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The vase life and quality of cut *Gerbera jamesonii* cv. 'Rosalin' flowers are affected by natural essential oils (in normal and nano forms) and nano-silver particles

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Abstract

Gerbera (*Gerbera jamesonii*, Asteraceae) is an important commercial cut-flower crop. A prominent problem of gerbera cut flowers is short vase life, mostly due to neck bending. This study aimed to screen the effects of the essential oils of thyme, clove and caraway, in addition to nano-silver particles, on vase life and on some parameters of gerbera cv. 'Rosalin' cut flowers. A factorial experiment was carried out with essential oils as the first factor (in the normal form at 25 and 50 mg/L), nano-silver as the second factor (at 5 and 10 mg/L), and distilled water as control. The measured traits were: vase solution uptake, relative fresh weight, flower vase life, neck bending, the enzyme activity of polyphenol oxidase and catalase, anthocyanin pigment and phenols. Results indicated that essential oils have significantly affected vase life and vase solution uptake positively and reduced neck bending, where the most effective treatments were caraway and clove oils in the normal form at 50 mg/L and 25 mg/L, respectively. Similarly, a significant increase was observed in catalase. In contrast, nano-silver particles had an insignificant effect on neck bending but a significant effect on vase life and vase solution uptake was detected.

Key words: Gerbera, essential oils, nano-silver, vase life, postharvest

Introduction

Cut flowers are perishable parts of plants with high economic value. Cut flower handling to prolong vase life, *i.e.,* postharvest life, is vital (Bayat *et al.*, 2013). Cut flowers' vase life is affected by plant genetics, vase solution condition as preservative, and the ambient conditioons surrounding the flower. In addition, water relations and microorganisms that grow in vase solutions affect vase life of cut flowers (Bidarigh, 2015), not to forget storage and transport conditions.

Gerbera (*Gerbera jamesonii* – Family, Asteraceae), known as Transvaal daisy, is one of the ten most popular and important commercial cut flowers. Gerbera is a perennial herbaceous plant with colorful and attractive flowers that are widely used as a decorative garden plant or as cut flowers. The most important problem of the gerbera-cut flowers is the short vase life, which is often due to neck bending and flower wilting (Ferrante *et al.*, 2007). The primary causes of these conditions stem from genetic factors or disruptions in water-related processes, as well as potential issues with postharvest storage temperatures (Çelikel and Reid, 2002). The genetic component significantly influences gerbera flowers' vase life and stem-bending tendencies (Emongor, 2004).

Essential oils (EOs) are safe and nature-friendly compounds extracted from blossoms, seeds, fruits, fruit peels, leaves, stems, barks, wood and roots (Bayat *et al.*, 2013). Application of EOs to extend vase life demonstrated a significant positive impact on cut flower traits coming from their properties as antimicrobial, antioxidant and regulatory effects. Many EOs were widely tried out, for example, thyme, lavender, savory, ajowan, geranium, artemisia, coriander, dill, anise, rosemary, peppermint and caraway (Banjaw *et al.*, 2017). Gladiolus cut flower vase life can be extended by using essential oils of thyme, savoury, and ajowan as an alternative to chemical additives (Mirdehghan and Aghamolayi, 2016).

Many reports showed that thyme essential oil improved the postharvest vase life and quality of cut gerbera flowers (Amini *et al.*, 2014; Dareini *et al.*, 2014; Jafarpour *et al.*, 2015). Also, Hashemi *et al.* (2013) reported the usefulness of thymol, menthol and eugenol in increasing chrysanthemum cut flower vase-life. Similar results were obtained for narcissus cut flowers (Sardoei *et al.*, 2014), chrysanthemum cut flowers (Bazaz *et al.*, 2015) and cut flowers of *Alstroemeria* (Babarabie *et al.*, 2015).

Silver ion (Ag^+) has long been recognized in medical applications and industrial processes as efficient in inhibiting the growth of bacteria and other microorganisms (Rai *et al.*, 2009). Nano-silver (NS) particles, serving as an innovative antiseptic, find applications in the medical sector, fabrics with embedded silver for water purification, and disinfection of vegetables (Rai et al., 2009). With their exceptional chemical and physical attributes and remarkable surface area to volume ratio, NS formulations establish optimal interaction with microorganisms, showcasing excellent efficiency as germicidal agents. The capacity of NS particles to adhere to cellular membranes and infiltrate bacteria is also noteworthy.

In cut flower applications, NS has been reported to be effective as an antimicrobial agent (Liu *et al.*, 2009, Solgi *et al.*, 2009, Lü *et al.*, 2010a), an ethylene inhibitor (Kim *et al.*, 2004) and a regulator of stomatal aperture (Lü *et al.*, 2010b).

This study aimed to study the effect of some natural essential oils, their nano form, and NS particles as a preservative solution on vase life and some physiological and biochemical traits of gerbera cv. 'Rosalin' cut flowers.

Materials and methods

Experimental site and time duration: The study was conducted at the Faculty of Agriculture, Ain Shams University, Shoubra, Cairo. Experiments were carried out in the laboratory of Ornamental plants, Horticulture Departmentt, from 4th till 15th of February, 2020.

