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# Prolonging Cyclamen Flower Vase Life via 8-HQS and $AgNO_3$ Treatments in a Controlled Release System

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**Abstract:** The current study applied electrospun fibers containing 8-hydroxyquinoline-5-sulfonic acid (8-HQS) (100, 150, and 200 mg $L^{-1}$) and silver nitrate ($AgNO_3$) (15 and 20 mg $L^{-1}$) to enhance the longevity and qualitative parameters of two cyclamen cultivars. The results indicated that the vase life of the flowers treated with 20 mg $L^{-1}$ $AgNO_3$ and 200 mg $L^{-1}$ 8-HQS was higher than that of the other treatments (16 days). Cyclamens treated with 8-HQS (100 mg $L^{-1}$) + $AgNO_3$ (15 mg $L^{-1}$) and 8-HQS (100 mg $L^{-1}$) + $AgNO_3$ (20 mg $L^{-1}$) had lower polyphenol oxidase (PPO) activity than the control group. Also, it was observed that the higher phenylalanine ammonia-lyase (PAL) enzyme activity of cyclamens in the 8-HQS (150 mg $L^{-1}$) + $AgNO_3$ (15 mg $L^{-1}$) treatment was longer than that of the other treatments and control groups. Treatment with 100 mg $L^{-1}$ 8-HQS and 20 mg $L^{-1}$ $AgNO_3$ showed higher peroxidase (POD) activity than the different treatments. This research indicated that adding $AgNO_3$ and 8-HQS to electrospun fibers is a promising method for enhancing the longevity and maintaining the quality of these cut flowers.

**Keywords:** electrospun fibers; controlled release system; cut flower; antioxidant enzymes; vase life



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## 1. Introduction

Cyclamen (*Cyclamen persicum* Mill.), a member of the Primulaceae family, is known for its graceful flowers and appealing foliage. It is commonly grown in the temperate zone and has been appreciated by numerous individuals as a potted or garden plant. This plant holds significant commercial value as an ornamental species in various countries [1]. Producers are increasingly becoming interested in approaching some cyclamen cultivars as cut flowers [2]. However, the short vase life of cyclamen as cut flowers poses a challenge for consumers, retailers, and growers. There is a lack of information regarding this flower's postharvest physiology and handling [3].

Neumaier et al. [4] investigated the effects of harvest time, water quality, and chemical additives on the longevity of cyclamen-cut flowers. They reported that late-season harvesting and using some additives in the vase water reduced the shelf-life of flowers. In contrast, Halevy et al. [3] found that a vase solution comprising 5% sucrose and 30 mg $L^{-1}$ $AgNO_3$ allowed for the preservation of cyclamen flowers for three weeks while maintaining their quality at a level equal to or superior to that of untreated fresh flowers.

Numerous studies have widely recognized the antibacterial properties of silver nitrate ($AgNO_3$) and 8-hydroxyquinoline-5-sulfonic acid (8-HQS), which enhance water and nutrient uptake by mitigating physiological stem blockage [5].

Silver nitrate ($AgNO_3$) is a prevalent form of silver salt widely utilized in commercial flower preservative solutions. Its primary function is to inhibit ethylene binding [6].

Utilizing silver nitrate as a solution for the vase exhibited notable improvements in fresh weight, water uptake, flower dimensions, and post-harvest longevity in the 'First Red' cultivar of rose cut flowers [7]. Doğan et al. [8] found that varying concentrations of silver nitrate ($AgNO_3$) and sucrose effectively prolong the vase life of gerbera cut flowers by delaying head dropping and discoloration. The utilization of a 30 mg $L^{-1}$ concentration of $AgNO_3$ produced a more favorable impact on the longevity of *Ranunculus asiaticus* cut flowers compared to applications of 2% and 6% sucrose, as well as the control group. Flowers in sucrose solutions wilted after eight days, but those treated with silver nitrate stayed fresh for up to 14 days.

In addition, 8-HQS plays a crucial role as a preservative in the floral industry, functioning as an antiseptic to combat germs. It is an antimicrobial and antifungal agent that enhances water uptake by minimizing physiological stem blockage [5].

Elgimabi and Sliai [9] demonstrated that the longevity of Taif rose cut flowers was extended by applying all 8-HQS treatments. Their findings revealed that the most effective concentration was 200 ppm, and the impact was enhanced when combined with 7% sucrose, resulting in the most extended vase life compared to other sucrose concentrations. Elhindi [10] proposed that the application of HQS and sucrose for 12 h is the optimal method for enhancing pigmentation and utilizing a commercial cut flower preservative solution to delay the senescence of sweet pea flowers, improve their quality, and extend their vase life.

Applying the electrospun fiber-based method as a controlled release system offers significant benefits, allowing the gradual and regulated release of chemical additives [11]. Furthermore, the controlled release mechanism enhances the efficacy of active compounds. It mitigates adverse effects, such as toxicity resulting from overexposure, losses due to evaporation, and degradation caused by environmental factors [12]. Due to the $AgNO_3$ and 8-HQS action in extending the vase life of cut flowers, as well as functioning nanofiber mats, we aimed to verify whether the combined application of $AgNO_3$ and 8-HQS loaded in nanofiber mats can retard the senescence of cyclamen cut flowers.

Furthermore, this study investigated the fresh weight and color characteristics, as well as the activity of phenylalanine ammonia-lyase (PAL), polyphenol oxidase (PPO), DPPH scavenging activity, total phenolic content (TPC), and peroxidase (POD) in two postharvest cut cyclamen cultivars.

## 2. Materials and Methods

### *2.1. Plant Material*

Two cyclamen cultivars, *Cyclamen persicum* 'Strauss' (red color) and *C. persicum* 'Pure White' (white color) of potted *C. persicum* flowers were procured from a standard greenhouse in Turin, Italy and subsequently transferred to a greenhouse located at the University of Turin. Uniform cut flowers (25 cm in length) were selected for the experiments, and their stem ends were re-cut underwater into 1 cm lengths to remove air bubbles.

Maltodextrins with a DE value of 2 (Glucidex 2®, GLU2) were provided by Ro-Quette Freres (Lestrem, France). Citric acid (99%) (CIT) was purchased from Sigma-Aldrich (Darmstadt, Germany). GLU2 was dried to a constant weight in an oven at 75 °C. An electrospinning device comprised a 3 mL syringe, a power supply, and a volumetric pump to process the GLU2 solutions. Then, 8-hydroxyquinoline-5-sulfonic acid (8-HQS) (100, 150, and 200 mg $L^{-1}$) and silver nitrate ($AgNO_3$) (15 and 20 mg $L^{-1}$) were blended separately in the GLU2 solution. Six nanofiber mat treatments were selected. The homogeneous solution was transferred into a 10 mL syringe with a stainless-steel needle (18 gauge). A working distance of 15 cm, a field strength of 30 kV, and a flow rate of 1.2 mL $h^{-1}$ were set. The deposition was conducted at a relative humidity of 30–45% at room temperature. An aluminum cylinder-equipped rotary system (Linari NanoTech Easy Drum, Pisa, Italy) was

the collector at a rotation speed of 75 rpm. Then, the mats were exposed to 180 °C in an oven for 30 min.

