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ARTICLE

Efficiency of foliar application of calcium sources on morphological traits, nutritional status, and vase life of two rose cultivars

Eficiência da aplicação foliar de fontes de cálcio em características morfológicas, estado nutricional e vida de vaso de duas cultivares de rosa

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Abstract: Calcium is critical in enhancing cut flower growth and quality. Despite the availability of several calcium sources, limited research has focused on identifying the most effective source of this nutrient for roses. This study aimed to determine the optimal calcium source for two rose cultivars, 'Samurai' and 'Jumilia,' by investigating the effects of foliar applications of calcium nitrate ($Ca(NO_3)_2$), calcium silicate (Ca_2O_4Si), and calcium amino acid chelate with glycine ($Ca(Glys)_2$), compared to a control containing distilled water. The results demonstrated that $Ca(NO_3)_2$ significantly improved stem length in 'Jumilia,' while Ca_2O_4Si notably increased stem diameter, fresh mass, and the number of flowers. Additionally, $Ca(Glys)_2$ was the most effective in enhancing carotenoid content. Both Ca_2O_4Si and $Ca(NO_3)_2$ applications elevated the levels of chlorophyll *a* and *b* and total chlorophyll, thereby enhancing photosynthetic rates. The results of this study indicate the effectiveness of $Ca(NO_3)_2$ in supplying calcium to petals, consequently increasing the membrane stability index, delaying wilting, and extending the vase life. Additionally, $Ca(Glys)_2$ was effective in supplying calcium to the roots and phosphorus to the leaves. $Ca(NO_3)_2$ also enhanced nitrogen and copper concentrations, while Ca_2O_4Si increased the leaves' potassium, iron, and manganese contents. The results indicate that using $Ca(NO_3)_2$ as a foliar spray is especially beneficial for improving cut roses' quality and vase life.
Keywords: calcium, flower quality, growth, mineral nutrients, *Rosa hybrida*.

Resumo: O cálcio é fundamental para melhorar o crescimento e a qualidade de flores de corte. Apesar da disponibilidade de várias fontes de cálcio, a pesquisa sobre a identificação da fonte mais eficaz desse nutriente para as rosas é limitada. Este estudo teve como objetivo determinar a fonte ideal de cálcio para duas cultivares de rosa, 'Samurai' e 'Jumilia', investigando os efeitos das aplicações foliares de nitrato de cálcio ($Ca(NO_3)_2$), silicato de cálcio (Ca_2O_4Si) e quelato de cálcio com aminoácido e glicina ($Ca(Glys)_2$), em comparação com um controle contendo água destilada. Os resultados demonstraram que o $Ca(NO_3)_2$ melhorou significativamente o comprimento do caule em 'Jumilia', enquanto o Ca_2O_4Si aumentou notavelmente o diâmetro do caule, a massa fresca e o número de flores. Além disso, o $Ca(Glys)_2$ foi o mais eficaz em aumentar o conteúdo de carotenoides. Tanto o Ca_2O_4Si quanto o $Ca(NO_3)_2$ elevaram os níveis de clorofila *a* e *b* e clorofila total, melhorando assim as taxas fotossintéticas. Os resultados deste estudo indicam a eficácia do $Ca(NO_3)_2$ no fornecimento de cálcio para as pétalas, aumentando consequentemente o índice de estabilidade das membranas, retardando a murcha e estendendo a vida de vaso. Além disso, o $Ca(Glys)_2$ foi eficaz no fornecimento de cálcio para as raízes e fósforo para as folhas. O $Ca(NO_3)_2$ também aumentou as concentrações de nitrogênio e cobre, enquanto o Ca_2O_4Si aumentou os conteúdos de potássio, ferro e manganês nas folhas. Os resultados indicam que o uso de $Ca(NO_3)_2$ através da pulverização foliar é especialmente benéfico para melhorar a qualidade e a vida de vaso das rosas de corte.
Palavras-chave: cálcio, crescimento, qualidade das flores, nutrientes minerais, *Rosa hybrida*.

Introduction

The rose (*Rosa hybrida* L.) is widely recognized as a top decorative plant globally due to its attractive appearance, pleasant scent, and extended blooming period. It holds significant cultural importance and is widely used as both garden ornamentals and cut flowers (Simin et al., 2024). Increasing the yield and quality of roses is the primary goal for producers. Among the macronutrients present in nutrient solutions, calcium (Ca) plays a significant role in enhancing growth and preserving the quality of cut flowers. Calcium (Ca) is an essential nutrient for plant growth and development, playing a key role in cell wall stability, membrane integrity, and signal transduction pathways (Weng et al., 2022). While studies on poplar have shown that Ca enhances crop quality by increasing leaf area, improving stomatal conductance, and boosting photosynthesis rates (Weng et al., 2022), similar effects have been observed in ornamental crops such as roses, particularly in improving aesthetic and postharvest traits (Banijamali et al., 2018).

Ca plays a crucial role at the metabolic level by stabilizing the cell walls through the formation of calcium pectates, maintaining membrane integrity, and acting as a secondary messenger in signal transduction pathways (An et al. 2014). It regulates various enzymatic activities and influences hormone metabolism, particularly auxins, which are crucial for growth processes, such as cell division and elongation (Mohammed and Abood, 2020). These metabolic roles contribute to enhanced physiological responses such as improved nutrient uptake, photosynthesis, and stress tolerance. For example, Torre et al. (1999) demonstrated that Ca application increased the longevity and size of rose flowers. Bar-Tal et al. (2001) reported that higher Ca levels in flower parts reduced susceptibility to *Botrytis cinerea*, likely due to its role in strengthening cell walls. Similarly, Khalili et al. (2023) showed that calcium chloride preserved fresh weight and quality in *Solanum lycopersicum*. Furthermore, Weng et al. (2022) observed improved growth and nutrient absorption in poplar under Ca application, which may be attributed to enhanced cellular metabolism.

However, Ca is considered a non-mobile element, and plants require a continuous Ca supply for strong leaf and root growth (Duan et al., 2022). Different sources of calcium have demonstrated varying degrees of effectiveness in enhancing plant quality. Therefore, exploring various calcium sources for foliar application is important to identify the most effective option for boosting the yield and quality of cut flowers. For example, Bennett et al. (2023) investigated the impact of six different Ca sources — both laboratory and commercial grades, including Ca nitrate, Ca chloride, Ca amino acid chelate, Ca ethylenediaminetetraacetic acid

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chelate, and Ca silicate – on managing *Botrytis cinerea* in *Petunia* × *hybrida* flowers. According to the findings, Ca chloride proved to be the most efficient Ca source in mitigating *Botrytis blight*.

Ca is commonly applied as Ca nitrate and Ca silicate in pre-harvest foliar sprays, and their positive effects on reducing ethylene production, and increasing post-harvest shelf life have been reported (Coutinho et al., 2020). In addition, metal chelates are one of the forms used today to supply nutrients to plants. Recently, various chelating agents have been developed specifically for agricultural use. Aminochelates have recently been developed as advanced fertilizer options, offering more natural and environmentally friendly chelating agents while ensuring high effectiveness without ecological damage (Souri, 2016). Specifically, amino acids like glycine and glutamic acid enhance the uptake of nutrients such as calcium by plant roots (Souri, 2016). Consequently, numerous companies incorporate glycine in the production of calcium fertilizers.

Despite the evaluation of various Ca sources for ornamental crops, few studies have identified the most effective Ca source for roses. Owing to the lack of information in this area, this research aimed to compare the impact of different forms of Ca on Ca provision and the improvement of quantitative and qualitative characteristics of roses. Additionally, considering that Ca spray performs better than Ca fertilization, this factor was also considered in our research.

