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The addition of glucose in holding solution enhances vase life and inflorescence quality of cut hydrangea flower over the application of sucrose or mannitol

Piyatida Amnuaykan

Faculty of Agricultural Production, Maejo University, Chiang Mai, Thailand. E-mail: piyatida.chou@gmail.com

Abstract

This study aimed to investigate the effect of different sugar types on the vase life of cut hydrangea flowers. There were 19 treatments based on concentrations and combinations of sucrose, glucose, and mannitol. The results showed that the vase solution with 5% glucose provided the most extended vase life, which was 12.4 d, while the control solution with distilled water recorded 8.86 d. The results were correlated with the total solution uptake, the number of days for reaching maximum inflorescent diameter, maximum sepal hardness score, chlorophyll content, and sepal electrolyte leakage. It could be implied that glucose alone extends hydrangea vase life by inactivating the ethylene signalling pathway. Based on the sepal size and colour, 3% glucose treatment, which generated the second-highest vase life, could be the appropriate concentration for improving flower quality and longevity. This study provides the essential information that will lead to understanding hydrangea flower senescence and developing better vase solutions for cut hydrangea flowers.

Key words: *Hydrangea macrophylla*, glucose, sucrose, mannitol, vase life

Introduction

Hydrangea macrophylla is an important cut flower worldwide, and increasing its vase life for the market requirement is challenging (Olsen *et al.*, 2015). There were several studies to enhance cut hydrangea vase life. It has been found that the holding solution with sucrose, 8-hydroxyquinoline (8-HQ), and citric acid can prolong its vase life for five days (Pei *et al.*, 2013). Later, surfactant and biocide in holding solution were introduced but did not prolong the vase life of antique hydrangea (Aros *et al.*, 2016). In recent years, the effective application of 8-hydroxyquinoline sulfate (8-HQS) in a vase solution has been observed (Kazaz *et al.*, 2019), followed by the finding of its suitable concentration used (Kazaz *et al.*, 2020). The current studies have been mainly focusing on extending hydrangea vase life by reducing vascular occlusion by utilizing the combination of sucrose and thymol (Kazaz *et al.*, 2020; Kiliç *et al.*, 2020) and the application of chrysal professional III (CPIII) together with sucrose (Yang *et al.*, 2021). According to these studies, there is no variation of sugar types used in the vase solution until the investigation of 1% glucose together with 8-HQS that can effectively prolong cut hydrangea vase life (Suntipabvivattana *et al.*, 2020). Interestingly, sugar type might be the critical factor involving hydrangea vase life extension.

Sugar supply is necessary for extended life of flower (Chuang and Chang, 2013). There have been applications of sucrose to increase the longevity of many flowers such as *Dendrobium* (Chandran *et al.*, 2006), *Paeonia lactiflora* (Xue *et al.*, 2018), *Gerbera* sp. (Muraleedharan *et al.*, 2019), and *Rosa* sp. (Kshirsagar *et al.*, 2021). Additionally, sucrose and glucose can improve the vase life extension activity. The study in cut *Lilium* suggested that sucrose and glucose levels are upregulated during flower opening (Arrom and Munné-Bosch, 2012). In cut *Dendrobium*, sucrose and glucose suppress the abscission of the flower which results in vase life extension (Pattaravayo *et al.*, 2013). Moreover, the investigation into *Antirrhinum majus* has suggested that sucrose, glucose, and preservatives can significantly increase vase life (Ichimura *et al.*, 2022). Glucose alone can enhance water solution uptake to retain water content in petals (Hirose *et al.*, 2019). The sugar can improve the vase life of *Chamelaucium* sp. (Dung *et al.*, 2017), *Rosa* sp. (Sudaria *et al.*, 2017), *Protea* sp. (Vardien *et al.*, 2017), *Dahlia variabilis* (Azuma *et al.*, 2018), *Hypericum* sp. (Oguta, 2019), and *Dianthus caryphyllus* (Kaviani and Sharafshah Rostami, 2021). However, it is not only metabolizable but also non-metabolizable sugar that is relevant in vase life extension. Mannitol has been recognized as an important non-metabolizable sugar that increases the vase life of some cut flowers such as *Delphinium* (Norikoshi *et al.*, 2015), and *Antirrhinum* (Ichimura *et al.*, 2016).