### 2.2. Experimental Design

The experiment was designed according to a randomized plot. The cut flowers were randomly assigned to eight treatment groups per cultivar, totaling 16 experimental units with three replicates per treatment.

Electrospun fibers loaded with $AgNO_3$ (15 and 20 mg $L^{-1}$) were combined with 100, 150, and 200 mg $L^{-1}$ 8-HQS in a preservative solution containing sucrose 1%. These combinations were selected as vase solutions. The control groups comprised distilled water and 1% sucrose solution (Table 1). The nanofibers were cut to approximately 4–8 $cm^2$ (50–100 mg). The initial fresh weight of the cut flowers was recorded. Then, each stem end was coated with nanofiber (Figure 1A), and the flowers were placed in 250 mL glass cylinders filled with prepared preservative solutions of sucrose 1% (Figure 1B). The flowers were placed under laboratory conditions (24 h illumination with fluorescent light, 18 °C ± 2, and 50 to 40% RH) until the end of the experiment.

**Table 1.** Treatment groups with electrospun fibers containing silver nitrate and 8-HQS at different concentrations on two cyclamen cut flower cultivars.

| Groups | Treatments |
|---|---|
| T1 | Electrospun fibers + 8-HQS (100 mg $L^{-1}$) + $AgNO_3$ (15 mg $L^{-1}$) |
| T2 | Electrospun fibers + 8-HQS (100 mg $L^{-1}$) + $AgNO_3$ (20 mg $L^{-1}$) |
| T3 | Electrospun fibers + 8-HQS (150 mg $L^{-1}$) + $AgNO_3$ (15 mg $L^{-1}$) |
| T4 | Electrospun fibers + 8-HQS (150 mg $L^{-1}$) + $AgNO_3$ (20 mg $L^{-1}$) |
| T5 | Electrospun fibers + 8-HQS (200 mg $L^{-1}$) + $AgNO_3$ (15 mg $L^{-1}$) |
| T6 | Electrospun fibers + 8-HQS (200 mg $L^{-1}$) + $AgNO_3$ (20 mg $L^{-1}$) |
| C1 | Electrospun fibers (control 1) |
| C2 | Water (control 2) |

(**A**) (**B**)

**Figure 1.** (**A**) application of nanofibers at the end of the stem of cut flowers, (**B**) cut flowers treated with nanofibers.

### *2.3. Physiological and Postharvest Attributes*

#### 2.3.1. Vase Life, Weight Loss

Each flower was evaluated for vase life at 8 a.m. and 8 p.m. each day, according to a method described by Zhao et al. [13]. The duration of vase life was determined as the number of days during which the flowers maintained their aesthetic qualities, which was considered to be until the cyclamen cut flowers lost their ornamental value due to scape bending or corolla detachment [3].

The weight loss percentage was determined by measuring sample weight every two days.

#### 2.3.2. Color

A colorimeter (CM-2600D, Konica Minolta Sensing, Inc., Osaka, Japan) enabled evaluations of changes in the flowers' color attributes immediately following treatment and throughout the storage period. Both chroma (C*) and hue (h°) were derived from $a^*$ and $b^*$ using the following equations [14].

$$chroma = \sqrt{(a^*)^2 + (b^*)^2} \quad (1)$$

$$Hue\ angle = arctan(b^*/a^*) + 180 \quad (2)$$

#### 2.3.3. DPPH Scavenging Activity, Total Phenolic Content (TPC)

Fresh petal samples (1 g) were blended in 9 mL of 80% ($v/v$) methanol using an Ultra-Turrax for 3 min at 4 °C. The resulting mixture was centrifuged at 10,000× $g$ for 10 min to eliminate undesirable impurities. Free radical 2,2-dipheynl-1-picrylhydrazyl (DPPH) scavenging activity was assessed by measuring the extract ability to neutralize DPPH radicals. Specifically, 100 µL of the extract was combined with 900 µL of 0.5 mM DPPH solution, and the mixtures were allowed to stabilize for 60 min in the dark at room temperature. Absorbance values of each mixture were measured at 517 nm using a spectrophotometer. DPPH scavenging activity was calculated using Equation (3). The control sample comprised 100 µL methanol and 900 µL DPPH solution [15].

$$AA\% = \left[\left(Abs_{blank} - Abs_{sample}\right)/Abs_{blank}\right] \times 100 \quad (3)$$

Total phenolic content (TPC) was assessed according to information provided by Sayah et al. [16] with slight modifications. This study mixed 30 µL of the prepared extract with 2 mL distilled water and 250 µL Folin-Ciocalteu reagent. Subsequently, 250 µL of a 20% sodium carbonate solution ($Na_2CO_3$) was added after 2 min. The mixture was then incubated at 40 °C for 30 min, and the absorbance was measured at 760 nm using a spectrophotometer. A standard curve was established using gallic acid, with the results appearing as fresh weight (mg $kg^{-1}$).

#### 2.3.4. Enzyme Activities

Frozen petals (0.5 g) were pulverized in a chilled mortar and pestle with liquid nitrogen to extract the enzymes. The resulting powder was then homogenized with 1 mL of 100 mM phosphate buffer (pH 7) containing 0.5 mM EDTA and 6% ($w/v$) polyvinylpolypyrrolidone (PVPP). Subsequently, the extract was centrifuged at 15,000× $g$ for 20 min at four °C, and the resulting supernatant was sampled for measuring enzyme activities.

Peroxidase (POD) activity was assessed by measuring the rate of guaiacol oxidation at 470 nm for 1 min in the presence of hydrogen peroxide. A reaction mixture consisting of 1400 µL guaiacol (45 mM) and 200 µL enzyme extract in a measured volume of 3 mL was used. The reaction was initiated by adding 1400 µL hydrogen peroxide at a final concentration of 15 mM. The enzyme activity appeared as fresh weight ($kg^{-1}$) [17].

To assess PAL activity, 0.1 mL of the supernatant was combined with a reaction mixture of 10 mM l-phenylalanine, 1 mL of 50 mM phosphate buffer (pH 7), and 0.4 mL of double

distilled water (0.5 mL). After incubation at 40 °C for 1 h, the reaction was stopped by adding six mM HCl (0.5 mL). Measuring the solution's absorbance at 290 nm determined PAL activity based on cinnamic acid production. PAL enzyme activity was expressed on a fresh weight basis as units $kg^{-1}$ [18].

PPO was purified according to a protocol described by Koushesh Saba et al. [17]. The supernatant was separated into two solutions, one containing catechol at a final concentration of 0.05 M and the other containing Pyrrogallol at a final concentration of 0.02 M. Changes in absorbance at 420 nm were measured for 1 min at room temperature to assess enzyme activity, and the results were expressed as fresh weight ($kg^{-1}$).

### *2.4. Statistical Analysis*

Using a three-way ANOVA, statistical analyses were performed using SAS software version 9.4 to assess significant differences among the treatments, i.e., longevity after harvest and cyclamen cultivars. The experiment functioned on a factorial randomized design with three replicates. Data were subject to Duncan's multiple range test ($p \leq 0.05$).

