

Blooming Longer: Tailoring Preservative Concentration and Silicon to Extend the Vase Life of Peony (*Paeonia lactiflora* Pall.)

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Abstract

The market for fresh-cut peony flowers is booming globally, but their short vase life limits their commercial value. This study evaluated the effects of silicon and commercial preservatives on the postharvest performance of best-selling *Paeonia lactiflora* varieties, including the challenging 'Bartzella' variety that wilts the day after flowering. It was found that a diluted freshness preservative combined with silicon significantly enhanced the vase life and bloom quality of the peonies. A four-fold dilution of the recommended concentration of commercial freshness preservative was suggested. Additionally, there is a variety-specific response to the preservative; diluted Chrysal + Si treatment significantly increased flower size and prolonged the optimal viewing period for 'Monsieur Jules Elie' and 'Kelway's Glorious' varieties, while diluted Oasis + Si treatment was preferred for 'Sarah Bernhardt' and 'Bartzella' varieties.

Introduction

Peony (*Paeonia lactiflora* Pall.) is highly sought after in the international fresh-cut flower market due to its diverse varieties, rich flower colors, and various flower shapes. However, because of the larger flowers, which require more water and nutrients, the vase life of *Paeonia lactiflora* is shorter. Especially for varieties such as Bartzella, which begin to wither the next day after blooming, seriously affecting its ornamental value(Xue *et al.*, 2018). The postharvest performance of the peony is extremely critical to its market performance and industrial development. Studies have shown that the vase life of paeoniflora can be effectively prolonged through appropriate postharvest management and preservation techniques, significantly enhancing its market competitiveness.

Chemical flower preservatives are widely used because of their low cost, ease of use, and remarkable preservation effect, which can effectively delay the aging of flowers and maintain their ornamental value. Chemical flower preservatives usually contain ingredients such as sugar, fungicides, and plant growth regulators, which significantly extend the vase life of cut flowers by providing energy, inhibiting bacterial growth, and regulating plant growth(Sun, Guo and Tao, 2022)(Rabiza-Świder *et al.*, 2020)(Skutnik *et al.*, 2020). There are several fresh-cut flower preservatives available on the market and the most well-known commercial preservatives are Chrysal from Dutch and Oasis from American. The composition and concentration needs of flower preservatives vary for each flower species and cultivar variant(Nguyen and Lim, 2021). The sucrose acts as an energy source for cut flowers and the right concentration will have a positive effect on blooming, increasing flower size, improving petal color, and extending vase life. Dehydration and wilting are usually caused by the formation of air embolisms within the xylem of the stem or by bacterial invasion of the stem from the vase water that prevents water uptake. Different concentrations of acid fungicides affect and kill harmful bacteria, preventing clogging of plant tissues and promoting water uptake(Shabanian *et al.*, 2019). Various surfactants reduce the surface tension of water helping to improve water uptake by flowers(Redman *et al.*, 2002). These ingredients work together to ensure that flowers continue to take up water and gain energy during the vase-life period, which is essential to keep flowers open. However, no studies have been reported on the efficacy and optimum concentration ratios of commercial preservatives (Chrysal and Oasis) for fresh cut flowers of different peony cultivars.

Silicon is an important component of plant cell walls and is the second most abundant element in soil, and it has been reported to successfully prolong the vase life and improve flower quality of Silverleaf

chrysanthemums (M. Kazemi, 2012), carnations (Chen *et al.*, 2018), roses (Geerdink *et al.*, 2020), and peonies among others (Song *et al.*, 2021) (Song, Yang and Jeong, 2022). Studies have shown that Si helps plants maintain an upright posture by increasing the rigidity of the plant cell wall, which is potentially valuable in solving the problem of drooping heads caused by the high weight of flowers in peonies. Silicon's effects include not only direct inhibition of pathogen growth, but also indirectly induce systemic resistance, and these findings support the use of silicon as an alternative to traditional chemical fungicides in postharvest treatments (Elsherbiny and Taher, 2018) (Wang, Wang and Gao, 2015). As an environmentally friendly and safe preservative, research related to Si is still in its infancy (Chen *et al.*, 2018). The main components of commercial flower preservatives are glucose and citric acid, among others, and do not contain silicon (Bayat and Aminifard, 2018).

Field experiments on the effect of Si fertilizer on paeony cultivars 'Taebaek' and 'Euseong' were conducted where plants were subsequently placed in a holding solution containing a 75 Si solution. The results of the experiments showed that the addition of Si prolonged the vase life of cut flowers, maintained fresh weight, and increased antioxidant enzyme activity and stem mechanical strength, suggesting that the combination of pre-harvest Si treatments and post-harvest Si preservation solution is the best way to maintain the quality of cut flowers (Song *et al.*, 2021). The group further studied 'Taebaek', 'Sagok', and 'Euseong' peony varieties for three consecutive years. For this study, the combination of silicon with glucose and citric acid significantly improved postharvest performance and also promoted early flowering and extended vase life (Song, Yang and Jeong, 2022). It was found that silicon treatment significantly enhanced the water retention capacity of cut flowers, enhanced antioxidant defense mechanisms, increased the concentration of antioxidant enzymes, and reduced the accumulation of reactive oxygen species in petals, but had little effect on carbohydrate content. So far, no studies have been conducted on the preservation effect of Si on the key paeony variety, Bartzella, and there are no reports on whether Si can further promote paeoniflora preservation with branded flower preservatives (Chrysal and Oasis).

