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Pre-Harvest Chemical Compounds Influence Lily (*Lilium* × *elegans*) Leaf and Flower Indigenous Phenols, Flavonoids and Gibberellic Acid Levels

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Abstract: The global cut flower industry, including lilies, represents a highly promising investment. Therefore, improving the quantity and quality of these commercially significant flower species is crucial. The objectives of this study were to (1) evaluate the influence of different pre-harvest chemical compounds on endogenous GA_3, phenol, flavonoids and total antioxidants levels on the leaf and petals parts of Longiflorum-Asiatic (*Lilium* × *elegans* cv. Cevennes, yellow) lily and to (2) assess the effect of these compound on the flower quality component. The study was conducted over two cycles in both greenhouse and laboratory settings. Lily bulbs were transplanted into 10 L pots and grown for 70 days. Treatments were applied by spraying twice with a five-day interval on the flowers still on the plants and not yet fully opened. The treatments included 8-hydroxyquinoline sulfate (8HQS) at 100, 200, and 400 mg L^{-1}; salicylic acid (SA) at 100 and 200 mg L^{-1}; SmartFresh™ at 1 and 2 mg L^{-1}; Harvista™ at 150 mg L^{-1}; GA_3 at 50 mg L^{-1}; and a control (water). The lily stems were harvested when one of the flowering buds began to open but was not fully opened. A post-harvest assessment was conducted in the laboratory at room temperature (20 ± 2 °C). The results showed that the lily leaf had a much higher endogenous concentration of GA_3 (256%) and lower concentrations of total phenols (22%), flavonoids (28%), and antioxidant activity (14%) when compared to flower petals. In addition, the foliar application of flower preservative compounds one week before harvesting significantly improved the endogenous levels of GA_3, total phenols, flavonoids, and antioxidants activity, especially SmartFresh™ at rate of 1 mg L^{-1}. In terms of flower quality, SmartFresh™, at rate of 1 mg L^{-1}, and 8-HQS, at rate of 200, had consistently higher vase lives compared to the control treatment across the two experimental cycles. Compared to the control, SmartFresh™ (the post-harvest ethylene control) increased the vase life of lily flowers by 35% at cycle 1 and 31% at cycle 2 while 8-HQS, at rate of 200 mg L^{-1}, increased the vase life by 21% and 15% at cycles 1 and 2, respectively. However, no significant effect was found in the petal flower color coordinates (L*, a* and b*) across the treatments. Overall, the foliar application of preservative compounds (such as SmartFresh™) at the pre-harvest stage potentially stimulates the endogenous levels of GA_3, total phenols, flavonoids, and antioxidants activity, leading to better improvements in post-harvest flower quality, specifically vase life.

Keywords: Lilium; vase life; phenolic compound; antioxidants; floriculture

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1. Introduction

The Liliaceae family, belonging to the flowering plant order Liliales, includes 16 genera and 635 species native to subtropical and temperate zones [1]. Many Liliaceae genera are important in the floriculture and horticulture industries, particularly *Tulipa* spp. and *Lilium* spp. The *Lilium* genus exhibits a wide array of characteristics, including various flower colors, shapes, and sizes. The herbaceous leaves typically have parallel veins, which alternate along the stem or are arranged in whorls. Additionally, lily plants have an underground storage structure (which varies in size) known as a bulb [1]. Numerous

lily cultivars are commercially grown under controlled microclimates (greenhouses) with temperature requirements between 16 and 21 °C in the daytime and 10 to 17 °C during the night [2,3]. Worldwide, the lily is one of the top five cut flower species auctioned in flower stock markets, in addition to roses, tulips, and gerbera [3]. In 2022, the Royal FloraHolland (RFH), the largest marketplace for the floriculture industry in the world, disclosed a revenue of $5.6 billion [4]. During that period, the RFH sold about 300 million lily flowers, contributing to a total value of around $150 million.

