According to the results, the first two principal components (PC1 and PC2) explained 32.4% and 16.9% of the total variance respectively, accounting for a cumulative variance of 49.3% in the traits.

The correlation circle of variables revealed that PC1 is dominantly associated with floret and corm characteristics, including floret dry weight, floret fresh weight, floret diameter, corm weight, number of cormels, and vase life. These traits are projected strongly on PC1, as indicated by their high cos2 value, so they explain a large part of the variance. On the contrary, PC2 was found to be linked with vegetative traits, including chlorophyll content, plant leaf area, and number of florets per plant. The intensity of the cos² color gradient also supports the relevance of floral and corm traits, especially floret diameter and weight, since they are strongly represented in the PCA space. The scree plot shown below indicates an abrupt fall off in eigenvalues after the third PC that contributes a total of 62.9% of the total variance (PC1: 32.4%; PC2: 16.9%; PC3: 13.7%). This implies that the most significant variation in the data can be captured using the first three components, as exists well on a spatial plot.

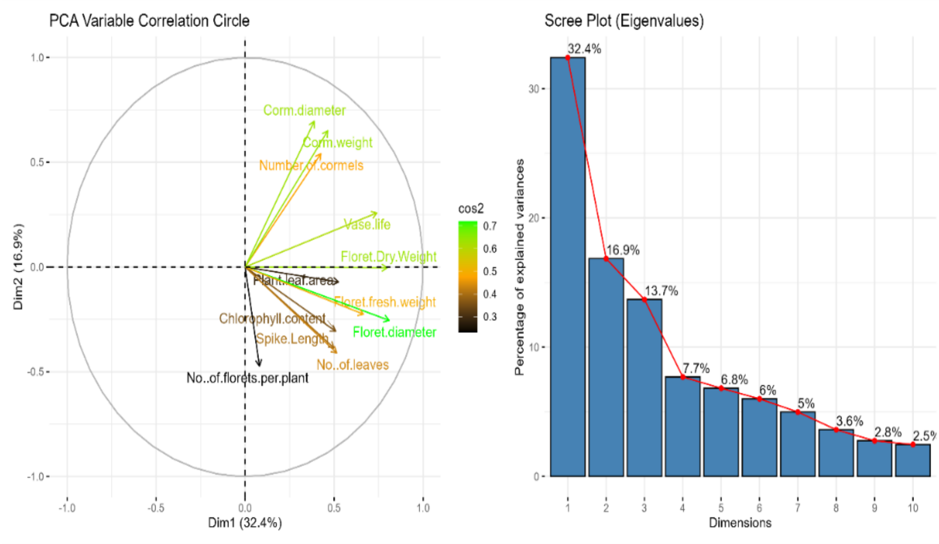


Figure 2. Principal Component Analysis and Scree Plot of the Studied Attributes of Gladiolus Cultivars

Along with PCA, a heat map was prepared to show the correlation among the studied traits (Fig. 3). It shows a strong positive correlation between the measured floral attributes of floret diameter, floret fresh weight, and floret dry weight. In addition, it records a similar trend between corm weight and number of cormels. Furthermore, vase life shows a moderate to strong positive correlation with several floral traits, suggesting that enhanced floral development contributes to increased post-harvest longevity. Vegetative growth parameters, particularly the number of leaves and plant leaf area, are also positively correlated. Conversely, some traits, such as chlorophyll content, exhibit a weaker or statistically insignificant association with floral and corm traits, as indicated by the presence of non-significant correlations marked with an 'X'.

