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Article

Understanding the dynamics of flower development during postharvest in *Ornithogalum saundersiae* Baker.: anthochron and floral stem longevity

Entendendo a dinâmica do desenvolvimento floral durante a pós-colheita em *Ornithogalum saundersiae*: antocrono e longevidade de hastes florais

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Abstract: Among cut flowers, *Ornithogalum saundersiae* is relatively new in the Brazilian flower market and little is known about the dynamics of flower development and longevity of its floral stems during postharvest. The objective in this study was twofold: to determine the anthochron during postharvest in *Ornithogalum saundersiae* and to determine the longevity of floral stems in *Ornithgalum saundersiae* using both calendar days and thermal time considering different postharvest management practices. A postharvest experiment was conducted from 03/05/2022 to 22/07/2022. Three treatments of postharvest management practices were used: Static tap water = tap water with no replacement, Tap water changed = tap water replaced every 3 days, and Tap water changed and stem recut = tap water and cutting 2cm at the base of the floral stem every 3 days. Seven replications were used and each replication was a 1 l plastic bottle filled with 5 cm of tap water and one floral stem. Floral stems with 3 to 5 opened flowers on the raceme and 70cm in length from a commercial farm were used. The anthochron did not differ between postharvest management treatments, with an average of 0.9 days flower^{-1} and 9.4 °C days flower^{-1}, respectively. The longevity of floral stems was not affected by postharvest management treatments, with an average of 45 days and 497 °C day. It was concluded that tap water with no need of periodically replacing the water nor cutting the base of the floral stem maintain the longevity of floral stems of *Ornithogalum saundersiae*.
Keywords: commercialization period, giant Chincherinchee, shelf life, vase life, thermal time.

Resumo: Entre as flores de corte, o *Ornithogalum saundersiae*, também conhecido como ornitogalo ou estrela-de-belém, é uma espécie recém introduzida no mercado brasileiro de flores e pouco se conhece sobre o desenvolvimento floral e a longevidade de suas hastes florais. Os objetivos neste trabalho foram: (i) determinar o antocrono durante o período de pós-colheita de ornitogalo e (ii) determinar a longevidade de hastes florais em ornitogalo em dias e em soma térmica considerando diferentes manejos de pós-colheita. O experimento de pós colheita foi conduzido no período de 03/05/2022 à 22/07/2022. Foram utilizados três tratamentos de manejo pós-colheita: Água da torneira sem troca = água da torneira sem reposição, Água trocada a cada 3 dias = água da torneira substituída a cada 3 dias e Água trocada e caule cortado = água da torneira e corte de 2 cm na base da haste floral a cada 3 dias. Foram utilizadas sete repetições para cada tratamento e cada repetição foi uma garrafa plástica de 1 l com 5 cm de água de torneira e uma haste floral. Foram utilizadas hastes florais com 3 a 5 flores abertas no racemo, e 70 cm de comprimento de uma produção comercial. O antocrono não diferiu entre os tratamentos de manejo pós-colheita e apresentou uma média de 0,9 dias flor^{-1} e 9.4 °C dias flor^{-1}, respectivamente. A longevidade das hastes florais não foi afetada pelos tratamentos de manejo pós-colheita, com uma média de 45 dias e 497 °C dia. Concluiu-se que a água da torneira, sem necessidade de troca periódica, nem de corte da base da haste floral, mantém a longevidade das hastes florais de *Ornithogalum saundersiae.*
Palavras-chave: ornitogalo, período de comercialização, soma térmica, vida de prateleira, vida de vaso.

Introduction

Floriculture is an important sector of Brazilian agribusiness. During the last decade (2014 to 2023), the sector increased steadily by an average of about 10% per year and the gross domestic product of the sector increased from 10 million Reals in 2017 to 18 million Reals in 2022 and 2023 (IBRAFLOR, 2024). Cut flowers currently represent 15% of the Floriculture sector in Brazil (IBRAFLOR, 2024) and there is a potential to increase the contribution of cut flowers to the Brazilian flower market, mainly among small farmers (Alves et al., 2025).

Among the diverse range of cut flowers, *Ornithogalum saundersiae*, also called the giant Chincherinchee, is a beautiful flower, bringing elegancy to bouquets and flower arrangements. This species, is relatively recent in the Brazilian flower market, being first reported as a cut flower in Brazil in 2010 (Tombolato et al., 2010). *Ornithogalum saundersiae* is the fifth cut flower, introduced in 2023, of the Flowers for All Project, the largest inclusive floriculture extension project in Brazil, led by the PhenoGlad Teams from several Brazilian states, that aims to promote sustainable floriculture practices and enhance the social and economic inclusion of small farmers (Streck and Uhlmann, 2021; Fonseca et al., 2024).

Postharvest longevity is a very important trait in cut flowers, so that the longer the longevity the longer the vase life (Krause et al., 2021; Mattos et al., 2023). Several factors affect floral stem longevity, including pre-harvest field management practices and flower developmental stage at harvest, postharvest physiological factors, and postharvest management practices (Dias et al., 2005; Janowska and Andrzejak, 2022). Native of South Africa, *Ornithogalum saundersiae* is propagated by bulbs and by seeds, with bulbs being more often the propagating material used by cut flower farmers (Kariuki and Kako, 1999; Salachna and Zawadzińska, 2013). While there are some reports on growth, development and flowering of *Ornithogalum saundersiae* (Kariuki and Kako, 1999; Salachna and Zawadzińska, 2013; Salachna and Zawadzinska, 2015; Salachna et al., 2016), little information on flower development, postharvest management practices, and longevity of floral stems for this flower crop is reported in the literature. In a thorough literature search, a single paper was found and reported a longevity of 23 to 34 days (Andżelika, 2018), which is longer