Previous studies about the effect of different sugar types on the vase life of several other cut flowers have proposed that sugar type can also be essential to improving cut hydrangea vase life. Likewise, many types of sugar content are discovered in the hydrangea flower (Kao, 1963). This investigation aims to offer a novel and potentially more efficient and cost-effective vase solution for enhancing the longevity of cut hydrangea flowers by understanding the impact of various sugar types, including sucrose, glucose, mannitol, and their combinations at different concentrations, on the vase life of cut hydrangea flowers. Additionally, how do these sugar solutions induce physiological changes that contribute to extending the hydrangea vase life.

Materials and methods

Plant materials: *H. macrophylla* '031' flowers were harvested in the morning from a commercial grower (Khun Pae Royal Project Foundation, Chiangmai, Thailand) at the commercial

stage of flower development (approximately 50% of the fully open decorative florets). The quality, including inflorescence size (approximately 15 cm in diameter) and stem diameter (approximately 1.2 cm), were selected consistently. Flowers were placed in tap water and transported to the postharvest laboratory within half an hour.

Treatments with different sugar types: The stems were re-cut underwater to 30 cm long to prevent an air embolism. Only two upper leaves were retained on each stem. After that, the flowers were individually placed in a 1000-mL glass bottle containing 700 mL of different freshly prepared sugar solutions. There were three types of sugars used such as glucose (KemAusTM, CAS:50-99-7), sucrose (KemAusTM, CAS: 57-50-1), and mannitol (HiMedia, CAS: 69-65-8), and there were 19 treatments, including control based on different sugar combinations (Table 1). The seven replicates per treatment were placed randomly under 25 ±1 °C with a 12-h photoperiod.

Table 1. Treatments with different sugar types and combinations used in the experiment.

Treatments	Combinations
Glu 1	1% Glucose
Glu 3	3% Glucose
Glu 5	5% Glucose
Suc 1	1% Sucrose
Suc 3	3% Sucrose
Suc 5	5% Sucrose
Man 1	1% mannitol
Man 3	3% mannitol
Man 5	5% mannitol
Glu + Suc 1	0.5% Glucose + 0.5% Sucrose
Glu + Suc 3	1.5% Glucose + 1.5% Sucrose
Glu + Suc 5	2.5% Glucose + 2.5% Sucrose
Glu + Man 1	0.5% Glucose + 0.5% Mannitol
Glu + Man 3	1.5% Glucose + 1.5% Mannitol
Glu + Man 5	2.5% Glucose + 2.5% Mannitol
Suc + Man 1	0.5% Sucrose + 0.5% Mannitol
Suc + Man 3	1.5% Sucrose + 1.5% Mannitol
Suc + Man 5	2.5% Sucrose + 2.5% Mannitol
Control	Distilled water

Determination of vase life, relative fresh weight, daily solution uptake, and total solution uptake: The vase life of each flower was investigated by observing the number of days from the first day placed in sugar treatment solutions to the day the flower exhibited sepal browning and wilting. To obtain relative fresh weight (RFW), each glass bottle with and without flower stem was weighed at a three-day interval. At the same time, the measurements were carried out daily during vase life for daily solution uptake (DSU) and total solution uptake (TSU). The formula for RFW (%) and DSU (g stem^{-1} day^{-1}) were $(W_t/W_0) \times 100$ and S_{t-1}-S_t, respectively. The used formulas consisted of W_t, the flower weight (g) at day t; W_0, the flower weight (g) at day 0; S_t, sugar solution weight (g) at day t; and S_{t-1}, sugar solution weight (g) on the previous day. TSU (g stem^{-1}) and the sum of the entire DSU of each treatment were estimated (Kazaz *et al.*, 2020).

Determination of maximum flower diameter, days until maximum flower diameter, and maximum sepal hardness: Each flower diameter (DIA) was measured using a 600 mm vernier calliper (RS Components Co., Ltd., Thailand) at three-day interval during vase life. Then, the maximum diameter of the replicates was used to calculate the average number of the maximum diameter (DIA_{max}) for each treatment. In addition, the number of days each flower used to reach its DIA_{max} ($DtDIA_{max}$) was also recorded. For maximum sepal hardness (SH_{max}), the observation was completed at three-day intervals during vase life. A five-score rating criterion was created to evaluate the sepal hardness (SH) of hydrangea inflorescence from the softest (score 1) to the hardest (score 5).

Determination of total leaf chlorophyll content: The leaf chlorophyll content of hydrangea inflorescence was determined using SPAD-502 Plus (Konica Minolta Optics, Japan). Three measurements were taken per leaf to obtain an average SPAD value of the leaf for each flower.