The economic value of a lily depends on several quality components, such as flower shape, size, petal color, and longevity [5]. Cultural practices, including applying external hormones, managing nutrients, selecting growing substrates, and planting depth, have a potential influence on the anatomy, physiology, yield, and quality of lily flowers [3,5,6]. For example, 6-Benzylaminopurine (BA, cytokinins) and gibberellic acid (GA_3, Gibberellins) at 50 mg L^{-1} significantly increase the leaf thickness, total number of vascular bundles, leaf area, flower number per stem, and vase life in lilies [5]. Pre-harvest applications of salicylic acid (SA) and calcium chloride have been suggested as eco-friendly alternatives to chemical products for extending the post-harvest life of cut rose flowers [7]. The application of ethylene inhibitors represents an approach to reduce indigenous production and delay post-harvest senescence [8]. For instance, the foliar application of 1-Methylcyclopropene (1-MCP, ethylene inhibitor) at a concentration of 10 µL L^{-1} before harvest (pre-harvest management) showed positive effects on rose flower vase life [8]. In terms of post-harvest management practices, which primarily aim at increasing flower longevity (the vase life), numerous preservative solutions have been used, including silver thiosulfate, 8-hydroxyquinoline sulfate (8-HQS), sucrose, silver nitrate, and GA_3 [9–11]. Hayat et al. [12] found that silver thiosulfate (STS) acts as a "weapon" against ethylene action. A combination of 25 mg L^{-1} of STS and 7.5% sucrose significantly increased the vase life of cut roses [12].

The cut flower industry is a promising investment, and any study associated with improving the quantity and quality of these commercially important cut flower species is of great interest to cut flower producers. Several studies have been conducted to assess the effect of pre- and post-harvest application of chemical compounds on flower yield and quality [11–15]. In a recent review, Sun et al. [16] demonstrated that endogenous phytohormones contribute to enhancing the vase life of cut flowers by influencing the diverse physiological processes that delay senescence. However, the effect of pre-harvest treatments, especially ethylene action inhibitor compounds as well as plant growth promoters (e.g., gibberellins), is not fully understood. In addition, the influence of these applied pre-harvest compounds on the indigenous plant levels of the total phenols, flavonoids, and GA_3 is not completely comprehended, specifically in lilies. The objectives of this study were to (1) assess the influence of pre-harvest chemical compounds on the endogenous GA_3, phenol, flavonoid, and total antioxidant levels in both the leaf and flower petals of lilies and (2) assess the effect of these compounds on flower quality components (petal color and vase life).

2. Materials and Methods

2.1. Study Sites and Plant Material

The study was conducted in both greenhouse and laboratory facilities at the Department of Horticulture and Crop Science, The University of Jordan, Jordan. During the study period, two cycles were carried out: cycle 1 was between January and June 2023, while cycle 2 was from July to November 2023. Longiflorum-Asiatic (*Lilium* × *elegans* cv. Cevennes, yellow) lily bulbs were transplanted into 10 L pots filled with perlite: peat moss (1:3 *v*/*v*) medium. The pots were placed on a bench (6 m × 3 m) within the greenhouse facility. Fertigation was applied once every two weeks starting four weeks after the planting date using the commercial fertilizers 20N-20P_2O_5-20K_2O, 20N-20P_2O_5-30K_2O at a rate of 220 mg L^{-1}-N, 65 mg L^{-1}-P, and 300 mg L^{-1}-K. Irrigation was manually applied by applying about 500 mL per pot every three days. Weather data (temperature and light

intensity) were recorded over the experimental period using the weather unit data logger (Figure 1).