Plant material: Cut flowers of *Gerbera jasmonii* cv. 'Rosalin' was purchased from the Floramex Company in El Mansourieh, Giza. Plants of gerbera were initially grown under soilless culture conditions. Flowers were collected in the early morning from a protected fiber glasshouse and arranged in special boxes specially designed and dedicated for the export of gerbera flowers.

The height of flower stems were cut to 60 cm, weighed and placed in 300 mL of vase solution according to the allocated treatments. All experiments were performed in a postharvest room equipped with a controlled environment maintained at 22±2 °C, 65±5 % relative humidity and 16 µmol/m/s light intensity for 12 h/day with cool-white fluorescent lamps.

Essential oils and nano-silver particle treatments: The essential oils (EOs) were acquired from the natural oils extraction unit at the National Research Centre (NRC) in El-Dokki, Giza, through squeezing and extraction processes. The scope of this experiment encompassed the assessment of the impact of thyme, clove, and caraway oils, both in their natural state at concentrations of 25 and 50 mg/L, and in nano form at concentrations of 5 and 10 mg/L. A control group was treated with distilled water, while the addition of 2% sucrose served as a carbon source. To facilitate oil dissolution, a mixture of 10 mL of ethanol alcohol and 10 mL of tween-80 was employed, and the volume was completed to 100 mL using distilled water.

Nano emulsion form of essential oil was initially prepared according to the process suggested by Ghosh *et al.* (2013). Silver nitrate ($AgNO_3$) was used to synthesize SN particles, as marked out by Entsar (2016).

Vase life (day): The vase life was calculated by counting the days from applying the treatments (first day) until wilting of leaves and the flowers, as outlined by Nabigol *et al.* (2007).

Vase solution uptake (g/flower/day): During the vase life evaluation, the weight of the vases containing water solutions without cut flowers was recorded every two days. The vase solution uptake (VSU) rate was calculated during the vase life period of each treatment by the following formula as pointed out by Bazaz *et al.* (2015):

Vase solution uptake [g/flower/day] = [St^{-1} - St];

Where St is the weight of water solution (g) at t = day 2,4,6, etc., and St^{-1} is the weight of water solution (g) on the previous day (0, 2, 4, 6, etc.).

Neck bending: Neck bending was determined and classified based on the method of Çelikel and Reid (2002).

Determination of polyphenol oxidase and catalase: To determine polyphenol oxidase, samples of fresh petals (1 g) were taken and processed as per Pütter (1974). To determine catalase activity, fresh petals (1 g) were utilized and prepared according to the method instigated by Aebi (1984).

Experimental design and statistical analysis: A factorial experiment was arranged in a completely randomized design with four flowers in each replication. Statistical analysis of data was performed using Co-stat analysis (Cardinali and Nason, 2013). Means were separated according to either LSD or DMRT at a probability level of 5 % (Dodge, 2008).

Results and discussion

Vase life (day): Notable longer vase life of cut flowers of gerbera cv. 'Rosalin' was observed as a result of clove oil in the normal form at 25 mg/L when compared with the other treatments (Fig. 1A). In the meantime, NS had a positive significant effect on vase life when compared to zero-level NS as shown in Fig. 1B. Results of the interaction in Fig. 1C revealed a positive impact of caraway oil on vase life at 50 mg/L in normal form with Nano-silver. Also,

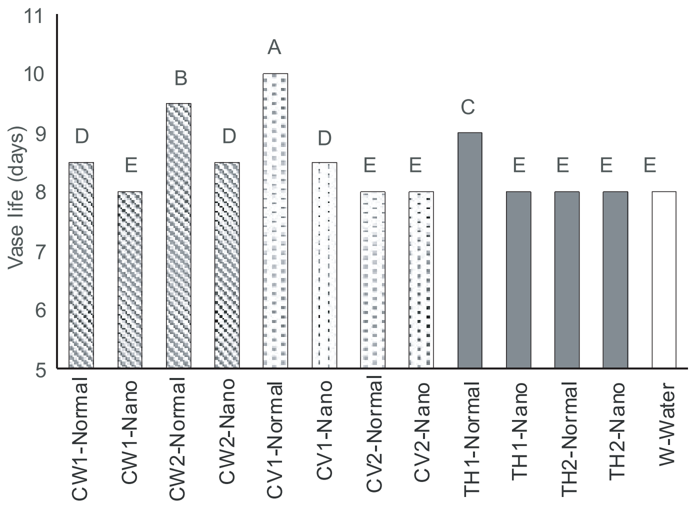

Fig. 1A. Effect of essential oils on vase life (days) in Gerbera cut flowers 'Rosalin' cultivar. CW Caraway, CV clove, TH thyme water. Letters indicate significant differences by Duncan's test ($P < 0.05$).

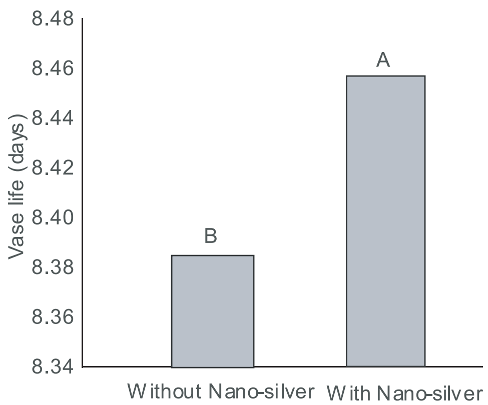

Fig. 1B. Effect of nano-silver on vase life (days) in Gerbera cut flowers 'Rosalin' cultivar. Letters indicate significant differences by Duncan's test ($P < 0.05$).