Determination of sepal electrolyte leakage: Ten sepal disks (0.5 cm in diameter) from each flower were cleaned in distilled water three times. Then, the disks were placed in a test tube containing 10 mL of double-distilled water. After that, the tube was incubated in a 40 °C water bath WNE 45 (Memmert, Germany) for 30 min. The electrical conductivity (EC_1) of the solution in the tube was measured. After obtaining EC_1, the tube was autoclaved at 121 °C for 15 min, followed by incubation under 25 °C for 24 h. Then, the EC_2 was measured. The sepal electrolyte leakage (%) was calculated using the formula: $(EC_1/EC_2) \times 100$.

Statistical analysis: This experiment was carried out in a completely randomized design (CRD) with 19 treatments, including control and seven replicates per treatment. Statistical significance between mean values was evaluated using one-way ANOVA and the Tukey test (Assaad *et al.*, 2014).

Results

Vase life, total solution uptake, maximum flower diameter, days until reaching maximum flower diameter, and maximum sepal hardness of hydrangea cut flower: Vase life, TSU, DIA_{max}, $DtDIA_{max}$, and SH_{max} of hydrangea differed depending on the vase solution's sugar combination (Table 2). Glu 5 exhibited the most extended vase life, approximately 12.4 days and 3.54 days longer than the control. However, colour change in the inflorescence of this treatment was clearly evident. The colour was lighter than all treatments in this study (data not shown). Glu 3 provided the second most extended vase life. It lasted approximately ten days, which was 1.14 days longer than the control. However, it was not significantly different with the Glu+Suc 3, Glu+Suc 5, and Glu+Man 1 treated samples, which were also more prolonged than the control. At the same time, Man 5 provided the shortest vase life, which was approximately 2.29 days. Noticeably, the accumulation of white powder was observed on the sepals of all flowers treated with mannitol. Glu 5, with the highest vase life, also obtained the highest $DtDIA_{max}$ and SH_{max}. However, the highest DIA_{max} was not found in such treatment. DIA_{max} of Glu 5 was shorter than Glu 1. While Glu 5 generated longer vase life than Glu 3, the other factors, such as DIA_{max}, $DtDIA_{max}$, TSU, and SH_{max} values, were not significantly different. Although the vase life was not significantly different among Glu 3, Glu+Suc 3, Glu+Suc 5, and Glu+Man 1 treated samples, the DIA_{max}, $DtDIA_{max}$, TSU, and SH_{max} values were different. Among these four treatments, Glu 3 presented the longest DIA_{max} and the highest SH_{max}. Also, Glu 3 and Glu+Suc 3 provided the highest $DtDIA_{max}$ and TSU. Comparing all treatments together, the high TSU was found in the Glu 1, Glu 3, Glu 5, Glu+Suc 1, Glu+Suc

Table 2 The effects of different sugar types and their combinations on vase life and other physiological characteristics in cut hydrangea flower