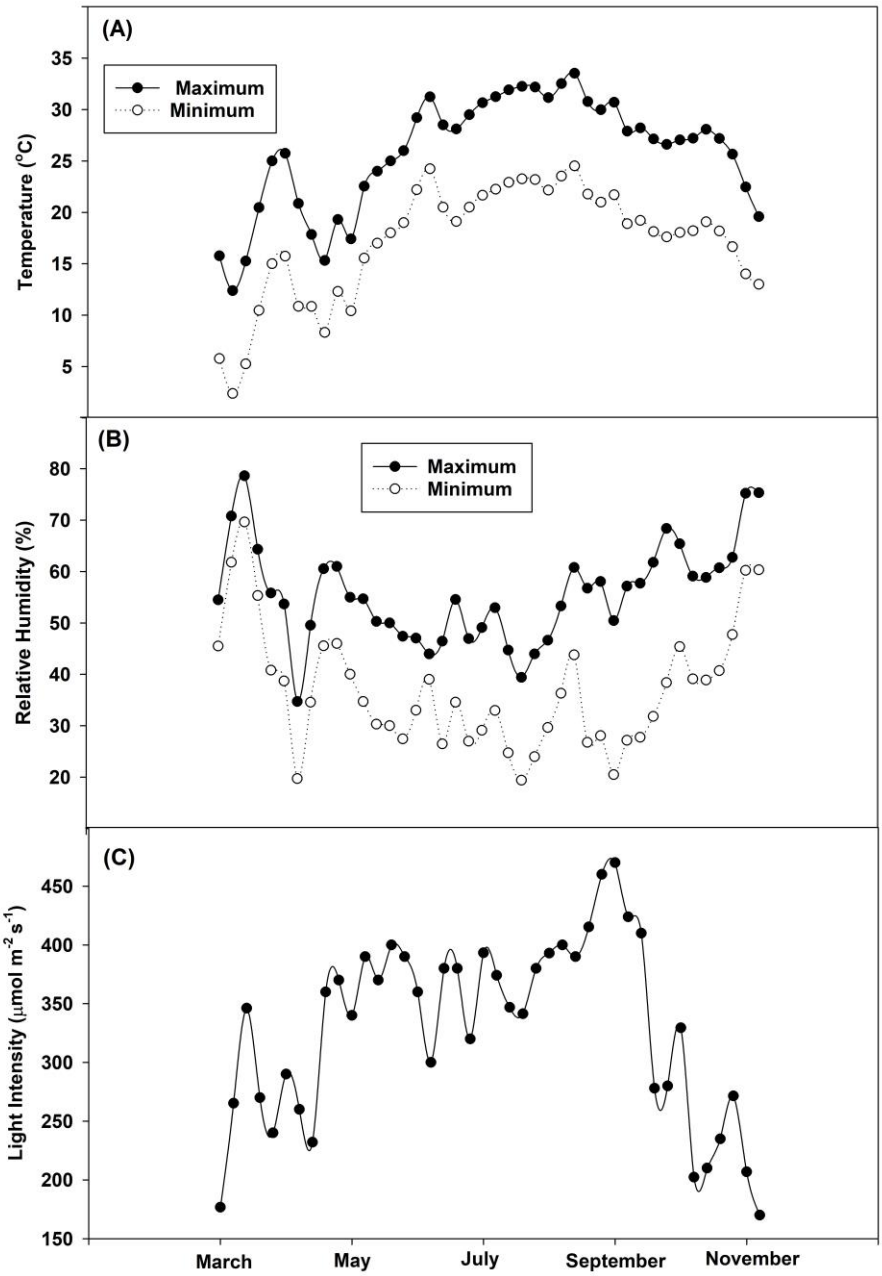

Figure 1. (**A**) Temperature, (**B**) relative humidity, and (**C**) light intensity in the greenhouse during the experimental period in 2023.

2.2. Treatments

Five foliar chemical compounds were used to assess the influence of this pre-harvest material on lily flower quality and the indigenous content of phenols, flavonoids, GA3, and antioxidant activity. The treatments were 8-hydroxyquinoline sulfate (8HQS) at rates of 100, 200, and 400 mg L^{-1}, salicylic acid (SA) at rates of 100 and 200 mg L^{-1}, SmartFresh™ at rates of 1 and 2 mg L^{-1}, Harvista™ at a rate of 150 mg L^{-1}, GA_3 at a rate of 50 mg L^{-1}, and a control (water). Both SmartFresh™ and Harvista™ are the commercial forms of 1-MCP. Harvista™ was designed to act as the pre-harvest ethylene control, while SmartFresh™ played a key role in controlling ethylene production at the post-harvest stage. In both growing cycles, the treatments were sprayed twice on the flowers at five-day intervals

while they were on the plants and not fully opened, about one week before harvesting (Figure 2). After 48 h of the second application, the flowers were harvested (four replicates) and placed in 2 L vases filled with an acidic preservative solution. The vase preservative solution pH was adjusted to extremely acidic levels (pH = 3.5–4.0) using citric acid. The lily stems were harvested when one of the flowering buds began to open but was not fully opened. The post-harvest assessment was carried out in the laboratory at room temperature (20 ± 2 °C).