This study aimed to evaluate the effect of commercial preservation solutions on the postharvest performance of Bartzella paeoniflora, as well as to assess the synergistic effect of Si with commercial preservatives on the postharvest performance of most popular peony varieties including Japanese Itoh hybrids 'Bartzella', Chinese native variety 'Ching Wen', and European varieties ('Sarah Bernhardt' and 'Kelway's Glorious'), which have different characteristics such as flower size and degree of hard stem strength. Their vase performance was assessed by the vase life, floral size, bloom duration, and fresh weight loss characteristics of cut flowers, and by dividing the late stages of cut flowers of different varieties into six periods based on condition and appearance. The results will provide a scientific basis for the development of more effective preservative formulations and promote the sustainable development of the peony-cut flower industry.

Section snippets

Flowers and treatments

'Bartzella', 'Ching Wen', 'Monsieur Jules Elie', 'Sarah Bernhardt' and 'Kelway's Glorious' cut flower branches were harvested following industry standards from Mudan District, Heze City (35°95'N, 116°47'E), provided by Heze Baiyi Peony Horticulture Co. The Japanese Itoh peony variety 'Bartzella' is a cross between a Chinese peony variety and Reath's hybrid peony, which is known for its late-flowering, rose-type bloom, and sturdy stalks, and

was recognized as one of the most popular varieties in the world when it won the American Peony Society's Gold Medal in 2006. China's native 'Ching Wen' is also a late-flowering variety, known for its daisy-shaped flowers and sturdy stalks. The Japanese import 'Monsieur Jules Elie' is an early-flowering, heavy-flowered variety with very large, floor-shaped flowers but thin stalks. The European varieties 'Sarah Bernhardt' and 'Kelway's Glorious' are both heavy petals with very large flowers, late and mid-flowering varieties, respectively, and both possess strong stalks.

The experiment was carried out in May 2023, the uniform flowers were cut and immediately placed upright in partially filled water boxes. They were then stored in cold storage for 1 week, and after transportation to the laboratory, two compound leaves were retained and the stem ends were cut to 25 cm in length by 45° diagonal cuts under deionized water. All floral material for the test was individually labeled and randomly grouped with three replicates and immediately transferred to a configured vase solution (200 ml), which was changed with a new solution every two days. The temperature of the laboratory was controlled to be 21±2°C, relative humidity 50-70%, and natural diffused light in the room.

The preservative solutions designed for this study consisted of seven treatments (Table 1): 1. Distilled water (W), 2. Standard Chrysal (Std. Chrysal), 3. Standard Oasis (Std. Oasis), 4. Diluted Chrysal (Dil.Chrysal), 5. Diluted Oasis (Dil.Oasis), 7. Diluted Chrysal+Si (Dil.Chrysal+Si), 8. Diluted Oasis+Si (Dil.Oasis+Si). For the diluted Chrysal and Oasis, the concentration is one-quarter of the recommended concentration of the product. This concentration refers to the performance of 'Ching Wen' in different acid solutions (0%, 0.01%, 0.1%, 1%, and 2% concentration of acetic acid) in our preliminary experiments, which 'Ching Wen' proved the best effect of acetic acid treatment of the concentration of 0.1% with a pH around 5-6, while the standard commercial preservative prepared following the manufacturer's manual has a pH around 4. So the standard commercial preservation solution was diluted four times to achieve a more desirable pH. To obtain suitable acidity, a concentration of 0.3 mg/ml of silicon fertilizer was used, and the application of Si waste was obtained by adding 0.06 g of sodium silicate to 200 ml of preservative.

Table 1 Composition and pH of seven preservation solutions

Composition	W	Std.Chrysal	Std.Oasis	Dil.Chrysal	Dil.Oasis	Dil.Chrysal+Si	Dil.Oasis+Si
pH	7.00	4.17	4.20	5.11	4.87	5.87	5.76

Definitions of postharvest flower opening stages

The flowering process of cut peonies during their vase life can be categorized into different flowering stages. There are many ways of dividing the flowering stages of flowers, such as four, six, and seven phases. According to the appearance and condition of peony cut flowers, the six-phase flower opening stage of peonies in the literature (Song, Yang and Jeong, 2022) is adopted, including pre-opening (stage I), initial-opening (stage II), half-opening (stage III), full-opening (stage IV), petal-wilting (stage V), and Stamen or pistil-wilting (stage VI). The postharvest stage of peony flowers was recorded immediately after the cut flowers were placed in the preservation solution. Figure 1 shows different flower opening stages for the representative peony in our experiment.

