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Optimizing Nutrient Levels for Enhanced Rose Growth and Quality

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ABSTRACT

This study evaluated the impact of different nutrient supply levels on the growth, flowering, and biochemical responses of two rose (*Rosa hybrida* L.) cultivars, 'Samurai' and 'Jumilia', under soilless culture. The aim was to optimize fertilizer use for improved flower quality and sustainability. A factorial experiment with four Hoagland nutrient solution levels (25%, 50%, 75%, and 100%) was conducted in a completely randomized design. Increasing nutrient concentrations improved flower diameter, stem length, leaf area, and vase life, while root length declined. Application of 75% nutrient solution increased chlorophyll a content by 38.44% and stem length by 11.19%, and also enhanced nutrient accumulation in roots and leaves, particularly in 'Samurai'. At this level, antioxidant enzyme activities in 'Samurai' rose increased, with superoxide dismutase (SOD) rising by 3.57%, catalase (CAT) by 20%, and peroxidase (POD) by 12.53%. The 100% solution resulted in the highest nitrogen and magnesium levels in 'Jumilia' leaves, with 1.34- and 1.57-fold increases, respectively. Lower concentrations (25% and 50%) reduced chlorophyll content and membrane stability. The 75% Hoagland nutrient supply offered optimal growth, flower quality, and resource efficiency, supporting sustainable floriculture, profitability, and export-quality production while reducing fertilizer use and environmental impact.

Keywords: Antioxidant enzyme activity, Nutrient solution concentration, *Rosa hybrida*, Vase life.

INTRODUCTION

Fertilizers are essential in modern agriculture to meet plant nutrient demands. However, their excessive use can harm the environment. A practical approach to minimize environmental impacts is reducing the concentration of applied fertilizers and nutrient solutions.

Rose is a widely cultivated plant valued for its beauty, fragrance, medicinal uses, and essential oil. Its frequent blooming makes it ideal for landscaping (Khosravi et al., 2025). In Iran, the cultivated area of rose includes about 210 ha in open fields and 185 ha under greenhouse conditions (Horticultural Statistics Yearbook, Ministry of Agriculture-Jahad, 2024). Proper nutrient management significantly affects rose growth and flower quality,

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including stem size, color, and shelf life (Savvas, 2002; Khosravi et al., 2025). However, different cultivars respond differently to nutrient solution compositions due to varying nutritional needs (Khoshgoftarmanesh et al., 2008).

Hydroponics has emerged as a major method in floriculture, where optimal nutrient concentration and composition are essential for high yield (Sirin, 2011).

Meanwhile, nutrient ratios critically affect plant physiology and yield (Khoshgoftarmanesh et al., 2008). In soilless systems, nutrient composition depends on factors like plant stage, solution volume, uptake rate, reformation frequency, and environmental conditions (Melo & dos Santos, 2011; Sirin, 2011). Hoagland's nutrient solution is widely used in hydroponics and supports the growth of various crops (Waheed et al., 2019). So, it is necessary to apply good and appropriate nutrient solutions to rose plants for great yield and well competent flower production in hydroponic culture.

While fertilizers enhance crop yield and quality, excessive or unbalanced use increases costs and environmental risks. In roses, improper nutrition reduces floral quality and yield. Supplying a balanced dose of fertilization improves use efficiency, reduces stress and improves production. In other words, the aim of optimizing fertilizer consumption is to achieve maximum income with minimum fertilizer consumption. This is the hypothesis that controlled fertilizer consumption not only improves the growth and performance of roses but also improves the absorption of nutrients by plants. A better understanding of fertilizer application rates for growth, yield, and mineral absorption can help develop optimal strategies for rose fertilization. Therefore, the main aim of this study is to optimize fertilization using four ratios of Hoagland nutrient solution (25%, 50%, 75% and 100% fertilizer) to improve the quality, yield and growth of two cut rose cultivars.

MATERIALS AND METHODS

Plant Material, Treatments and Growth Conditions

Two grafted rose (Rosa hybrida L.) cultivars, 'Samurai' and 'Jumilia', were grown in pots containing 100% perlite (particle size 3–5 mm) as the growth medium, which was selected due to its excellent aeration, drainage capacity, and inert nature, making it suitable for hydroponic rose cultivation (Khosravi et al., 2025). 'Samurai' has dark red, high-petal flowers on long, sturdy stems, while 'Jumilia' is a bicolor rose with creamy white petals edged in pink and medium to large blooms. They were selected as two contrasting but commercially important rose cultivars, widely grown and traded, enabling meaningful comparisons. Plants were cultivated under greenhouse conditions using a hydroponic system equipped with an open dripper irrigation setup to ensure uniform delivery of water and nutrients. To facilitate proper establishment, both cultivars were irrigated with tap water for the first three days, and its chemical composition was analyzed prior to the experiment. The concentrations of major nutrient elements in the water were as follows: Mg (0.0022%), K (0.0003%), Ca (0.0090%), SO_4 (0.0249%), and Cl (0.0001%). Thereafter, plants received an N: P: K (10:50:10) fertilizer to stimulate root development and were treated with methyl thiophanate fungicide (0.5:1000) for one week to prevent potential fungal infections. Following this period, plants were fertigated with Hoagland's full-strength nutrient solution.

Environmental parameters in the greenhouse were carefully controlled, with daytime and nighttime temperatures maintained at 25 ± 2 °C and 16 ± 2 °C, respectively. The average relative humidity was 65%, and the mean midday photosynthetic photon flux density (PPFD) was 240 ± 5 μmol m^{-2} s^{-1}. A factorial experiment was carried out in a completely randomized design (CRD) with four nutrient concentrations based on the standard Hoagland solution. Each treatment was replicated four times, with six plants per replication. In total, 192 rose plants were studied (96 plants per cultivar, with four nutrient treatments, four replications, and six plants per replication).

The experimental treatments including concentrations of 100% Hoagland, 75% Hoagland, 50% Hoagland, and 25% Hoagland based on standard Hoagland fertilizer formulation (Table 1) were applied to each treatment separately after adjusting the pH of the solution at the range of 5.6-5.9. It is worthy to note that the volume of the required water for the rose plants was not changed in each treatment and only the concentration of the Hoagland solution was decreased. These regimes were applied for 180 days. At experiment's end, key parameters were assessed. EC and pH were monitored daily, with EC ranging from 900 to 1900 μS cm^{-1} based on treatment.

Morphological Traits Measurement

Stem length (crown to apex) was measured with a ruler and categorized into six quality classes according to the grading standards of the Iranian Rose Society: A++ (≥90 cm), A+ (75–89 cm), A (60–74 cm), B (45–59 cm), C (30–44 cm), and D (<30 cm). Root length was measured with a ruler; root volume by water displacement. Flower length and diameter were recorded using a digital caliper. Leaf area (cm^2) was measured with a WinArea-UT-11 leaf areameter.

