Çukurova Tarım Gıda Bil. Der. *Çukurova J. Agric. Food Sci.*
39(1):231-240
doi: 10.36846/CJAFS.2024.146

Research Article

The Effects of Silver and Copper Nano Particle-Infused Vase Solutions on the Vase Life of Cut Narcissus (*Narcissus* L.) Flowers

Akife DALDA ŞEKERCİ[1], Gülşen BARUT[2], Hande Seda ÖZDAL[2*], Hasan Talha ÜNSAL[2]

ABSTRACT
Narcissus has become increasingly preferred as a cut flower due to its pleasant fragrance and ability to bloom during winter. The most important parameters determining the quality of cut flowers are vase life and flower quality. In this study, the effects of six different vase solutions containing nano copper, nano silver, and sodium hypochlorite on the vase life, relative fresh weight, and daily solution uptake of cut narcissus flowers were investigated. The longest vase life in cut narcissus flowers was achieved with the 20 ppm nano copper and 30 ppm nano copper applications, lasting 7.33 days, followed by the 30 ppm nano silver application with a vase life of 6.25 days. The control group recorded the shortest vase life at 4.25 days, and it was observed that vase solutions containing nanoparticles approximately doubled the vase life. Nanoparticle applications positively affected vase life and flower quality, with the addition of nano copper to the vase water showing a higher effect than nano silver, and extending vase life more than all other applications. The results indicated that, like nano silver, nano copper extends vase life by reducing antimicrobial activity and providing a nourishing effect in the vase water.
Keywords: Cut flower, narcissus, ornamental plant, nano particle, vase life

Gümüş ve Bakır Nano Partikül İçerikli Vazo Solüsyonlarının Kesme Nergis (*Narcissus* L.) Çiçeklerinin Vazo Ömrüne Etkileri

ÖZ
Nergis, hoş kokusu ve kışın çiçek açabilmesi nedeniyle son yıllarda kesme çiçek olarak yaygın şekilde tercih edilmeye başlanmıştır. Kesme çiçeklerde kaliteyi belirleyen en önemli parametreler vazo ömrü ve çiçek kalitesidir. Bu çalışmada, nano bakır, nano gümüş ve sodyum hipoklorit içeren altı farklı vazo solüsyonunun kesme nergis çiçeklerinde vazo ömrü, oransal taze ağırlık ve günlük solüsyon alımı üzerindeki etkileri incelenmiştir. Kesme nergis çiçeklerinde en uzun vazo ömrü, 7.33 gün ile 20 ppm nano bakır ve 30 ppm nano bakır uygulamalarında elde edilirken, 30 ppm nano gümüş uygulaması 6.25 gün vazo ömrüne sahip olmuştur. Kontrol grubunda vazo ömrü en düşük 4.25 gün olarak kaydedilmiş ve nanopartikül içeren vazo solüsyonlarının vazo ömrünü yaklaşık iki kat artırdığı gözlemlenmiştir. Nanopartikül uygulamaları vazo ömrü ve çiçek kalitesini olumlu yönde etkilemiş olup, vazo suyuna ilave edilen nano bakır uygulaması, nano gümüşten daha yüksek bir etki göstermiş ve vazo ömrünü tüm diğer uygulamalardan daha fazla artırmıştır. Elde edilen sonuçlar, nano bakırın da nano gümüş gibi antimikrobiyal aktiviteyi azaltarak vazo ömrünü uzattığını ve vazo suyuna besleyici bir etki oluşturduğunu ortaya koymuştur.
Anahtar Kelimeler: Kesme çiçek, nergis, süs bitkisi, nano partikül, vazo ömrü

ORCID ID (Yazar sırasına göre)
0000-0001-8554-6501, 0009-0004-4814-799X, 0000-0001-5557-3138, 0000-0002-1022-7255

Yayın Kuruluna Geliş Tarihi: 29.04.2024
Kabul Tarihi: 27.06.2024
[1] Erciyes Üniversitesi, Ziraat Fakültesi, Bahçe Bitkileri Bölümü, Kayseri, Türkiye
[2] Erciyes University, Graduate School of Natural and Applied Sciences, Horticulture Department, Kayseri, Türkiye
*E-posta: handesedaozdal12@gmail.com

The Effects of Silver and Copper Nano Particle-Infused Vase Solutions on the Vase Life of Cut Narcissus (*Narcissus* L.) Flowers