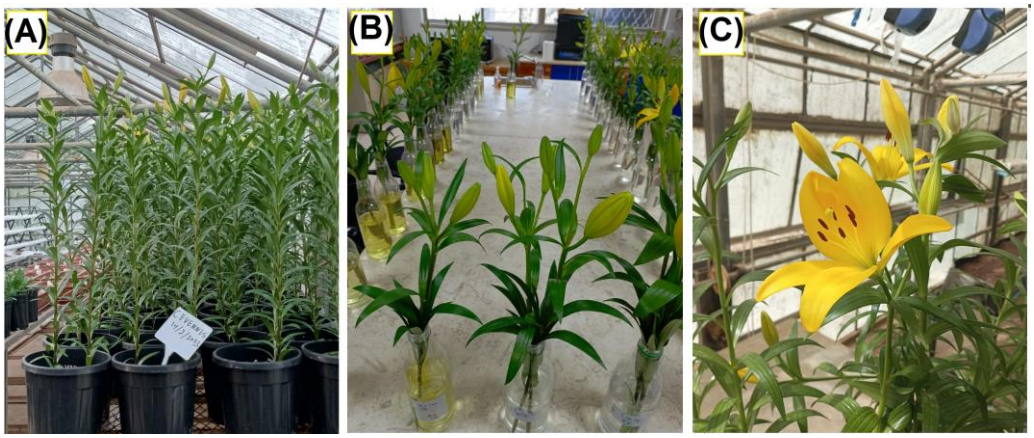

Figure 2. (**A**) Lily plants in the greenhouse on the day of foliar application, (**B**) after being placed in a 2 L vase filled with an acidic preservative solution in the laboratory, and (**C**) during the flower quality assessment.

2.3. Flower Quality Measurements

The flower quality components, including leaf chlorophyll content, petal color coordinates, and vase life, were determined. Five days following harvesting, the leaf chlorophyll content was determined using a chlorophyll concentration meter (MC-100; Apogee Instruments, Logan, UT, USA). The vase life was determined by re-cutting the stems (2–3 cm from the base) under water to remove the emboli (small bubbles of air in the xylem) and placing them directly in a preservative solution (acidic water). The vase life of a lily flower was specified as the duration in days from the harvesting of the stems and their placement in the holding solution until the first lily flower per stem either fell off or wilted [5]. The petal color coordinates (L*, a*, and b*) were determined on two flowers per stem using a colorimeter (3Color® CP-100, Narama, Poland) and following the procedure of Alsmairat et al. [17]. The L* color component represents the lightness of the color. It ranges from 0 to 100, where 0 represents black and 100 represents white. The a* coordinate represents the position of the color along the red–green axis, while the b* coordinate represents the position of the color along the yellow–blue axis. For water uptake, the amount of acidic water from the day of harvest to the end until the first lily flower per stem either fell off or wilted was measured.

2.4. GA_3, Phenol, Flavonoid, and Antioxidant Activity Measurements

During the harvesting period (one flower was fully opened while on the plant), flower petals and leaves from each treatment and replicate were collected and stored in plastic bags and transferred to the laboratory for GA3, total phenol, flavonoid, and antioxidant capacity analyses. The Bruker Daltonik Impact II ESI-Q-TOF system equipped with a Bruker Daltonik Thermo UPLC system was employed for the determination of GA_3 concentration. The mass accuracy was less than 1 ppm, the mass resolution was 50,000 FSR (full sensitivity resolution), and the TOF repetition rate was up to 20 kHz. Standards were utilized for the identification of the m/z values using a high-resolution Bruker TOF MS, and the exact retention time of each analyte post chromatographic separation was recorded. A total of 10 mL of Acetonitrile with temephose was added to 10 g of sample. Then, buffer salts ($MgSO_4$, NaCl, Na_3 Citrate, and Na_2H Citrate) were added to the sample and centrifuged

at 4000 rpm for 2.0 min. The extract (1.0 mL) was then transferred into a centrifuge tube already containing $MgSO_4$ and PSA for the measurements. For the total phenol, flavonoid, and antioxidant capacity, a representative leaf and petal sample (20 g) from each replicate was digested using 70% methanol. The resulting solution was filtered using fast filter paper, and the total volume of the extracted sample was adjusted to 50 mL using 70% methanol. The total antioxidant capacity analysis was determined following the procedure of Brand-Williams et al. [18]. The antioxidant capacity was measured using DPPH (1,1-Diphenyl-2-picrylhydrazyl) dissolved in methanol (0.025 g/50 mL). For each test, 0.2 mL of the plant extract was added to a test tube, followed by the addition of 3.7 mL of methanol and 0.2 mL of DPPH, resulting in a total volume of 4 mL. The mixture was incubated in the dark for one hour. The blank consisted of 0.2 DPPH and 3.8 mL of methanol. The absorbance of the reaction mixture was measured at 516 nm using a spectrophotometer against DPPH + methanol. The radical scavenging activity of the tested samples was quantified as the inhibition percentage of free radicals, calculated using the following formula:

$$\text{Inhibition \%} = (\text{Absorbance of control} - \text{Absorbance of sample})/(\text{Absorbance of control}) \times 100\%$$