Vase Life

Cut flowers were placed in 500 mL distilled water under controlled conditions (25±2°C, 65 ± 5% RH, 12 h light photoperiod, light intensity of 20 µmol $m^{-2}s^{-}$ (PPFD^{1}). Vase life (days) was recorded as the time until petal drop or neck bending (Jin et al., 2006).

Relative Water Content

Measured using five discs from fully expanded young leaves based on Cherki et al. (2002):

$$RWC = \left[\frac{(FW - DW)}{(TW - DW)}\right] \times 100$$

where FW = fresh weight, TW = turgid weight (after 4 h rehydration in darkness), DW = dry weight (after 24 h at 70 °C).

Membrane Stability Index

Calculated following Singh et al. (2008):

$$MSI = 1 - \frac{c1}{c2} \times 100$$

where C1 and C2 are conductivity after 30 min at 40 °C and 15 min at 100 °C, respectively.

Chlorophyll Determination

Chlorophyll a and b were extracted in 80% acetone from 0.1 g fresh leaf, centrifuged, and absorbance was recorded at 664 and 647 nm (Lichtenthaler, 1987). Results (mg g^{-1} FW) were calculated using standard equations.

$$\text{Chlorophyll a (mg/gFW)} = \frac{12.25(\text{A}_{664}) - 2.79(\text{A}_{647}) \times \text{Volume made}}{\text{Wt of the sample}}$$

$$\text{Chlorophyll b (mg/g FW)} = \frac{21.21(\text{A}_{647}) - 5.10(\text{A}_{664}) \times \text{Volume made}}{\text{Wt of the sample}}$$

where Wt is the weight of the sample, and Aλ is the absorption at wavelength λ (nm).

Antioxidant Enzyme Activity

Enzymes were extracted from 0.2 g frozen tissue (Ozden et al., 2009):

CAT: H_2O_2 decomposition at 240 nm (Chen et al., 2009)

POD: o-dianisidine oxidation at 470 nm (pH 7.4)

SOD: Inhibition of NBT photoreduction at 560 nm (Giannopolitis & Ries, 1977).

Activities expressed as µmol min^{-1} mg^{-1} protein.

Mineral Elements

Oven-dried samples were dry-ashed (500 °C, 4 h) and extracted with 2N HCl. Concentrations of K, P, Ca, Fe, and Zn were determined via ICP-MS (Volpin & Elad, 1991). Total N was measured using modified macro-Kjeldahl with salicylic acid (Kacar, 1994).

Statistical Analysis

Data were analyzed using SAS (v.9.4), and treatment means were compared by LSD test at the 5% significance level ($p \leq 0.05$). Pearson correlation analysis was performed using SAS. Software. ver.9.4. Principle component analaysis (PCA) was performed using Minitab sotware (ver.16)

RESULTS

Root length and volume

Root length increased with decreasing Hoagland concentration in both cultivars. The maximum length (38.25 mm) was recorded in 'Samurai' at 50%, while 'Jumilia' showed a marked decrease at 75% (Figure 1A). Root volume was highest in 'Jumilia' at 25% (98.00 cm^3), with no significant difference from 75% and 100%. In contrast, 'Samurai' had the lowest volume (58.50 cm^3) at 25%. Across treatments, 'Jumilia' consistently exhibited higher root volume than 'Samurai' (Figure 1B).

Stem length

Hoagland concentrations significantly affected stem length in both cultivars (Figure 1C). The longest stems (69.64 mm) were recorded in 'Samurai' at 75% Hoagland, with no significant difference from 100%. Generally, 'Samurai' marginally outperforming 'Jumilia' under all Hoagland solution. According to standard cut flower grading criteria, stem length quality was classified as grade A.

Flower diameter and length

With the increase in the concentration of Hoagland solution to 100%, there was an increase in flower diameter and length. Plants treated with 50% Hoagland solution showed the lowest flower diameter and length (Figure 2A and 2B). Nonetheless, there was no significant difference in flower length between 75% and 25% Hoagland solution in rose cultivars.

Leaf area

Leaf area increased as a result of increase in the concentration of Hoagland solution in both cultivars. The maximum area (807.17 cm^2) was observed in 'Samurai' at 100%. In 'Jumilia', leaf area declined notably under 25% and 50% Hoagland (508.5 and 511.04 cm^2, respectively) (Figure 1D).

Vase life

The plants fertigated with 100% Hoagland solution caused an increase in vase life of rose flowers (15.97%) compared with the lowest value in 25% Hoagland solution (Figure 2C).

Relative water content and membrane stability index

The highest relative water content (67.29%) was observed in 'Jumilia' at 75% Hoagland, while 'Samurai' had the lowest (58.19%) at 50% (Figure 3E). However, the maximum membrane stability index recorded in plants treated with 100% Hoagland nutrient solution (76.74%), having no significant differences occurred in rose flowers treated with 75% and 50% Hoagland solution. The lowest membrane stability index was obtained in both cultivars fertigated with 25% Hoagland nutrient solution (72.05%) (Figure 3C).

Antioxidant enzyme activity

Catalase activity increased by 16.66% in roses treated with 75% Hoagland compared to the lowest value at 25% (1.60 $\mu mol\ min^{-1}\ mg^{-1}$ protein), with no significant difference at 100% (Figure 3A). The highest peroxidase activity was recorded at 100% and 75% Hoagland (42.85 and 42.65 $\mu mol\ min^{-1}\ mg^{-1}$), while the lowest (37.90 $\mu mol\ min^{-1}\ mg^{-1}$) occurred at 25% (Figure 3B). Superoxide dismutase activity varied significantly across cultivars and treatments. Generally, 'Samurai' is as higher than under all concentrations. In 25% Hoagland nutrient solution, 'Jumilia' had the lowest superoxide dismutase enzyme activity (1.44 U mg^{-1} protein), having no significant difference with 75% Hoagland nutrient solution in this cultivar. Cultivar 'Samurai' in 75% Hoagland nutrient solution results in the greatest rise in superoxide dismutase enzyme activity (2.03 1.44 U mg^{-1} protein), while having no significant difference with some concentrations in both cultivars (Figure 3D).

Photosynthetic pigments (chlorophyll a, b and total)

Photosynthetic pigments were influenced by Hoagland concentrations. In 'Samurai', chlorophyll a peaked at 100% and 75% Hoagland (27.21 and 27.01 mg g^{-1}, respectively), while lower values were observed at 50% and 25% (Figure 4A). In 'Jumilia', the highest chlorophyll b (29.43 mg g^{-1}) and total chlorophyll (54.52 mg g^{-1}) occurred at 100% Hoagland. Both cultivars showed reduced pigment content at lower concentrations (Figures 4B, 4C).