Introduction

Narcissus L., is a widely preferred cut flower worldwide due to its attractive appearance, pleasant fragrance, and ability to bloom in winter (Gun, 2020). Belonging to the *Amaryllidaceae* family, *Narcissus* L. is extensively cultivated in Mediterranean-climate countries, including Turkey, especially in regions with dense Mediterranean conditions (Özzambak et al., 2007). Given the limited variety of cut flowers available in winter and autumn and the feasibility of narcissus cultivation during these seasons, narcissus significantly contributes to the flower market during these times (Hunter et al., 2004; Zeybekoğlu and Özzambak, 2014). The vase life of cut flowers is a critical factor in determining cut flower quality and plays a significant role in preserving their value in the market. Maintaining the freshness of the product from harvest and ensuring a long vase life are crucial for a quality cut flower trade (Batt, 2001; Akça et al., 2019). Therefore, studies focusing on practices to extend the vase life of cut flowers starting from harvest are highly important. Various factors influence the vase life of cut flowers, including the genetic makeup of the plant, pre-harvest conditions (cultivation practices and cultural treatments), timing of harvest, and post-harvest procedures. The vase life of cut flowers tends to decrease due to various factors, primarily the clogging of microbial vessels, interruption of water uptake and transport, and depletion of respiratory substrates limiting energy for sustaining life processes (Elgimabi and Ahmed, 2009; Danaee et al., 2011; Fanourakis et al., 2013). Additionally, in ethylene-sensitive species, ethylene has an aging-accelerating effect, and reactive oxygen species (ROS) produced during oxidative stress on flower stems have harmful effects (Skutnik et al., 2021). Previous studies have also demonstrated that microbial activity in the stems of cut flowers shortens their vase life (Balestra et al., 2005), highlighting the importance of identifying vase solutions that limit microbial activity. To extend the vase life of cut flowers, various antimicrobial chemicals such as 8-hydroxyquinoline sulfate (8-HQS), silver thiosulfate (STS), aluminum sulfate, silver nitrate, and sodium hypochlorite are used in vase solutions (Çelikel et al., 2020; Kazaz et al., 2020). The 8-hydroxyquinoline citrate has been reported to be effective in limiting the microbial population in vase solution (Islam et al., 2003; Bahrami et al., 2013; Sharifzadeh et al., 2014), while aluminum sulfate (Liao et al., 2001), sodium hypochlorite (Kathari-Lakshmaiah et al., 2019), silver nitrate (Hutchinson et al., 2013), nano-silver (Lü et al., 2010), and silicon and silver (Kiamohammadi, 2012) have been reported to extend the vase life when added to vase solution. It has been reported that sodium hypochlorite addition to the vase can reduce bacterial counts and extend the vase life of cut flowers (Halevy and Mayak, 1981; Macnish et al., 2010). Silver nitrate has been reported to act as an antimicrobial agent (van Doorn, 2010) or as an inhibitor of ethylene synthesis and ethylene action. As a vase solution treatment for cut flowers, nano silver has been found important as an antibacterial agent (Alt et al., 2004; Morones et al., 2005). Nano silver releases Ag^+, which has been reported to interact with cytoplasmic components and nucleic acids, inhibit respiratory chain enzymes, and interfere with membrane permeability (Park et al., 2005). It is also possible that Ag^+ has positive effects on plant stem hydraulic conductivity (van Ieperen, 2007; Koohkan et al., 2014). In many studies, the antimicrobial properties of nano silver have been investigated. However, no studies on vase solutions containing nano copper have been found. Nano copper may also be a suitable vase component as it both exhibits antimicrobial properties and provides nutritional supplements. In this study, the effect of silver and copper nanoparticles on the vase life was evaluated comparatively with the commonly used chemical sodium hypochlorite. The study investigated the effects of nanoparticles added to the vase solution on the vase life and flower quality of cut narcissus flowers.

Material and Methods

Plant Material, Vase Solutions, and Environmental Conditions

The research was conducted at the pomology laboratory of Department of Horticulture, Erciyes University. The study aimed to determine the vase life and cut flower quality of

cut narcissus flower in different vase solutions. The narcissus flowers (*Narcissus* L.) were harvested at a commercial stage, when approximately 80% of the flowers on each stem had bloomed (Kitamura et al., 2016). Following harvest, they were transported to the laboratory under cold chain conditions without undergoing any processing. To minimize contamination in the vase life room, the stems were recut. Subsequently, they were placed in glass bottles (1000 ml) containing 750 ml of different vase solutions. The study was designed in a randomized complete block design with three replications, each consisting of three vases with four stems per vase. A total of six different vase solutions and one control were prepared (Table 1). The experimental environment was maintained at 22-24°C room temperature and 30% humidity, aiming to simulate conditions similar to those found in a home setting.