Materials and methods

Plant materials

The study was performed in a greenhouse with conditions including day/night temperatures of 25/16 ± 2 °C, a midday photosynthetic photon flux density (PPFD) between 300 and 1500 µmol m^{-2} s^{-1}, and a relative humidity range of 65% - 75%. Within a completely randomized design framework, a factorial design was implemented, including four replications with six observations in each replication. The treatments under investigation included two rose cultivars ('Jumilia' and 'Samurai') and foliar application of four Ca sources (distilled water (control), calcium nitrate ($Ca(NO_3)_2$), calcium silicate (Ca_2O_4Si), and calcium amino acid chelate with glycine ($Ca(Glys)_2$).

The rose cultivars 'Jumilia' and 'Samurai', grafted onto *Rosa canina* L. rootstock, were grown in a hydroponic substrate consisting of 100% perlite (3 - 5 mm). A half-strength modified Hoagland solution (Table 1) was formulated using tap water (refer to Table 2) and administered for a period of 30 days to support initial plant development and promote consistent growth. Following these 30 days and continuing until the conclusion of the experiment, plants were fertigated with a full-strength Hoagland nutrient solution but with a low Ca content (10% Ca). Ca at a rate of 160 mg L^{-1} from various sources, including $Ca(NO_3)_2$, Ca_2O_4Si, and $Ca(Glys)_2$, was applied weekly to spray the rose bushes. Additionally, a control treatment (distilled water) was sprayed simultaneously with other treatments. Nutrient solutions were prepared using tap water, and the quantities of different nutrient elements present in the tap water were adjusted to meet the requirements for preparing the Hoagland solution. Fertigation was performed using microtubes and drip emitters in an open system. Each fertigation cycle lasted 2 - 4 min with drip emitters delivering 35 - 40 mL min^{-1}, repeated eight times per day. Evaluation of various traits was conducted over a period of six months, and their averages are presented.

Table 1. The nutritional program used, prepared according to the Hoagland formulation.

	Compound	Concentration of stock Solution (g L^{-1})	Volume of Stock Solution Per Liter of Final Solution (mL)	Element	Final concentration of Element Macro (mmol L^{-1}) Micro (µmol L^{-1})
Macro Nutrients				N	16
	KNO_3	101.10	6	K	6
	$Ca(NO_3)2\text{-}4H_2O$	236.16	4	Ca	4
	$NH_4H_2PO_4$	115.08	2	P	2
	$MgSO_4\text{-}7H_2O$	246.49	1	S	1
				Mg	1
Micro Nutrients	KCl	1.864	2	Cl	50
	H_3BO_3	0.773	2	B	25
	$MnSO_4\text{-}H_2O$	0.169	2	Mn	2
	$ZnSO_4\text{-}7H_2O$	0.288	2	Zn	2
	$CuSO_4\text{-}5H_2O$	0.062	2	Cu	0.5
	$H_2MoO_4(85\%MoO_3)$	0.040	2	Mo	0.5
	NaFeDTPA (10% Fe)	30.0	0.3 - 1	Fe	18 - 54

Table 2. Levels of nutrient elements found in the irrigation water.

Cl (%)	SO_4 (%)	Ca (%)	K (%)	Mg (%)
0.0001	0.0249	0.0090	0.0003	0.0022

Measured parameters

Before harvesting, measurements of photosynthesis, photosynthetic pigments, and transpiration were conducted, and petals and leaves were sampled to determine the levels of macro and micro elements. Then, when the flowers had formed cylindrical shapes and sepals bent downward, they were harvested, and growth parameters were measured.

Growth Parameters

Flower and stem diameters were measured with a digital caliper, stem height was recorded with a ruler immediately after harvesting, and the number of flowers was counted visually. Fresh mass of rose shoots was determined with a precision balance. Root volume was measured by submerging roots in water and recording the displaced volume, as described by Rose et al. (1991).

Pigment of photosynthesis

To assess carotenoids, chlorophyll *a* (Chl *a*), chlorophyll *b* (Chl *b*), and total chlorophyll (Chl T), we utilized the procedure described by Lichtenthaler (1987). We homogenized 0.1 g of leaf tissue with 4 mL of 80% acetone. After centrifugation for 10 min at 3000 rpm, the absorbance of the supernatant obtained was evaluated with a spectrophotometer at 470, 647, and 664 nm to determine the levels of carotenoids, Chl *a*, and Chl *b*. The concentrations were determined in mg per gram of fresh leaf tissue using the provided formula.

Chl *a* = 12.25A664-2.79A647
Chl *b* = 21.21A647- 5.1A664
Chl T = Chl *a*+Chl *b*
Carotenoid = 1000A470-1.8Chl *a*-85.02Chl *b*/198

A647, A664, and A470, representing the optical absorbance at wavelengths of 647, 664, and 470 nm, respectively.

Photosynthesis and transpiration rates

Photosynthetic metrics, including the transpiration rate (mmol H_2O m^{-2} s^{-1}) and rate of photosynthesis (µmol CO_2 m^{-2} s^{-1}), were assessed using fully mature leaves and a calibrated portable infrared gas exchange system (Li-Cor, Li-6400, USA). These measurements were taken from 11 am to 1 pm, during two hours of light saturation (Haghighi et al., 2023).

Macro-and micro nutrients

The concentrations of Ca, phosphorus (P), potassium (K), manganese (Mn), iron (Fe), and copper (Cu) in both leaves and roots were analyzed with an inductively coupled plasma optical emission spectrometer (ICP-OES) (Model 730-ES, Varian, Australia). Additionally, the Ca content in petals was also analyzed using the same instrument. Total nitrogen content (N) in the leaves and roots was measured using the micro-Kjeldahl method (Huang and Peng, 2004).

Postharvest quality determination

During the postharvest period, we assessed the membrane stability index, Percentage changes in fresh mass, and vase life. Underwater, the flower stems were shortened to two cm, with the leaves on the lower 10 cm being removed. The flowers were kept in containers filled with 500 mL of distilled water, which was refreshed every two days. The receptacles were kept at a relative humidity of 65% ± 5%, with a temperature of 25 ± 2 ˚C, and subjected to a 16-hour light period followed by eight hours of darkness. Illumination was provided by fluorescent tubes yielding a light intensity of 20 µmol per square meter per second.

Vase life

Vase life refers to the duration from the time of harvest until more than half of the petals and leaves of the cut flower have turned yellow or dried, and the stem begins to bend (bent neck, i.e., the stem bends and the angle of the flower from the vertical position exceeds 45˚) (Wei et al., 2021).

Percentage changes in fresh mass

To calculate the percentage change in fresh mass, the flower stem's initial mass was recorded immediately after harvest and subsequently on days 2, 4, 6, 8, and 10. Finally, the percentage of mass gain or loss was reported.

Membrane stability index

Following Singh et al. (2008), the membrane stability index (MSI) was measured using an electrical conductivity meter. Petal samples of 200 mg each were submerged in 10 mL of double-distilled water and heated for 30 min at 40 °C in a water bath. The electrical conductivity of the solution at its initial state (EC1) was registered. Subsequently, the samples were heated for 15 min to 100 °C, allowed to cool to room temperature, and then a second measurement of electrical conductivity (EC2) was recorded. MSI was calculated using the formula:

$$MSI\ (\%) = [1 - (EC1 / EC2)] \times 100$$

Data Analysis

The experiment followed a completely randomized design with a factorial arrangement, including four replications and six observations per replication. Data were analyzed using SAS software (version 9.4), and mean comparisons for all traits were performed using the least significant difference (LSD) test at a 5% significance level.

Results

Growth Parameters

Rose varieties showed different responses to Ca treatment (Table 3). No notable increase in stem length was recorded for the 'Samurai' with foliar application of Ca sources, while $Ca(NO_3)_2$ and Ca $(Glys)_2$ treatments increased stem length in 'Jumilia' by 38.2% and 20.2%, respectively, compared with the control. Control plants of 'Jumilia,' which received no Ca, exhibited poor growth. Stem length in roses was shown to be dependent on the variety, and in all treatments, the stem length of the 'Samurai' variety was greater than that of 'Jumilia'(Table 3).