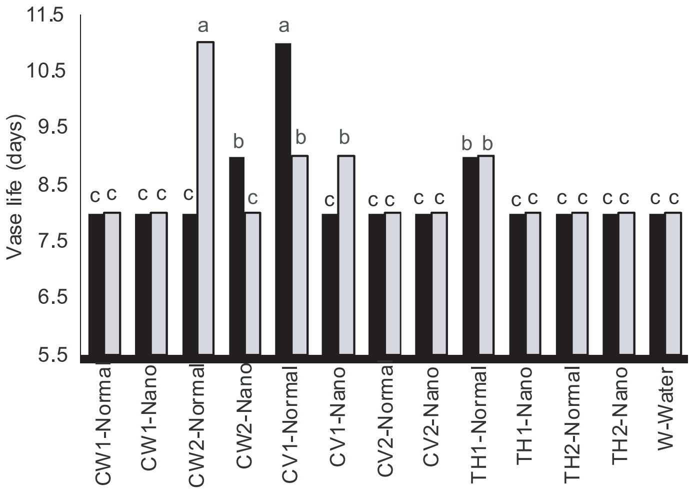

Fig. 1C. Effect of essential oils and nano-silver interaction on vase life (days) in Gerbera cut flowers 'Rosalin' cultivar. ■ without nano-silver □ with nano-silver. Letters indicate significant differences by Duncan's test ($P < 0.05$).

the treatment with clove oil at 25 mg/L in normal form without nano-silver showed a significant positive effect compared to the control and the other remaining treatments. In agreement, thyme essential oil was found to improve postharvest vase life and the quality of cut gerbera flowers (Jafarpour *et al.*, 2015). Also, Hashemi *et al.* (2013) reported the usefulness of thymol, menthol and eugenol in increasing chrysanthemum cut flower vase life. According to Dashtbay and Hashemabadi (2015), 10 % geranium essential oil improved the vase life of chrysanthemum cut flowers. Furthermore, both 30 % Artemisia essential oil and 200 mg L^{-1} rifampin (Hashemabadi *et al.*, 2013) and geranium essential oil (Hashemabadi *et al.*, 2016) were suggested as the most efficient in enhancing cut chrysanthemum postharvest vase life. Bazaz and Tehranifar (2011) also reported extended shelf-life of *Alstroemeria* cut flowers using thyme oil. Similarly, Manfredini *et al.* (2017) mentioned that eucalyptus, cinnamon, lemongrass, and peppermint (1 %), and clove oil (0.1 %) enhanced floral stems in postharvest of rose cut flowers. Furthermore, the vase life of the cut carnation was prolonged with the addition of thymol 25 or 50 mg/L (Solgi, 2018). In a study conducted by El-Sayed and El-Ziat (2021), it was observed that incorporating thyme oil and clove oil into the preservative solution led to a significant extension of the vase life of gerbera cut flowers. Gerbera flowers often experience a reduction in water uptake due to bacterial vascular blockage, which can eventually lead to stem breakage, bending, and wilting petals (Nair *et al.*, 2003; Balestra *et al.*, 2005; Meman and Dabhi, 2006). Thus, maintaining water balance and turgidity plays a crucial role in prolonging the longevity of gerbera flowers in a vase.

These findings may be explained by the fact that thyme oil contains several phenols, such as thymol, which have antimicrobial activities that prevent or diminish bacterial growth and decrease the blockage of xylem tissues (Jalili Marandi *et al.*, 2011). Also, it improved the water uptake; prevent water stress, and wilting of flowers, which leads to an increase in the vase life of cut flowers by delaying their senescence as proven earlier (Solgi and Ghorbanpour, 2014; Zheng and Guo, 2019).

Vase-solution uptake (g/flower/day): As shown in Fig. 2A, vase solution uptake (VSU) was greater in flowers treated with clove in the normal form at 25 mg/L than in the control and the other remaining treatments. NS increased VSU on the 2nd, 6th and 8th, with insignificant effect on the 4th day (Fig. 2B). The interaction results in Table 1 showed a positive impact on VSU with clove oil at 25 mg/L in normal form without NS when compared with the rest of the treatments. In the same trend, the treatment with caraway oil at 50 mg/L in normal condition with NS had a significant positive effect. It is a well-known fact that, measuring water uptake after flower harvest is one of the most important indicator of flower durability (Bayat and Moradinezhad, 2020). Solgi *et al.* (2009) indicated that thyme oil in combination with 6 % sucrose significantly impacted the relative solution uptake of