Table 1. Contents of vase solutions for cut narcissus flowers

Treatments	Vase Solutions
T1	20 ppm Nano Copper
T2	20 ppm Nano Silver
T3	30 ppm Nano Copper
T4	30 ppm Nano Silver
T5	Sodium Hypochlorite (3mg/L)
T6	Control- tap water

The assessed characteristics encompassed vase life, relative fresh weight, and solution uptake. Vase life was documented on a daily basis, with conclusion reached upon the observation of wilting, browning of sepals, or drying of sepals in roughly 80% of the flowers (Kitamura et al., 2017). Weights of vases were measured both with and without flowers, and evaluations of fresh weight and solution uptake were conducted every other day.

Relative fresh weight (%); Relative fresh weight, expressed as a percentage, was determined by measuring the change in fresh weight using the formula: Relative Fresh Weight (%) = (Wt/Wt-0) x 100, where Wt represents the weight of the stem (in grams) at t = 0, 1, 2 days, and so forth, and Wt-0 denotes the weight of the same stem (in grams) at t = 0 day (He ve ark., 2006).

Solution uptake; Solution uptake was assessed on a daily basis and quantified in terms of both daily and total solution uptake. The formula for daily solution uptake is: Daily Solution Uptake (g stem−1 day−1) = (St−1 – St), where St represents the weight (in grams) of the vase solution on days 1, 2, 3, and so forth, and St−1 denotes the weight of the vase solution on the preceding day (He ve ark., 2006; Lü ve ark., 2010).

Statistical analyses

The experiment involved six treatments and followed a completely randomized design (CRD) with three replicates, each comprising three flowers. Statistical analysis of the data collected was performed using analysis of variance (ANOVA) with IBM SPSS Statistics 20.0. Mean differences were evaluated using Duncan's test ($p < 0.05$ and $p < 0.001$) to identify significant variations.

Results and Discussion

Vase Life (Day)

The vase life is terminated when the rate of wilting in flower spikes or the rate of leaf drying reaches 80% (Kitamura et al., 2017). In this study, six different vase solutions were used to evaluate the vase life of cut narcissus flowers. According to the results obtained, all nano particle and sodium hypochlorite applications increased the vase life compared to the control group. The longest vase life in cut narcissus

flowers was obtained with T1 (20 ppm nano copper) and T3 (30 ppm nano copper) applications, reaching 7.33 days. This was followed by the application of 30 ppm nano silver with a vase life of 6.25 days. In the control group, the vase life was the lowest at 4.25 days, while it was observed that nano particle-containing vase solutions increased the vase life by approximately two-fold (Table 2 and Figure 1). The results obtained in this study are consistent with previous researches. Most of the studies on silver nanoparticle in vase solution focused on its anti-bacterial properties and reported that it increased vase life by reducing antimicrobial activity (Solgi et al., 2009; Liu et al., 2012; Safa et al., 2015; Carrillo-López et al., 2016). In addition, there are studies evaluating the function of silver nanoparticles as anti-ethylene agents (Koohkan et al., 2014). In a similar study, they reported that silver nanoparticles reduced ethylene production and bacterial growth in the vase solution and caused the vase life of cloves to extend. In accordance with existing literature, it is plausible that in this study, the high surface area-to-volume ratio and potent antibacterial activity of silver and copper nano particles may have suppressed bacterial population growth in the vase solution and xylem vessels, consequently extending the vase life. In similar studies, various chemical substances known for their antimicrobial effects, such as silver thiosulfate (STS), silver nitrate (AgNO3), hydroxyquinoline sulfate (8-HQS), and hydroxyquinoline citrate (8-HQC), have been used and found to be highly effective in extending the vase life of gerbera flowers (Rahman et al., 2019; Singh et al., 2022). Previous studies have reported that the addition of silver nitrate to vase water prevents the occlusion of vascular bundles and effectively prolongs vase life (Damunupola and Joyce, 2008). In another study, it was noted that the highest vase life in cut rose flowers was achieved when the flowers were placed in preservative solutions, and sodium hypochlorite-containing vase solutions were reported to inhibit bacterial formation, thus extending vase life (Masoome et al., 2003). Norikoshi et al. (2016) indicated that sucrose application increased the concentrations of glucose and fructose within the vacuole, thereby enhancing water uptake and supporting cell expansion during flower opening. However, it has also been reported that carbohydrates, especially sucrose, may lead to an increase in bacterial populations in vase water, potentially causing blockages in the cut flower xylem vessels (Hajizadeh et al., 2012). In line with these views, nanoparticles have been observed to contribute to a longer vase life by reducing antimicrobial activity.