The varieties 'Samurai' and 'Jumilia' sprayed with Ca_2O_4Si had the maximum stem diameter, experiencing increases of 18.7% and 32.2%, respectively. Additionally, no substantial difference was found between the treatments involving $Ca(NO_3)_2$ and $Ca(Glys)_2$ (Table 3).

For 'Samurai', the treatment that showed the greatest effectiveness in enhancing stem fresh mass was Ca_2O_4Si, although no notable differences were detected among the treatments. Foliar application of different Ca sources in 'Jumilia' improved stem fresh mass compared to the control, with $Ca(NO_3)_2$ and Ca_2O_4Si being more prominent, resulting in a 37.5% and 37.3% increase in stem fresh mass, respectively, in contrast to the control (Table 3).

The use of different Ca sources via foliar spraying did not lead to an improvement in root volume; instead, we noted a reduction in root volume across the various treatments. $Ca(NO_3)_2$ treatment had the greatest effect on reducing root volume in 'Samurai', resulting in a 28.1% decrease (Table 3).

The flower diameter of 'Samurai' increased by 12.8% with $Ca(NO_3)_2$ and Ca_2O_4Si compared to the control. The treatments with $Ca(Glys)_2$ and Ca_2O_4Si resulted in the largest flower diameter increases in 'Jumilia', with 21.4% and 21% respectively, compared to the control (Table 3).

By adding Ca_2O_4Si, the highest number of flowers was achieved. Treatment with this combination significantly differed from both control plants and those treated with $Ca(NO_3)_2$ and $Ca(Glys)_2$. The treatment with Ca_2O_4Si resulted in a 32.3% rise in the number of flowers in 'Jumilia' compared to the control. However, the number of flowers in 'Samurai' was not affected by the Ca source (Table 3).

Table 3. Effect of foliar application with different Ca sources on the growth parameters of the two studied rose cultivars.

Cultivar	Treatment	Stem length (cm)	Stem diameter (mm)	Stem fresh mass (gr)	Root volume (mL)	Flower diameter (mm)	Number of flowers
'Samurai'	Control	68.37 ± 5.3^{a}	5.02 ± 0.14^{c}	48.86 ± 2.3^{ab}	75.13 ± 3.9^{a}	31.05 ± 0.8^{d}	7.04 ± 0.33^{b}
	$Ca(NO_3)_2$	69.96 ± 6.1^{a}	5.83 ± 0.38^{ab}	49.06 ± 7.6^{ab}	54.00 ± 3.2^{b}	35.04 ± 2.5^{bc}	6.77 ± 0.24^{b}
	Ca_2O_4Si	67.16 ± 4.7^{a}	5.96 ± 0.43^{a}	51.86 ± 4.7^{a}	64.63 ± 7.2^{ab}	35.03 ± 1.0^{bc}	7.39 ± 0.62^{b}
	Ca $(Glys)_2$	66.44 ± 3.5^{a}	5.43 ± 0.21^{bc}	47.86 ± 4.6^{ab}	57.63 ± 14.7^{ab}	34.44 ± 0.9^{c}	7.80 ± 0.23^{b}
'Jumilia'	Control	42.12 ± 1.1^{d}	4.31 ± 0.09^{d}	31.67 ± 0.2^{d}	75.25 ± 2.4^{a}	30.90 ± 0.5^{d}	6.88 ± 0.24^{b}
	$Ca(NO_3)_2$	58.23 ± 1.1^{b}	5.59 ± 0.17^{ab}	43.54 ± 1.0^{bc}	71.25 ± 4.6^{ab}	36.89 ± 1.2^{ab}	7.72 ± 0.84^{b}
	Ca_2O_4Si	42.66 ± 2.2^{d}	5.70 ± 0.19^{ab}	43.49 ± 2.6^{bc}	63.75 ± 1.3^{ab}	37.40 ± 0.8^{a}	9.10 ± 1.19^{a}
	Ca $(Glys)_2$	50.64 ± 4.4^{c}	5.61 ± 0.21^{ab}	40.79 ± 3.5^{c}	74.75 ± 10.4^{a}	37.51 ± 1.8^{a}	7.72 ± 1.06^{b}

In each trait, numbers that share common letters are not significantly different at the 5% level according to the LSD test.

Pigment of photosynthesis

The roses treated with $Ca(NO_3)_2$ and Ca_2O_4Si contained higher amounts of Chl *a* and Chl *b* than the control treatment and $Ca(Glys)_2$. The use of $Ca(Glys)_2$ did not influence the chlorophyll concentration of the roses. The roses treated with Ca_2O_4Si exhibited the highest Chl T content. Compared with the control, Chl T in 'Samurai' increased by 66.9% with Ca_2O_4S exposure in 'Jumilia', the treatment with Ca_2O_4Si resulted in a 67.8% increase in Chl T in comparison with the control (Table 4).

The role of $Ca(NO_3)_2$ and $Ca(Glys)_2$ in increasing carotenoids in rose flowers was greater than that of Ca_2O_4S. 'Samurai' plants exposed to $Ca(NO_3)_2$ and $Ca(Glys)_2$ demonstrated increases in carotenoid concentration of 20.4% and 17.2%, respectively, compared to the control plants. When 'Jumilia' roses were treated with $Ca(NO_3)_2$and $Ca(Glys)_2$, the carotenoid content increased by 31.1% and 30.4%, respectively (Table 4).

Table 4. Effect of foliar application with different Ca sources on the photosynthetic pigments of the two studied rose cultivars.

Cultivar	Treatment	Chlorophyll *a* (mg g^{-1})	Chlorophyll *b* (mg g^{-1})	Total chlorophyll (mg g^{-1})	Carotenoid (mg g^{-1})
'Samurai'	Control	20.84 ± 0.3^{d}	13.34 ± 2.7^{c}	34.18 ± 3.0^{c}	4.47 ± 0.78^{b}
	$Ca(NO_3)_2$	27.65 ± 2.6^{a}	21.68 ± 2.7^{b}	49.33 ± 5.3^{b}	5.38 ± 0.46^{ab}
	Ca_2O_4Si	26.80 ± 1.1^{a}	30.25 ± 2.7^{a}	57.06 ± 3.0^{a}	4.91 ± 0.38^{ab}
	$Ca(Glys)_2$	22.58 ± 1.0^{cd}	13.92 ± 1.1^{c}	36.50 ± 2.7^{c}	5.24 ± 0.37^{ab}
'Jumilia'	Control	22.60 ± 0.3^{cd}	13.24 ± 2.9^{c}	35.84 ± 3.0^{c}	4.50 ± 1.06^{b}
	$Ca(NO_3)_2$	27.34 ± 1.7^{a}	21.95 ± 3.3^{b}	49.29 ± 5.3^{b}	5.90 ± 0.29^{a}
	Ca_2O_4Si	26.64 ± 1.1^{ab}	33.50 ± 4.4^{a}	60.15 ± 4.8^{a}	5.02 ± 0.66^{ab}
	$Ca(Glys)_2$	24.32 ± 1.4^{bc}	15.58 ± 0.6^{c}	39.90 ± 1.9^{c}	5.87 ± 0.43^{a}

In each trait, numbers that share common letters are not significantly different at the 5% level according to the LSD test.

Photosynthesis and transpiration rates

The photosynthetic rate exhibited significant improvement under the Ca_2O_4Si and $Ca(Glys)_2$ treatments for the 'Samurai' variety, showing increases of 58.6% and 44.5% in comparison to the control, respectively. In contrast, the highest photosynthetic rate for the 'Jumilia' variety was observed with the $Ca(NO_3)_2$ treatment (Fig. 1A).

The transpiration rate was significantly affected by Ca treatment, regardless of the source. The highest transpiration rate in the 'Samurai' variety was recorded under Ca_2O_4Si and $Ca(Glys)_2$ treatments. Foliar application with various Ca sources improved transpiration rates in 'Jumilia', but no meaningful differences identified among them. Conversely, the lowest rates of photosynthesis and transpiration were observed in the control treatments across different rose varieties (Fig. 1B).