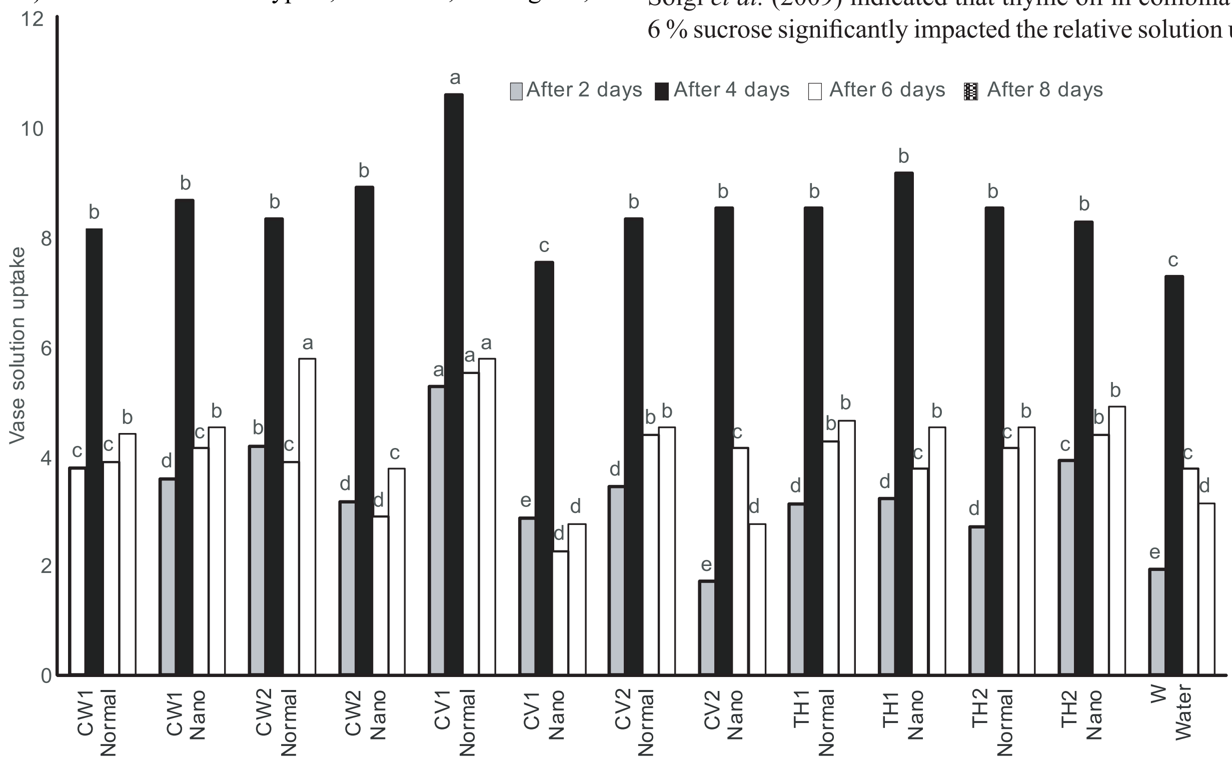

Fig. 2A. Effect of essential oils and nano-silver and their interaction on vase solution uptake in Gerbera cut flowers 'Rosalin' cultivar.

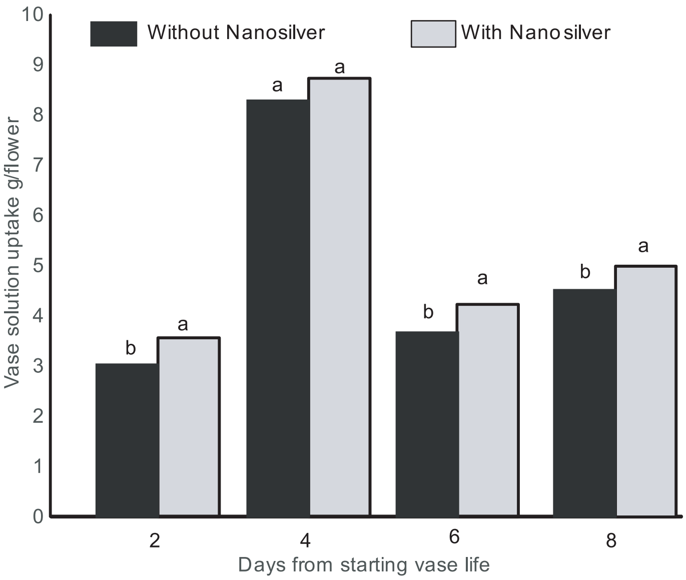

Fig. 2B. Effect of nano-silver on vase solution uptake in Gerbera cut flowers 'Rosalin' cultivar. Letters indicate significant differences by

gerbera flowers (*G. jamesonii* cv. Dune'). Bazaz and Tehranifar (2011) have reported the positive effect of herbal essential oils (peppermint, thyme and black cumin) on water uptake of cut flowers of astroemeria. *G. jamesonii* as cut flowers are composed of a terminal capitulum and a scape, have no leaves in the floral stem, and present a severe water deficit during the postharvest period, presumably as a result of water loss exceeding water consumption (Huang *et al.*, 2018). Due to this, the ligules' dehydration becomes more severe by the end of the storage period Li *et al.* (2019) reported that if the water loss is higher than 5 % of the flower weight, the cells lose turgor, and the petals start withering. The ideal flower preservative is that which allows water absorption through flower tissues. Water absorption from the preservative solution maintains a better water balance and flower freshness, saving from early wilting and reflecting on the vase life improvement. The antibacterial agents keep the water free from bacteria and other microorganisms which can form occlusion inside the stem, obstructing water flow to the flower (Koohkan *et al.*, 2014).