Mineral elements

Leaf nitrogen content was the highest in 'Jumilia' at 100% Hoagland (31.95%), while the lowest (3.13%) was found in 'Samurai' at 75% (Table 2). Phosphorus increased by 87.80% in 'Samurai' (100%) and 'Jumilia' (25%) compared to the lowest in 'Samurai' at 50%. Maximum potassium (1.65%) and magnesium (66.66% increase) were recorded in 'Samurai' at 100%, while zinc content peaked in 'Jumilia' (0.011%) and 'Samurai' (0.010%) under 100% and 75%, respectively. Iron increased by 3.33% in 'Samurai' (100%), and calcium reached it's the highest in 'Jumilia' (100%), with a 41.80% rise over the lowest in 'Samurai' (50%).

Treatment with 100% Hoagland solution significantly increased root nutrient concentrations in both cultivars, especially in cv. 'Samurai'. This cultivar showed the highest root nitrogen (34.87% increase), phosphorus (2.49%), calcium (55.60% increase), and magnesium (29.41% increase) compared to the lowest values at reduced Hoagland levels (Table 3). With the decrease in the concentration of Hoagland solution to 25%, there was a reduction in root potassium content in both cultivars, that the highest content was observed in cv. 'Samurai' supplied with 100% Hoagland solution treatment (0.76%). The maximum and minimum concentration of iron in root was recorded in cv. 'Samurai' fertigated with 100% Hoagland solution and 25% Hoagland solution, respectively. In cv. 'Jumilia', 100% Hoagland also boosted root zinc by 55.56% relative to its minimum in 'Samurai' under 25% Hoagland.

Correlation

Significant correlations were observed among physiological, biochemical, and morphological traits, revealing interrelated growth responses. Flower length was strongly and positively correlated with flower diameter. Stem length showed positive associations with both stem diameter and leaf area, indicating coordinated vegetative growth. In contrast, flower traits (length and diameter) were negatively correlated with stem traits, suggesting a trade-off between vegetative and reproductive development. Leaf area aligns positively with chlorophyll content and membrane stability, linking it to photosynthesis and cell health. Chlorophyll a, b, and total chlorophyll increases photosynthetic efficiency. Relative water content is positively associated with flower traits and antioxidant enzymes (CAT, POD), underscoring its role in maintaining floral quality under water-limited conditions. Antioxidant enzymes (CAT, SOD, POD) are interrelated and linked to physiological traits, with catalase strongly related to vase life. Furthermore, nutrient elements such as magnesium, potassium, and phosphorus demonstrate strong positive correlations with antioxidant enzyme activities and total chlorophyll, highlighting their roles in enhancing metabolic processes and stress tolerance. Total chlorophyll also reveals strong positive relationships with chlorophyll a and b and leaf iron content, reflecting coordinated pigment accumulation and nutrient status (Table 4).

Principal component analysis (PCA)

Principal component analysis revealed that over 75% of the total variance was explained by the first two components, with PC1 and PC2 accounting for 41.7% and 33.8%, respectively (Figure 5a). The results also showed a high correlation pattern between some variables, such as total chlorophyll, leaf and root potassium, magnesium, and phosphorus in the first component, and stem length, leaf area and superoxide enzyme activity in the second component. The biplot indicates that higher Hoagland concentrations are linked to increased pigment and nutrient accumulation (PC1), whereas vegetative growth and antioxidant activity contribute to variation along PC2 (Figure 5b).

Cultivars treated with 100% Hoagland solution were positively associated with traits loading on PC1 (primarily those related to chlorophyll content and nutrient concentrations). In contrast, lower concentration treatments such as Cultivars ‘Jumilia’ and ‘Samurai’ fertigated with 25% Hoagland solution are clustered on the negative side of first component, indicating lower association with these traits (Figure 5c).

DISCUSSION

The formulation, concentration, and composition of nutrient solutions are critical determinants of plant performance and yield in hydroponic systems, as plant growth relies entirely on these solutions. According to previous studies, both overly diluted and highly concentrated nutrient solutions can negatively affect plant growth and reduce yield in certain species (spinach, rocket, or lettuce cultivars) (Hosseini et al., 2021). Moreover, choosing the inexpensive and economic nutrient solution as well as the analysis of cost in hydroponic technique are expected (Melo & dos Santos, 2011).

Optimal nutrient solution concentration is a key factor in maximizing root development in hydroponic crops. In this study, increased root length and volume at lower Hoagland concentrations were likely due to enhanced nutrient uptake efficiency, which promotes overall plant growth (Baiyin et al., 2021).

Key morphological traits of cut flowers include color, scent, size, architecture, number per stem, and vase life (Al-Ajlouni et al., 2017). In this study, rose growth and floral traits improved under 100% Hoagland solution, likely due to increased plant biomass, consistent with findings in bedding plants (Kang & van Iersel, 2002). However, 75% Hoagland also produced acceptable stem length for cut flower export. Excessively high nutrient concentrations, due to elevated electrical conductivity (EC), negatively affected growth—while moderate EC levels have been shown to improve traits like leaf area and stem length (Ding et al., 2018; Hosseini et al., 2021). High EC can induce salinity stress, reducing osmotic potential and water uptake, which limits cell expansion and causes ion imbalances (Albornoz & Lieth, 2015; Ding et al., 2022). Conversely, low nutrient concentrations can also limit growth. Thus, managing EC by adjusting nutrient levels is crucial for maintaining floral quality. Similar reductions in floral traits due to excess nutrients have been reported in Calla (Scagel & Schreiner, 2006) and other lily cultivars (Al-Ajlouni et al., 2017).

Postharvest life of rose flowers is defined by the period before wilting or petal curling occurs (Khosravi et al., 2025). The shortest vase life was observed in roses treated with 25% Hoagland solution. Alterations in chemical and physiological processes shorten flower longevity, accelerating senescence during long-distance transport and marketing (Alaey et al. 2011). The decline in relative water content, membrane stability and calcium content due to the inadequate application of Hougland nutrient solution resulted in decrease in rose vase life.

Antioxidant enzyme activities serve as key indicators of plant responses to biotic and abiotic stresses (Ding et al., 2018; Cheheltanan et al., 2024). In this study, the activities of SOD, POD, and CAT increased under high EC conditions (100% and 75% Hoagland solution), while the lowest activities were observed at 25% Hoagland concentration. Elevated CAT and POD activities under high EC suggest their critical role in mitigating stress by detoxifying reactive oxygen species (Ding et al., 2018; 2022). Specifically, SOD, CAT, and POD scavenge superoxide radicals and hydrogen peroxide, with CAT converting hydrogen peroxide to water, and POD using phenolic compounds or antioxidants to break it down (Chen et al., 2009). This upregulation of antioxidant enzymes under stress conditions likely contributes to maintaining plant growth (Cheheltanan et al., 2024), as supported by previous studies (Ding et al., 2018).