The determination of total phenols was conducted using a 0.2 N Folin and sodium carbonate (Na_2CO_3) solution at a concentration of 75 g L^{-1}. Then, 0.2 mL of the sample extract was placed in a test tube, after which 2.5 mL of the Folin mixture was added, and the sample was allowed to stand for 5 min. Then, 2 mL of sodium carbonate solution was added, and the samples were incubated at room temperature for two hours. The absorbance of the reaction mixture was then measured at 750 nm using a spectrophotometer against a methanol blank. Gallic acid (0–400 mg L^{-1}) served as the standard to generate the calibration curve, and the estimation of total phenols was performed in duplicates. The results were calculated using the gallic acid calibration curve, and the total phenolics were expressed as gallic acid equivalents (mg GAE/100 g of plant fresh extract). In terms of total flavonoids, the procedure involved the use of sodium hydroxide (NaOH, 4%) wt/v, aluminum chloride ($AlCl_3$, 10%) wt/v, and sodium nitrate ($NaNO_2$, 15%) wt/v. In the assay, 0.2 mL of the plant extract was placed in the test tubes, followed by the addition of 2 mL of distilled water. Subsequently, 0.15 mL of $NaNO_2$ was added, and the mixture was allowed to stand for six minutes. Afterward, 0.15 mL of $AlCl_3$ was added, and the mixture was again allowed to stand for 6 min. Next, 2 mL of NaOH was added, and distilled water was used to bring the final volume to 5 mL. The samples were then incubated for 15 min at room temperature, and the absorbance of the mixture was measured at 510 nm using a spectrophotometer against a distilled water blank. The total flavonoid content was calculated based on the standard curve for the catechen hydrate solutions, ranging from 10 to 200 mg L^{-1}. The results were expressed as catechen equivalents in mg 100 g^{-1} of the fresh plant extract sample.

2.5. Statistical Analysis

All treatments were arranged randomly using RCBD with four replicates. In the statistical analysis, we utilized SAS software (Version 9.1 for Windows; SAS Institute, Cary, NC, USA). An ANOVA and the least significant difference test (LSD) at $p < 0.05$ were employed in SAS (Version 9.4 for Windows; SAS Institute, Cary, NC, USA) to detect the differences between the treatments and their interactions.

3. Results

The ANOVA and mean separation (LSD) results for water uptake, flower vase life, and petal color coordinates (L*, a*, and b*) of lilies (cv. Cevennes) subjected to different pre-harvest flower preservative treatments during cycle 1 are presented in Table 1. During this cycle, untreated control plants and those exposed to the foliar application of salicylic acid had higher leaf chlorophyll content than SmartFresh™, 8-HQS, GA_3, and Harvista™ (Table 1). However, the foliar application of preservative chemical compounds one week

before harvesting resulted in a significant increase in the stem water uptake and vase life compared to the control. For example, SmartFresh™ increased the vase life of lily flowers by 35% compared to the control. In terms of the petal color coordinates (L*, a*, and b*), no significant difference was noticed between the treatments in cycle 1 (Table 1). The L* values ranged from 42 to 45.5, a* ranged from 2.3 to 3.1, and the b* coordinate values were between 38.2 and 42.9.

Table 1. Leaf chlorophyll content, water uptake, flower vase life, and petal color coordinates (L*, a*, and b*) of lilies (cv. Cevennes) subjected to different pre-harvest flower preservative treatments. Cycle 1.