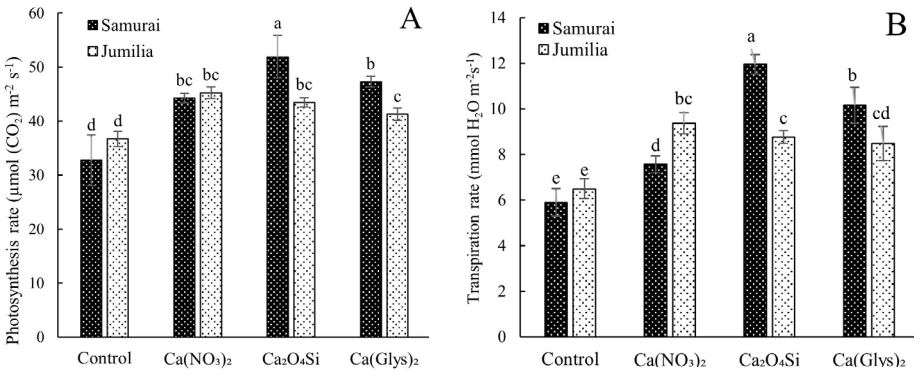

Fig. 1. Effect of foliar application with different Ca sources on the photosynthesis rate (A) and transpiration rate (B) of 'Jumilia' and 'Samurai' cultivars. In each trait, numbers that share common letters are not significantly different at the 5% level according to the LSD test.

Membrane stability index

Ca treatment significantly increased the MSI in rose varieties. 'Jumilia' achieved the highest MSI under $Ca(NO_3)_2$ treatment, showing a 13.6% rise in comparison with the control. Additionally, there was no notable distinction between Ca_2O_4Si and $Ca(Glys)_2$ treatments. $Ca(NO_3)_2$ resulted in a 10.4% increase in MSI in 'Samurai'. The 'Samurai' control treatment exhibited the lowest MSI (Fig. 2A).

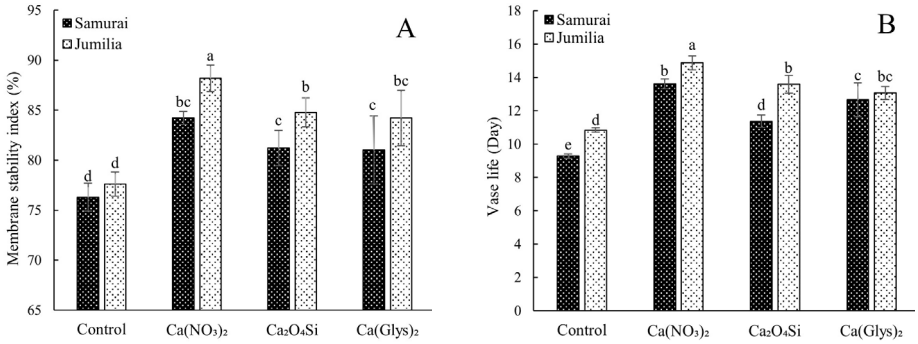

Fig. 2. Effect of foliar application with different Ca sources on the membrane stability index (A) and vase life (B) in 'Jumilia' and 'Samurai' cultivars. In each trait, numbers that share common letters are not significantly different at the 5% level according to the LSD test.

Vase life

The vase life varied among different rose cultivars, with the 'Jumilia' cultivar having a longer vase life compared to the 'Samurai' cultivar. Additionally, plants treated with Ca showed a longer vase life than untreated plants (Fig. 2B). Among the various treatments, $Ca(NO_3)_2$ had the greatest effect on increasing vase life, as this increase in the rose cultivars 'Samurai' and 'Jumilia' treated with $Ca(NO_3)_2$ was 4.3 and 4 days longer, respectively, compared to untreated plants. Additionally, Ca $(Glys)_2$ increased the vase life of 'Samurai' and 'Jumilia' by 3.4 and 2.2 days, in relation to the control, respectively. The use of $Ca(NO_3)_2$ and Ca $(Glys)_2$ was more effective in delaying senescence in 'Samurai' flowers compared to 'Jumilia'.

Percentage changes in fresh mass

In the present study, mass changes in the roses were significantly influenced by Ca treatment. For both cultivars, the increase in fresh mass persisted until the sixth day following $Ca(NO_3)_2$ treatment, whereas in the other treatments, it continued until the fourth day, after which the fresh mass started to decline. On the sixth day after harvest, the fresh mass of 'Samurai' and 'Jumilia' treated with $Ca(NO_3)_2$ increased by 14% and 12%, respectively. After 10 days, the percentage mass reduction in untreated flowers was greater than that in the other treatments, reaching less than the mass measured on the first day. In contrast, 'Samurai' plants exposed to $Ca(NO_3)_2$ and Ca $(Glys)_2$, as well as 'Jumilia' plants treated with $Ca(NO_3)_2$ and Ca_2O_4Si, exhibited a greater fresh mass (Fig. 3).

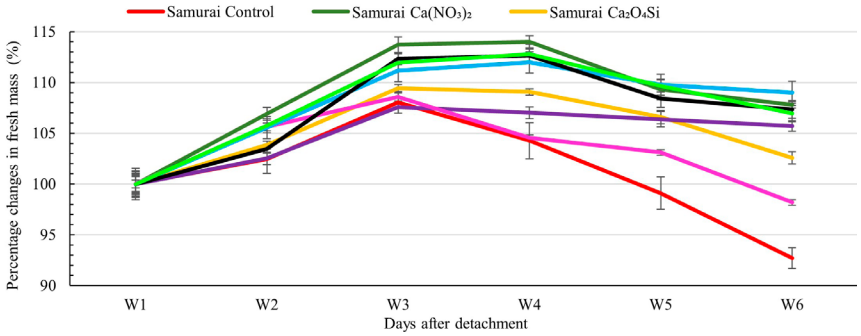

Fig. 3. Effect of foliar application with different Ca sources on percentage changes in fresh mass in 'Jumilia' and 'Samurai' cultivars.

Macro elements

The highest leaf and petal Ca concentrations were obtained in plants treated with $Ca(NO_3)_2$, with increases in the 'Samurai' variety being 2.9 and 2.5 times, respectively, and in the 'Jumilia' variety being 1.8 and 1.6 times, respectively (Fig. 4A - 4B). There was no significant variation in leaf Ca levels between the foliar applications of Ca_2O_4Si and $Ca(Glys)_2$ (Fig. 4B). The greatest increase in root Ca levels in the 'Samurai' and 'Jumilia' varieties was achieved with $Ca(Glys)_2$ treatment, with increases of 91.8% and 65.7%, relative to the control, respectively (Fig. 4c). The lowest levels of Ca in the leaves, petals, and roots were associated with the control treatment (Fig. 4A, 4B and 4C).

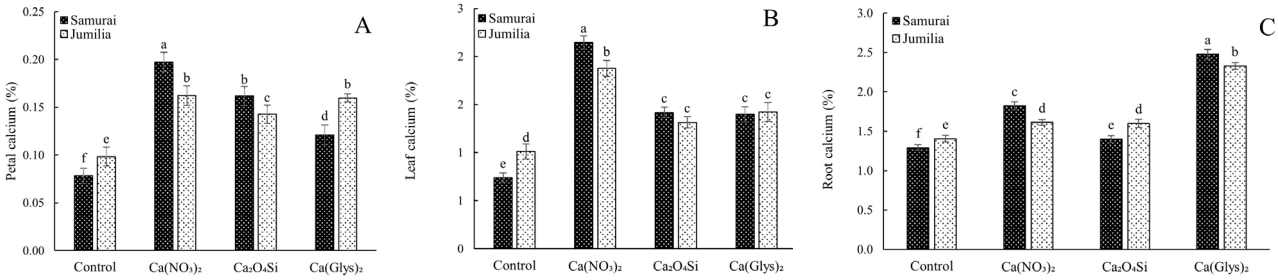

Fig. 4. Effect of foliar application with different Ca sources on the Ca concentration in petal (A), leaf (B), and root (C) of 'Jumilia' and 'Samurai' cultivars. In each trait, numbers that share common letters are not significantly different at the 5% level according to the LSD test.