Low fertilizer concentrations often reduce plant growth and chlorophyll content due to mild nutrient deficiencies, while excessive levels may induce salt stress and growth inhibition (Kang & van Iersel, 2002). Similar responses have been reported in New Guinea impatiens (Kent & Reed, 1996).

In our experiment, roses treated with the lowest concentration of Hoagland nutrient solution showed signs of mineral deficiency. Nutrient scarcity limited leaf growth and leaf area index, likely due to reduced photosynthesis and impaired cell elongation (Roosta & Afsharipoor, 2012). Nitrogen deficiency, linked to smaller leaf cells, was associated with reduced water conductance and tissue hydration. Phosphorus deficiency hindered leaf cell expansion or increased cell density per unit area, resulting in smaller, dark green leaf sheaths (Roosta & Afsharipoor, 2012). However, application of 100% Hoagland nutrient solution increased phosphorus content, which improved flower primordia formation and enhanced both flower number and size in roses (Dangi et al., 2019). Additionally, optimal vegetative growth, particularly leaf area expansion, was closely linked to adequate nitrogen levels in leaves and roots, achieved through a balanced nutrient supply (Roosta & Afsharipoor, 2012). Higher calcium content in roots compared to leaves is likely due to greater root access to calcium in the nutrient solution, consistent with Sobczak et al. (2024). Adequate iron and zinc levels in the 100% Hoagland treatment help maintain membrane protein and phospholipid stability (Marschner, 2012). In contrast, low concentrations of iron, magnesium, and zinc under diluted Hoagland solution reduce antioxidant enzyme activity, leading to elevated free radical production, lipid peroxidation, and membrane degradation (Marschner, 2012).

Overall, PCA analysis indicates that treatment effects are clearly distinguishable and closely linked to specific physiological and biochemical traits, reflecting the complex nature of plant responses. Correlation analysis further highlights the interplay between morphology, stress resilience, and nutrient status, offering useful insights for breeding and management strategies to enhance rose growth and stress tolerance.

CONCLUSIONS

In ornamental plants, understanding resource partitioning throughout the growth cycle is essential for developing efficient production systems. This knowledge enables growers to optimize flower yield while reducing input costs at precise growth stages. This study demonstrated that applying an optimal concentration of nutrient solution allows rose growers to reduce fertilizer usage and input costs while maintaining plant growth and flower quality. Application of an optimal concentration of Hoagland nutrient solution enhanced flower longevity by improving relative water content, leaf area, and mineral nutrient uptake. Overall, optimizing fertilizer use with 75% and 50% Hoagland nutrient solution can promote rose growth and development while maximizing profit through reduced fertilizer input. Moreover, since 75% Hoagland solution produced Grade A stem length based on cut flower quality standards, it is recommended for export-quality rose production.

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Table 1. Concentration of salts in nutrient solutions.

	Compound	Concentration of stock solution (g/L)	Volume of stock solution per liter of final solution (ml)	Element	Final concentration of element (ppm)
Macro Nutrients				N	224
	KNO_3	101.10	6	K	235
	$Ca(No_3)_2$-$4H_2O$	236.16	4	Ca	160
	$NH_4H_2Po_4$	115.08	2	P	62
	$MgSo_4$-$7H_2O$	246.49	1	S	32
				Mg	24
Micro Nutrients	KCl	1.864	2	Cl	1.77
	H_3Bo_3	0.773	2	B	0.27
	$MnSo_4$-H_2O	0.169	2	Mn	0.11
	$ZnSo_4$-$7H_2O$	0.288	2	Zn	0.13
	CuSo4-5H2O	0.062	2	Cu	0.03
	H_2MoO_4(85%MoO3)	0.040	2	Mo	0.05
	NaFeDTPA(10%Fe)	30.0	0.3-1	Fe	1-3

Table 2. Effect of Hoagland nutrient concentration on leaf nitrogen, phosphorous, potassium, zinc, iron, calcium and magnesium content in two rose cultivars.

Cultivar	Hoagland concentration (%)	Nitrogen (%)	Phosphorous (%)	Potassium (%)	Zinc (%)	Iron(%)	Calcium (%)	Magnesium (%)
	100	4.31^{b}	0.77^{a}	1.65^{a}	0.010^{ab}	0.033^{a}	1.21^{a}	0.45^{a}
	75	3.13^{f}	0.65^{e}	0.95^{d}	0.0084^{f}	0.031^{b}	1.15^{ab}	0.34^{c}
'Samurai'	50	3.55^{d}	0.41^{g}	0.75^{e}	0.0086^{ef}	0.027^{d}	0.71^{d}	0.30^{d}
	25	3.84^{c}	0.53^{f}	0.33^{f}	0.0091^{cd}	0.029^{c}	1.04^{c}	0.15^{f}
	100	4.60^{a}	0.74^{b}	1.52^{b}	0.1063^{b}	0.026^{ab}	1.22^{a}	0.44^{b}
	75	3.31^{ef}	0.68^{d}	1.06^{c}	0.0095^{c}	0.032^{ab}	1.18^{a}	0.33^{c}
'Jumilia'	50	3.46^{de}	0.70^{c}	1.03^{c}	0.0088^{de}	0.022^{e}	1.06^{bc}	0.30^{d}
	25	3.44^{de}	0.77^{a}	1.04^{c}	0.0110^{a}	0.026^{d}	1.21^{a}	0.28^{e}

Means followed by the same letter within a column are not significantly different according to LSD test at P<0.05.

Table 3. Effect of Hoagland nutrient concentration on root nitrogen, phosphorous, potassium, zinc, iron, calcium and magnesium content (%) in two rose cultivars.

Cultivar	Hoagland concentration (%)	Nitrogen	Phosphorous	Potassium	Zinc	Iron	Calcium	Magnesium
'Samurai'	100	3.24^{a}	2.49^{a}	0.76^{a}	0.0145^{b}	0.118^{a}	2.05^{a}	0.34^{a}
	75	2.86^{b}	1.84^{c}	0.45^{e}	0.0115^{e}	0.114^{b}	1.99^{a}	0.33^{b}
	50	2.38^{d}	1.20^{e}	0.23^{f}	0.0099^{f}	0.051^{f}	1.25^{e}	0.26^{e}
	25	2.77^{bc}	0.83^{g}	0.18^{g}	0.0084^{h}	0.033^{g}	0.91^{g}	0.27^{d}
'Jumilia'	100	2.65^{c}	2.06^{b}	0.65^{b}	0.0189^{a}	0.091^{c}	1.74^{b}	0.28^{c}
	75	2.26^{de}	1.58^{d}	0.56^{c}	0.0131^{d}	0.070^{d}	1.62^{c}	0.25^{ef}
	50	2.22^{ef}	0.92^{f}	0.49^{d}	0.0136^{c}	0.073^{d}	1.38^{d}	0.24^{f}
	25	2.11^{f}	0.73^{h}	0.11^{h}	0.0091^{g}	0.062^{e}	0.98^{f}	0.25^{ef}

Means followed by the same letter within a column are not significantly different according to LSD test at P<0.05.