Treatment	Vase life (d)	DIA_{max} (cm)	$DtDIA_{max}$ (d)	TSU (g)	SH_{max} (score)
Glu 1	7.43 ± 0.297^{cd}	23.5 ± 0.408^{a}	3 ± 0.309^{ab}	277 ± 8.62^{a}	4.00 ± 0.309^{ac}
Glu 3	10.00 ± 0.436^{b}	22.3 ± 0.596^{ab}	3.29 ± 0.286^{ab}	255 ± 15.1^{a}	4.43 ± 0.297^{ab}
Glu 5	12.4 ± 0.369^{a}	21.6 ± 0.484^{b}	4.14 ± 0.8^{a}	272 ± 12.7^{a}	4.86 ± 0.143^{a}
Suc 1	4.71 ± 0.286^{ef}	19.7 ± 0.214^{cd}	2.29 ± 0.18^{4b}	108 ± 5.42^{df}	3.00 ± 0.218^{ce}
Suc 3	4.00 ± 0.309^{fh}	18.3 ± 0.214^{de}	2.43 ± 0.202^{b}	90.9 ± 2.89^{df}	2.71 ± 0.184^{def}
Suc 5	3.57 ± 0.202^{fh}	18.1 ± 0.297^{e}	2.29 ± 0.184^{b}	129 ± 9.36^{d}	2.29 ± 0.184^{eg}
Man 1	6.43 ± 0.429^{de}	19.4 ± 0.385^{ce}	2.14 ± 0.143^{b}	170 ± 2.57^{c}	2.14 ± 0.261^{eg}
Man 3	4.86 ± 0.261^{ef}	19.8 ± 0.286^{cd}	2.14 ± 0.143^{b}	85.6 ± 3.27^{ef}	1.57 ± 0.202^{fg}
Man 5	2.29 ± 0.184^{h}	15.9 ± 0.0922^{f}	2.00 ± 0^{b}	41.7 ± 3.89^{g}	1.29 ± 0.184^{g}
Glu+Suc 1	9.00 ± 0.535^{bc}	22.1 ± 0.254^{ab}	3.29 ± 0.522^{ab}	275 ± 12.4^{a}	3.29 ± 0.184^{bce}
Glu+Suc 3	9.71 ± 0.522^{b}	19.9 ± 0.18^{c}	3.14 ± 0.829^{ab}	263 ± 10.2^{a}	3.86 ± 0.261^{acd}
Glu+Suc 5	9.29 ± 0.36^{b}	19.9 ± 0.18^{c}	2.29 ± 0.184^{b}	193 ± 5.3^{bc}	4.14 ± 0.261^{ac}
Glu+Man 1	9.86 ± 0.261^{b}	19.4 ± 0.335^{ce}	2.14 ± 0.143^{b}	210 ± 5.2^{b}	3.14 ± 0.34^{ce}
Glu+Man 3	4.71 ± 0.286^{ef}	17.9 ± 0.17^{e}	2.14 ± 0.143^{b}	116 ± 6.68^{de}	3.14 ± 0.261^{ce}
Glu+Man 5	4.29 ± 0.184^{fg}	21.6 ± 0.18^{b}	2.14 ± 0.143^{b}	73.9 ± 2.45^{fg}	1.57 ± 0.202^{fg}
Suc+Man 1	4.14 ± 0.34^{fg}	19.9 ± 0.261^{c}	2.14 ± 0.143^{b}	103 ± 4.19^{df}	1.43 ± 0.202^{g}
Suc+Man 3	4.57 ± 0.297^{fg}	16.4 ± 0.143^{f}	2.00 ± 0^{b}	89.1 ± 1.87^{ef}	1.71 ± 0.184^{fg}
Suc+Man 5	2.86 ± 0.34^{gh}	18 ± 0.218^{e}	2.00 ± 0^{b}	76.1 ± 5.37^{fg}	1.14 ± 0.143^{g}
Control	8.86 ± 0.459^{bc}	18.5 ± 0.189^{ce}	2.00 ± 0^{b}	253 ± 6.62^{a}	3.71 ± 0.184^{acd}

Values are means ± SEM, n = 7 per treatment group. As analysed by one-way ANOVA and the TUKEY test, means in a column without a common superscript letter differ ($P<0.05$). Abbreviations: DIA_{max}, maximum flower diameter; $DtDIA_{max}$, days until reaching maximum flower diameter; TSU, total solution uptake; and SH_{max}, maximum sepal hardness

3, and control. In contrast, the lowest one was detected in Man 5. Interestingly, the treatments with sucrose, the most popular sugar used for hydrangea vase life extension, did not show outstanding results in prolonging the vase life. The results indicate that glucose inclusion without mannitol could prolong the vase life of cut hydrangea flowers, which can be linked to TSU, $DtDIA_{max}$, and SH_{max}.

Effect of sugar types on daily solution uptake of hydrangea cut flower: From the results above, the treatments with a combination of sugars did not strongly support the vase life extension, and one sugar-type treatment provided better results. Therefore, only Glu 1 (provided the longest DIA_{max} and the highest TSU), Glu 3 (provided the longest DIA_{max}), Glu 5 (provided the most extended vase life, the highest TSU, and the highest SH_{max}), Man 5 (provided the shortest vase life, the shortest DIA_{max}, the lowest TSU, and the lowest SH_{max}), and control were selected to present in the graphs for the clearer vision (Fig. 1). Since the vase life of Man 5 was the lowest, DSU could be recorded only on the second day. DSU of all treatments apart from Man 5 decreased dramatically after the second day of the experiment and slightly fluctuated to the end of their vase life. On the second day, DSU in Glu 1 seemed the highest. However, there was no significant difference between Glu 1, Glu 3, Glu 5, and the control. A significant difference was only observed between Glu 1 and Man 5. On the third to fifth days, all treatments had no statistical difference. Glu 1, 3, and 5 exhibited small peaks of DSU around the sixth day, while there was no peak from the control. The difference was observed, and the control provided the lowest DSU compared to the others. After the sixth day, DSU from Glu 1, 3, and 5 were reduced, which made the difference disappear. Although the patterns of DSU were different, the highest TSU was found commonly in Glu 1, 3, 5, and control. The peaks and the higher rates of DSU in Glu 1, 3, and 5 exhibited the improvement of hydrangea solution uptake by glucose.