The flowering stage (change in flowering phase), flower performance (picture), flower diameter, and fresh weight of each flower were observed and recorded at 24-hour intervals from the date of vase insertion to

record the flowering performance of each flower. Determination of flower diameter was conducted using vernier calipers (Deli DL91300 digital calipers), two independent measurements were taken in a criss-cross fashion and the average value was calculated. The rate of change of fresh weight was calculated by subtracting the initial flower weight from the daily flower weight, then dividing by the initial flower weight and multiplying by 100%. The vase life of the postharvest cut peony flowers could be defined by summing the number of days from harvest to the initial wilting and/or petals falling. Each data has at least three sets of replications, and the data are expressed as mean or mean $\pm$ standard deviation.

Diameter of cut flowers as affected by seven treatments

Figure 2 shows the effect of seven fresh-cut flower preservative treatments on the mean flower diameter of peonies 'Monsieur Jules Elie', 'Sarah Bernhardt', 'Kelway's Glorious', and 'Bartzella'. The preservation solution concentration and compositional adjustments appear to be very important. As shown in Figure 2a, the maximum flower diameter of 'Monsieur Jules Elie' in different preservative solutions ranked as Dil.Oasis+Si > Dil.Chrysal+Si > Dil.Chrysal > Dil.Oasis > Std.Chrysal > W > Std.Oasis. Direct application of the standard concentration of Oasis to Monsieur Jules Elie (Std. Oasis) without dilution will result in its inability to flower opening, even worse than pure water treatment. Oasis with dilution can improve the flower diameter but accelerate its decay, while the addition of Si (Dil.Oasis+Si) can significantly improve the average flower diameter, obtaining the maximum flower diameter (16.0 cm) in the experiment. Chrysal seems more reliable for Monsieur Jules Elie peony preservation than Oasis, and Std. Chrysal was able to increase the average flower diameter during the ornamental period, and the effect was even more significant after dilution. Adding Si to Dil.Chrysal (Dil.Chrysal+Si) can effectively improve the flowering status of Monsieur Jules Elie, not only increasing the maximum diameter of flowers but also maximizing the best viewing time. As shown in Fig. 3a, Monsieur Jules Elie was already entering the fourth stage of flowering on day 3 under the treatment of Dil.Chrysal+Si, maintaining it at the fourth stage for about five days and slowing down its entry into the fifth and sixth stages of flowering, resulted in a better ornamental value for these treatment groups.

For the peony Sarah Bernhardt variety Fig. 2b, both Std.Oasis and Std. Chrysal is counterproductive, barely usable after concentration adjustment, and Dil. Oasis performs slightly better than Std.Chrysal. The maximum flower diameter of Sarah Bernhardt with different preservative fluids is ordered as follows: Dil.Oasis+Si > Chrysal+Si > Dil.Oasis > Dil.Chrysal > W > Std.Oasis > Std.Chrysal. The effect of Si addition on Sarah Bernhardt varieties was decisive, and both Dil.Oasis+Si and Dil.Chrysal+Si significantly improved peony's Both Dil.Oasis+Si and Dil.Chrysal+Si significantly improved the average flower diameter of peonies, with a maximum increase of more than 50% in flower diameter, with the effect of Chrysal being even more pronounced. Under the treatment of Dil.Oasis+Si, Sarah Bernhardt had a significantly longer time in the third and fourth flowering stages (Fig. 3b), and the maximum flower diameter reached 12.3 cm.

Fig. 2c Maximum floral diameter of Kelway's Glorious in different preservative solutions ranked as Dil.Chrysal > Dil.Chrysal+Si > Dil.Oasis+Si > Dil.Oasis > Std.Chrysal > Std.Oasis > W. It can be seen that Dil. Chrysal, Dil.Chrysal+Si, and Dil.Oasis+Si preservation solutions are more suitable for use in preserving Kelway's Glorious variety. Adding Si and dilution both improved the preservation of Oasis to some extent, but the preservation ability was still not as good as that of Chrysal. Dilution, and Dil.Chrysal was able to obtain a maximum flower diameter of 11.3 cm. Although the addition of Si was not the maximum, the Chrysal+Si was able to achieve optimal flower opening and maintain it for a longer period.