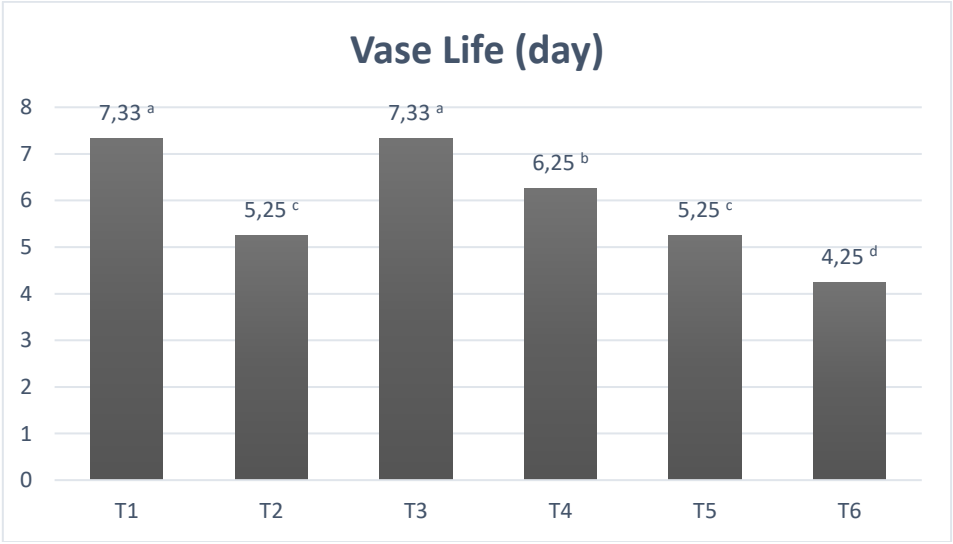

Figure 1. Graph showing the effects of different vase solutions on the vase life of cut narcissus flower

Table 2. Vase life periods of cut narcissus flower depending on different vase solution

Treatments	Vase Solutions	Vase Life (day)
T1	20 ppm Nano Copper	7.33[a]
T2	20 ppm Nano Silver	5.25[c]
T3	30 ppm Nano Copper	7.33[a]
T4	30 ppm Nano Silver	6.25[b]
T5	Sodium Hypochlorite (3mg/L)	5.25[c]
T6	Control- tap water	4.25[d]

**Means indicated with different letters in the same column are significantly different significant at $p<0.001$

Figure 2. Visual representation of cut narcissus flowers with 30 ppm nano silver treatment.

Relative Fresh Weight Value (%) Results

Different vase solution applications were found to cause statistically significant differences in relative fresh weight among cut narcissus flowers, with applications made on days 2, 4, 6, 7, and 8 being statistically significant. Relative fresh weights of cut narcissus flowers increased during the first two days, then began to decrease after the second day (Figure 3). On the second day, relative fresh weights among treatments ranged from 103% to 140%. On the final day, flowers with the highest relative fresh weights were recorded in the application of 20 ppm nano copper (T1) and 30 ppm nano copper (T3). A positive correlation was observed between vase life and relative fresh weights (Table 3, Figure 3). In the results of this study, it is observed that as the vase life approaches its end, the relative fresh weight decreases (Figure 2). However, due to the rapid increase in bacterial population not occurring in nano particle applications, the relative fresh weight did not decrease rapidly. It has been reported that although there was an increase in relative fresh weight throughout the vase life, a sharp decrease in relative fresh weight of the cut flower occurred due to the high number of isolated bacteria in the vase solution (Li et al., 2012). Previous studies have also indicated increases in relative fresh weights with vase applications, which continued for a certain period and then declined (Alaey et al., 2011; Ünsal, 2022). In another study, the stem fresh weight of Movie Star cut roses rapidly increased in the first 40 hours of the vase period, and then gradually decreased (Lu et al., 2011). Blockage of vessels caused by bacteria leads to reduced water uptake and ultimately results in bending, breaking of stems, and wilting of leaves in cut

flowers (Nair et al., 2003; Balestra et al., 2005; Meman and Dabhi, 2006; Solgi et al., 2009). Soleımany-Fard et al. (2013) noted a significant increase in relative fresh weight during the first 4 days in alstroemeria flowers, followed by a significant decrease until the end of the experiment. Similar change patterns have been reported for cut rose flowers; proportional decreases in fresh weight in the days following harvest can be attributed to decreased water uptake (Lu et al., 2010; Alaey et al., 2011; Soleımany-Fard et al., 2013).