The continuous water supply to cut spikes prevents fresh weight loss, thus maintaining RFW (Hatamzadeh *et al.*, 2012). Our results are in harmony with the previous findings by Solgi *et al.* (2009), who revealed that the EOs (thyme or zataria oils) as antimicrobial agents in combination with 6 % sucrose had a significant influence on the relative fresh weight of gerbera cut flowers. Similarly, Bayat *et al.* (2011) observed the highest mean value of the relative fresh weight of carnation in treatments including thyme, summer savory, and Ajwain oils compared to the control on the 6th day with a higher rate of water uptake. Additionally, Bayat *et al.* (2013) reported a significant positive response of Zataria and Echinophora oils on relative fresh weight and freshness of the lisianthus flower. Also, El-Sayed and El-Ziat (2021) reported a substantial response of thyme and clove to relative fresh weight and freshness of the gerbera flower. The reduction of relative flower weight may occur due to insufficient solution absorption or the rise of water loss (El-Sayed and El-Ziat, 2021). Reduction of the fresh weight of cut flowers is one of the phases of flower senescence; the more the flowers advance into senescence, the less their ability to absorb water becomes. Eventually, a drastic cell reduction occurs (Bayat and Moradinezhad, 2020). Like stem bending, weight loss is a crucial parameter in the postharvest quality of cut flowers. One of the most evident symptoms of senescence in the final stage is weight loss due to dehydration, mainly of the petals, observed as withering (Rani and Singh, 2014). It is one of the disorders associated with turgor and quality loss, a determining factor in the flowers' commercial value (Saeed *et al.*, 2016). A similar effect of NAg on bacterial growth in cut-stem surfaces and xylem vessels has been reported in rose, gerbera, and gladiolus (Liu *et al.*, 2009; Li *et al.*, 2017).

Table 1. Effect of the interaction between essential oils and nano-silver on vase solution uptake (g/f) in gerbera cut flowers 'Rosalin' cultivar.

Oil conc.	Oil form	Vase solution uptake (g/f)							
		After 2 days		After 4 days		After 6 days		After 8 days	
		Without NS	With NS	Without NS	With NS	Without NS	With NS	Without NS	With NS
Cara1	Normal	3.54	3.97	8.00	8.25	3.50	4.25	4.00	4.75
Cara1	Nano	4.41	2.72	9.50	7.75	4.00	2.75	4.75	4.25
Cara2	Normal	2.83	6.73	8.63	9.75	3.75	5.50	5.25	5.75
Cara2	Nano	3.15	3.18	9.25	8.50	3.25	2.50	4.25	3.25
Clov1	Normal	5.45	4.41	11.50	9.63	6.50	5.00	6.25	3.75
Clov1	Nano	2.88	2.82	6.75	8.25	1.75	2.75	0.50	5.00
Clov2	Normal	2.74	4.13	7.63	9.00	4.25	4.50	5.00	4.00
Clov2	Nano	0.95	2.47	8.75	8.25	4.75	3.50	3.00	2.50
Thym1	Normal	3.69	2.55	8.50	8.50	5.00	3.50	5.75	3.50
Thym1	Nano	3.78	3.61	8.75	9.50	2.75	4.75	4.50	4.50
Thym2	Normal	2.71	2.70	7.25	8.00	3.25	5.00	5.25	5.75
Thym2	Nano	2.35	3.92	8.00	8.50	3.75	5.00	4.50	5.25
Water	Water	1.74	2.10	6.75	7.75	1.00	3.50	3.00	2.50
$LSD_{0.05}$		1.32		2.03		1.21		1.02	

Neck bending: EOs were associated with significant positive effects on reduced neck bending of gerbera cv. 'Roaslin' cut flower, especially clove or thyme oils in the normal form at 25 mg/L than other treatments (Fig. 3A). Whereas, NS application did not exhibit any significant effect on neck bending as shown in Fig. 3B.

Results of the interaction in Fig. 3C revealed a positive effect on reducing neck bending with caraway oil at 50 mg/L in normal form with Nano-silver. Besides, the treatment with clove oil at 25 mg/L in normal form without NS showed a significant effect compared to the control and other remaining treatments.

In gerbera, stem bending mainly occurs by turgor loss in the mid-stem region, which is related to the central cavity that starts 5 cm above the basal region and ends 10 cm below the flower head (Mohamed *et al.*, 2018). Firmness loss due to reduced turgidity causes stem bending, severely impairing the quality of cut flowers.

Bending in cut *G. jamesonii* flowers related to adverse water relations and lack of stem sclerenchyma development, not to expansion of the stem central cavity or stem elongation (Perik *et al.,* 2012). Water uptake was low in stems that bent early. It is hypothesized that material from dead stem cells resulted in a xylem blockage, leading to early bending (de Witte *et al.*, 2014). Similar results about the effect of antimicrobial compounds on the time to gerbera stem bending have been reported by Nair