Table 4. Correlation analysis of physiological, nutritional and morphological parameters of the rose cultivars.

	RL	RV	SL	SD	FD	FL	VL	LA	RWC	MSI	CAT	SOD	POD	CHA	CHB	TCH	IL	MgL	KL	ZnL	PL	NL
RL	1																					
RV	0.22	1																				
SL	0.29	-0.68**	1																			
SD	0.19	-0.64**	0.78**	1																		
FD	-0.26	0.63**	-0.75**	-0.67**	1																	
FL	-0.29	0.63**	-0.76**	-0.67**	0.93**	1																
VL	-0.24	0.68**	-0.57**	-0.65**	0.81**	0.80**	1															
LA	0.28	-0.56**	0.89**	0.64**	-0.50**	-0.55**	-0.36*	1														
RWC	-0.60**	0.16	-0.57**	-0.44*	0.73**	0.70**	0.50**	-0.32	1													
MSI	0.14	-0.19	0.52**	0.28	-0.30	-0.25	-0.08	0.49**	-0.46**	1												
CAT	-0.29	0.70**	-0.71**	-0.67**	0.76**	0.80**	0.82**	-0.55**	0.54**	-0.24	1											
SOD	0.11	-0.63**	0.76**	0.68**	-0.52**	-0.59**	-0.45**	0.73**	-0.24	0.34	-0.62**	1										
POD	-0.36*	0.67**	-0.65**	-0.65**	0.83**	0.85**	0.93**	-0.47**	0.56**	-0.11	0.83**	-0.44*	1									
CHA	-0.04	-0.03	0.39*	0.13	0.15	0.08	0.36*	0.62**	0.07	0.34	0.17	0.28	0.27	1								
CHB	0.13	0.12	0.21	-0.07	0.36	0.31	0.48**	0.47**	0.27	0.22	0.30	0.19	0.36	0.74**	1							
TCH	0.07	0.06	0.29	0.0006	0.30	0.24	0.46**	0.56**	0.21	0.28	0.27	0.23	0.35	0.89**	0.96**	1						
IL	0.21	-0.06	0.35*	0.06	0.09	0.006	0.19	0.67**	0.07	0.21	-0.03	0.25	0.05	0.74**	0.67**	0.74**	1					
MgL	0.07	0.33	0.14	-0.16	0.35	0.37*	0.63**	0.29	0.04	0.43	0.35*	0.007	0.55**	0.74**	0.73**	0.78**	0.47**	1				
KL	0.006	0.40*	-0.03	-0.31	0.52**	0.53**	0.68**	0.13	0.20	0.30	0.42*	-0.15	0.62**	0.65**	0.68**	0.72**	0.40*	0.95**	1			
ZnL	0.21	0.38	-0.27	-0.38	0.52	0.53	0.39	-0.07	0.33	-0.18	0.22	-0.41	0.29	0.15	0.36	0.30	0.28	0.44	0.62	1		
PL	-0.20	0.37*	-0.38*	-0.49**	0.74**	0.68**	0.65**	-0.18	0.51**	-0.16	0.52**	-0.36*	0.60**	0.45**	0.43*	0.46**	0.20	0.54**	0.73**	0.68**	1	
NL	0.17	-0.02	0.17	-0.04	0.22	0.27	0.16	0.35*	0.23	0.28	-0.04	0.10	0.07	0.22	0.64**	0.52**	0.37*	0.47**	0.52**	0.56**	0.25	1

*$p < 0.05$ (2-tailed). **$p < 0.01$ (2-tailed).

RL= root length	RV=root volume	SL= stem length	SD= stem diameter	FL=flower length	FD=flower diameter	VL=vase life	LA=leaf area
RWC=relative water content	MSI=membrane stability index	CAT=catalase enzyme	SOD=superoxide enzyme	POD=peroxidase enzyme	CHA= chlorophyll a	CHB= chlorophyll b	TCH=total chlorophyll
IL= leaf iron	MgL= leaf magnesium	KL=leaf potassium	ZnL= leaf zinc	PL= leaf phosphorous	NL= leaf nitrogen		