## 3. Results

### *3.1. Vase Life, Fresh Weight*

Electrospun fibers with 8-HQS and $AgNO_3$ in the solution significantly extended the vase life of cut cyclamen flowers (Figure 2A,B and Supplementary Table S1). In particular, the vase life (16 days) of cut cyclamen flowers treated with 8-HQS (200) + $AgNO_3$ (20) nanofiber mats was longer than that of the control (12 days) and all other treatment groups (Figure 3). There was no significant variation ($p < 0.05$) in the vase life of the T1, T2, T3, and T4 treatments, and no significant difference ($p < 0.05$) occurred between the two cultivars regarding vase life.

A comparison between the fresh weight of 'Pure White' and 'Strauss' cultivars of cyclamen cut flowers revealed that 'Pure White' lost fresh weight more rapidly during a 16-day vase life period, with longer fresh weight (123.2%), compared to 'Strauss' cut flowers (Table 2).

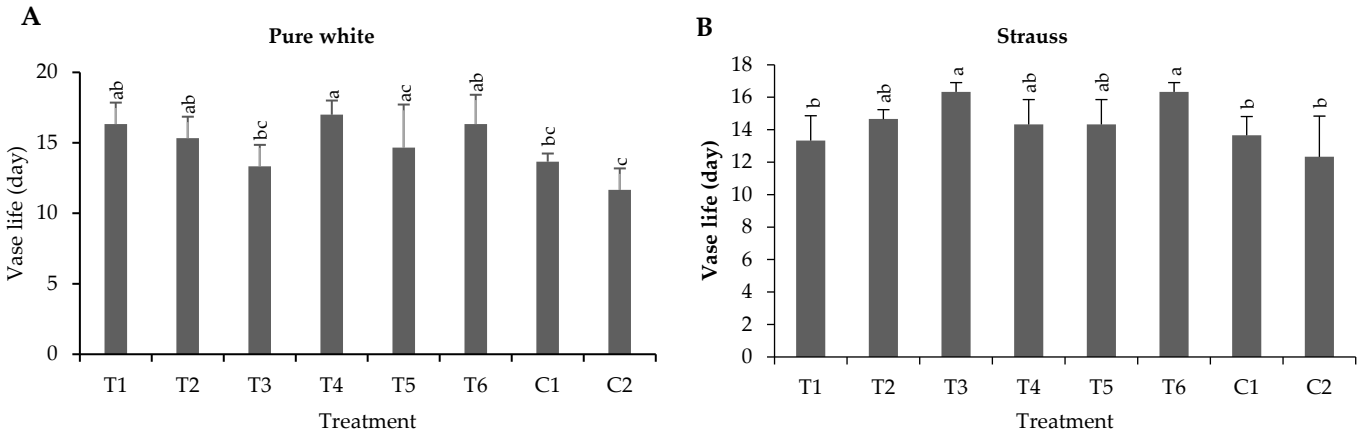


**Figure 2.** Effects of different nanofiber-based treatments of 8-hydroxyquinoline-5-sulfonic acid and silver nitrate on the vase life of (**A**) 'Pure white' and (**B**) 'Strauss' cut flowers. T1, Nanofiber+ 8-HQS (100) + $AgNO_3$ (15); T2, Nanofiber + 8-HQS (100) + $AgNO_3$ (20); T3, Nanofiber + 8-HQS (150) + $AgNO_3$ (15); T4, Nanofiber + 8-HQS (150) + $AgNO_3$ (20); T5, Nanofiber + 8-HQS (200) + $AgNO_3$ (15); T6, Nanofiber + 8-HQS (200) + $AgNO_3$ (20); C1, Nanofiber (control 1); and C2, Water (control 2). Vertical bars represent the SE. Means (n = 3) with the same letter in the columns do not differ significantly.

In this study, applying 15 and 20 mg $L^{-1}$ $AgNO_3$ in combination with 100 and 150 mg $L^{-1}$ 8-HQS nanofiber mats to the vase solution for cut cyclamen flowers markedly increased ($p < 0.001$) the fresh weight compared to the other treatments (Table 2, Supple-

mentary Table S2). The control group and the 15 and 20 mg $L^{-1}$ $AgNO_3$ with 200 mg $L^{-1}$ 8-HQS nanofiber mats varied insignificantly ($p < 0.05$) in their effects on the fresh weight.

**Table 2.** Fresh weight in cyclamen cut flowers treated with nanofiber loaded with $AgNO_3$ and 8-HQS during vase life at 18 °C for 16 days.

| Treatment | Fresh Weight (g) | |
|---|---|---|
| | **Pure White** | **Strauss** |
| Electrospun fibers + 8-HQS (100) + $AgNO_3$ (15) | 5.08 $^{a}$ | 3.34 $^{fg}$ |
| Electrospun fibers + 8-HQS (100) + $AgNO_3$ (20) | 5.22 $^{a}$ | 3.27 $^{fg}$ |
| Electrospun fibers + 8-HQS (150) + $AgNO_3$ (15) | 5.14 $^{a}$ | 3.85 $^{c–e}$ |
| Electrospun fibers + 8-HQS (150) + $AgNO_3$ (20) | 4.39 $^{b}$ | 3.25 $^{fg}$ |
| Electrospun fibers + 8-HQS (200) + $AgNO_3$ (15) | 4.57 $^{b}$ | 3.60 $^{d–f}$ |
| Electrospun fibers + 8-HQS (200) + $AgNO_3$ (20) | 4.17 $^{bc}$ | 3.41 $^{e–g}$ |
| Electrospun fibers (control 1) | 4.13 $^{bc}$ | 3.05 $^{g}$ |
| Water (control 2) | 4.08 $^{c}$ | 3.13 $^{fg}$ |
| Significant | | |
| Cultivar | *** | |
| Treatment | *** | |
| Time | *** | |
| Cultivar × Treatment | *** | |
| Cultivar × Time | ns | |
| Treatment × Time | ns | |
| Cultivar × Treatment × Time | ns | |
| CV | 15.66 | |