The highest leaf N concentration in the 'Samurai' and 'Jumilia' varieties was observed with $Ca(NO_3)_2$ treatment, showing increases of 42.3% and 31.1%, respectively, compared to the control treatment. Ca_2O_4Si had no effect on leaf N. In 'Samurai', $Ca(Glys)_2$ caused a decrease in leaf N, whereas in 'Jumilia', it led to a 13.9% increase in leaf N, indicating a different response of rose varieties to $Ca(Glys)_2$ treatment (Table 5).

There was an increase of 34.9% and 10.6% in leaf P in 'Samurai' treated with $Ca(Glys)_2$ and $Ca(NO_3)_2$, respectively, in comparison with the control. Ca application caused a reduction in leaf P levels in 'Jumilia' (Table 5).

The highest leaf K concentration in the 'Samurai' variety was achieved with Ca_2O_4Si treatment, while in 'Jumilia' it was obtained with $Ca(Glys)_2$ foliar spray (Table 5).

Ca_2O_4Si and $Ca(NO_3)_2$ treatments resulted in a 31.3% and 27% increase in root N in 'Samurai', respectively, while Ca treatments did not significantly effect on improving root N in 'Jumilia' (Table 5).

Foliar application of Ca sources resulted in higher root P levels in 'Samurai', with the greatest increases observed in the $Ca(NO_3)_2$ and $Ca(Glys)_2$ treatments, showing 2.4 and 1.2 times increases, respectively. In contrast, Ca resulted in a decrease in root P in 'Jumilia' (Table 5).

Ca treatment improved root K in the roses. The highest root K concentration in 'Samurai' and 'Jumilia' was observed with $Ca(NO_3)_2$ and $Ca(Glys)_2$ treatments (Table 5).

Table 5. Effect of foliar application with different Ca sources on the macro elements of the two studied rose cultivars.

		Leaf (%)			Root (%)		
Cultivar	**Treatment**	**N**	**P**	**K**	**N**	**P**	**K**
'Samurai'	Control	3.76 ± 0.30^{c}	0.985 ± 0.006^{cd}	1.652 ± 0.045^{d}	2.59 ± 0.42^{cd}	1.633 ± 0.051^{e}	0.419 ± 0.003^{f}
	$Ca(NO_3)_2$	5.35 ± 0.19^{a}	1.090 ± 0.009^{b}	1.579 ± 0.030^{e}	3.29 ± 0.30^{ab}	4.009 ± 0.030^{a}	3.457 ± 0.056^{a}	3.457 ± 0.056^{a}
	Ca_2O_4Si	4.00 ± 0.24^{c}	0.968 ± 0.016^{d}	1.889 ± 0.023^{a}	3.40 ± 0.51^{a}	1.995 ± 0.049^{c}	1.323 ± 0.050^{e}	1.323 ± 0.050^{e}
	$Ca(Glys)_2$	2.42 ± 0.20^{d}	1.329 ± 0.039^{a}	1.568 ± 0.015^{e}	2.98 ± 0.28^{a-c}	2.029 ± 0.044^{bc}	1.667 ± 0.040^{d}	1.667 ± 0.040^{d}
'Jumilia'	Control	3.82 ± 0.22^{c}	1.111 ± 0.012^{b}	1.646 ± 0.036^{d}	2.80 ± 0.20^{bc}	4.055 ± 0.049^{a}	0.480 ± 0.008^{f}
	$Ca(NO_3)_2$	5.01 ± 0.13a	0.921 ± 0.007^{e}	1.278 ± 0.032^{f}	2.53 ± 0.35^{cd}	1.901 ± 0.028^{d}	2.074 ± 0.063^{c}	2.074 ± 0.063^{c}
	Ca_2O_4Si	3.68 ± 0.32^{c}	0.849 ± 0.017^{f}	1.721 ± 0.013^{c}	2.21 ± 0.10^{d}	1.633 ± 0.071^{e}	1.632 ± 0.043^{d}	1.632 ± 0.043^{d}
	$Ca(Glys)_2$	4.53 ± 0.29^{b}	1.002 ± 0.018^{c}	1.824 ± 0.012^{b}	2.89 ± 0.15^{a-c}	2.087 ± 0.057^{b}	2.744 ± 0.048^{b}	2.744 ± 0.048^{b}

In each trait, numbers that share common letters are not significantly different at the 5% level according to the LSD test.

Micro elements

Treatment of 'Samurai' plants with Ca_2O_4Si resulted in a 10.7% increase in leaf Fe concentration, whereas it did not significantly impact the 'Jumilia' variety. Treatment of 'Jumilia' plants with various Ca sources led to an increase in leaf Mn, whereas in the 'Samurai' variety, only the Ca_2O_4Si treatment improved leaf Mn levels (Table 6).

The highest leaf Cu concentrations in 'Samurai' and 'Jumilia' were obtained with $Ca(NO_3)_2$ and $Ca(Glys)_2$ treatments, respectively, showing increases of 15.8% and 11.1% compared to the control. Treatment of 'Samurai' plants with $Ca(NO_3)_2$ resulted in increased the levels of Mn and Fe in the roots, whereas all Ca treatments in the variety 'Jumilia' led to a decrease in root Fe and Mn concentrations (Table 6).

The $Ca(NO_3)_2$ and $Ca(Glys)_2$ treatments resulted in 72.7% and 31.8% increases in root Cu in 'Samurai', respectively. Additionally, treatment of the variety 'Jumilia' with $Ca(Glys)_2$ led to a 15.4% increase in root Cu (Table 6).

Table 6. Effect of foliar application with different Ca sources on the micro elements of the two studied rose cultivars.

Cultivar	**Treatment**	Leaf (%)			Root (%)		
		Fe	**Mn**	**Cu**	**Fe**	**Mn**	**Cu**
'Samurai'	Control	0.028 ± 0.0003^{c}	0.011 ± 0.0001^{d}	0.019 ± 0.0002^{bc}	0.172 ± 0.0043^{d}	0.004 ± 0.0001^{g}	0.022 ± 0.0004^{e}
	$Ca(NO_3)_2$	0.030 ± 0.0002^{b}	0.011 ± 0.0004^{d}	0.022 ± 0.0003^{a}	0.243 ± 0.0035^{b}	0.021 ± 0.0001^{a}	0.038 ± 0.0010^{a}
	Ca_2O_4Si	0.031 ± 0.0008^{a}	0.052 ± 0.0004^{a}	0.019 ± 0.0006^{bc}	0.092 ± 0.0028^{h}	0.010 ± 0.0003^{e}	0.022 ± 0.0004^{e}
	$Ca(Glys)_2$	0.026 ± 0.0006^{de}	0.012 ± 0.0003^{d}	0.020 ± 0.0009^{b}	0.113 ± 0.0033^{g}	0.017 ± 0.0006^{b}	0.029 ± 0.0008^{c}
'Jumilia'	Control	0.027 ± 0.0002^{cd}	0.009 ± 0.0001^{e}	0.018 ± 0.0003^{c}	0.253 ± 0.0036^{a}	0.015 ± 0.0003^{c}	0.026 ± 0.0004^{d}
	$Ca(NO_3)_2$	0.025 ± 0.0002^{e}	0.014 ± 0.0003^{c}	0.019 ± 0.0003^{bc}	0.120 ± 0.0026^{f}	0.008 ± 0.0001^{f}	0.022 ± 0.0002^{e}
	Ca_2O_4Si	0.027 ± 0.0008^{cd}	0.039 ± 0.0014^{b}	0.019 ± 0.0008^{bc}	0.158 ± 0.0059^{e}	0.010 ± 0.0004^{e}	0.019 ± 0.0005^{f}
	$Ca(Glys)_2$	0.026 ± 0.0007^{de}	0.011 ± 0.0002^{d}	0.020 ± 0.0020^{b}	0.195 ± 0.0055^{c}	0.013 ± 0.0004^{d}	0.030 ± 0.0006^{b}

In each trait, numbers that share common letters are not significantly different at the 5% level according to the LSD test.