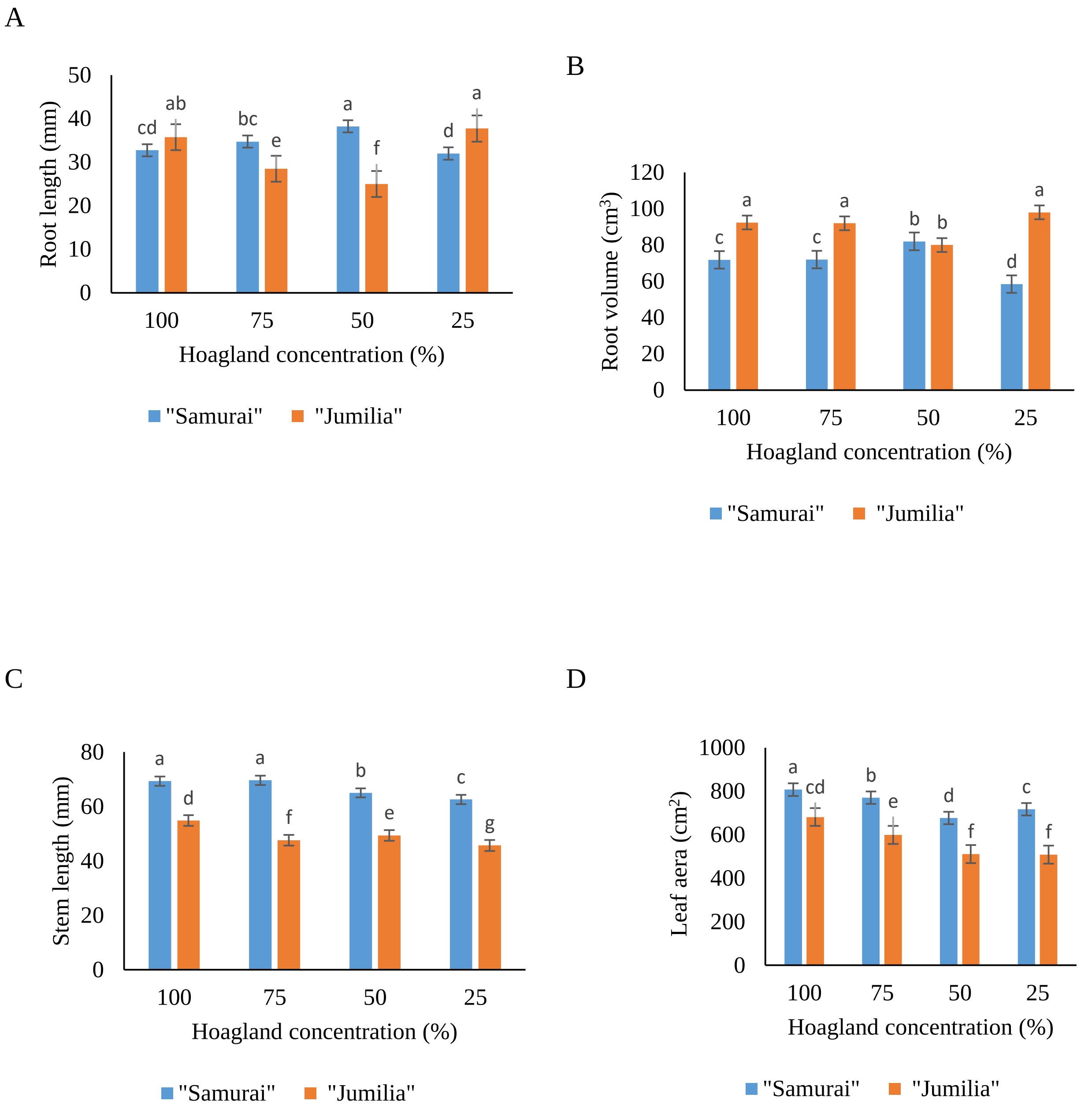

Figure 1. Interaction between different concentrations of Hoagland nutrient solution and cultivars on root length (A), root volume (B), stem length (C), and leaf area (D). The graph's bars represent the average value over three replicates, while the error bars denote the standard deviation.

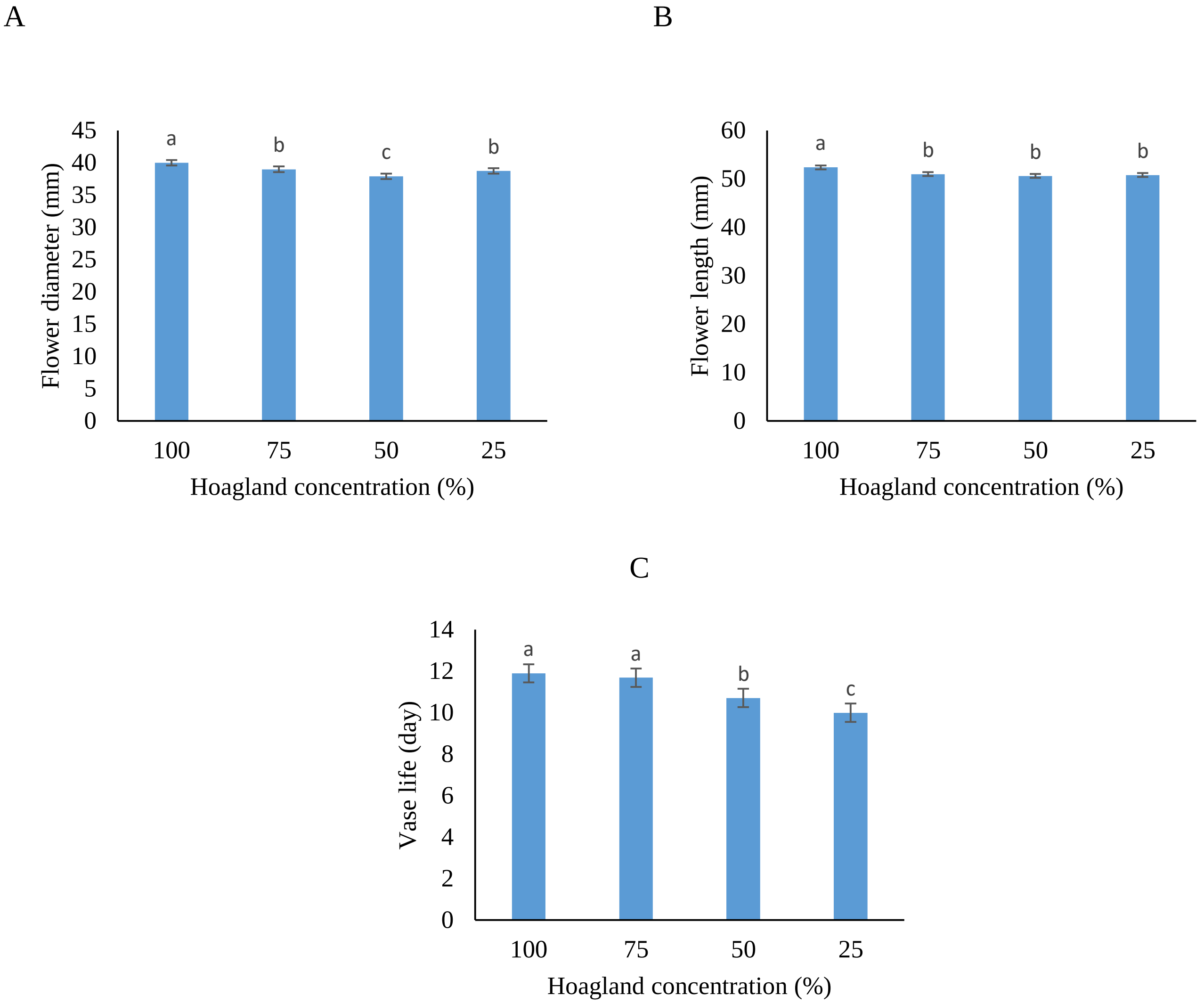

Figure 2. Effect of different concentrations of Hoagland nutrient solution on flower diameter (A), flower length (B) and vase life (C) of rose. The graph's bars represent the average value over three replicates, while the error bars denote the standard deviation.