ns not significantly correlated. *** Correlation is significant at the 0.001 level. $^{c–e}$ cde, $^{d–f}$ def, $^{e–g}$ efg. In the table, the letters a to g next to the fresh weight values represent statistical groupings. Explanation of Each Letter (a to g): $^{a}$ This letter signifies the highest level of fresh weight, with no significant difference between treatments labeled with the letter "a". In other words, if multiple treatments share the letter $^{a}$, their fresh weight values are statistically equivalent. -Example: Fresh weight values 5.08 $^{a}$, 5.22 $^{a}$, and 5.14 $^{a}$ for the cultivar Pure White indicate that these treatments show no significant difference in maintaining fresh weight. $^{b}$ This letter indicates that treatments labeled with $^{b}$ have lower fresh weights than those in group $^{a}$ and are statistically different from them. However, there is no significant difference within treatments labeled $^{b}$. -Example: 4.39 $^{b}$ and 4.57 $^{b}$ for Pure White indicate that these treatments are lower than group $^{a}$ and statistically distinct from it. $^{bc}$ This grouping suggests that the treatments lie between $^{b}$ and $^{c}$, meaning they may not differ significantly from one of these groups but are statistically different from others. -Example: 4.17 $^{bc}$ and 4.13 $^{bc}$ for Pure White fall between groups $^{b}$ and c. $^{c–e}$ This combination shows that treatments are sta-tistically grouped within $^{c}$, $^{d}$, and $^{e}$. The fresh weight of these treatments can fall into any of these categories and exhibit significant differences from other groups. -Example: 3.85 $^{c–e}$ for Strauss. $^{d–f}$ This grouping indicates that the results fall between d and f. There is a statistically significant difference between this group and other groups with different letters. -Example: 3.60 $^{d–f}$ for Strauss. $^{e–g}$ This group shows that treatments are statistically between e and g, and as such, they differ significantly from other groups. -Example: 3.41 $^{e–g}$ for Strauss. $^{fg}$ This letter signifies that the fresh weight for these treatments is statistically similar to groups f and g, with no significant difference between them. However, these treatments may differ from groups higher in the sequence. -Example: 3.34 $^{fg}$ and 3.27 $^{fg}$ for Strauss. $^{g}$ This letter represents the lowest level of fresh weight, significantly lower than all the groups above it. -Example: 3.05 $^{g}$ for Strauss, which is the lowest value and statistically distinct from other groups. Conclusion: Treatments sharing the same letter (e.g., "$^{a}$" or "$^{fg}$") do not show a statistically significant difference in fresh weight. -Treatments labeled with different letters (e.g., "$^{a}$" and "$^{b}$" or "$^{e–g}$" and "$^{fg}$") show a significant difference in fresh weight. These letters assist in identifying which treatments were more effective in maintaining the fresh weight of the flowers and highlight significant differences between them.

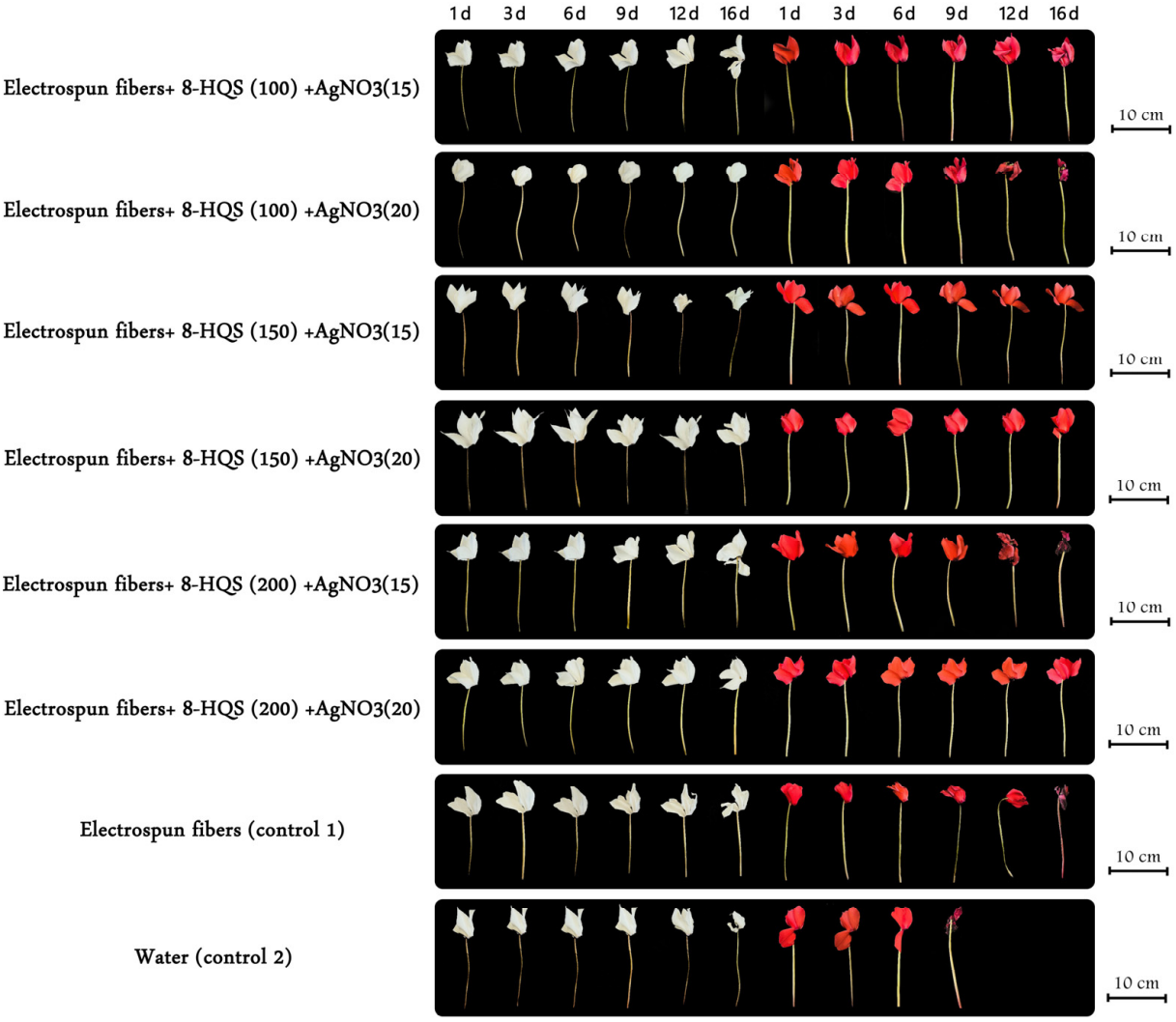


**Figure 3.** Effects of different nanofiber-based treatments of 8-hydroxyquinoline-5-sulfonic acid and silver nitrate on vase life of cut flowers of two *Cyclamen persicum* cultivars 'Strauss' and 'Pure White'.

### *3.2. Color*

The chroma and hue angle of cyclamen cut flowers showed significant differences depending on cyclamen varieties, different treatments, and storage time. The maximum chroma (59.98) was recorded in cyclamen cut flowers 'Strauss' (T6, day 3). However, a minimum value (56.26) occurred in the control group on day 6 (Table 2), the maximum chroma value of cyclamen 'Pure White' (10.27) occurred on day 10, and the lowest value of T1 (2.27) occurred on day 10.

The hue angle reached a maximum value in 'Pure White' in response to T2 (182.43°) on day 10, and a minimum value occurred in response to C2 (178.32°) on day 10.

Regarding 'Strauss', the maximum hue angle occurred in response to T4 (182.26°) on day six and a minimum in T6 (177.81°) on day 6 (Table 3).