Bartzella, as a flower hybridized from tree peony and herbaceous peony, has very large flowers when fully open. Fig. 2d and Fig. 3d show that Bartzella is a fleeting beauty that fades as soon as it blooms. Although it can reach a large flower diameter (max. 17.3 cm) in various solutions when blooming, the petals fall off rapidly after blooming, and the time of vase insertion is much smaller than that of the other varieties. On the 5th day of vase life, all petals had fallen off except for cut flowers treated with Dil.Oasis+Si, Dil.Chrysal+Si, and Dil.Oasis, the cut flowers under Dil.Oasis+Si and Dil.Oasis treatments maintained their petal morphology up to day 7, while the fresh cut flowers under Dil.Chrysal+Si treatment was maintained up to day 6. Although Dil.Oasis remained in the bud stage during the pre-bottling period, it rapidly entered the third and fourth flowering stages after day 6, after which it wilted rapidly. Observing the daily flower status, Dil.Oasis + Si was more favorable for maintaining Bartzella in optimal ornamental condition. Thus the greatest function of the preservative was not to increase flower size but to prolong vase placement. Therefore Chrysal is not suitable for Bartzella species. However, Dil. Chrysal +Si can extend its optimal ornamental period by more than 2-3 days.

Figure 4 shows a photo of the best seven days of bottle insertion performance in the life of a representative flower of each of the four varieties in the four solutions, Dil. Oasis, Dil.Oasis+Si, Dil.Chrysal, and Dil.Chrysal+Si. By comparing the above pictures, it is clear that for Monsieur Jules Elie, the Dil.Chrysal+Si bottling solution had the best results, with the best opening of flowers, fresh flowers, and an observable Typhlosion-type bloom pattern, whereas the cut flowers in the other preservation solutions withered more quickly. For Sarah Bernhardt, the Chrysal treatment did not open as perfectly as Dil.Oasis+Si. For Kelway's Glorious, the silicon treatment resulted in a greater degree of openness and kept it at its optimum ornamental stage for a longer period. For Bartzella, a species that blooms very large and fades very easily, Dil.Oasis+Si significantly extends its viewing time.

Overall, a fourfold dilution of the recommended concentrations of commercial preservatives used for fresh-cut flowers of *Paeonia lactiflora* showed significant improvement in preservation. The diluted freshness preservative has a better state of flower growth than the standard freshness preservative, which can effectively promote the rapid flowering of paeoniae and increase the flower size. Regardless of the variety of cut flowers, the diameter of fresh cut flowers was larger, the flowers were fuller, the flowering period was changed, the duration of the optimal ornamental period was increased, and the phenomenon of rapid flowering and rapid failure could be suppressed by the addition of silicon. It has been reported in the literature that this may be because the incorporation of Si into plant tissues can control stomatal conductance and at the same time regulate the water status well by reducing the transpiration rate. The effect of different preservation solutions on water status will be discussed in the next section. For different peony varieties commercial preservatives quadruple diluted with Si all gave better preservation, but the recommended commercial preservatives were different, Monsieur Jules Elie and Kelway's Glorious recommended Dil.Chrysal+Si; Sarah Bernhardt and Bartzella recommended Dil.Oasis+Si.

The Impact of Seven Treatments on the Moisture Status of Cut Flowers

Moisture is a pivotal factor influencing the senescence of cut flowers. Peony flowers, with their high water content, demonstrate their freshness and vigor through their fresh weight, which is a reflection of their aging status. As cut flowers lack a complete plant body, the internal moisture balance is disrupted. The absence of a root system means there is no mechanism to absorb water, leading to a continuous loss of water due to foliage transpiration without a replenishing supply. This results in water stress, which in turn triggers the

accumulation of harmful substances such as proline and peroxides, compromising the physiological health of the cut flowers and leading to wilting or even the inability to bloom properly.

When the equilibrium between water uptake and transpiration in cut flowers is positive, they can sustain a longer vase life. However, in the advanced stages of senescence, the water uptake by the cut flowers diminishes, and their capacity to absorb water decreases. This leads to a negative balance between water uptake and transpiration, ultimately causing the cut flowers to lose water and wilt. Thus, the fluctuation in the moisture balance value significantly affects the vase life of peony flowers.

The rate of change in fresh weight is indicative of the current weight relative to the initial weight. A positive rate suggests that the current fresh weight exceeds the initial weight, with a larger value indicating a greater weight gain. Conversely, a negative rate indicates that the current fresh weight is below the initial weight. The Si-treated samples exhibited an enhancement in antioxidant enzyme activity and a reduction in the concentration of reactive oxygen species (ROS), which was not correlated with the content of starch and sugars, demonstrating an orthogonal relationship.

Figure 5 shows the average fresh weight loss of four peony varieties in seven preservative solutions, which were not weighed separately for different peony varieties. For all four peony varieties, the freshness preservatives significantly improved the water absorption of fresh-cut flowers compared to the control, suggesting that improved water absorption is one of the reasons why fresh-cut flower preservatives work. The rate of fresh weight loss in most of the treatments, on the other hand, showed a decreasing trend with time. However, in the treatment solution with Si preservative, the peonies obtained the maximum value of fresh weight on the second day, and the rate of change of fresh weight showed a tendency to increase and then decrease with time, suggesting that Si was effective in promoting the water absorption of peonies at the early stage of vase insertion. It is worth noting that although diluted Chrysal maintained the water stability of paeonies for more than a week, it did not become the best-performing freshness preservative, which also indicates that the magnitude of fresh weight loss rate does not determine the freshness preservation of fresh cut flowers. The water absorption rates of different species of paeoniflora fresh cut flowers are generally different, and the changing patterns of fresh weight loss rate and water equilibrium value of different species of paeoniflora can be examined in more detail in the future study of the water status of cut flowers.