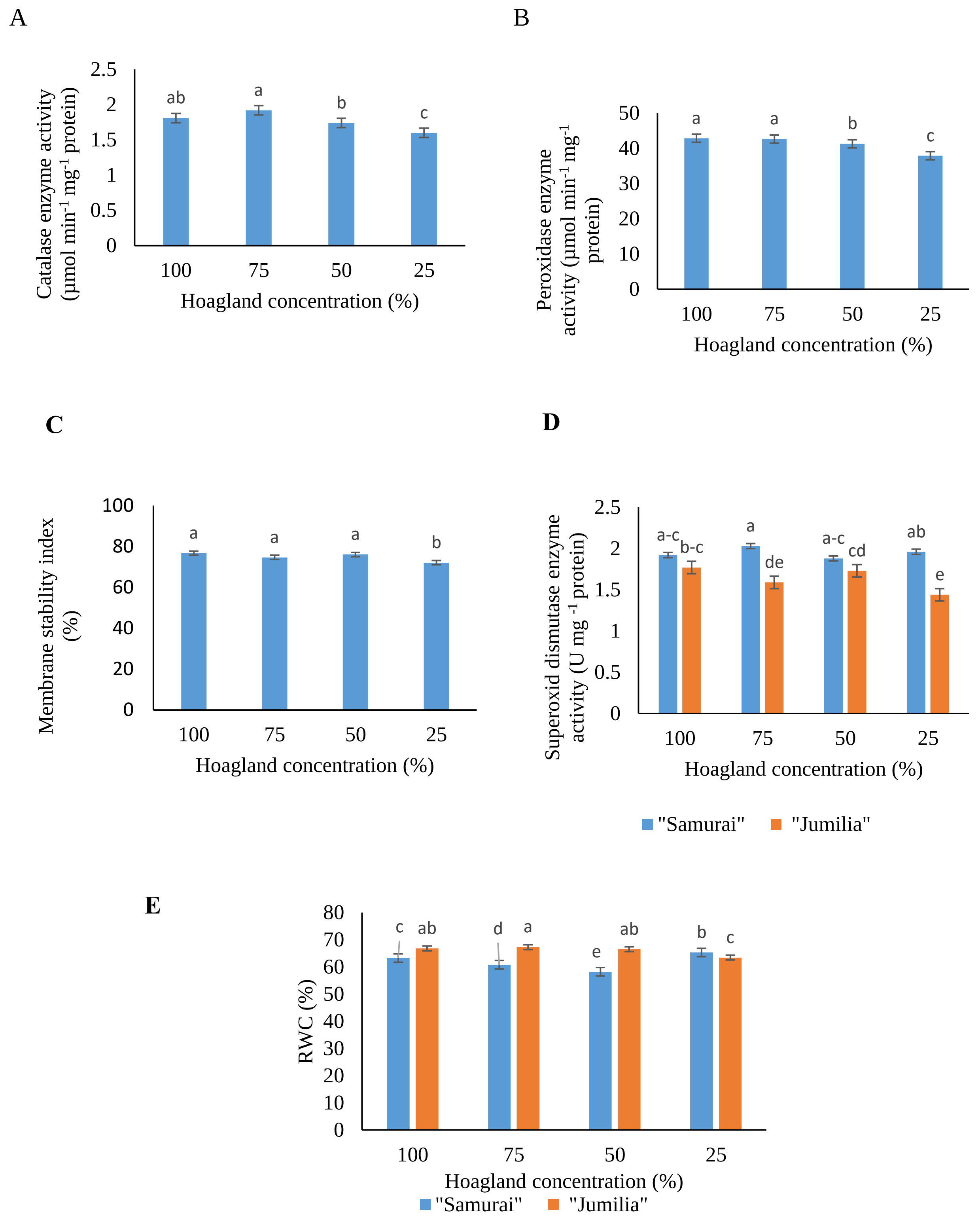

Figure 3. Effect of concentrations of Hoagland nutrient solution on CAT (A) and POD (B) enzyme activities, and membrane stability index (C) in rose. The interaction between concentrations of Hoagland nutrient solution and cultivars is shown for SOD enzyme activity (D) and relative water content (E). The graph's bars represent the average value over three replicates, while the error bars denote the standard deviation.