Discussion

Roses are highly valued in the commercial flower industry, with a primary focus on producing high-quality flowers with long vase life. Ca plays a crucial role in achieving these goals, particularly through its impact on stem strength and flower quality.

The 'Samurai' cultivar demonstrated greater stem length and stem diameter than 'Jumilia,' regardless of the calcium treatment. In contrast, the 'Jumilia' cultivar displayed a longer vase life compared to 'Samurai,' indicating potential differences between the two cultivars. In addition, our study highlights how different Ca treatments affect various growth parameters in the 'Jumilia' and 'Samurai' rose cultivars. Our results indicate that foliar applications of $Ca(NO_3)_2$ and $Ca(Glys)_2$ significantly increased stem length in 'Jumilia' roses (Table 3). This is consistent with the role of Ca in promoting cell elongation and division (Al-Ibraheemi et al., 2021). The observed increase in stem length can also be attributed to the enhanced nitrogen (N) content in the leaves, which supports auxin synthesis (Mohammed and Abood, 2020). Previous studies have similarly reported that $Ca(NO_3)_2$ improves stem length in Rose Moss (*Portulaca grandiflora* L.) (Al-Ibraheemi et al., 2021) and that Ca chelated with tryptophan enhances vegetative growth in *Brassica oleracea* L. var. italica (Haghighi et al., 2023).

Additionally, Ca treatments led to increases in flower diameter, stem diameter, and shoot fresh mass (Table 3). Consistent with our findings, Banijamali et al. (2018) observed a 7% increase in flower diameter in *Rosa hybrida* cv. 'Vendetta' due to Ca treatment. The largest flower diameter in 'Jumilia' was observed under $Ca(Glys)_2$ treatment (Table 3). The $Ca(Glys)_2$ treatment produced the largest flower diameter in 'Jumilia', aligning with Saeedi et al. (2015) who noted that Ca amino acid chelates can enhance flower diameter and overall plant growth. Similarly, Ca-EDTA was more effective than $Ca(NO_3)_2$ in increasing head diameter in *Cynara scolymus* (Ismail et al., 2022).

The application of calcium sources negatively affected root volume in both 'Samurai' and 'Jumilia', with $Ca(NO_3)_2$ causing a more significant reduction (Table 3). Although some researchers have reported improvement in root growth due to Ca treatments (Weng et al., 2022), an insignificant impact of Ca application on root growth in *Glycine max* (An et al., 2014) and *Brassica oleracea* (Haghighi et al., 2023) under non-stress conditions has been reported. This may be due to differences in experimental conditions or variations between plant species.

While higher Ca levels have been linked with increased flower number in some research (Saeedi et al., 2015; Mahajan and Pal, 2020), Banijamali et al. (2018) and Bar-Tal et al. (2001) found no significant relationship. In our study, Ca_2O_4Si treatment led to a higher number of flowers in 'Jumilia', possibly due to improved photosynthetic activity and nutrient uptake, increasing flower number (Table 3). This suggests that Ca_2O_4Si may enhance vegetative growth, indirectly increasing flower number.

For carotenoid levels, treatments with $Ca(NO_3)_2$ and $Ca(Glys)_2$ were more effective compared to other treatments (Table 4). Amino acid chelates are known to improve chlorophyll and carotenoid biosynthesis (Souri, 2016), which is consistent with our findings that $Ca(Glys)_2$ increased carotenoid levels in 'Samurai' and 'Jumilia'.

The increase in Chl *a*, Chl *b*, and Chl T was more pronounced with Ca_2O_4Si and $Ca(NO_3)_2$ treatments (Table 4). Previous research highlights that N and Mn are essential for chlorophyll synthesis (Roosta et al., 2024). Our results suggest that these treatments enhanced N and Mn uptake, thereby increasing chlorophyll content. For example, the treatment of poplar with Ca resulted in an rise in Chl *a* and Chl *b* indices by 45.54% and 45.80%, respectively, compared to plants grown without Ca treatment (Weng et al., 2022). Furthermore, Ca_2O_4Si resulted in an increase of 13% and 68% in the Chl T content in the leaves of *Solanum lycopersicum* and *Amaranthus hypochondriacus*, respectively (Amkha and Rungcharoenthong, 2020). Higher chlorophyll content is closely associated with improved photosynthetic ability (Qian et al., 2021). Therefore, it is expected that increasing photosynthetic pigments will increase photosynthesis in roses. Previous research has emphasized calcium's role in sustaining photosynthesis by controlling leaf gas exchange, the processes of PSII, and the expression of genes involved in chlorophyll production (Zhang et al., 2020). Among various Ca sources, foliar application of Ca_2O_4Si was more effective in increasing chlorophyll and photosynthesis in 'Samurai' and 'Jumilia' compared to other sources. Calcium is closely linked to photosynthetic metabolism (Wang et al., 2022). Furthermore, Ca_2O_4Si application also provides an additional source of silicon, which has been shown to increase the absorption of radiation, thereby enhancing photosynthetic efficiency (Coutinho et al., 2020), indicating the effective role of these two nutrients (Ca and silicon) in improving photosynthetic activity. In support of this, improved photosynthetic efficiency has been reported in tomato plants treated with Ca_2O_4Si (Coutinho et al., 2020).

Increasing photosynthesis is accompanied by higher levels of CO_2 assimilation (Seydmohammadi et al., 2020). Transpiration is one of the factors indirectly responsible for CO_2 fixation (Haghighi et al., 2023). Ca has been shown to increase stomatal conductance, thereby enhancing transpiration. Specifically, one of the factors involved in stomatal opening is the H^+-ATPase on the plasma membrane, whose activity is regulated by a protein kinase activated by Ca. Consequently, Ca regulates stomatal opening and the activity of H^+-ATPase, thereby increasing transpiration (Palta, 1996). In this study, the highest transpiration and photosynthesis rates in the 'Samurai' cultivar were achieved with foliar application of Ca_2O_4Si, while in 'Jumilia', these rates were highest with $Ca(NO_3)_2$ treatment (Fig. 1). Simultaneous increases in photosynthesis and transpiration due to foliar application of Ca have also been reported in previous studies. For instance, Ca foliar spraying increased transpiration and photosynthesis rates in corn by 43% and 45%, respectively (Naeem et al., 2018).

Ca treatments, particularly $Ca(NO_3)_2$, were effective in increasing the initial fresh mass of flowers and delaying mass loss in 'Samurai' and 'Jumilia' (Fig. 3). This aligns with previous studies showing that Ca enhances water flow through stems and maintains water balance, which is crucial for extending vase life (Jiang et al., 2019).

Also calcium's contribution to prolonging the longevity of cut flowers is well-established, as it helps in maintaining membrane integrity and reducing cell wall breakdown (Sairam et al., 2011). Our results show that foliar application of various Ca sources, particularly $Ca(NO_3)_2$, increased Ca concentration in rose petals and improved MSI (Fig. 2A).

Furthermore, higher Ca levels in the petals are linked to lower ethylene synthesis and a slower senescence process (Torre et al., 1999). Any source that effectively enhances the Ca concentration in petals can significantly contribute to improving the vase life of rose flowers. The beneficial impact of Ca on the longevity of different cut flowers has been documented, such as roses, and *Gladiolus grandifloras* (Torre et al., 1999; Sairam et al., 2011). The similar responses observed in different rose cultivars with distinct genetic backgrounds indicate an overall effect of Ca on vase life and senescence (Torre et al., 1999).