**Table 3.** Mean values for hue angle, and chroma of cut cyclamen 'Pure White' and 'Strauss' flowers. Treatments with nanofibers loaded with different concentrations of $AgNO_3$ and 8-HQS. Samples were placed at 18 ± 1 °C and 50 ± 10% RH during the vase-life evaluation period.

| | | Hue | | | | Chroma | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Cultivar** | **Treatment Group** | **1 d** | **3 d** | **6 d** | **10 d** | **1 d** | **3 d** | **6 d** | **10 d** |
| Cultivar 'Pure White' | T1 | 181.0 ± 0.4 $^{c–g}$ | 180.7 ± 1.1 $^{c–k}$ | 181.3 ± 0.2 $^{b–d}$ | 180.7 ± 0.2 $^{c–j}$ | 3.0 ± 0.09 $^{l–n}$ | 2.7 ± 0.01 $^{n}$ | 3.3 ± 0.1 $^{j–l}$ | 2.2 ± 0.04 $^{o}$ |
| | T2 | 180.5 ± 1.0 $^{c–k}$ | 179.9 ± 1.1 $^{g–l}$ | 180.5 ± 0.3 $^{c–k}$ | 182.4 ± 0.1 $^{a}$ | 3.1 ± 0.05 $^{l–n}$ | 4.5 ± 0.04 $^{d–f}$ | 3.7 ± 0.3 $^{ij}$ | 3.2 ± 0.2 $^{k–m}$ |
| | T3 | 181.0 ± 0.7 $^{c–f}$ | 180.9 ± 0.9 $^{c–h}$ | 181.4 ± 0.2 $^{a–c}$ | 181.0 ± 0.5 $^{c–f}$ | 2.2 ± 0.02 $^{o}$ | 4.7 ± 0.03 $^{de}$ | 4.8 ± 0.3 $^{d}$ | 4.5 ± 0.1 $^{a–g}$ |
| | T4 | 179.8 ± 1.4 $^{h–m}$ | 181.0 ± 0.4 $^{c–f}$ | 180.4 ± 0.1 $^{c–k}$ | 180.5 ± 0.3 $^{c–k}$ | 4.4 ± 0.2 $^{dg}$ | 4.5 ± 0.1 $^{d–f}$ | 4.3 ± 0.1 $^{e–g}$ | 5.5 ± 0.2 $^{c}$ |
| | T5 | 178.3 ± 0.6 $^{p–r}$ | 181.2 ± 0.6 $^{b–e}$ | 180.6 ± 0.2 $^{c–k}$ | 180.5 ± 0.05 $^{c–k}$ | 4.7 ± 0.2 $^{de}$ | 4.4 ± 0.3 $^{d–g}$ | 3.6 ± 0.3 $^{i–k}$ | 4.6 ± 0.3 $^{de}$ |
| | T6 | 179.7 ± 1.0 $^{j–n}$ | 180.7 ± 1.8 $^{c–j}$ | 178.6 ± 0.3 $^{o–r}$ | 178.4 ± 0.1 $^{p–r}$ | 4.5 ± 0.04 $^{d–g}$ | 4.2 ± 0.2 $^{fg}$ | 4.1 ± 0.09 $^{gh}$ | 3.8 ± 0.1 $^{hi}$ |
| | T7 | 180.4 ± 0.8 $^{c–k}$ | 179.7 ± 0.8 $^{i–n}$ | 178.7 ± 0.1 $^{n–r}$ | 181.1 ± 0.05 $^{c–f}$ | 4.4 ± 0.03 $^{d–g}$ | 3.5 ± 0.4 $^{i–k}$ | 3.3 ± 0.1 $^{k–m}$ | 2.9 ± 0.1 $^{mn}$ |
| | T8 | 180.9 ± 0.6 $^{c–h}$ | 179.7 ± 0.2 $^{i–n}$ | 181.3 ± 0.1 $^{b–e}$ | 178.3 ± 0.2 $^{p–r}$ | 4.4 ± 0.3 $^{d–g}$ | 5.5 ± 0.5 $^{c}$ | 6.0 ± 0.06 $^{b}$ | 10.2 ± 0.3 $^{a}$ |
| | **Treatment Group** | **1 d** | **3 d** | **6 d** | **10 d** | **1 d** | **3 d** | **6 d** | **10 d** |
| Cultivar 'Strauss' | T1 | 180.8 ± 0.3 $^{c–j}$ | 179.2 ± 0.4 $^{l–p}$ | 180.4 ± 0.2 $^{c–k}$ | 180.4 ± 0.3 $^{c–k}$ | 53.4 ± 0.3 $^{g}$ | 51.5 ± 0.2 $^{ij}$ | 59.6 ± 0.3 $^{k}$ | 55.8 ± 0.6 $^{d}$ |
| | T2 | 180.8 ± 0.6 $^{c–i}$ | 180.5 ± 0.8 $^{c–k}$ | 180.4 ± 0.2 $^{c–k}$ | 180.3 ± 0.1 $^{d–l}$ | 47.2 ± 0.1 $^{m}$ | 54.4 ± 0.2 $^{ef}$ | 51.1 ± 0.1 $^{j}$ | 52.1 ± 0.2 $^{h}$ |
| | T3 | 179.6 ± 1.1 $^{k–o}$ | 180.2 ± 1.4 $^{e–l}$ | 180.5 ± 1.1 $^{c–k}$ | 180.5 ± 1.1 $^{c–k}$ | 59.5 ± 0.3 $^{b}$ | 54.9 ± 0.3 $^{e}$ | 52.1 ± 0.5 $^{h}$ | 51.3 ± 0.1 $^{ij}$ |
| | T4 | 181.0 ± 0.8 $^{c–g}$ | 178.9 ± 0.7 $^{m–q}$ | 182.2 ± 0.2 $^{ab}$ | 180.5 ± 0.3 $^{c–k}$ | 57.1 ± 0.3 $^{c}$ | 51.4 ± 0.1 $^{ij}$ | 56.0 ± 0.1 $^{n}$ | 54.2 ± 0.1 $^{f}$ |
| | T5 | 180.1 ± 1.3 $^{e–l}$ | 178.0 ± 0.4 $^{qr}$ | 180.4 ± 0.2 $^{c–k}$ | 180.5 ± 0.2 $^{c–k}$ | 59.5 ± 0.3 $^{k}$ | 52.0 ± 0.07 $^{h}$ | 49.2 ± 0.09 $^{k}$ | 48.6 ± 0.2 $^{l}$ |
| | T6 | 180.8 ± 0.3 $^{c–h}$ | 177.8 ± 0.7 $^{r}$ | 180.5 ± 0.1 $^{c–k}$ | 180.4 ± 0.1 $^{c–k}$ | 59.9 ± 0.6 $^{a}$ | 46.2 ± 0.03 $^{n}$ | 59.9 ± 0.5 $^{d}$ | 53.0 ± 0.1 $^{g}$ |
| | T7 | 181.3 ± 1.1 $^{a–d}$ | 178.5 ± 1.1 $^{c–k}$ | 181.4 ± 0.1 $^{a–c}$ | 180.5 ± 0.2 $^{c–k}$ | 57.3 ± 0.07 $^{c}$ | 51.1 ± 0.1 $^{j}$ | 51.6 ± 0.1 $^{hi}$ | 55.8 ± 0.1 $^{d}$ |
| | T8 | 180.7 ± 0.8 $^{c–k}$ | 179.9 ± 0.5 $^{h–m}$ | 180.5 ± 0.2 $^{c–k}$ | 180.3 ± 0.1 $^{d–k}$ | 59.4 ± 0.1 $^{b}$ | 46.2 ± 0.3 $^{n}$ | 49.2 ± 0.2 $^{k}$ | 51.4 ± 0.1 $^{ij}$ |

$^{a–c}$ abc, $^{a–d}$ abcd, $^{a–g}$ abcdefg, $^{b–d}$ bcd, $^{b–e}$ bcde, $^{c–f}$ cdef, $^{c–g}$ cdefg, $^{c–h}$ cdefgh, $^{c–i}$ cdefghi, $^{c–j}$ cdefghij, $^{c–k}$ cdefghijk, $^{d–f}$ def, $^{d–g}$ defg, $^{d–k}$ defghijk, $^{d–l}$ defghijkl, $^{e–g}$ efg, $^{e–l}$ efghijkl, $^{g–l}$ ghijkl, $^{h–m}$ hijklm, $^{i–k}$ ijk, $^{i–n}$ ijklmn, $^{j–n}$ jklmn, $^{k–m}$ klm, $^{k–o}$ klmno, $^{l–n}$ lmn, $^{l–p}$ lmnop, $^{m–q}$ mnopq, $^{n–r}$ nopqr, $^{o–r}$ opqr, $^{p–r}$ pqr.