Effect of sugar types on relative fresh weight of hydrangea cut flower: There was no significant difference in RFW in all treatments on the first day. From the second day, there were two different types of RFW patterns for all treatments (Fig. 2).

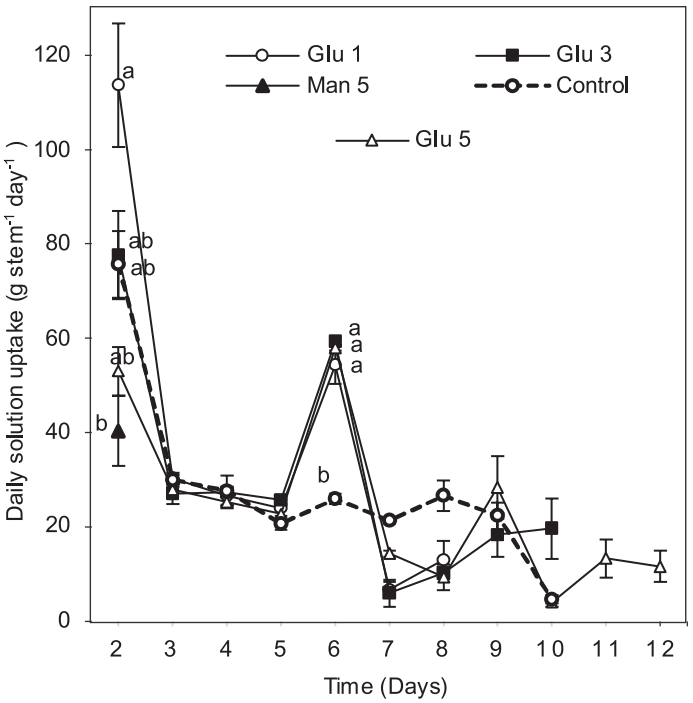

Fig. 1. Effects of different sugar treatments on daily solution uptake of a cut hydrangea flower. Daily solution uptake was expressed as mean ± SE (n = 7 flowering stems from each experiment).

The first pattern was found in Glu 1, Glu 3, Glu 5, and control. RFW suddenly increased before it dropped later, and the RFW of all glucose treatments were considerably higher than that of the control. For the peaks of RFW on day two, Glu 3 and Glu 5 provided the highest value, followed by Glu 1 and the control, respectively, while there was no significant difference between Glu 1 and the control. After the second day, all RFW were dropped. The control provided the lowest, and Glu 3 exhibited the highest RFW until the sixth day, when the significant difference among all treatments disappeared. Although the trends of Glu 1, 3, and 5 were similar, Glu 3 showed the best RFW. The second pattern was observed in Man 5. This pattern showed a sharp reduction in RFW until the end of their vase life. Interestingly,

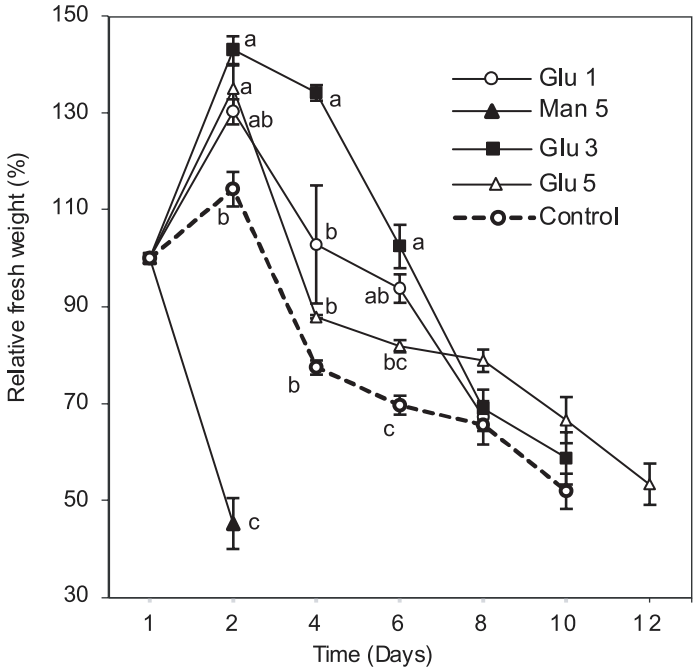

Fig. 2. Effects of different sugar treatments on relative fresh weight of cut hydrangea flower. Relative fresh weight was expressed as mean ± SE (n = 7 flowering stems from each experiment).

the treatment with the highest vase life provided the first pattern of RFW, and the treatment with the lowest vase life showed the second. The results suggested that glucose affected cut hydrangea fresh weight alteration, linked to its vase life extension.