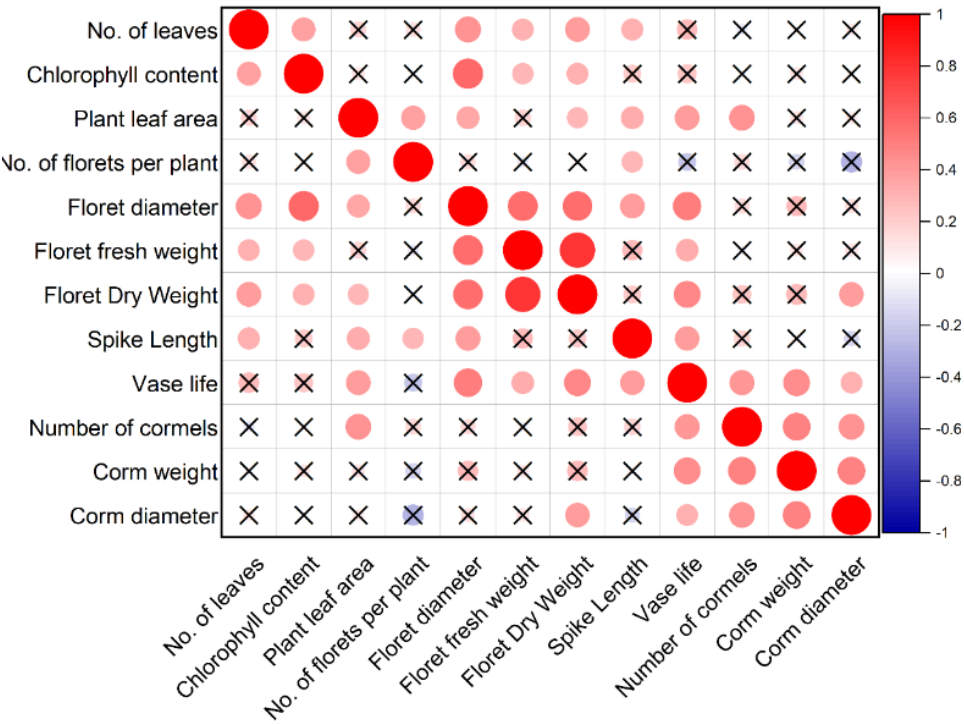


Figure 3. Heatmap of the Studied Attributes of Gladiolus Cultivars

Fig. 4 presents the correlation matrix and pairwise relationships among quality attributes, such as fresh weight, dry weight, spike length, vase life, and number of cormels across the four gladiolus varieties (Advance Red, Nova Lux, Rosa Supreme, and White Prosperity). Fresh weight exhibits a strong and highly significant positive correlation with dry weight (r = 0.788**), indicating that plants producing a heavier fresh biomass also tend to have a higher dry matter accumulation. This relationship remains consistently strong within varieties, particularly in Advance Red (r = 0.947**) and Rosa Supreme (r = 0.830**). Spike length shows a moderate association with vase life (r = 0.385*), suggesting that longer spikes slightly enhance post-harvest longevity. In contrast, the number of cormels display a weak correlation with most floral quality traits, implying that cormel production is physiologically less linked to floral biomass or post-harvest performance.