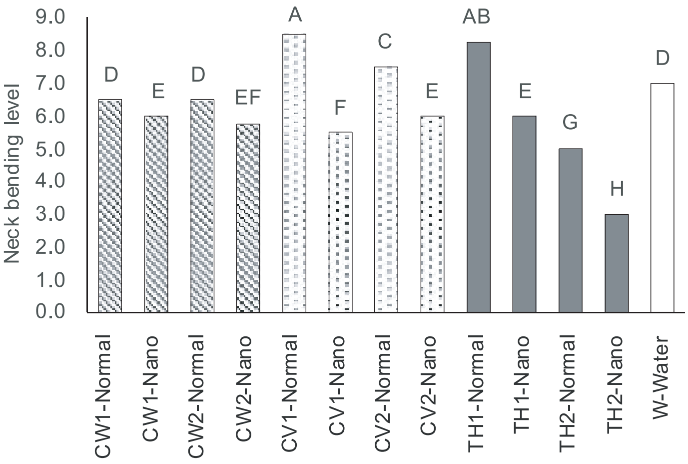

Fig. 3A: Effect of essential oils on neck bending in Gerbera cut flowers 'Rosalin' cultivar. Letters indicate significant differences by Duncan's test ($P < 0.05$).

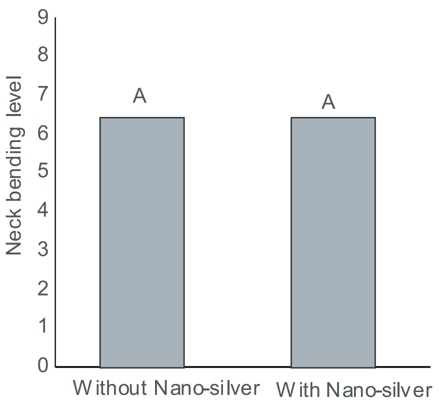

Fig. 3B: Effect of nano-silver on neck bending in Gerbera cut flowers 'Rosalin' cultivar. Letters indicate significant differences by Duncan's test ($P < 0.05$).

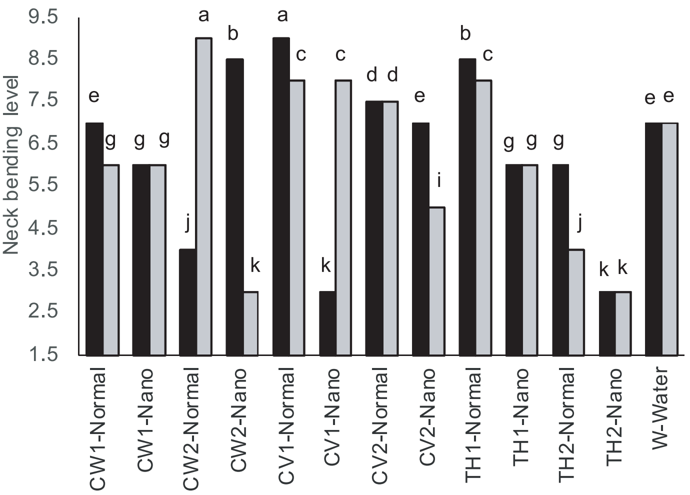

Fig. 3C. Effect of essential oils and nano-silver interaction on neck bending in Gerbera cut flowers 'Rosalin' cultivar. Letters indicate significant differences by Duncan's test ($P < 0.05$).

et al. (2003). Essential oils such as carvacrol and thymol have antimicrobial properties (Bakkali *et al.*, 2008). Solgi *et al.* (2009) reported that the inclusion of 50 or 100 mg L^{-1} carvacrol or thymol (0.33 and 0.66 mM, for both compounds) together with 6 % sucrose, in the vase solution considerably improved the vase life of Gerbera cv. Dune flowers.

EOs have an antimicrobial effect where it decrease their activity and leads to less xylem vessel blocking. In turn, this lessens problems assisted with both of available water inside cells and fullness of the flower stem with water (Nair *et al.*, 2003; Balestra *et al.*, 2005; Meman and Dabhi, 2006). Ultimately, this reduces the neck bending problem in gerbera-cut flower.

Determination of polyphenol oxidase enzyme (IU/mgFw): As shown in Fig. 4A, polyphenol oxidase (PPO) was decreased in flowers treated with clove oil in the normal form at 25 mg/L than in the control and other remaining treatments. At the end of the experiment (on the 8th day) the treatments with caraway in normal (25 mg/L) and nano (5 mg/L) forms both gave a significant decrease in PPO activity. There was a considerable decrease in PPO activity in flowers treated with NS (Fig. 4B). Results of the interaction in Table 2 showed a reduction in PPO activity with clove oil at 25 mg/L in normal form without NS when compared to the control and other remaining treatments. Similarly, the treatment with caraway oil at 50 mg/L in normal form with NS showed a significant reduction in PPO. PPO is a strong oxidizer of phenols and its activity in plants increases with biotic and abiotic stresses (Shyam and Aery, 2012). PPO increases tissues' rotting and browning during storage by accelerating phenol oxidation. If the activity of this enzyme can be reduced in some way, postharvest longevity and quality can be improved (AliPour