Total leaf chlorophyll content: The leaf chlorophyll content is represented in the SPAD value. The SPAD values were not significantly different among all treatments on the first day. After that, the value reduction occurred in all treatments presented in the graph, and Glu 5 provided the highest SPAD value throughout the vase life (Fig. 3). There were two graph patterns. The first pattern contained a gradual drop line (Glu 1, Glu 3, Glu 5, and control), whereas the second pattern provided a sudden fall (Man 5). For the first pattern on the second day, the SPAD values of control were not significantly different to Glu 3 and 5. However after that, the value was gradually reduced and showed a statistical difference compared to Glu 5. Interestingly, the total leaf chlorophyll content in every treatment with the first pattern apart from Glu 1 was higher than that of the control. This pattern also included the treatment with the most extended vase life. Hence, it can be implied that glucose might be necessary in delaying hydrangea leaf senescence by maintaining hydrangea leaf chlorophyll content.

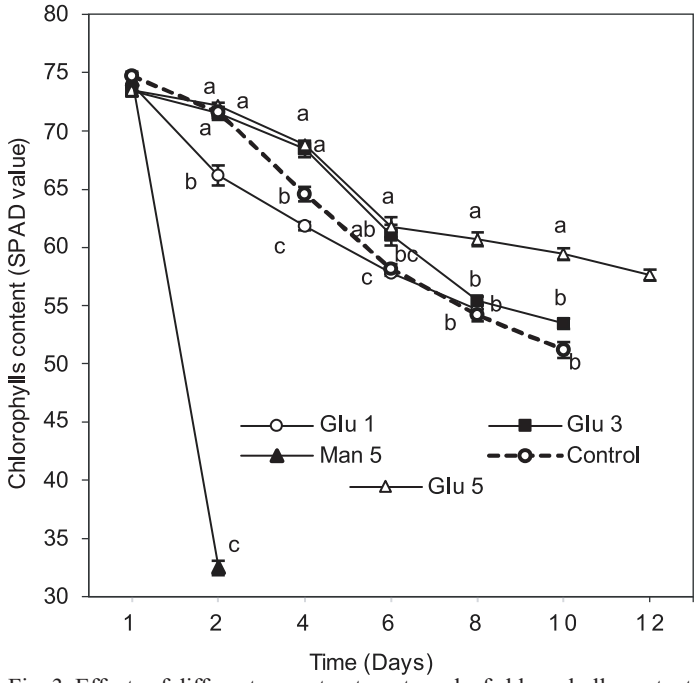

Fig. 3. Effects of different sugar treatments on leaf chlorophylls content (SPAD) of cut hydrangea flower. Leaf chlorophylls content was expressed as mean ± SE (n = 7 flowering stems from each experiment).

Sepal electrolyte leakage: Overall, sepal electrolyte leakages (SEL) were slightly increased throughout the experiment (Fig. 4). On the first day, the SEL of Man 5 was the highest, followed by control. The values of all glucose treatments were not significantly different and were the lowest until day four. After that, there was a fluctuation in SEL value comparisons. The values of all glucose treatments were significantly different on the sixth and tenth days, not day eight. However, all glucose treatments exhibited lower

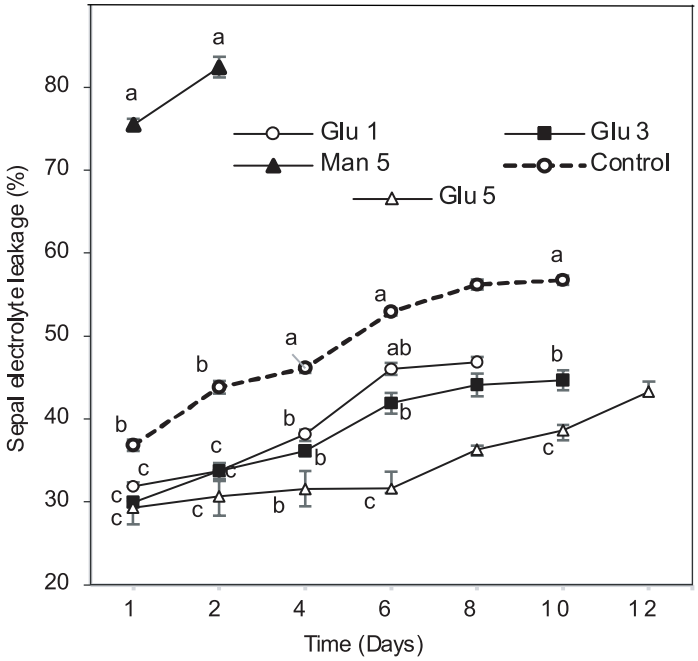

Fig. 4. Effects of different sugar treatments on sepal electrolyte leakages of cut hydrangea flower. Sepal electrolyte leakages were expressed as mean ± SE (n = 7 flowering stems from each experiment).