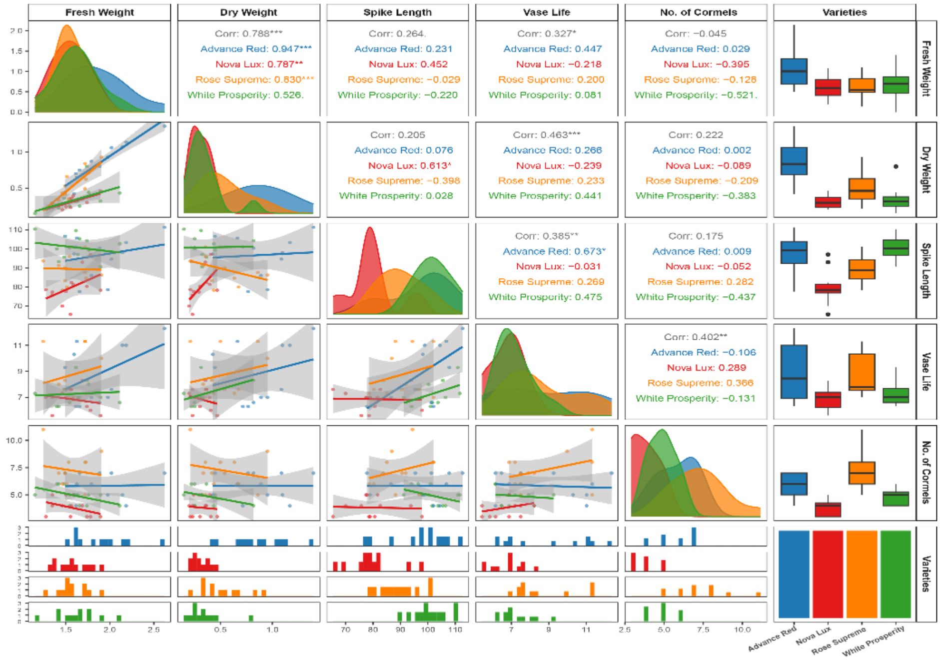


Figure 4. Correlation Matrix of the Quality Attributes of Gladiolus Varieties

Together, these multivariate analyses underscore the role of Epsom salt in influencing a network of interrelated growth parameters in gladiolus cultivars. The clustering of floral and corm traits within the same principal component, along with their strong intercorrelations, suggests that Epsom salt enhances assimilate partitioning toward reproductive development, potentially mediated through an improved nutrient uptake and photosynthetic efficiency.

4. DISCUSSION

In this study, the use of Epsom salt was found to significantly affect the gladiolus cultivars for their various morphological and physiological characteristics, mainly due to the essential role of Epsom salt in metabolism. Magnesium (Mg^{2+}) is the core element in chlorophyll. It directly takes part in photosynthesis, energy transfer (ATP synthesis), and enzyme activation. Whereas, the production of amino acids, vitamins, and coenzymes is assisted by sulfur. These nutrients enhance growth, photosynthesis, and reproductive development [11].

The number of leaves per plant increases with Epsom salt treatment, especially at 4% concentration. Epsom salt application generally favors chlorophyll formation, resulting in increased photosynthesis. Magnesium helps to maintain ribosomal stability and cell division. Likewise, sulfur is a crucial component of amino acids including cysteine and methionine, which support leaf expansion and development [12]. Optimal nutrient levels potentially enhance the production of cytokinins, which are plant hormones that promote cell division in leaf primordia and inhibit senescence, thus resulting in improved vegetative growth [13]. The findings correlate with those of Mushtaq et al. [14] and Hossain et al. [15].

Higher levels of chlorophyll suggest that magnesium in the Epsom salt may help to stabilize chlorophyll. Besides, it also strengthens chloroplasts, the sites of photosynthesis. Studies suggest that the magnesium in Epsom salt increases the efficiency of photosystem II and electron transport work [8, 16]. Sulfur is also essential, since it is utilized in the composition of glutathione, a powerful antioxidant that protects chloroplasts. Maintaining chloroplasts assists in preventing plants from losing pigment. Research indicates that applying magnesium and sulphur-based fertilizers in an appropriate dosage can enhance the chlorophyll content of different crops, such as sugar beet [8, 15, 17]. Using Epsom salt on plants aids in the growth of leaves and roots, thus help the plants to manage water more effectively and expand the cells. Magnesium activates the enzymes that control the transport of ions. This is important for turgidity and growth. Sulfur compounds also help to make proteins found in cell walls, allowing leaves to expand more easily. Research on other plants showed similar results, indicating that the external application of nutrients favors the healthy development of plants [18].

The increase in the number of florets per spike and the diameter of florets could be due to improved production and distribution of assimilates regulated through hormonal and metabolic changes. Magnesium helps the movement of carbohydrates into the phloem and other tissues, including flower buds. This likely stimulates floral initiation and development. The availability of Mg^{2+} also increases the biosynthesis of gibberellins and auxins, hormones crucial for floral organogenesis and elongation, while reducing ethylene synthesis that could prematurely abort developing florets [19, 20]. Similar results were observed by Chopde et al. [21], who reported foliar application of various nutrients, including magnesium fertilizers, on different cultivars of gladiolus.

Floret fresh and dry weights increased significantly with Epsom salt application, particularly in the cultivar Advance Red. Such a reaction is likely associated with a higher metabolic rate and photosynthate accumulation in young floral tissues. Mg^{2+} stimulates the activity of most of the important enzymes in carbohydrate metabolism, such as ribulose-1, 5-bisphosphate carboxylase/oxygenase (Rubisco), and sucrose synthase, which enhance biomass synthesis [22]. The synthesis of proteins via sulfur can also contribute to structural development and floret turgidity [23]. Similar observations were recorded by El-Naggar and El-Nasharty [24] and Gómez-Pérez et al. [25] in the case of foliar nutrition of various gladiolus cultivars using various concentrations of nutrients.