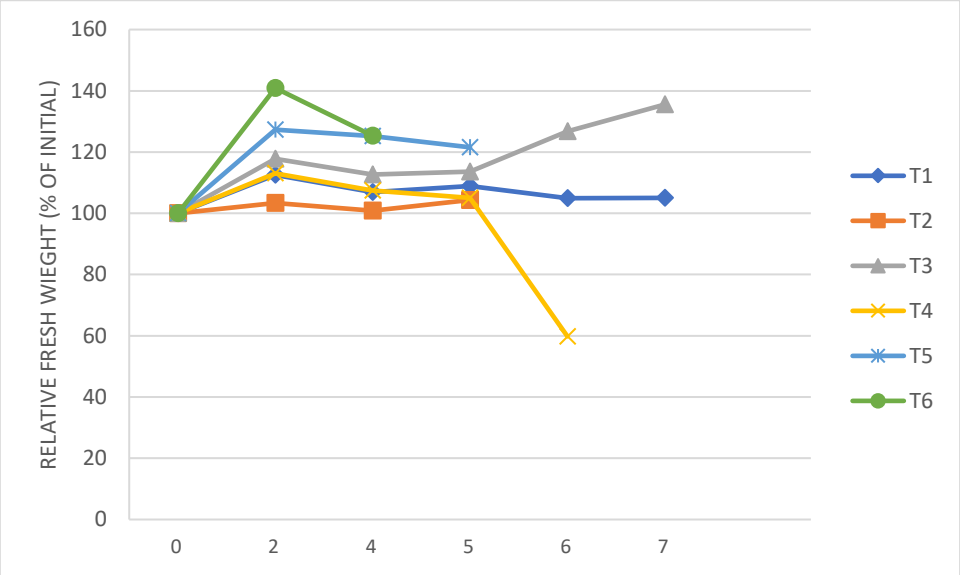

Figure 3. Graph showing changes in relative fresh weight of cut narcissus flower during vase life

Table 3. Changes in relative fresh weight of cut narcissus flowers over vase life

TREATMENTS	RFW2	RFW4	RFW5	RFW6	RFW7
T1	112,52 b	106,95 a	108,88 a	104,89 ab	105,01 b
T2	103,37 b	100,88 a	104,35 a	-	-
T3	117,83 ab	112,69 a	113,59 a	126,74 a	135,53 a
T4	113,03 ab	107,42 a	104,98 a	59,81 b	-
T5	127,31 ab	125,23 a	121,53 a	-	-
T6	140,9 a	125,34 a	-	-	-

***RFW; Relative Fresh Weight**

*Means indicated with different letters in the same column are significantly different significant at $p<0.05$

Daily Solution Uptake Results

In cut narcissus flowers, the highest solution uptake was observed in the control group at the initial measurement of daily solution uptake. The lowest daily solution uptake was recorded in the application of 20 ppm nano copper (T1). In the control group, daily solution uptake rapidly decreased after the second day, progressing towards the end of the vase life. Similarly, in sodium hypochlorite treatment, daily solution uptake stabilized after the second day. However, in nano particle applications, daily solution uptake continued until the 7th day and then decreased, progressing towards the end of the vase life (Table 4, Figure 4). Cut flowers' quality and longevity are primarily determined by water balance, which is influenced by two main processes; water uptake and transpiration (Da Silva, 2003).

The obtained results are consistent with previous studies. Application of nano silver-containing vase solution has been reported to have positive effects on daily solution uptake in cut carnations, with the maximum solution uptake occurring on the first day and decreasing over time (Koohkan et al., 2014).