According to our findings, pre-harvest spraying of Ca-containing compounds on rose flowers enhances the accessibility of Ca to leaves and petals (Fig. 4A – 4B). The consistent effect of the various Ca sources used in this experiment on Ca concentration in leaves and petals can be attributed to the desirable permeability of $Ca(NO_3)_2$, Ca_2O_4Si, and $Ca(Glys)_2$ into plant tissues for Ca supply. Due to the significant difference in transpiration rates between flowers and leaves, more Ca is directed towards transpiring leaves. This leads to a several-fold rise in the Ca concentration in the leaves compared to that in petals. In this context, we noted that the Ca concentration in leaves was 8 to 12 times higher than in petals. Similar differences in Ca concentrations between leaves and petals have also been demonstrated in other studies on rose flowers (Bar-Tal et al., 2001). The application of $Ca(Glys)_2$ provided the greatest benefit in increasing Ca concentration in roots (Fig. 4C). This indicates that the movement of Ca from the shoot to the root in the form of Ca chelates is more efficient than that of other Ca sources. Since Ca is an immobile element, its deficiency in growing roots is more likely to occur after foliar application. However, amino acids, owing to their chemical structure and properties, can be easily distributed in the cell cytoplasm. Therefore, after complexation with metals, they improve their accessibility to various plant parts, including the roots.

Our study revealed that Ca treatments led to specific changes in nutrient levels. For instance, $Ca(NO_3)_2$ increased leaf N content (Table 5), which supports previous findings (Banijamali et al., 2018; Sajid et al., 2020). $Ca(Glys)_2$ enhanced phosphorus (P) levels in 'Samurai', while $Ca(NO_3)_2$ decreased P levels in 'Jumilia', reflecting the variability in nutrient uptake among cultivars. Similarly, in *Cynara scolymus*, Ca-EDTA treatment was more effective at increasing P than $Ca(NO_3)_2$ (Ismail et al., 2022). Additionally, the differences in P levels between cultivars may be due to their varying needs or abilities to absorb P. Although $Ca(NO_3)_2$ treatment reduced leaf K concentration, it increased K uptake by roots (Table 5). Similarly, the role of Ca in increasing root K in wheat (Akhtar et al., 2022) and decreasing leaf K in roses has been reported (Banijamali et al., 2018). The highest rise in Cu concentration in the leaves and roots of 'Samurai' was achieved with $Ca(NO_3)_2$ treatment, and in 'Jumilia' with $Ca(Glys)_2$ treatment. Ca_2O_4Si also increased Fe and Mn levels in leaves (Table 6). Research has demonstrated that Ca plays a role in increasing the concentrations of Mn and Fe in rose leaves (Banijamali et al., 2018). Therefore, foliar application of Ca could be an effective method for improving the nutritional status of roses.

Conclusions

The 'Samurai' cultivar exhibited larger stems, while the 'Jumilia' cultivar demonstrated a longer vase life. Foliar application of $Ca(NO_3)_2$ improved N uptake, resulting in increased fresh mass and stem length of 'Jumilia' roses. The highest number of flowers and stem diameter were obtained in the Ca_2O_4Si treatment. Ca_2O_4Si was able to improve chlorophyll content and, consequently, photosynthesis by increasing the Mn concentration. The results showed that the use of $Ca(NO_3)_2$, by increasing Ca uptake in leaves and petals, improved MSI and delayed

the reduction in fresh mass of roses. Consequently, it was able to extend the vase life more effectively than the other treatments. The results demonstrated the effectiveness of $Ca(Glys)_2$ in directing Ca distribution towards the roots. In general, considering the effect of $Ca(NO_3)_2$ in increasing stem length and extending vase life, it is recommended as a preferred Ca source.

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Author Contribution

SKH: Data Curation, Formal Analysis, Writing – Original Draft. **AT:** Conceptualization, Writing - Review & Editing. **YS:** Methodology. **AHK**: Methodology, Writing - Review & Editing. **LC:** Data Curation.

Conflict of Interest

The authors declare that they have no conflict of interest.

Data Availability Statement

Data will be made available upon request to the authors.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that the use of AI and AI-assisted technologies was not applied in the writing process.

References

AKHTAR, N.; ILYAS, N.; ARSHAD, M.; MERAJ, T.A.; HEFFT, D.I.; JAN, B.L.; AHMAD, P. The impact of calcium, potassium, and boron application on the growth and yield characteristics of durum wheat under drought conditions. **Agronomy**, v.12, n.8, p.1917, 2022. https://doi.org/10.3390/agronomy12081917

AL-IBRAHEEMI, R.A.; ALRUBYE, H.K.; MASHKOOR, S.A.; ALAUNAIBI, R.M. The effect of calcium on the growth and flowering of rose moss (*Portulaca grandiflora* L.) using hydroponic system. **Natural Volatiles & Essential Oils**, v.8, n.6, p.2531-2535, 2021.

AMKHA, S.; RUNGCHAROENTHONG, P. Effect of calcium silicate on number of trichomes, leaf thickness, and chlorophyll in tomato. **AHC2020 1312**, p.249-254, 2020. https://doi.org/10.17660/ActaHortic.2021.1312.36

AN, P.; LI, X.; ZHENG, Y.; ENEJI, A.E.; INANAGA, S. Calcium effects on root cell wall composition and ion contents in two soybean cultivars under salinity stress. **Canadian Journal of Plant Science**, v.94, n.4, p.733-740, 2014. https://doi.org/10.4141/cjps2013-291

BANIJAMALI, S.M.; FEIZIAN, M.; BAYAT, H.; MIRZAEI, S. Effects of nitrogen forms and calcium amounts on growth and elemental concentration in *Rosa hybrida* cv. 'Vendentta'. **Journal of Plant Nutrition**, v.41, n.9, p.1205-1213, 2018. https://doi.org/10.1080/01904167.2018.1443127

BAR-TAL, A.; BAAS, R.; GANMORE-NEUMANN, R.; DIK, A.; MARISSEN, N.; SILBER, A.; DAVIDOV, S.; HAZAN, A.; KIRSHNER, B.; ELAD, Y. Rose flower production and quality as affected by Ca concentration in the petal. **Agronomie**, v.21, n.4, p.393-402, 2001. https://doi.org/10.1051/agro:2001132

BENNETT, K.; SCHNABEL, G.; FAUST, J.E. Evaluation of calcium sources for the management of Botrytis blight on petunia flowers. **HortTechnology**, v.33, p.262-267, 2023. https://doi.org/10.21273/HORTTECH05097-22

COUTINHO, P.W.R.; DE MORAES ECHER, M.; BRAGA, G.C.; GUIMARÃES, V.F.; DO CARMO LANA, M.; ALVES, T.N.; BRITO, T.S. Effect of pre-harvest calcium silicate on post-harvest quality of tomatoes. **Research, Society and Development**, v.9, n.11, e74791110148, 2020. https://doi.org/10.33448/rsd-v9i11.10148

DUAN, S.; ZHANG, C.; SONG, S.; MA, C.; ZHANG, C.; XU, W.; BONDADA, B.; WANG, L.; WANG, S. Understanding calcium functionality by examining growth characteristics and structural aspects in calcium-deficient grapevine. **Scientific Reports**, v.12, n.1, p.3233, 2022. https://doi.org/10.1038/s41598-022-06867-4

HAGHIGHI, M.; KHOSRAVI, S.; SEHAR, S.; SHAMSI, I.H. Foliar-sprayed calcium-tryptophan mediated improvement in physio-biochemical attributes and nutritional profile of salt-stressed *Brassica oleracea* var. italica. **Scientia Horticulturae**, v.307, p.111529, 2023. https://doi.org/10.1016/j.scienta.2022.111529