Treatment	Level (mg L^{-1})	Chlorophyll Content (μmol m^{-2})	Water Uptake (mL $Plant^{-1}$)	Vase Life (Day)	Petal Color Coordinate		
					L*	a*	b*
SmartFresh™	1.0	176 ^{c}	84.0 ^{a}	13.0 ^{a}	45.5 ^{a}	2.68 ^{a}	42.4 ^{a}
SmartFresh™	2.0	196 ^{c}	74.0 ^{b}	11.0 ^{bcd}	42.1 ^{a}	2.50 ^{a}	40.5 ^{a}
Gibberellic acid (GA_3)	50	185 ^{c}	88.0 ^{a}	12.0 ^{ab}	44.8 ^{a}	3.05 ^{a}	42.9 ^{a}
8-hydroxyquinoline sulfate	100	188 ^{c}	86.0 ^{a}	10.8 ^{cd}	43.6 ^{a}	2.93 ^{a}	40.9 ^{a}
8-hydroxyquinoline sulfate	200	197 ^{c}	82.0 ^{ab}	11.6 ^{bc}	41.9 ^{a}	2.41 ^{a}	39.3 ^{a}
8-hydroxyquinoline sulfate	400	175 ^{c}	94.0 ^{a}	11.6 ^{bc}	44.9 ^{a}	2.77 ^{a}	40.5 ^{a}
Salicylic acid	100	185 ^{c}	91.0 ^{a}	11.2 ^{bcd}	44.1 ^{a}	2.88 ^{a}	40.5 ^{a}
Salicylic acid	200	238 ^{ab}	90.0 ^{a}	11.0 ^{bcd}	43.0 ^{a}	2.32 ^{a}	38.2 ^{a}
Harvist™	150	204 ^{bc}	95.0 ^{a}	12.0 ^{ab}	42.5 ^{a}	2.36 ^{a}	39.9 ^{a}
Control (water)	0.0	317 ^{a}	76.0 ^{b}	9.6 ^{e}	43.6 ^{a}	2.67 ^{a}	39.6 ^{a}
p-value		0.02	0.04	<0.0001	0.93	0.85	0.78

The means in the columns followed by different letters are significantly different at $p \leq 0.05$, as determined using the least significant difference (LSD) test.

The ANOVA and LSD for the second cycle showed that the chlorophyll content was similar for most treatments (Table 2). The foliar application of 8-HQS at a higher rate (400 mg L^{-1}) had the highest chlorophyll value. Interestingly, SmartFresh™ at a rate of 1 mg L^{-1} and 8-HQS at rates of 200 and 400 mg L^{-1} had higher vase lives than the control. However, the petal color coordinates (L*, a*, and b*) of the control lily plant were similar to or higher than the other treatments (Table 2).

Table 2. Leaf chlorophyll content, water uptake, flower vase life, and petal color coordinates (L*, a*, and b*) of lilies (cv. Cevennes) subjected to different pre-harvest flower preservative treatments. Cycle 2.

Treatment	Level (mg L^{-1})	Chlorophyll Content (μmol m^{-2})	Water Uptake (mL $Plant^{-1}$)	Vase Life (Day)	Petal Color Coordinate		
					L*	a*	b*
SmartFresh™	1.0	469 ^{abc}	56.0 ^{ab}	10.2 ^{a}	31.1 ^{ab}	1.16 ^{ab}	25.5 ^{ab}
SmartFresh™	2.0	477 ^{abc}	44.0 ^{cde}	8.60 ^{bcd}	33.5 ^{ab}	1.06 ^{ab}	30.9 ^{a}
Gibberellic acid (GA_3)	50	458 ^{bc}	60.0 ^{a}	8.20 ^{cd}	32.5 ^{ab}	1.27 ^{ab}	27.7 ^{ab}
8-hydroxyquinoline sulfate	100	463 ^{bc}	49.0 ^{bcd}	8.40 ^{bcd}	32.0 ^{ab}	1.11 ^{ab}	24.5 ^{b}
8-hydroxyquinoline sulfate	200	452 ^{bc}	56.0 ^{ab}	9.00 ^{bc}	33.5 ^{ab}	1.18 ^{ab}	29.3 ^{ab}
8-hydroxyquinoline sulfate	400	492 ^{a}	52.0 ^{abc}	9.40 ^{ab}	28.3 ^{b}	0.98 ^{ab}	24.6 ^{b}
Salicylic acid	100	474 ^{abc}	52.0 ^{abc}	8.60 ^{bcd}	33.9 ^{ab}	1.09 ^{ab}	30.4 ^{a}
Salicylic acid	200	465 ^{bc}	48.0 ^{bcd}	8.00 ^{cde}	29.0 ^{b}	0.52 ^{b}	22.4 ^{b}
Harvista™	150	489 ^{ab}	52.0 ^{abc}	8.20 ^{cd}	32.3 ^{ab}	1.04 ^{ab}	27.8 ^{ab}
Control (water)	0.0	484 ^{ab}	42.0 ^{cde}	7.80 ^{def}	35.7 ^{a}	1.40 ^{a}	30.5 ^{a}
p-value		0.04	0.0006	<0.0001	0.04	0.05	0.03

The means in the columns followed by different letters are significantly different at $p \leq 0.05$, as determined using the least significant difference (LSD) test.