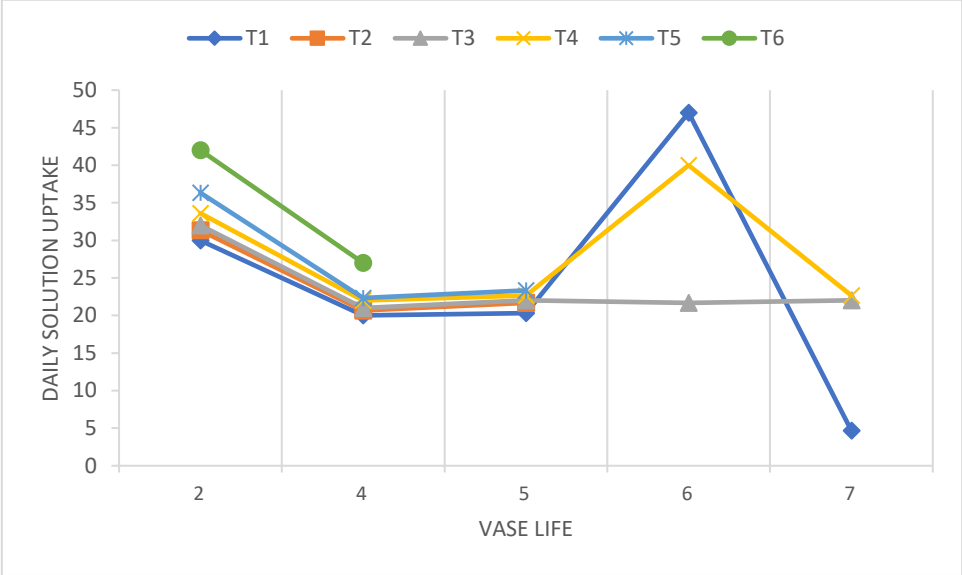

Figure 4. Graph showing changes on the daily solution uptake of cut narcissus flowers during vase life

Table 4. Changes on the daily solution uptake of cut narcissus flowers over vase life

TREATMENTS	DSU2	DSU4	DSU5	DSU6	DSU7
T1	30 a	20 b	20,33 a	47 a	4,67 b
T2	31,33 a	20,67 b	21,67 a	-	-
T3	32 a	21 ab	22 a	21,67 b	22 a
T4	33,67 a	22 ab	22,67 a	40 a	-
T5	36,33 a	22,33 ab	23,33 a	-	-
T6	42 a	27 a	-	-	-

***DSU; Daily solution uptake**

*Means indicated with different letters in the same column are significantly different significant at $p<0.05$

Conclusion

This study has determined that when the correct vase solution is used, cut narcissus flowers can have a vase life of more than 7 days. It has been found that the addition of silver and copper nanoparticles to the vase solution significantly increases vase life compared to other applications. This study is supportive of previous research demonstrating that components added to vase solutions such as sodium hypochlorite, silver nitrate, and silver nanoparticles limit microbial activity, thus increasing vase life. Previous studies have reported that silver is a potent inhibitor of ethylene effects in plant tissues; therefore, copper nanoparticles, which were hypothesized to exhibit a similar effect, were tested in this study and were found to demonstrate even higher activity than silver-containing vase solutions. This could be attributed to the copper nanoparticle-containing vase solution not only reducing microbial activity in the vase solution but also having the ability to nourish the tissues. This study has presented an alternative method for vase solutions and contributed to the identification of a vase solution that can increase vase life by nearly double.

References

Akça, Ş. B., Yazıcı, K., Karaelmas, D., (2019). Zonguldak İli Kesme ÇiçekPerakendecilerinin Analizi. Bartın Orman Fakültesi Dergisi, 21(3), 580-588.

Alaey, M., Babalar, M., Naderi, R., & Kafi, M. (2011). Effect of pre-and postharvest

salicylic acid treatment on physio-chemical attributes in relation to vase-life of rose cut flowers. *Postharvest Biology and Technology*, *61*(1), 91-94.

Alt, V., Bechert, T., Steinrücke, P., Wagener, M., Seidel, P., Dingeldein, E., Schnettler, R. (2004). An in vitro assessment of the antibacterial properties and cytotoxicity of nanoparticulate silver bone cement. Biomaterials, 25(18), 4383-4391.

Bahrami, S. N., Zakizadeh, H., Hamidoghli, Y., Ghasemnezhad, M. (2013). Salicylic acid retards petal senescence in cut lisianthus (*Eustoma grandiflorum* 'Miarichi Grand White') flowers. Horticulture, Environment, and Biotechnology, 54, 519-523.,

Batt, P. J. (2001). Strategic lessons to emerge from an analysis of selected flower export nations. Journal of International Food and Agribusiness Marketing, 11(3): 41-54

Carrillo-López, L. M., Morgado-González, A., & Morgado-González, A. (2016). Biosynthesized silver nanoparticles used in preservative solutions for *Chrysanthemum* cv. Puma. Journal of Nanomaterials, 2016.

Celikel, F. G., Joyce, D. C., & Faragher, J. D. (2011). Inhibitors of oxidative enzymes affect water uptake and vase life of cut *Acacia holosericea* and *Chamelaucium uncinatum* stems. Postharvest Biology and Technology, 60(2), 149-157.

Da Silva, J. T. (2003). The cut flower: postharvest considerations. J. Biol. Sci, 3(4), 406-442.

Damunupola, J. W., Joyce, D. C. (2008). When is a vase solution biocide not, or not only, antimicrobial. Journal of the Japanese Society for Horticultural Science, 77(3), 211-228.

Danaee, E., Mostofi, Y., Moradi, P. (2011). Effect of GA 3 and BA on postharvest quality and vase life of gerbera (*Gerbera jamesonii*. cv. Good Timing) cut flowers. Horticulture, Environment, and Biotechnology, 52, 140-144.