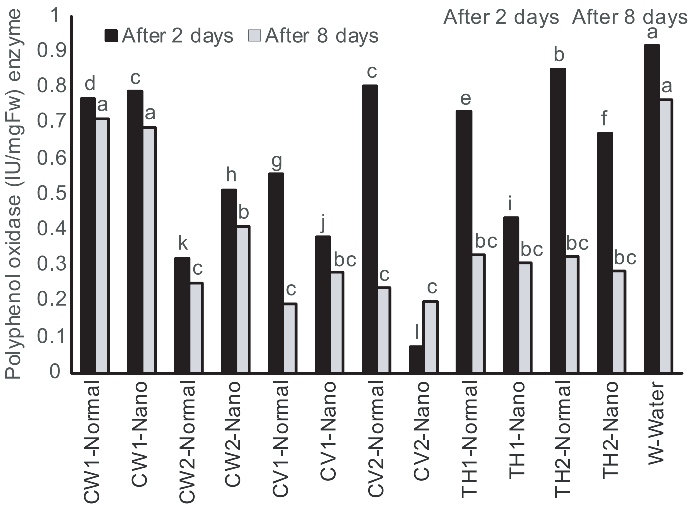

Fig. 4A. Effect of essential oils on polyphenol oxidase activity in Gerbera cut flowers 'Rosalin' cultivar.

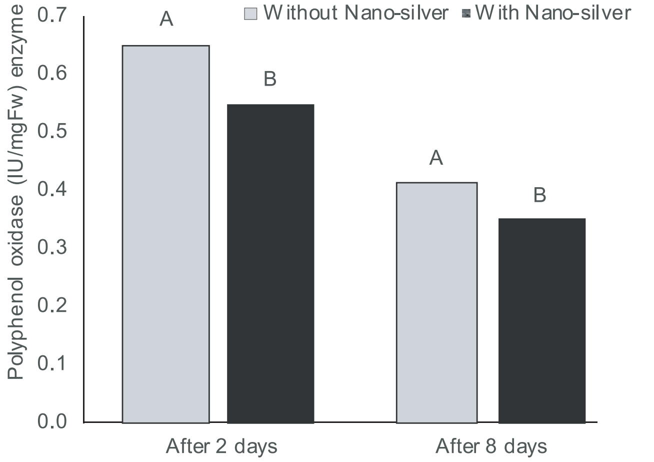

Fig. 4B. Effect of nano-silver on polyphenol oxidase activity in Gerbera cut flowers 'Rosalin' cultivar. Letters indicate significant differences *et al.*, 2015). Reducing the activity of this enzyme can be obtained by postharvest life-prolonging compounds such as nitric oxide (AliPour *et al.*, 2015), heat treatment (Dogan and Dogan, 2004), pH-reducing agents (Kang and Yu, 2005) and EOs (Khan *et al.*, 2021). From the results obtained here, PPO activity was lower in flowers with longer vase life. Arguably, essential oils of clove and caraway led to reduced PPO activity which is a good indicator for promoting vase life. Presumably, clove and caraway oils are favorable treatments that could be recommended to improve the vase life of cut flowers of gerbera cv. 'Rosalin'.

Table 2. Effect of the interaction between essential oils and nano-silver on polyphenol oxidase activity in gerbera cut flowers 'Rosalin' cultivar

Oil conc.	Oil form	Polyphenol oxidase (IU/mgFw) enzyme			
		After 2 days		After 8 days	
		Without Nano-silver	With Nano-silver	Without Nano-silver	With Nano-silver
Cara1	Normal	0.53i	0.63de	0.13g	0.16fg
Cara1	Nano	0.54hi	0.65cd	0.47a-f	0.56a-c
Cara2	Normal	0.35n	0.70b	0.52a-d	0.63a
Cara2	Nano	0.38m	0.63e	0.28b-g	0.34a-g
Clov1	Normal	0.25p-q	0.24q	0.20d-g	0.18e-g
Clov1	Nano	0.26p	0.31o	0.19e-g	0.23d-g
Clov2	Normal	0.55h	0.66c	0.17e-g	0.20e-g
Clov2	Nano	0.05r	0.06r	0.14g	0.16e-g
Thym1	Normal	0.50j	0.60f	0.49a-e	0.23d-g
Thym1	Nano	0.30o	0.36n	0.21d-g	0.25c-g
Thym2	Normal	0.58g	0.42l	0.22d-g	0.27b-g
Thym2	Nano	0.46k	0.55h	0.20e-g	0.23d-g
Water	Water	0.75a	0.75a	0.58ab	0.27b-g

Determination of catalase enzyme: In Fig. 5A, there was a noticeable rise in catalase enzyme activity (CAT) throughout the entire duration of the experiment in flowers treated with 25 mg/L of clove oil in its natural form, in comparison to the control group and other treatments. In contrast, Fig. 5B illustrates that NS didn't elicit any impact on CAT activity.

Results of the interaction in Table 3 showed a positive effect on CAT activity with clove oil at 25 mg/L in normal form without NS compared to the control and other remaining treatments. Also, treating thyme oil at 25 mg/L in normal form with NS behaved