CONCLUSION

The results of this study indicate that although standardized formulations are available for commercial flower preservatives such as Chrysal and Chrysal, in practice these formulations may need to be adapted to specific cut flower varieties. For peonies, diluting the preservative up to four times improved the preservation significantly. In addition, the addition of silicon (Si) to commercial preservatives has a significant positive effect on enhancing the post-harvest performance of cut flowers, helping to maintain moisture status, which can significantly increase flower diameter, optimally regulate flowering time, delay senescence, enhance commercial value and prolong ornamental life. In addition, different varieties of peonies are suitable for different commercial preservatives, for example, in this experiment, Chrysal was recommended for Monsieur Jules Elie and Kelway's Glorious, while for Bartzella, Chrysal was significantly more effective. The combined use of silicon and preservatives has proven to be an effective strategy for improving the postharvest performance of cut flowers. With the revelation of the positive role of Si in the postharvest performance of

fresh cut flowers, it is expected to become an important part of future research and practice in flower preservation such as peonies. In the future, we will further explore the preservation effect of Si in combination with homemade preservatives for paeonies and further examine the levels of oxidative stress markers and carbohydrates in fresh-cut flowers based on floral diameter, floral period, and fresh weight loss rate to gain a deeper understanding of the mechanism of silicon in enhancing postharvest performance.

Declarations

Compliance with Ethical Standards

The authors declare that there are no potential conflicts of interest, financial or non-financial, that could be perceived as prejudicing the impartiality of the research reported. The research presented in this manuscript did not involve human participants or animals, thus no ethical approval or informed consent was required. The manuscript was written through the contributions of all authors, and the authors have no relevant financial or non-financial interests to disclose. All authors have been informed about the submission and have consented to the publication of the manuscript.

Author Contributions:

Huimin Zheng: Conceptualization, Methodology, Formal Analysis, Investigation, Writing - Original Draft, Supervision, Project Administration, Funding Acquisition.