Elgimabi, M. N., Ahmed, O. K. (2009). Effects of bactericides and sucrose-pulsing on vase life of rose cut flowers (*Rosa hybirida*). Botany Research International, 2(3), 164-168.

Fanourakis, D., Pieruschka, R., Savvides, A., Macnish, A. J., Sarlikioti, V., Woltering, E. J. (2013). Sources of vase life variation in cut roses: a review. Postharvest Biology and Technology, 78, 1-15.

Gun, S. (2020). The effect of herbal oil and citric acid on vase life of cut narcissus (*Narcissus tazetta* L.) flower. J Postharvest Technol, 8(4), 18-26.

Hajizadeh, H. S., Farokhzad, A., Chelan, V. G. (2012). Using of preservative solutions to improve postharvest life of *Rosa hybrid* cv. Black magic.

Halevy, A. H., Mayak, S. (1981). Senescence and post-harvest physiology of cut flowers-part 11. Horticulture Review, 3, 59-143.

He, S., Joyce, D.C., Irving, D.E., Faragher, J.D., (2006). Stemend blockage in cut Grevillea 'Crimson yul-lo' inflorescences. Postharvest Biology and Technology, 41:78–84.

Hunter, D. A., Yi, M., Xu, X., & Reid, M. S. (2004). Role of ethylene in perianth senescence of daffodil (*Narcissus pseudonarcissus* L.'Dutch Master'). Postharvest Biology and Technology, 32(3), 269-280.

Hutchinson, M. J., Muchiri, J. N., Waithaka, K. (2013). Effects of chemical preservatives and water quality on postharvest keeping quality of cut Lisianthus (*Eustoma grandiflorum* L).

Islam, N., Patil, G. G., Gislerod, H. R. (2003). Effects of pre-and postharvest conditions on vase life of *Eustoma grandiflorum* (Raf.) Shinn. European Journal of Horticultural Science, 68(6), 272-278.

Kathari Lakshmaiah, M. G., Subramanian, S., & Santhi, R. (2019). Role of post-harvest

treatments in improving vase life of lisianthus (*Eustoma grandiflorum*) variety Mariachi Blue. IJCS, 7(6), 247-249.

Kazaz, S., Kılıç, T., Doğan, E., & Sekmen, Ş. (2020). Vase life extension of cut hydrangea (*Hydrangea macrophylla*) flowers. The Journal of Horticultural Science and Biotechnology, 95(3), 325-330.

Kiamohammadi, M. (2012). The effects of different floral preservative solutions on peduncle bending and quality attributes of lisianthus cut flowers. Acta Horticulturae, (943), 203-208.

Kitamura, Y., Kato, Y. Yasui, T., Aizawa, H., Ueno, S. (2017). Relation between Increases in Stomatal Conductance of Decorative Sepals and the Quality of Antique-Stage Cut Hydran- gea Flowers. The Horticulture Journal. 86(1), 87–93

Koohkan, F., Ahmadi, N., & Ahmadi, S. J. (2014). Improving vase life of carnation cut flowers by silver nano-particles acting as anti-ethylene agent. Journal of Applied Horticulture, 16(3), 210-214.

Li, H., Huang, X., Li, J., Liu, J. Joyce, D., He, S., (2012). Efficacy of Nano-silver in Alleviating Bacteria-related Blockage in Cut Rose cv. Movie Star Stems. Postharvest Biology and Technology, 74, 36-41.

Liao, L. J., Lin, Y. H., Huang, K. L., Chen, W. S. (2001). Vase life of *Eustoma grandiflorum* as affected by aluminum sulfate. Botanical Bulletin of Academia Sinica, 42, 41-49.

Liu, J., Ratnayake, K., Joyce, D. C., He, S., & Zhang, Z. (2012). Effects of three different nano-silver formulations on cut *Acacia holosericea* vase life. Postharvest Biology and Technology, 66, 8-15.

Lu P, Cao J, He S, Liu J, Li H, Cheng G, Ding Y, Joyce DC., (2010). Nano-silver pulse treatments improve water relations of cut rose cv. 'Movie' Star flowers. Postharvest Biol Technol 57:196-202.

Lü, P., Cao, J., He, S., Liu, J., Li, H., Cheng, G., ... Joyce, D. C. (2010). Nano-silver pulse treatments improve water relations of cut rose cv. Movie Star flowers. Postharvest Biology and Technology, 57(3), 196-202.

Lü, P., Huang, X., Li, H., 2011. Continuous Automatic Measurement of Water Uptake and Water Loss of Cut Flower Stems. Hortscience 46, 509-512.