### *3.3. Antioxidant Enzyme Activity*

Physical injury to a cut stem stimulates the activity of various oxidative enzymes, including PPO, POD, and PAL [19]. The antioxidant enzyme activity differed significantly ($p < 0.001$) between the treated cyclamen cut flowers and the control group (Supplementary Table S3). When electrospun fibers loaded with $AgNO_3$ and 8-HQS were included in the vase solution, there was a reduction in PPO activity in cyclamen-cut flowers of 'Pure White'. The decrease was 12% on day 3, 19% on day 6, and 8% on day 10 compared to the water control group (36%, 42%, and 23% on days 3, 6, and 10, respectively).

In the cut flowers of Strauss, PPO activity decreased by 17% on day 3, 11% on day 6, and 15% on day 10 compared to their corresponding water and electrospun fibers used alone control groups (30%, 23%, and 29% on days 3, 6, and 10, respectively). The lowest PPO activity occurred in the T1 and T2 treatments (Figure 4A,B and Supplementary Table S4).

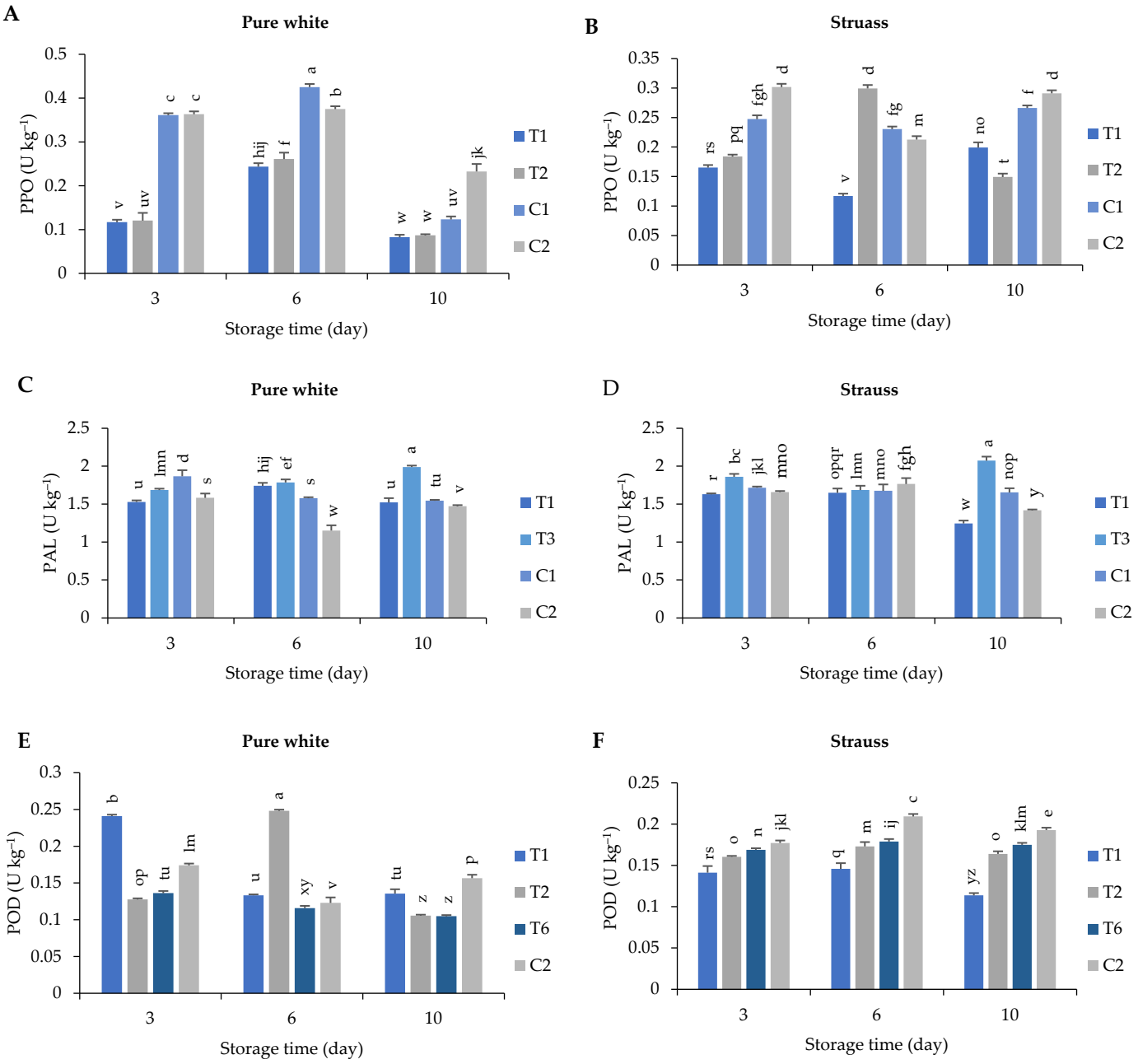


**Figure 4.** *Cont.*

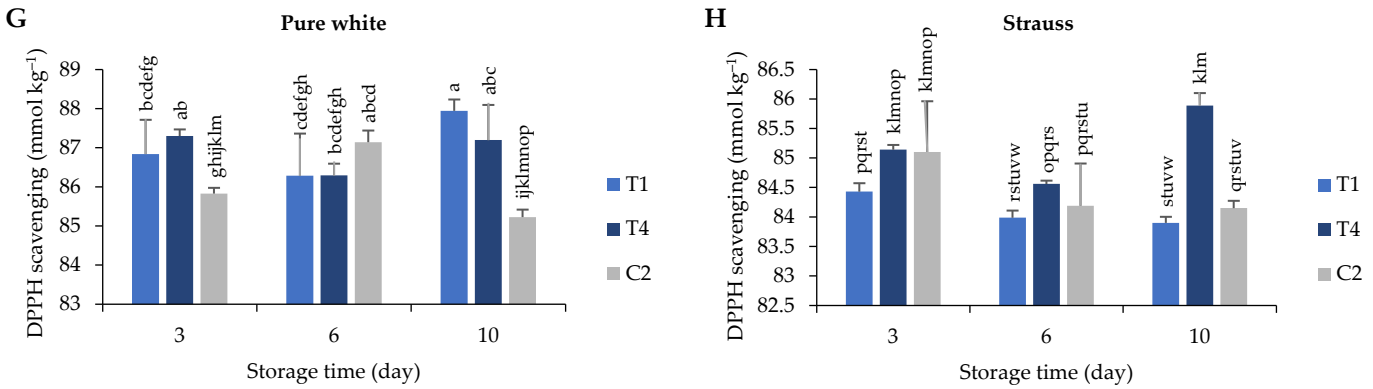


**Figure 4.** Effects of different nanofiber-based treatments of 8-hydroxyquinoline-5-sulfonic acid and silver nitrate on enzymatic activities in two cyclamen cultivars. (**A**,**B**) polyphenol oxidase (PPO), (**C**,**D**) phenylalanine ammonia-lyase (PAL), (**E**,**F**) peroxidase (POD), and (**G**,**H**) DPPH scavenging activity of cut cyclamen flowers (two cultivars) during storage. T1, Nanofiber + 8-HQS (100) + $AgNO_3$ (15); T2, Nanofiber + 8-HQS (100) + $AgNO_3$ (20); T3, Nanofiber + 8-HQS (150) + $AgNO_3$ (15); T4, Nanofiber + 8-HQS (150) + $AgNO_3$ (20); T6, Nanofiber + 8-HQS (200) + $AgNO_3$ (20); Nanofiber (control 1) and C2, Water (control); vertical bars represent the SE. Means (n = 3) with the same letter in the columns do not differ significantly. Relative values for each enzymatic activity mean are provided in Supplementary Table S4.

Placing cyclamen cut flowers into a vase solution containing electrospun fibers loaded with $AgNO_3$ and 8-HQS resulted in elevated levels of PAL enzyme activity compared to the respective water control group and electrospun fibers used alone as the control. Figure 4C,D and Supplementary Table S4 show that the highest PAL activity occurred in the cyclamen 'Pure White' on day 10 (51%) compared to the control (water) on the same day. Similarly, cyclamen cut flowers of Strauss exhibited an increase in PAL activities on day 10 (65%) compared to the control (water) on day 10.

PAL activity steadily increased in the early vase period and then declined, with an increase in longevity and vase life (10 days). In general, PAL activity in cyclamen cut flowers of Strauss was higher than that of cyclamen cut flowers 'Pure White'.

Figure 4E,F illustrates the POD activity of the two cultivars of cyclamen cut flowers. Although the POD activity was higher in response to T2 (0.25) on day six and T1 (0.24) on day 3, compared to the other treatments and controls, it decreased in time while the cut flowers were in the vase. However, the highest POD activity was observed in the control (water) and electrospun fibers used alone as the control group in 'Pure White' (day 10) and 'Strauss' (day 6).