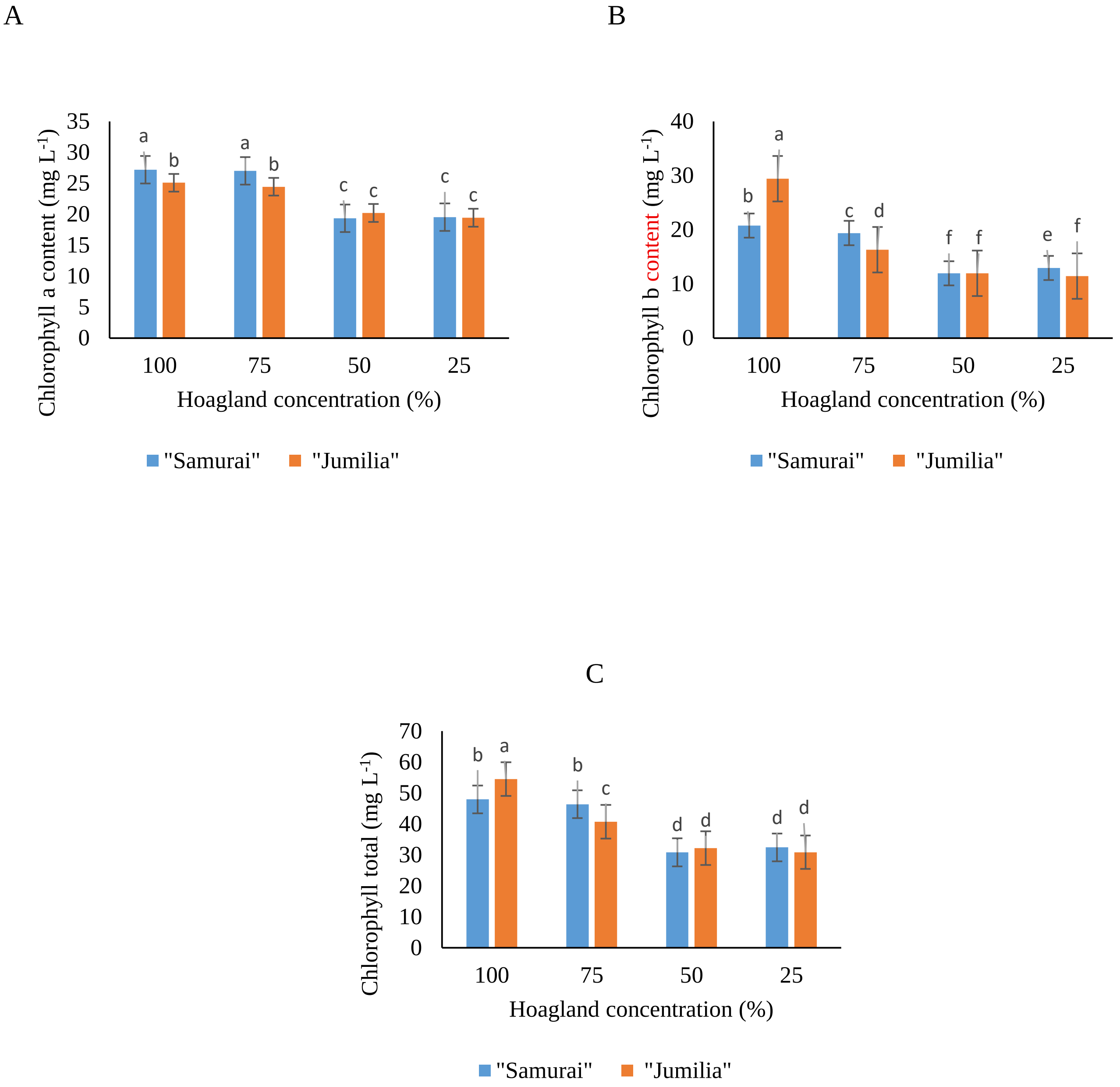

Figure 4. Interaction between concentrations of Hoagland nutrient solution and cultivars on chlorophyll a (A), chlorophyll b (B) and chlorophyll total (C) contents. The graph's bars represent the average value over three replicates, while the error bars denote the standard deviation.

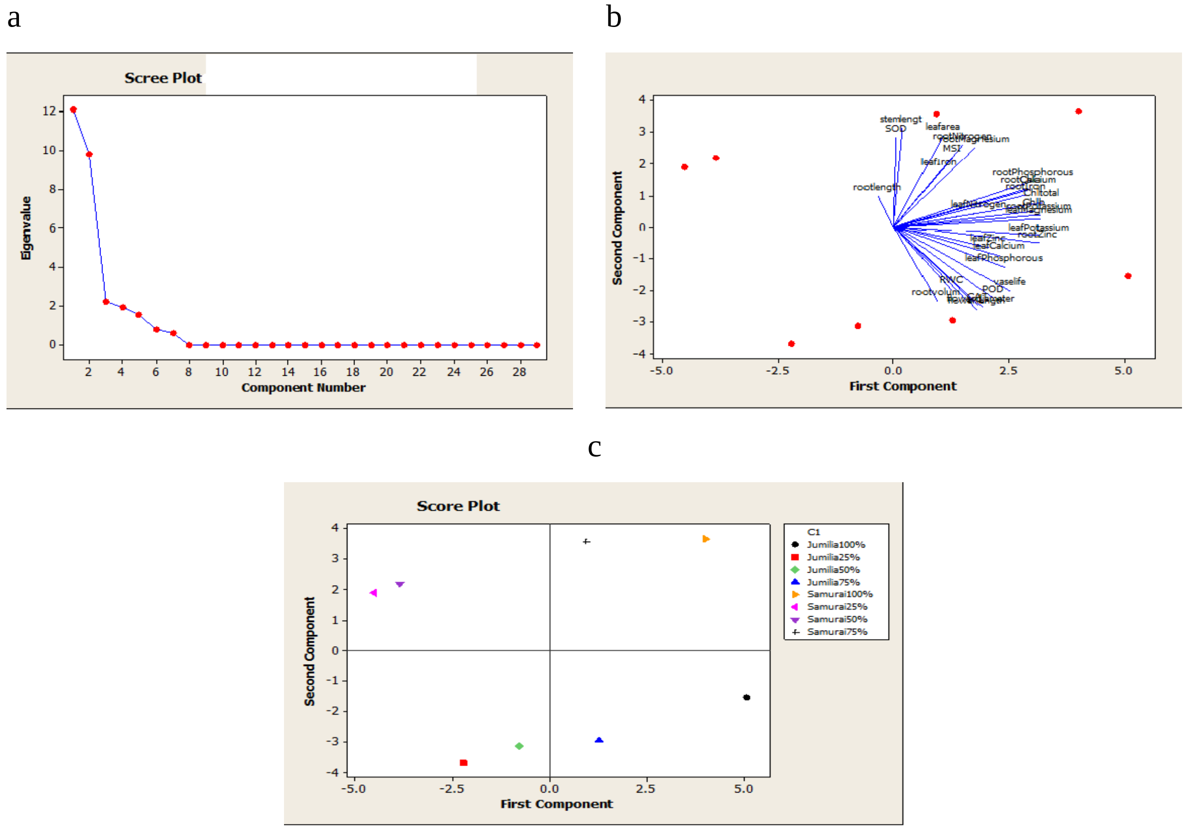

Figure 5. Models of principal component analysis (PCA) plots. Scree plot (a) and score for the rose variable (b), and biplot (c).

بهینه سازی سطوح عناصر غذایی برای بهبود رشد و کیفیت گل رز

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چکیده

این پژوهش به منظور بررسی تأثیر سطوح مختلف عناصر غذایی بر رشد، گلدهی و پاسخ بیوشیمیایی دو رقم رز، سامورایی و جومیلیا، در سیستم کشت بدون خاک طراحی شد. بنابراین هدف، بهینه‌سازی مصرف کود در راستای بهبود کیفیت و عمرگلجای گل رز بود. این آزمایش به صورت فاکتوریل و در قالب طرح کاملاً تصادفی با چهار سطح محلول غذایی هوگلند (25%، 50%، 75% و 100%) انجام شد. نتایج نشان داد که افزایش غلظت محلول غذایی، قطر گل، طول ساقه، سطح برگ و عمر گلجای را بهبود بخشید، در حالی که طول ریشه را کاهش داد. استفاده از محلول غذایی ۷۵٪، میزان کلروفیل a را ۳۸,۴۴٪ و طول ساقه را ۱۱,۱۹٪ افزایش داد و همچنین تجمع عناصر غذایی را در ریشه و برگ، به ویژه در رقم سامورایی افزایش داد. همچنین کاربرد این سطح از محلول غذایی، فعالیت آنزیم‌های آنتی‌اکسیدانی در سامورایی را افزایش یافت، به طوری که فعالیت سوپراکسید دیسموتاز، کاتالاز و پراکسیداز را به ترتیب ۳,۵۷%، 20% و ۱۲,۵۳٪ افزایش داد. محلول ۱۰۰٪ منجر به بالاترین سطح نیتروژن و منیزیم در برگ‌های جومیلیا شد که این افزایش به ترتیب ۱,۳۴ و ۱,۵۷ برابر بود. غلظت‌های پایین‌تر محلول غذایی (۲۵٪ و ۵۰٪) باعث کاهش محتوای کلروفیل و پایداری غشا شد. به‌طور کلی، تأمین ۷۵٪ محلول غذایی هوگلند در گل رز رشد بهینه، کیفیت گل و بهره‌وری از منابع را فراهم کرده و از گلکاری پایدار، حصول حداکثر سودآوری و تولید گل با کیفیت صادراتی پشتیبانی می‌کند و در عین حال مصرف کود و تأثیرات زیست‌محیطی را کاهش می‌دهد.