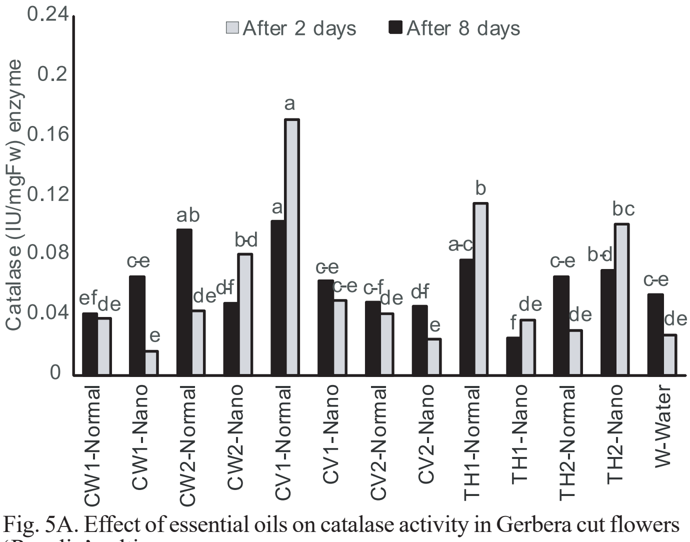

Fig. 5A. Effect of essential oils on catalase activity in Gerbera cut flowers 'Rosalin' cultivar.

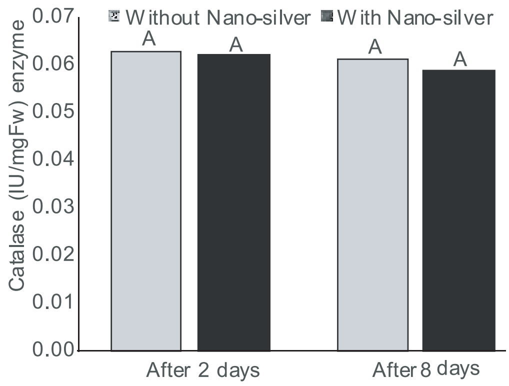

Fig. 5B. Effect of nano-silver on catalase activity in Gerbera cut flowers 'Rosalin' cultivar. Letters indicate significant differences by Duncan's test ($P < 0.05$).

Table 3. Effect of the interaction between essential oils and nano-silver on catalase activity in Gerbera cut flowers 'Rosalin' cultivar.

Oil conc.	Oil form	Catalase (IU/mgFw) enzyme			
		After 2 days		After 8 days	
		Without Nano-silver	With Nano-silver	Without Nano-silver	With Nano-silver
Cara1	Normal	0.036f-h	0.045e-h	0.102a-e	0.037d-g
Cara1	Nano	0.075a-f	0.057c-h	0.018fg	0.014g
Cara2	Normal	0.065b-g	0.096a-c	0.042d-g	0.127a-c
Cara2	Nano	0.051e-h	0.045e-h	0.087c-g	0.076c-g
Clov1	Normal	0.098ab	0.081a-e	0.176a	0.044d-g
Clov1	Nano	0.025gh	0.061b-h	0.050c-g	0.050c-g
Clov2	Normal	0.046e-h	0.052d-h	0.038d-g	0.043d-g
Clov2	Nano	0.024h	0.073b-f	0.025e-g	0.023fg
Thym1	Normal	0.092a-d	0.1140a	0.038d-g	0.167ab
Thym1	Nano	0.047e-h	0.045e-h	0.033d-g	0.040d-g
Thym2	Normal	0.059b-h	0.072b-f	0.027e-g	0.033d-g
Thym2	Nano	0.065b-f	0.075a-f	0.094b-f	0.108a-d
Water	Water	0.059b-h	0.050e-h	0.027e-g	0.027e-g

similarly. Increased enzymatic activities of CAT are related to the ability to mitigate oxidative stress and further inhibit floret senescence (Sharma *et al.*, 2012). It is well described that higher antioxidative-related enzyme activity scavenge reactive oxygen species (ROS) to relieve oxidative stress in cut gladiolus spikes (Elansary, 2020). Similarly, Shatoori *et al.* (2021) also observed higher antioxidative enzyme activities in ornamental sunflower that were attributed to mitigate oxidative stress.

In the present study, increased CAT activities were reported when clove oil (at 25 mg/L in the normal form) was used, confirming a positive role in reducing oxidative damage and increasing the vase life of gerbera cut flowers cv. 'Rosalin'. Higher enzymatic activity of CAT is helpful in extending the vase life as reports on cut flowers (Hassan and Fetouha, 2019; Maity *et al.*, 2019), chrysanthemum (Fan *et al.*, 2015), gerbera (Shabanian *et al.*, 2018), and rose (Kazemi *et al.*, 2018; Hassan *et al.*, 2020). This study demonstrates the promising potential of essential oils, notably clove oil, in enhancing the postharvest longevity and quality of gerbera cv. 'Rosalin' cut flowers. Previous research studies using other plant extracts, *i.e.* stevia, moringa and plant parts as preservative solutions were found to enhance the vase life of cut flowers which were all associated with higher antioxidative activities of CAT, POX and SOD were reported (Amin, 2017; Hassan and Fetouha, 2019; Hassan *et al.*, 2020; Elansary, 2020).

The increase in catalase enzyme (CAT) activity suggests that essential oils, particularly clove and thyme oils, contribute to enhanced antioxidant defense mechanisms, mitigating oxidative stress and ultimately promoting longer-lasting blooms. While the interaction with nano-silver (NS) showed varied effects, these findings collectively underscore the potential of essential oils as a natural and effective strategy for improving the overall postharvest performance of gerbera cut flowers, offering both aesthetic appeal and extended vase life. Further studies can delve into refining application methods and unraveling the precise biochemical pathways underlying these positive impacts.

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