As illustrated in Figure 4G,H, the DPPH scavenging activity of the various treatment groups exhibited a general pattern of initial increase, followed by a subsequent decrease in storage. Throughout the storage period, the DPPH scavenging activity of cyclamen cut flowers Strauss was consistently lower than that of cyclamen cut flowers 'Pure White'. The combined treatment group consistently showed a higher DPPH scavenging activity than the control group. As shown in Figure 4G,H and Supplementary Table S3, electrospun fibers loaded with $AgNO_3$ and 8-HQS significantly improved the DPPH scavenging activity of cyclamen cut flowers during the 10-day storage period at 18 °C ($p < 0.05$).

### *3.4. Total Phenolic Content*

The total phenolic content in the treated cut flowers of cyclamen 'Strauss' was lower than that of cyclamen cut flowers 'Pure White' by 0.27%, 0.24%, and 0.22% on days 3, 6, and 10 of the vase life, respectively (Figure 5A,B and Supplementary Table S4). In both cyclamen cultivars, the total phenolic content decreased in amounts similar to the control (0.55%, 0.43%, and 0.23% at 3, 6, and 10 days, respectively).

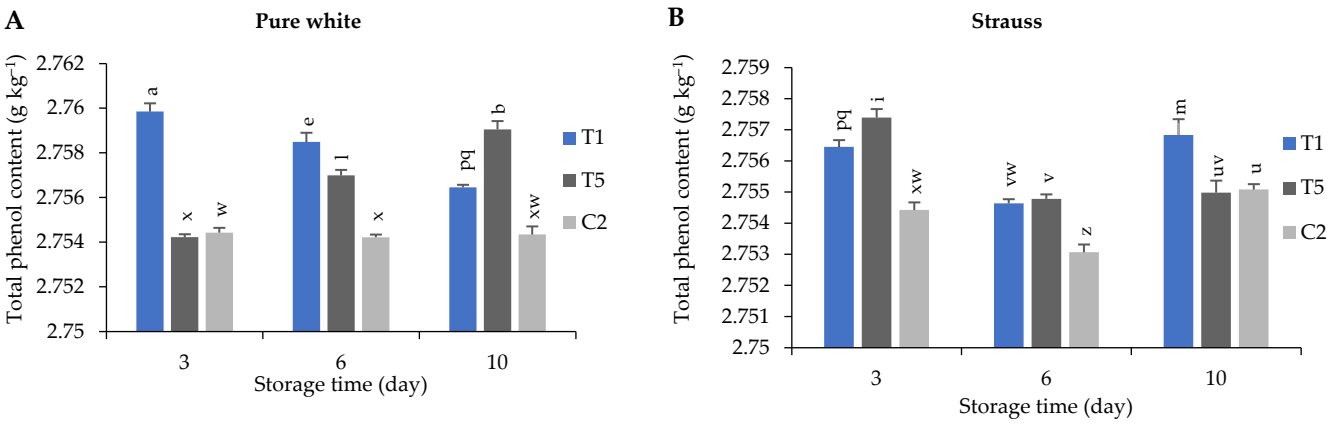


**Figure 5.** Effects of different nanofiber-based treatments of 8-hydroxyquinoline-5-sulfonic acid and silver nitrate on total phenol content in (**A**) 'Pure white' and (**B**) 'Strauss' cut flowers. T1, Nanofiber + 8-HQS (100) + $AgNO_3$ (15); T5, Nanofiber + 8-HQS (200) + $AgNO_3$ (15) and C2, water (control). Vertical bars represent the SE. Means (n = 3) with the same letter in the columns do not differ significantly. Relative values for each total phenol content and mean values are provided in Supplementary Table S3.

## 4. Discussion

Prolonging the vase life of cut flowers is a crucial quality factor for consumers. Increasing the longevity of cut flowers is essential for flower producers and consumers [20]. The potential application of 8-HQS may hinder the proliferation of microorganisms within xylem vessels and obstruct the blockage of xylem, owing to its antimicrobial characteristics, which could lead to a decrease in stem blockage [21]. Figure 2 and Supplementary Table S1 provide clear evidence of the considerable prolongation of the vase life of cut cyclamen flowers through the utilization of electrospun fibers containing 8-HQS and $AgNO_3$ in the vase solution. These results are consistent with earlier research, indicating that $AgNO_3$ positively influences water absorption and flower longevity [22]. Adding antimicrobial solid agents, such as $AgNO_3$ or silver nanoparticles, can improve water uptake and regulate water equilibrium in flowers, thus resulting in higher floral weight and prolonged vase life. Lü et al. [23] and Abdel Kader [24] also reported similar findings in their research on cut roses.