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Figures

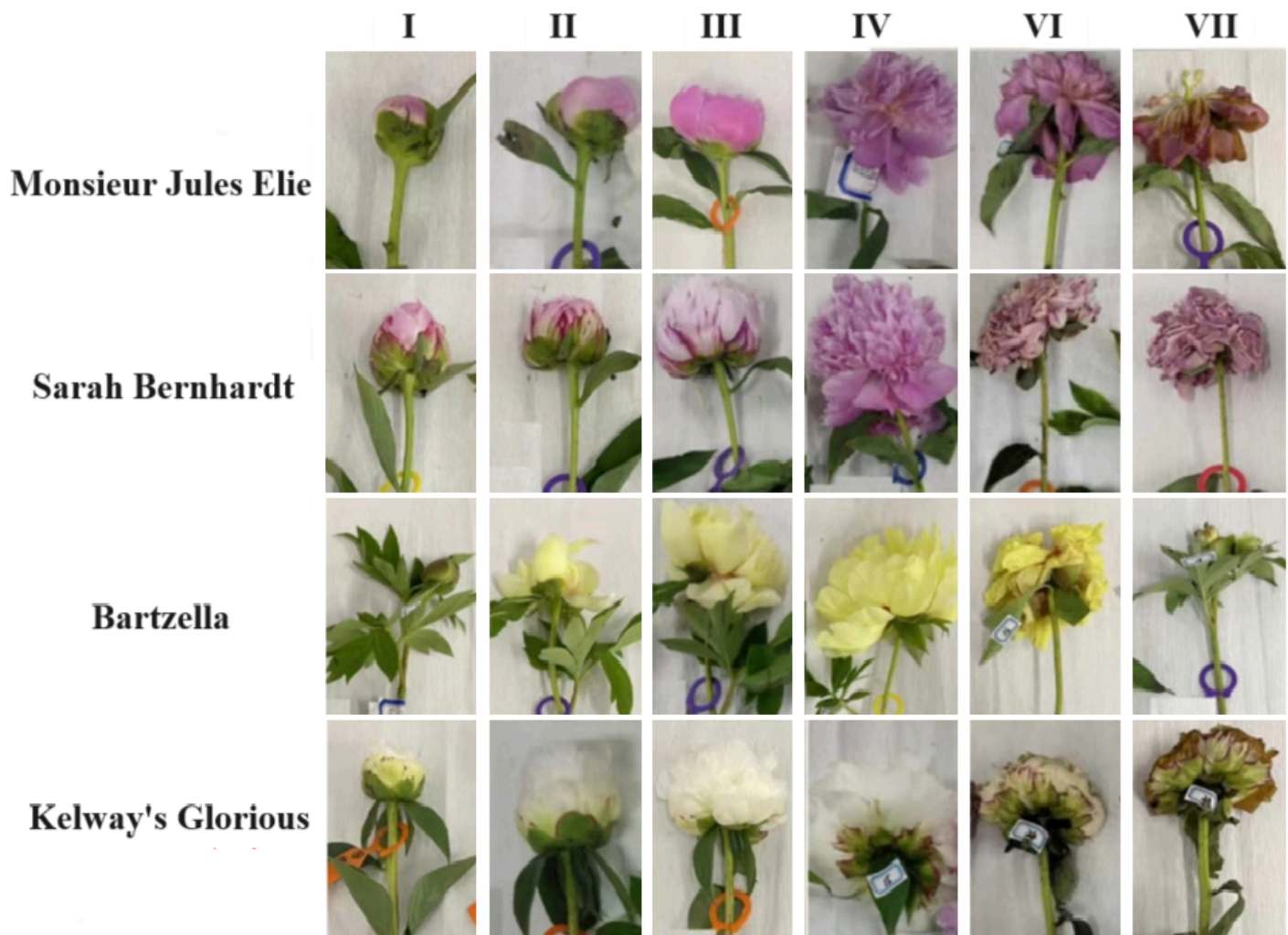


Figure 1

The representative cut peony flowers of ‘Monsieur Jules Elie’, ‘Sarah Bernhardt’, ‘Bartzella’, and ‘Kelway's Glorious’ in six phases.