SEL than the control throughout the vase life. The lowest SEL was found in Glu 5, with the most extended vase life, whilst the highest SEL was detected in Man 5, which had the shortest vase life. Therefore, SEL, affected by sugar types in vase solution, was one of the factors influencing cut hydrangea vase life.

Discussion

Sugar, including monosaccharides and disaccharides, involves stress recovery and can protect the plant from drought and senescence (Martínez-Noël and Tognetti, 2018). Therefore, it has been used as an ingredient in vase solutions to prolong the vast life of several cut flowers, including hydrangea. Although many studies have evaluated the appropriate vase solution for hydrangea flower, there are not many variations of sugar type used. In this study, three types of sugar and their combinations were used: metabolizable monosaccharide (glucose), metabolizable

disaccharide (sucrose), and non-metabolizable sugar alcohol (mannitol). The positive changes in vase life and other physiological characteristics occurred when the appropriate amounts of glucose were added to vase solutions. Glucose alone was more effective in extending the vase life of cut hydrangea flower than sucrose, mannitol, and the combinations of glucose with sucrose and mannitol. Besides extending vase life, glucose could also improve sepal strength and prolong the days to full opening flower—the results related to the total amount of vase solution uptake.

Although sucrose can delay senescence in many flowers (Arrom and Munné-Bosch, 2012), its ability on vase life extension can still be found to be inferior to glucose in several flowers, including *Antirrhinum* (Ichimura and Hisamatsu, 2006) and *Paeonia suffruticosa* (Wang *et al.*, 2014). It can be implied that different types of sugar work differently depending on flower species. These positive effects of glucose on hydrangea vase life extension and flower quality will likely involve sugar degradation. Glucose is a monosaccharide derived from sucrose cleavage (Stein and Granot, 2019). Hence, its molecule is smaller, easier to metabolize, and quicker to act than sucrose. Besides that, glucose incorporates antioxidant activity in plants (Gangola and Ramadoss, 2018; Li *et al.*, 2020; Osakabe *et al.*, 2014). Since the shortening of flower vase life is due to the overproduction of ROS, which leads to oxidative stress (Jędrzejuk *et al.*, 2018; Zhang and Becker, 2015), and antioxidant activity can protect the plants from ROS damage followed by increasing postharvest longevity (Mohammadi *et al.*, 2020; Pourzarnegar *et al.*, 2020; Safari Motlagh *et al.*, 2021; ul Haq *et al.*, 2021), glucose; undoubtedly, provides good quality of hydrangea flower during the vase life.

Although a high amount of glucose (5%) suggested the longest vase life, this treatment did not exhibit the maximum inflorescence diameter. Interestingly, the biggest, inflorescence was found in treatment with a slightly smaller amount of glucose (1%), with shorter vase life. In fact, glucose affects flower opening by controlling petal cell enlargement (Arrom and Munné-Bosch, 2012). As reported in the present study, 1% glucose might be the optimum concentration for the flower opening of hydrangea. The vase life of flowers with 1% glucose that provided the bigger size of inflorescence was reduced. This is likely due to the higher-rated sepal transpiration occurring when more florets are opened. A similar result was reported that the decorative florets removal led to the vase life extension of cut hydrangea flower (Kitamura and Ueno, 2015). However, the sepal transpiration rate might not have a major effect on vase life, considering that the vase life in 1% glucose treatment was not the shortest one. Types of sugar and its combinations should take into account.

Mannitol acts as an osmoprotectant (Sickler *et al.*, 2007), antioxidant (Parvaiz and Satyawati, 2008), and antibiotic (da Silva Brandão *et al.*, 2019) that influences flower longevity. However, the application of mannitol in hydrangea significantly accelerated flower senescence and reduced vase life. The visible mannitol white powder was also accumulated on the sepal surface. These findings might be caused by the toxicity of mannitol (da Silva Brandão *et al.*, 2019), and hydrangea is more susceptible to that. Moreover, the major carbohydrate content in petals can be considered. Mannitol extends *Antirrhinum* vase life because it is the major soluble carbohydrate the petal (Ichimura and Hisamatsu, 2006). In contrast, glucose is reported as the most abundant carbohydrate found in hydrangea sepal. The findings were related to the positive changes in hydrangea vase life due to the application of glucose. They emphasized the different effects of sugar types on the different types of flowers.