HUANG, J.; PENG, S. Influence of storage methods on total nitrogen analysis in rice leaves. **Communications in Soil Science and Plant Analysis**, v.35, n.5-6, p.879-888, 2004. https://doi.org/10.1081/CSS-120030364

ISMAIL, S.A.; FATHY, W.; GANZOUR, S.K. Impact of foliar application of calcium nitrate and chelated calcium in combination with boric acid on the vegetative growth, yield, quality components, and insect control of globe artichoke. **Journal of Plant Production**, v.13, n.9, p.743-752, 2022. https://dx.doi.org/10.21608/jpp.2022.159772.1165

JIANG, A.; ZUO, J.; ZHENG, Q.; GUO, L.; GAO, L.; ZHAO, S.; WANG, Q.; HU, W. Red LED irradiation maintains the postharvest quality of broccoli by elevating antioxidant enzyme activity and reducing the expression of senescence-related genes. **Scientia Horticulturae**, v.251, p.73-79, 2019. https://doi.org/10.1016/j.scienta.2019.03.016

KHALILI, Z.; NEKOUNAM, F.; BARZEGAR, T.; GHAHREMANI, Z.; FARHANGPOUR, M. The effect of foliar application of calcium chloride, ascorbic acid and harvest time on fruit quality of tomato (*Solanum lycopersicum* cv. SV8320TD). **Journal of Horticultural Science**, v.32, p.61-74, 2023. https://doi.org/10.22067/jhs.2023.82265.1265

LICHTENTHALER, H.K. Chlorophylls and carotenoids: pigments of photosynthetic biomembranes. **Methods in Enzymology**, v.148, p.350-382, 1987. https://doi.org/10.1016/0076-6879(87)48036-1

MAHAJAN, M.; PAL, P.K. Flower yield and chemical composition of essential oil from *Rosa damascena* under foliar application of Ca $(NO_3)_2$ and seasonal variation. **Acta Physiologiae Plantarum**, v.42, n.2, p.23, 2020. https://doi.org/10.1007/s11738-019-2996-5

MOHAMMED, R.A.J.; ABOOD, B.M.A. Effect of bacterial inoculum, spraying with calcium nitrate and salicylic acid on vegetative and flowering growth traits of *Gerbera jamesonii*. **Plant Archives**, v.20, n.1, p.633-638, 2020.

NAEEM, M.; NAEEM, M.S.; AHMAD, R.; IHSAN, M.Z,; ASHRAF, M.Y.; HUSSAIN, Y.; FAHAD, S. Foliar calcium spray confers drought stress tolerance in maize via modulation of plant growth, water relations, proline content, and hydrogen peroxide activity. **Archives of Agronomy and Soil Science**, v.64, n.1, p.116-131, 2018. https://doi.org/10.1080/03650340.2017.1327713

PALTA, J.P. Role of calcium in plant responses to stresses: linking basic research to the solution of practical problems. **HortScience**, v.31, p.51-57, 1996.

QIAN, X.; LIU, L.; CROFT, H.; CHEN, J. Relationship between leaf maximum carboxylation rate and chlorophyll content preserved across 13 species. **Journal of Geophysical Research: Biogeosciences**, v.126, n.2, e2020JG006076, 2021. https://doi.org/10.1029/2020JG006076

ROOSTA, H.; NILI, F.; POURKHALOEE, A.; ASKARI, N. Effects of supplemental light quality and foliar application with calcium on photosynthetic parameters and flower stem strength of cut gerbera (*Gerbera jamesonii* 'Bayadere'). **International Journal of Horticultural Science and Technology**, v.11, n.1, p.69-82, 2024. https://doi.org/10.22059/ijhst.2023.356795.625

ROSE, R.; ATKINSON, M.; GLEASON, J.; SABIN, T. Root volume as a grading criterion to improve field performance of Douglas-fir seedlings. **New Forests**, v.5, p.195-209, 1991. https://doi.org/10.1007/BF00028111

SAEEDI, R.; ETEMADI, N.; NIKBAKHT, A.; KHOSHGOFTARMANESH, A.H.; SABZALIAN, M.R. Calcium chelated with amino acids improves quality and postharvest life of lisianthus (*Eustoma grandiflorum* cv. Cinderella Lime). **HortScience**, v.50, n.9, p.1394-1398, 2015. https://doi.org/10.21273/HORTSCI.50.9.1394

SAIRAM, R.K.; VASANTHAN, B.; ARORA, A. Calcium regulates Gladiolus flower senescence by influencing antioxidative enzyme activity. **Acta Physiologiae Plantarum**, v.33, p.1897-1904, 2011. https://doi.org/10.1007/s11738-011-0734-8

SAJID, M.; ULLAH, I.; RAB, A.; SHAH, S.T.; AHMAD, N.; AHMAD, I.; ALI, A.; BASIT, A.; BIBI, F.; AHMAD, M. Foliar application of calcium improves growth, yield and quality of tomato cultivars. **Pure and Applied Biology**, v.9, n.1, p.10-19, 2020. http://dx.doi.org/10.19045/bspab.2020.90002

SEYDMOHAMMADI, Z.; ROEIN, Z.; REZVANIPOUR, S. Accelerating the growth and flowering of *Eustoma grandiflorum* by foliar application of nano-ZnO and nano-$CaCO_3$. **Plant Physiology and Biochemistry**, v.25, p.140-148, 2020. https://doi.org/10.1007/s40502-019-00473-9

SIMIN, N.; ŽIVANOVIĆ, N.; BOŽANIĆ TANJGA, B.; LESJAK, M.; NARANDŽIĆ, T.; LJUBOJEVIĆ, M. New Garden Rose (*Rosa× hybrida*) genotypes with intensely colored flowers as rich sources of bioactive compounds. **Plants**, v.13, n.3, p.424, 2024. https://doi.org/10.3390/plants13030424

SINGH, A.; KUMAR, J.; KUMAR, P. Effects of plant growth regulators and sucrose on post-harvest physiology, membrane stability, and vase life of cut spikes of gladiolus. **Plant Growth Regulation**, v.55, p.221-229, 2008. https://doi.org/10.1007/s10725-008-9278-3

SOURI, M.K. Aminochelate fertilizers: the new approach to the old problem; a review. **Open Agriculture**, v.1, n.1, p.118-123, 2016. https://doi.org/10.1515/opag-2016-0016

TORRE, S.; BOROCHOV, A.; HALEVY, A.H. Calcium regulation of senescence in rose petals. **Physiologia Plantarum**, v.107, n.2, p.214-219, 1999. https://doi.org/10.1034/j.1399-3054.1999.100209.x

WANG, G.; WANG, J.; HAN, X.; CHEN, R.; XUE, X. Effects of spraying calcium fertilizer on photosynthesis, mineral content, sugar–acid metabolism, and fruit quality of Fuji apples. **Agronomy**, v.12, p.2563, 2022. https://doi.org/10.3390/agronomy12102563

WEI, L.; WANG, C.; LIAO, W. Hydrogen sulfide improves the vase life and quality of cut roses and chrysanthemums. **Journal of Plant Growth Regulation**, v.32, p.1-16, 2021. https://doi.org/10.1007/s00344-021-10312-7

WENG, X.; LI, H.; REN, C.; ZHOU, Y.; ZHU, W.; ZHANG, S.; LIU, L. Calcium regulates growth and nutrient absorption in poplar seedlings. **Frontiers in Plant Science**, v.13, 887098, 2022. https://doi.org/10.3389/fpls.2022.887098

ZHANG, Z.; WU, P.; ZHANG, W.; YANG, Z.; LIU, H.; AHAMMED, G.J.; CUI, J. Calcium is involved in exogenous NO-induced enhancement of photosynthesis in cucumber (*Cucumis sativus* L.) seedlings under low temperature. **Scientia Horticulturae**, v.261, p.108953, 2020. https://doi.org/10.1016/j.scienta.2019.108953