Macnish, A. J., Leonard, R. T., Borda, A. M., & Nell, T. A. (2010). Genotypic variation in the postharvest performance and ethylene sensitivity of cut rose flowers. HortScience, 45(5), 790-796.

Meman, M. A., Dabhi, K. M. (2006). Effects of different stalk lengths and certain chemical substances on vase life of gerbera (*Gerbera jamesonii* Hook.) cv.'Savana Red'. Journal of Applied Horticulture, 8(2), 147-150.

Morones, J. R., Elechiguerra, J. L., Camacho, A., Holt, K., Kouri, J. B., Ramírez, J. T., Yacaman, M. J. (2005). The bactericidal effect of silver nanoparticles. Nanotechnology, 16(10), 2346.

Nair, S.A., Singh, V., Sharma, T.V.R.S., (2003). Effect of chemical preservatives on enhancing vase-life of gerbera flowers. J. Trop. Agric. 41, 56–58.

Norikoshi, R., Shibata, T., Niki, T., Ichimura, K. (2016). Sucrose treatment enlarges petal cell size and increases vacuolar sugar concentrations in cut rose flowers. Postharvest Biology and Technology, 116, 59-65

Özzambak, E., Zeybekoğlu, E., & Kahraman, Ö. (2007). Süs bitkileri yetiştiriciliğinde iyi tarım uygulamaları. Ege Üniv. Zir. Fak. Matbaası, 97-106.

Park, S. H., Oh, S. G., Mun, J. Y., & Han, S. S. (2005). Effects of silver nanoparticles on the fluidity of bilayer in phospholipid

liposome. Colloids and Surfaces B: Biointerfaces, 44(2-3), 117-122.

Rahman, M. M., Ahmad, S. H., Mohamed, M. T. M., & Ab Rahman, M. Z. (2019). Improving the vase life of cut Mokara red orchid flower using leaf extracts with silver nanoparticles. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 89, 1343-1350.

Safa, Z., Hashemabadi, D., Kaviani, B., Nikchi, N., & Zarchini, M. (2015). Studies on quality and vase life of cut *Gerbera jamesonii* cv.'Balance'flowers by silver nanoparticles and chlorophenol. Journal of Environmental Biology, 36(2), 425.

Sharifzadeh, K., Asil, M. H., Roein, Z., Sharifzadeh, M. (2014). Effect of 8-hydroxyquinoline citrate, sucrose and peroxidase inhibitors on vase life of lisianthus (*Eustoma grandiflorum* L.) cut flowers. Journal of Horticultural Research, 22(1), 41-49.

Singh, K., Sharma, R., Sahare, H. (2022). Implications of synthetic chemicals and natural plant extracts in improving vase life of flowers. Scientia Horticulturae, 302, 111133.

Skutnik, E., Łukaszewska, A., Rabiza-Świder, J. (2021). Effects of postharvest treatments with nanosilver on senescence of cut lisianthus (*Eustoma grandiflorum* (Raf.) Shinn.) flowers. Agronomy, 11(2), 215.

Soleımany-Fard, E., Hemmati, K., Khalighi, A. (2013). Improving the keeping quality and vase life of cut alstroemeria flowers by pre and post-harvest salicylic acid treatments. Notulae Scientia Biologicae, 5(3), 364-370

Solgi, M., Kafi, M., Taghavi, T. S., & Naderi, R. (2009). Essential oils and silver nanoparticles (SNP) as novel agents to extend vase-life of gerbera (*Gerbera jamesonii* cv.'Dune') flowers. Postharvest biology and technology, 53(3), 155-158.

Solgi, M., Kafi, M., Taghavi, T. S., Naderi, R. (2009). Essential oils and silver nanoparticles (SNP) as novel agents to extend vase-life of gerbera (*Gerbera jamesonii* cv.'Dune') flowers. Postharvest biology and technology, 53(3), 155-158.

Ünsal, H. T. (2022). Hasat sonrası ön uygulamaların kesme gül (*Rosa hybrida* L.) çiçeklerinin vazo ömrü ve çiçek kalitesine etkisi, Master's thesis, Fen Bilimleri Enstitüsü).

van Doorn, W. G. (2010). Water relations of cut flowers. Horticultural reviews, 18, 1-85.

van Ieperen, W. (2007). Ion-mediated changes of xylem hydraulic resistance in planta: fact or fiction. Trends in Plant Science, 12(4), 137-142.

Zeybekoğlu, E., & Özzambak, E. (2014). Effects of different solutions applied during hydration process on vase life of cut narcissus before and after storage.