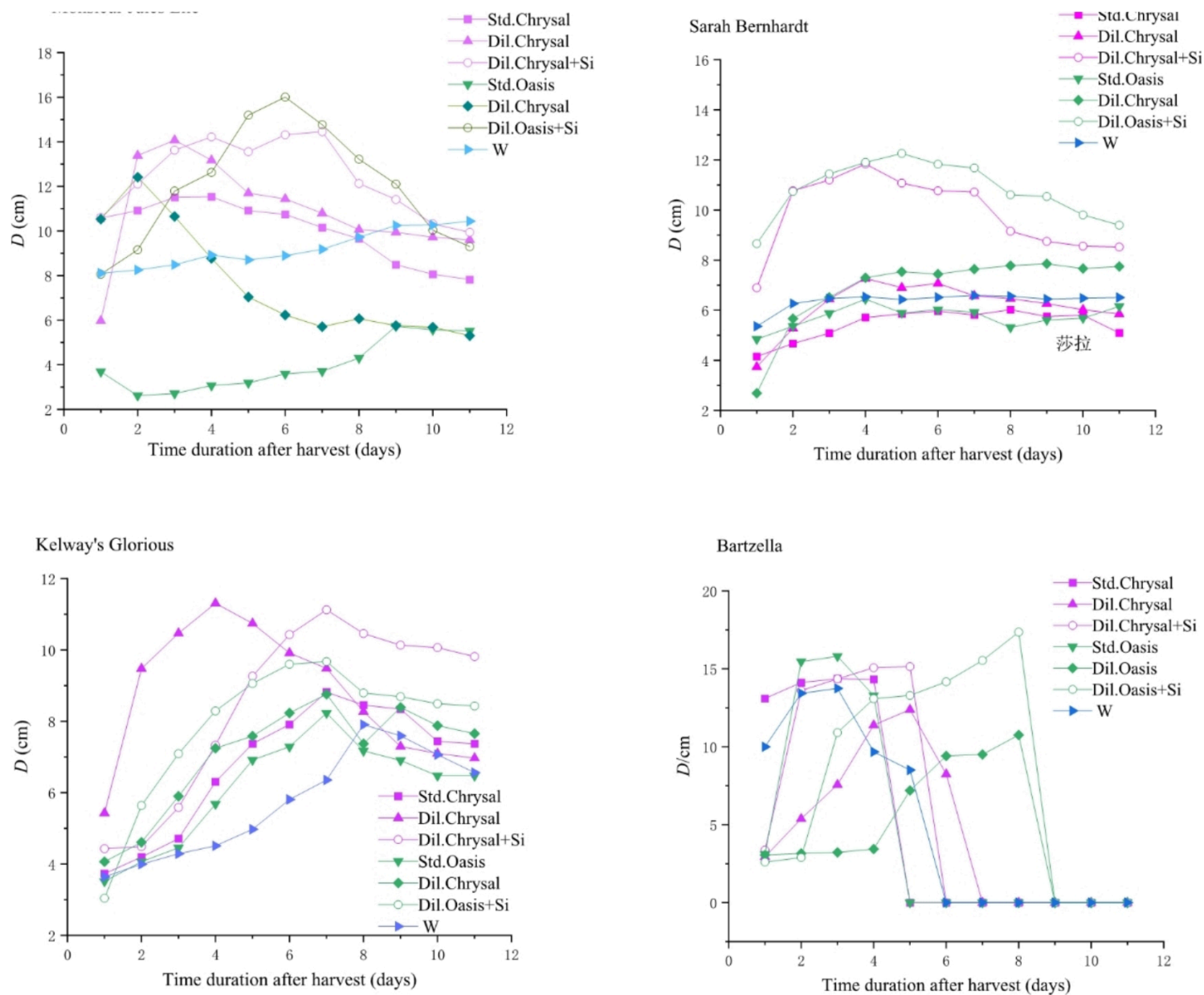
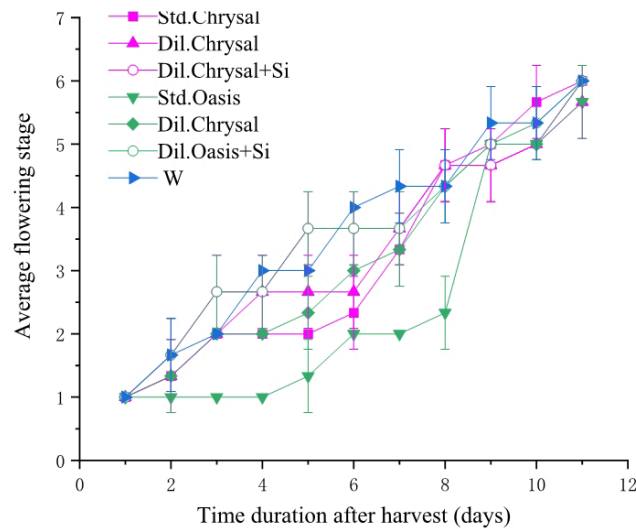
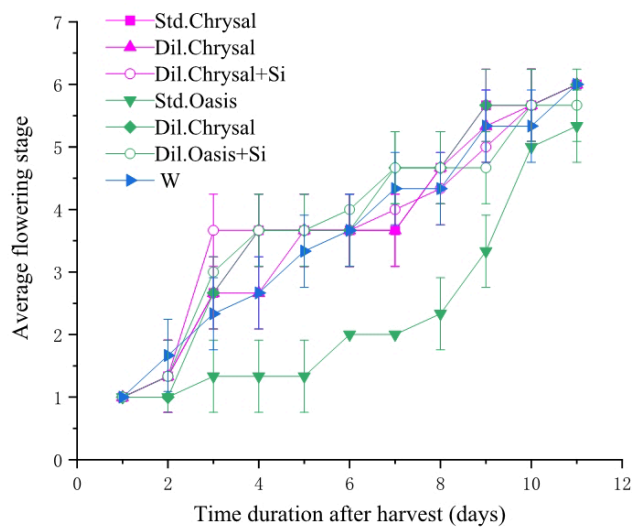
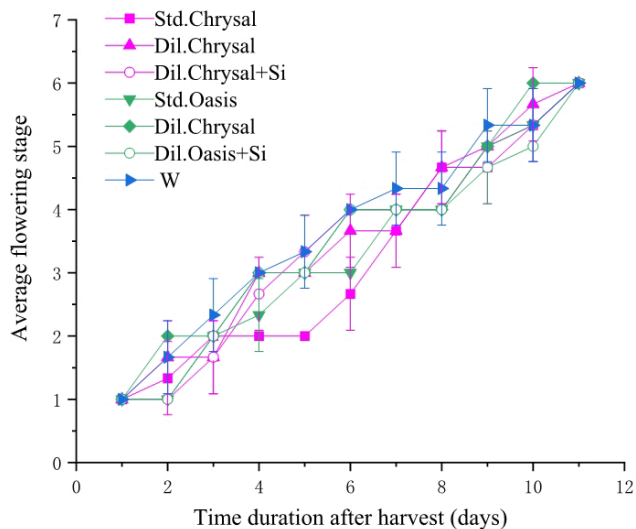


Figure 2

Mean flower diameter of a) Monsieur Jules Elie, b) Sarah Bernhardt, c) Kelway's Glorious, and d) Bartzella over time for seven preservative treatments



c) Kelway's Glorious



d) Bartzella

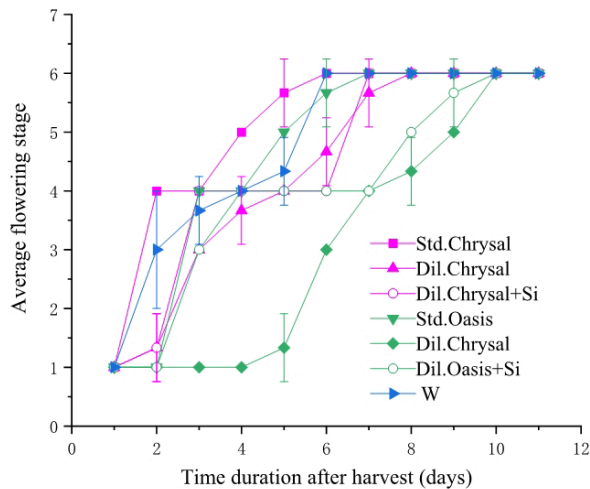


Figure 3

Changes in flowering stage over time of a) Monsieur Jules Elie, b) Sarah Bernhardt, c) Kelway's Glorious, and d) Bartzella treated with seven preservatives.