This study revealed that the lily leaves had higher endogenous concentrations of GA_3 and lower concentrations of total phenols and flavonoids, as well as antioxidant activity when compared to flower petals (Table 3). For example, the endogenous concentration of GA_3 in lily leaves was 3.5-fold that of flower petals. The foliar application of flower preser-

vative compounds significantly improved the endogenous levels of GA_3, total phenols, flavonoids, and antioxidant activity, especially SmartFresh™ at a rate of 1 mg L^{-1}. In fact, the endogenous concentrations of GA_3, total phenols, and flavonoids in the preservative compound treatments were similar to or higher than the control lily plants.

Table 3. Gibberellic acid, total phenols, flavonoids, and antioxidant activity for the leaves and flower petals of lilies (cv. Cevennes) subjected to different pre-harvest flower preservative treatments. These measurements are for cycle 2.

Treatment	Level (mg L^{-1})	Gibberellic Acid (GA_3, mg L^{-1})	Phenols (mg 100 g^{-1})	Flavonoids (mg 100 g^{-1})	Antioxidant Activity (%)
Plant part					
Leaf		0.32 ^{a}	111 ^{b}	0.73 ^{b}	0.38 ^{b}
Petal		0.09 ^{b}	143 ^{a}	1.02 ^{a}	0.44 ^{a}
Treatment					
SmartFresh™	1.0	0.64 ^{a}	134 ^{a}	1.00 ^{a}	0.63 ^{a}
SmartFresh™	2.0	0.09 ^{b}	119 ^{b}	0.91 ^{ab}	0.38 ^{bc}
Gibberellic acid (GA_3)	50	0.05 ^{b}	115 ^{b}	0.83 ^{ab}	0.41 ^{b}
8-hydroxyquinoline sulfate	100	0.16 ^{b}	137 ^{a}	0.90 ^{ab}	0.37 ^{bc}
8-hydroxyquinoline sulfate	200	0.28 ^{b}	130 ^{ab}	0.85 ^{ab}	0.39 ^{bc}
8-hydroxyquinoline sulfate	400	0.21 ^{b}	125 ^{ab}	0.78 ^{b}	0.35 ^{c}
Salicylic acid	100	0.12 ^{b}	130 ^{ab}	0.89 ^{ab}	0.39 ^{bc}
Salicylic acid	200	0.57 ^{a}	126 ^{ab}	0.90 ^{ab}	0.37 ^{bc}
Harvista™	150	0.08 ^{b}	135 ^{a}	0.86 ^{ab}	0.39 ^{bc}
Control (water)	0.0	0.01 ^{b}	117 ^{b}	0.83 ^{ab}	0.42 ^{b}
p-value					
Treatment (T)		0.0002	0.0382	0.04848	<0.0001
Part (P)		<0.0001	<0.0001	<0.0001	<0.0001
T × P		<0.0001	0.5183	0.5654	<0.0001

The means in the columns followed by different letters are significantly different at $p \leq 0.05$, as determined using the least significant difference (LSD) test. The total phenolic content is expressed as the gallic acid equivalent (GAE) (mg GAE/100 g dry weight basis). The total flavonoid content is expressed as the Catechin equivalent (CE) (mg CE/100 g dry weight basis).

4. Discussion

The application of preservatives and ethylene inhibitors presents a promising approach for enhancing the quality of cut flowers, particularly by extending their vase life [6]. Vase life is an essential variable for evaluating the post-harvest quality of cut flowers, including lilies [19,20]. In addition, visual attributes, such as leaf chlorophyll content and leaf size, play a significant role in marketing lilies [5]. In this study, SmartFresh™ (a form of 1-MCP) at a rate of 1 mg L^{-1} and 8-HQS at a rate of 200 had consistently higher vase lives compared to the control treatment across the two experimental cycles. Compared to the control, SmartFresh™, which acts as a post-harvest ethylene controller, increased the vase life of lily flowers by 35% at cycle 1 and 31% at cycle 2. In addition, 8-HQS, at a rate of 200, increased the vase life by 21% and 15% at cycles 1 and 2, respectively. A higher vase life can be partially attributed to higher water uptake by flowers during the post-harvest assessment. The water uptake by flowers from SmartFresh™ at a rate of 1 mg L^{-1} was about 11–33% higher than control across cycles. Enhanced water uptake in cut flowers resulted in better hydration and turgor maintenance and consequently prolonged the vase life. Research by Marini et al. [21] indicated that ethylene control compounds improved water uptake efficiency in cut roses, resulting in extended post-harvest longevity. In addition to water uptake, numerous studies have indicated that enhanced vase life and post-harvest quality of cut flowers following various preservative treatments are associated with an increased ability to scavenge reactive oxygen species [22,23]. The combination of 8-HQC (150 mg L^{-1}) and sucrose (20 g L^{-1}) was found to enhance the post-harvest flower quality of lilies and