Color attributes are significant qualitative characteristics of the floriculture sector. Color consistency in cut flowers is crucial for an extended period after harvest [25]. According to Naing et al. [20], using silver and nanosilver in carnations increased their vase life by suppressing the expression of ACS and ACO, interacting with ethylene receptors, and modulating the ethylene response. Ethylene is a hormone that plays a significant role in pigmentation and color degradation [26]. According to Khella et al. [6], it was found that the application of STS, followed by $AgNO_3$ at a concentration of 500 mg $L^{-1}$ for 30 min, resulted in increased pigment content in the cut flowers of *Limonium sinuatum* Girlie Wings. In our experiment, the application of electrospun fibers loaded with $AgNO_3$ and 8-HQS maintained stable chroma and hue values during the vase life for the two cultivars of cyclamen cut flowers.

Generally, cutting is an initial step in the postharvest management of cut flowers. When flowers are detached from their original plants and placed in a vase solution, they undergo physical injury and water stress, thus stimulating antioxidant enzyme activities that counteract the detrimental effects of reactive oxygen species [20]. Wounding stress triggers a range of physiological and biochemical defense mechanisms, as demonstrated by Gerabeygi et al. [27].

PPO is a critical enzyme in the physiological process of lignin biosynthesis. It plays a crucial role in the oxidation of various alcohols, such as coniferyl, sinapyl, and coumarin, i.e., precursors of lignin [28]. PPO genes are typically regulated in response to biotic

and abiotic stressors [29]. PPO occurs in chloroplasts and counters phenolic substrates in vacuoles due to wounding and the loss of cell membrane integrity [30].

Shabanian et al. [31] demonstrated that heightened PPO activity significantly decreased cut flowers' relative water uptake (RWU). Consequently, enhancing PPO activity in cyclamen cut flowers would indicate tissue damage during storage, whereas maintaining lower PPO activity in cyclamen cut flowers treated with electrospun fibers suggested that these flowers experienced less damage than the control groups. These results agree with previous findings by Elatafi and Fang. [32] on grapes using silver nitrate ($AgNO_3$) and nano-silver (Ag-NPs) treatments.

The phenylpropanoid pathway is essential for secondary metabolism in plants, resulting in the production of various phenolics with structural and defense-related functions [33]. Phenylalanine ammonia-lyase (PAL) is an essential enzyme in the phenylpropanoid metabolic pathway [33]. Different biotic and abiotic stressors trigger PAL, accumulating phenolic compounds such as phenolic acids and flavonoids [34]. Thus, the activity of PAL is crucial for phenolic compounds to take form and serves as a defense mechanism in response to various stimuli and adverse conditions [35].

This study noted increased PAL activity in both cultivars of cyclamen cut flowers, potentially contributing to an extended vase life for these flowers. The findings of this study are congruent with those reported by Nascimento Simões et al. [36] and Shabanian et al. [31].

Peroxidases have been demonstrated to play a role in many physiological functions, including lignification and tissue regeneration [37]. The primary role of peroxidase, an enzyme containing haem, is to catalyze the oxidation of phenolic compounds by utilizing $H_2O_2$ as a co-substrate [38]. In response to cell injury, peroxidase is released from the cell surface and moves into the apoplast, where peroxidative and oxidative activities occur [39].

The increased peroxidase activity in *Rosa hybrida* cut flowers reduced anthocyanin content, accompanied by browning and de-coloration of the petals [40]. POD inhibitors function by blocking the activities of enzymes involved in lignin and suberin accumulation [41]. Sharifzadeh et al. [41] proposed that POD plays a role in the physiological plugging of Lisianthus stems and reported that POD inhibitors likely delayed lignin production in xylem, which led to increased water uptake and relative fresh weight, ultimately extending the vase life of Lisianthus cut flowers.

The outcome indicates that adding $AgNO_3$ and 8-HQS enhanced the capacity of cut flowers to scavenge DPPH, which may be attributed to an increase in the accumulation of total phenols and flavonoids [19]. Sen et al. [42] reported that the increased scavenging activity of free radicals reduces oxidative stress and ion leakage by impeding membrane damage and diminishing the oxidation of unsaturated fatty acids in gladiolus cut flowers. Similar results have been reported by Saeed et al. [43] on gladiolus cut flowers and Soleimani Aghdam et al. [44] on anthurium cut flowers.

According to Chakrabarty et al. [45], antioxidant enzyme activity exhibited fluctuations during the storage of cut chrysanthemum flowers. Initially, there was an increase in activity, but it subsequently decreased. Zhao et al. [13] recommended that under stressful storage conditions, antioxidant enzyme activity initially rises in the petals, followed by a subsequent inhibition of the antioxidant system by cumulative ROS, leading to a decrease in enzyme activity. Our study is consistent with this hypothesis.

Phenolic compounds can effectively hinder lipid membrane oxidative damage by limiting the onset and transmission of oxidation reactions [46]. According to previous studies, antioxidant substances increase in cut flowers throughout their vase life [47]. The decline in the overall phenolic content in flowers at a later developmental stage makes them vulnerable to oxidative stress [48]. Hönig et al. [49] proposed a connection between the decline in TPC and tissue senescence with advancing longevity. Furthermore, according to Gill and Tuteja. [50], PAL is significantly involved in phenolic compound synthesis, as indicated by enhanced PAL activity in this research (Figure 4C,D and Supplementary Table S3).

## 5. Conclusions

Our study examined the impact of nanofiber mats loaded with $AgNO_3$ and 8-HQS on the vase life and postharvest quality of two cut cyclamen cultivars. Our results showed that treatments with electrospun fibers loaded with 8-HQS (200 mg $L^{-1}$) + $AgNO_3$ (20 mg $L^{-1}$) were the most effective in prolonging the vase life of cyclamen-cut flowers, extending it by up to 16 days compared to the control. Specifically, the growth and development parameters, such as fresh weight, total phenolic content, antioxidant activity, and PAL, were improved, leading to a prolonged vase life for the cyclamen cultivars. For all relevant parameters, the combined influence of treatment, cultivar, and storage time was statistically significant ($p < 0.001$) on the measured parameters, except for fresh weight. In all parameters, cyclamen cut flowers 'Pure White' demonstrated consistent and favorable outcomes. As a result, electrospun fibers can be used as a promising approach to improve the shelf life of cut flowers by providing a sustained release of substances that can nourish and preserve the flowers, ultimately contributing to their longevity.

**Supplementary Materials:** The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae10101012/s1, Table S1: The 3-way ANOVA for the effect of nanofiber loaded with AgNO3 and 8-HQS, two cultivars, storage time and their interactions on vase life of cut cyclamen flowers; Table S2: The 3-way ANOVA for the effect of nanofiber loaded with $AgNO_3$ and 8-HQS, two cultivars, storage time, and their interactions on fresh weight, Hue, and Chroma of cut cyclamen flowers; Table S3: The 3-way ANOVA for the effect of nanofiber loaded with $AgNO_3$ and 8-HQS, two cultivars, storage time and their interactions on antioxidant activity, total phenolic content, polyphenol oxidase, peroxidase, and phenylalanine ammonia-lyase on postharvest quality properties of cut cyclamen flowers; Table S4: Effect of different nanofibers loaded with $AgNO_3$ and 8-HQS × two cultivars × storage time interactions on postharvest quality properties of cut cyclamen flowers.

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