The use of Epsom salt increased spike length because it promoted the elongation of cells and elevation of gibberellins, following favorable magnesium and sulfur nutritional conditions. It is known that gibberellins promote stem elongation by relaxing the cell wall and increasing the water uptake. Magnesium also plays a role in the ATP-dependent reaction required in active transportation and vertical growth [26, 27]. Akhtar et al. [8] also observed similar results by the application of Epsom salt in the beetroot crop.

Plants treated with Epsom salt appear to have a longer vase life because of a more robust cell membrane, slower aging of flowers, and reduced stress due to toxic substances. Magnesium facilitates the balance between nutrients and maintains the cell membranes [28]. Conversely, sulfur assists in the synthesis of the antioxidant glutathione, promoting flower preservation despite the senescence process [23]. Elevated cytokinin levels due to Epsom salt result in delaying the aging process and enhancing flower quality after harvest [29].

The increase in the weight and size of the daughter corm as well as the number of cormels of the Epsom salt-treated plants occurred due to the good coordination between the plant's energy production and storage process. Magnesium improves the process of photosynthesis, which helps in the production of carbohydrates and supports their movement inside the plant to corms and cormels [22]. Sulfur also plays an important role in the synthesis of proteins and coenzymes, which are essential for the growth and development of corm. Certain plant hormones like auxin and cytokinin play an important part in the growth and development of corm [30]. Auxin helps to strengthen storage organs, while cytokinin helps in cell division in developing corms [31]. Similar differences regarding the number and size of cormels and corms were observed by Halder et al. [32] and Memon et al. [33] among gladiolus cultivars.

The response of plants to foliar application showed a clear concentration-dependent pattern, with performance improving from control to 4% and remaining superior to the control at 6%, although with reduced gains as compared to the 4% treatment. This trend suggests that moderate concentrations optimize foliar absorption and physiological utilization, whereas higher concentrations may approach a saturation threshold beyond which additional applied solutes do not proportionally enhance uptake or metabolic efficiency. Similar dose-dependent responses have been reported for foliar-applied biostimulants and nutrient solutions, where excessive concentrations result in diminishing returns, rather than toxicity. Therefore, 4% concentration appears optimal to maximize plant performance under the current experimental conditions.

Summarizing the above discussion, the use of Epsom salt resulted in a balanced hormone level, enhanced nutrient assimilation, and intense antioxidant defense, which enhanced the vegetative, flowering, and storage quality of the gladiolus flower. The above results signify that an optimum supply of magnesium and sulfur in floricultural crops is important to enhance growth performance and quality parameters.

4.1. Conclusion

The application of 4% Epsom salt was found to be the most effective in improving gladiolus growth and quality parameters. The treatment significantly improved vegetative vigor, flowering quality, and corm development among the cultivars, with Advance Red showing the maximum response. Moreover, the study found that Epsom salt regulates ATP synthesis and enzyme activation in order to improve photosynthesis. It enhances ribosomal stability and cell division and also aids in the production of different amino acids, such as methionine and cysteine, to support the growth and development of gladiolus cultivars. Further, it uplifts the vegetative and reproductive growth of the gladiolus plant by enhancing the synthesis of plant growth promoters, such as auxins and gibberellins. This results in the uplifting of antioxidants including glutathione, which reduces the production of ethylene and enhances the overall shelf-life of gladiolus spikes. Therefore, it is recommended that Epsom salt should be used (at the rate of 4%) to improve the productivity of gladiolus in similar agro-climatic conditions.

Author Contribution

Syed Saadullah Shah: data curation, formal analysis, investigation. **Masood Ahmad:** conceptualization, supervision, resources, project administration. **Hamza Ali:** writing - original draft, writing – review and editing, visualization, software. **Shahid Zaman:** data curation, methodology. **Saima Naz Malik:** data curation, writing – review and editing. **Ali Asghar:** data curation, validation. **Ikram Ullah:** writing – review and editing

Conflict of Interest

The authors of the manuscript have no financial or non-financial conflict of interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

Data supporting the findings of this study will be made available by the corresponding author upon request.

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