roses by stimulating ROS-scavenging activities [23]. Treatment with 1-MCP has been shown to significantly elevate the activities of antioxidant enzymes, such as superoxide dismutase, catalase, and peroxidase, in cut spray carnations [22]. Sisler et al. [24] concluded that 1-MCP acts as an inhibitor of ethylene receptors.

For a vast number of ornamental species, blocking the plant's response to ethylene via a chemical approach is an efficient strategy to enhance the longevity of the flowers [25]. Ethylene action inhibitors (1-MCP) interact with ethylene receptors and modulate ethylene responses [25,26]. The potential performance of 1-MCP has been noticed in a range of ornamental species, and it is now widely used commercially under the trade name of EthylBloc® and SmartFresh™ [26]. In carnations (*Dianthus caryophyllus*), the application of 1-MCP extended the vase life of cut spray by reducing fresh weight loss, ethylene production, as well as chlorophyll and anthocyanin degradation [27].

The lily leaf had a much higher endogenous concentration of GA3 (256%) and a lower concentration of total phenols (22%), flavonoids (28%), and antioxidant activity (14%) when compared to flower petals (Table 3). Gibberellins (GAs) are endogenous plant growth regulators involved in regulating various aspects of plant growth and development [28]. Additionally, these tetracyclic diterpenoid compounds (GAs) stimulate several physiological responses in plants and change the source-sink relationship [29]. The distribution and concentration of GA_3 can vary among different plant tissues due to tissue-specific biosynthesis, metabolism, and transport processes. A study conducted by Olszewski et al. [30] showed that GA_3 metabolism and response pathways integrate with other signaling pathways to regulate plant growth and development, and the biosynthesis genes are expressed at higher levels in actively growing tissues like leaves. In addition, GA_3 may be more rapidly metabolized or deactivated in flower petals compared to leaves, leading to lower concentrations in the petals [31]. The lower endogenous concentration of total phenols, flavonoids, and antioxidant activity in lily plants compared to flower petals (Table 3) can be attributed to several factors related to the physiological and biochemical differences between these plant tissues. Different plant tissues exhibit distinct metabolic activities and biosynthetic pathways. While flower petals may prioritize the synthesis and accumulation of phenolic compounds and antioxidants to fulfill specialized functions, such as attracting pollinators and protecting against environmental stressors, in contrast, leaves or other vegetative tissues may have relatively lower concentrations of these compounds due to their primary role in photosynthesis and structural support [32,33]. The expression of genes involved in phenolic compound biosynthesis and antioxidant pathways can vary among different plant tissues and species [34]. An increase in flavonoid levels can be achieved by over-expressing biosynthesis or regulatory genes [34].

The foliar application of flower preservative compounds significantly improved the endogenous levels of GA_3, total phenols, flavonoids, and antioxidant activity (Table 3). Phenolic compounds play a key role in mitigating oxidative stress by scavenging free radicals [35], leading to higher flower quality. In this study, the exogenous application of GA_3 resulted in higher endogenous levels of GA_3 (compared to the control). Previous studies revealed a positive association between applied and endogenous gibberellins in plants [36]. Exogenous GA_3 application on peonies (*Paeonia suffruticosa* L.) stimulated the synthesis of endogenous GA_3 and indole-3-acetic acid [37]. Interestingly, the foliar application of the post-harvest ethylene control compound (SmartFresh™) at a rate of 1 mg L^{-1} and salicylic acid at a rate of 200 mg L^{-1} had higher endogenous levels of GA_3 when compared to applied GA_3 (Table 3). Ethylene inhibitors modulate ethylene levels in plants, thereby potentially altering the balance and regulation of GA_3 biosynthesis and signaling pathways [38].

Overall, the foliar application of chemical compounds, especially SmartFresh™ (postharvest ethylene control) at a rate of 1 mg L^{-1} and 8-HQS at a rate of 200 at the pre-harvest stage (about 1 week before harvesting) stimulated the production of endogenous GA_3, phenols, and flavonoids, leading to higher water uptake (better hydration

and turgor maintenance) and consequently higher flower post-harvest quality, specifically vase life.

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