Figure 4

Photographs of representative one-flower vase life of four varieties of Dil.Oasis, Dil.Oasis+Si, Dil.Chrysal, and Dil.Chrysal+Si in four vase solutions screened for better performance over seven days, indicated by the red box

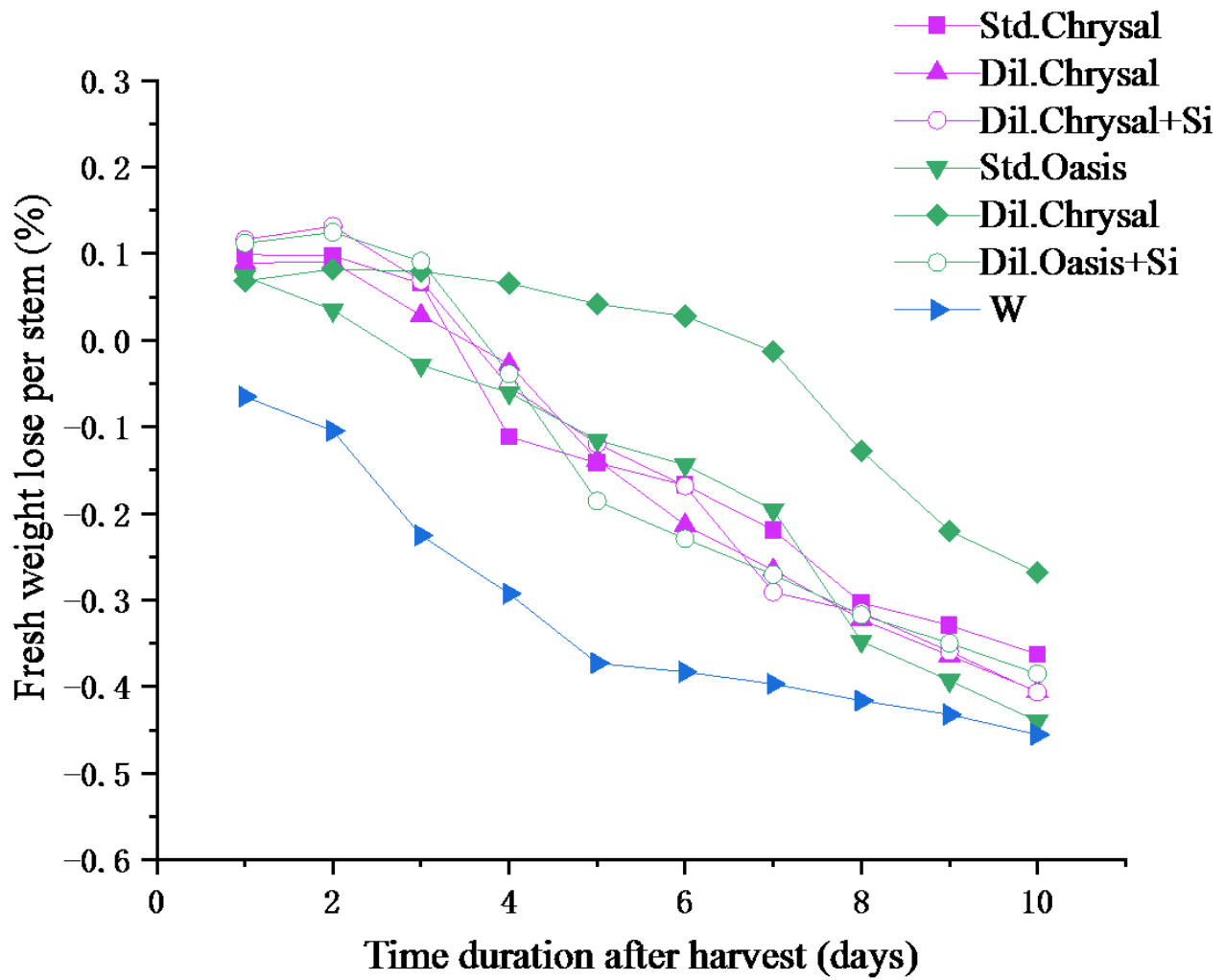


Figure 5

Average fresh weight loss of four peonies in seven preservative solutions