According to the results, glucose provided a different daily solution uptake pattern than other sugar types. Without mannitol, glucose could effectively increase the flower's daily and total solution uptake. Moreover, adding glucose together with other sugars, even with the ineffective mannitol, could increase flower daily solution uptake. The higher solution uptake could be linked to the reduction of xylem occlusion.

Glucose positively affected the relative fresh weight, while mannitol posed a negative one. Therefore, glucose decelerated the reduction of relative fresh weight. The outcomes correlate with vase life, undoubtedly.

The leaf's lower chlorophyll content is one of the processes involved with plant senescence (López-Fernández *et al.*, 2015). Interestingly, this factor is also an effective indicator of flower senescence (Liao *et al.*, 2012; Lim *et al.*, 2007). SPAD value is used in this study to indicate the quality of hydrangea leaf chlorophyll content. As expected, SPAD values of all treatments decreased from the beginning to the end of their vase life due to the ageing process. The reduction patterns of SPAD value were slower by glucose and quicker by mannitol.

Moreover, treatment with the highest glucose concentration containing the longest vase life exhibited the highest leaf chlorophyll concentration at the end. It can be suggested that leaf chlorophyll content influences the vase life quality of hydrangea. It is well-documented that ethylene plays a role in plant chlorophyll breakdown (Jibran *et al.*, 2013). Also, many investigations confirm that glucose activates the degradation of the ethylene signalling regulator and plays a crucial role in the senescence of ethylene-sensitive flowers (Kakhki *et al.*, 2009). Because hydrangea is an ethylene-sensitive flower (Lauridsen *et al.*, 2015), glucose is possibly involved with ethylene activity in hydrangea.

Degradation of the petal membrane, which leads to electrolyte leakage, is one of the common metabolic changes during flower senescence (Arora, 2008; Shahri and Tahir, 2011). Accordingly, glucose reduced sepal electrolyte leakage in hydrangea. The lower electrolyte leakage correlated with sepal hardness and vase life extension. This study accentuates the ability of glucose to prevent plant cells from protein degradation, phospholipids breakdown and the competence of ethylene. Moreover, there are clear associations between electrolyte leakage and ethylene. In ethylene-sensitive flowers, ethylene activates enzymes involving protease and nuclease activity during senescence (Hoeberichts *et al.*, 2007) through ETHYLENE-INSENSITIVE3 (EIN3) (Yanagisawa *et al.*, 2003) and ETHYLENE-INSENSITIVE3 -like 1 (EIL1) (Kakhki *et al.*, 2009), the transcriptional regulator in the ethylene signalling pathway. Also, an increase in ethylene increases ROS within the cells (Gan, 2008), and ROS contributes to the loss of membrane stability (Rogers, 2012). This data interestingly links to the ability of glucose to act as an antioxidant in plants mentioned earlier.

This study provides a new finding essential for improving hydrangea vase life. The type of sugar is an important factor in prolonging hydrangea cut flower life. Although sucrose is widely used in hydrangea vase solutions, this study observed that glucose was more effective in prolonging flower vase life than sucrose. Moreover, potent antioxidants like mannitol are unsuitable for making hydrangea vase life solutions. Glucose acts rapidly as an osmoprotectant and increases the solution uptake of the flower. Since hydrangea is a climacteric flower, it is evident that glucose might generate sepal strength and vase life extension via interrupting ethylene signalling. As a result, ethylene's ability to activate chlorophyll degradation, electrolyte leakage, and ROS accumulation is disturbed. However, the investigation of ethylene and antioxidant activity in hydrangea flowers treated with glucose is required for further research to emphasize the relationship between glucose and ethylene in hydrangea.

Another point to consider is the ornamental value of flowers treated with glucose solution. The appropriate concentration should be analyzed carefully. Although the solution with 5% glucose delivered the most extended vase life, the sepal colour of flowers in this treatment was changed to be lighter compared with others, and inflorescence size was the smallest among three concentration of glucose treatments. Therefore, the solution with 3% glucose could be applied as an effective holding solution if the sepal colour or inflorescence size is concerned.

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