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than the longevity of other cut flowers such as roses (Hashemabadi et al., 2021; Ha et al., 2024; Kim et al., 2024), gypsophyla (Tilahun et al., 2024), alstroemeria (Oliveira et al., 2024), calla lily (Sales at al., 2021; Janowska and Andrzejak, 2022), amaryllis (Brito et al., 2023), chrysanthemum, gerbera, carnation, ranunculus, lisianthus, and lily (Kalinowski and Dole, 2024**)**. Therefore, more studies are needed to quantify the postharvest dynamics of flower development and the influence of postharvest management practices on the longevity of floral stems in *Ornithogalum saundersiae.*

In studies of postharvest and floral stem longevity of cut flowers, it is important to understand the dynamics of flowering opening and senescence after harvesting. When the flower is harvested, the supply of water, carbohydrates and nutrients than were provided by the plant are cut (Dias et al., 2005). Among the postharvest management practices, periodically replacing the water or the preservative solution and/or cutting the base of the stem have the potential to maintain floral stem longevity (Campanha et al., 1997). The concept of anthochron, defined as the time interval required for two subsequent flowers to achieve the same developmental stage (Streck and Schwab, 2016), offers a novel approach to describe the dynamics of flowering opening, but so far it has only been applied in gladiolus (Schwab et al., 2014; Santos et al., 2021). *Ornithogalum saundersiae* has a raceme-type inflorescence, which is suitable for using the concept of anthochron (Streck and Schwab, 2016). Furthermore, floral stem longevity has been described in calendar days (Santos et al., 2021; Oliveira et al., 2024; Sukpitak et al., 2024), but it is highly dependent on temperature (Dias et al., 2005). Thermal time has been long been used as a better time descriptor for plant development compared to calendar days (Arnold, 1960). Therefore, a novel way to describe time during postharvest in cut flowers is using thermal time, but it has not been used so far.

The objective in this study was twofold: (i) to determine the anthochron during postharvest and (ii) to determine the longevity of floral stems in *Ornithgalum saundersiae* using both calendar days and thermal time considering different postharvest management practices.

Material and Methods

A postharvest experiment with *Ornithogalum saundersiae* floral stems was conducted in a room of a private house from 03/05/2022 to 22/07/2022. Minimum and maximum temperature, relative humidity at 7 p.m., and vapor pressure deficit at 7 p.m were measured daily in the room throughout the experimental period using a digital thermohygrometer. Three treatments of postharvest management practices were used: Static tap water = tap water with no replacement, tap water changed = tap water replaced every 3 days, and Tap water changed and stem recut = every 3 days the tap water was replaced and of the floral stem was cut 2 cm at the base. Each treatment had seven replications, with each replication consisting of a 1 L plastic bottle filled with 5 cm of tap water and one floral stem.

Floral stems with 3 to 5 opened flowers on the raceme and 70 cm in length were harvest from a commercial farm at Santa Maria (29.72 S latitude, 53.72 W longitude and 103 m a.s.l.) located in Rio Grande do Sul, Brazil, and immediately placed into the postharvest experiment. Because the number of floral stems available for harvesting in the farm was not enough to start the postharvest experiment at a single day, cohorts of floral stem were harvested and entered the experiment in different days. At the day of entering the postharvest experiment, the stem diameter at the insertion of the inflorescence and the diameter at the bottom of the stem in each replication were measured using a digital caliper at two specific points: immediately below the insertion of the first flower on the stem, and at the base of the stem.

The number of opened and senesced flowers on the raceme of each floral stem was counted daily from the first day of the experiment until all flowers were senesced. The daily thermal time (TT, ^{o}C day) was calculated as (Arnold, 1960):

$$TT = (Tmean - Tb) \cdot 1 \text{ day} \quad (1)$$

in which Tmean is the daily air mean temperature (^{o}C) calculated as the average between the minimum and maximum daily temperatures, and Tb is the lower base temperature, assumed as 5 ^{o}C (Lee and Miller, 2015). The accumulated thermal time (ATT, ^{o}C day) was calculated as ATT = $\sum$TT.

The number of accumulated flowers (NAF) on each floral stem was calculated daily as the sum of the opened and senesced flowers. The NAF was linear regressed against both the number of days after the onset of the experiment (DAE) and ATT. The anthochron on a calendar basis (days/flower) and on a thermal time basis (^{o}C day flower^{-1}) for each floral stem was estimated as the inverse of the slope of the linear regression between NAF versus DAE, and NAF versus ATT (Streck and Schwab, 2016).

The period recommended for commercialization was assumed to be from the day of harvest (DAY = 0) to the day the first flowers senesced, and the longevity was assumed to be from the day of harvest (DAY = 0) to the day the last flowers senesced. The duration of the period recommended for commercialization and the longevity in each replication were calculated in days and in ^{o}C day. With the duration in ^{o}C day, the period recommended for commercialization and the longevity, in days, as a function of temperature was calculated and a non-linear model was fit to the data.

Statistical analysis consisted in testing the effect of the treatments on the anthochron (in days flower^{-1} and in ^{o}C days flower^{-1}r), on the period recommended for commercialization and on the longevity (in days and in ^{o}C day) using ANOVA and Tukey test at 5% probability using the SISVAR software.

Results and discussion

Minimum and maximum air temperature in the room during the postharvest experiment varied from 10.4 to 20.5 ^{o}C and from 12 to 22.3 ^{o}C, respectively, whereas relative humidity and vapor pressure deficit varied from 51% to 100% and from 0 to 10.97 kPa, respectively (Fig. 1). These temperatures were in the mild range, and air moisture was in the high range as represented by high relative humidity (above 50%) and low VPD (below 11 kPa).

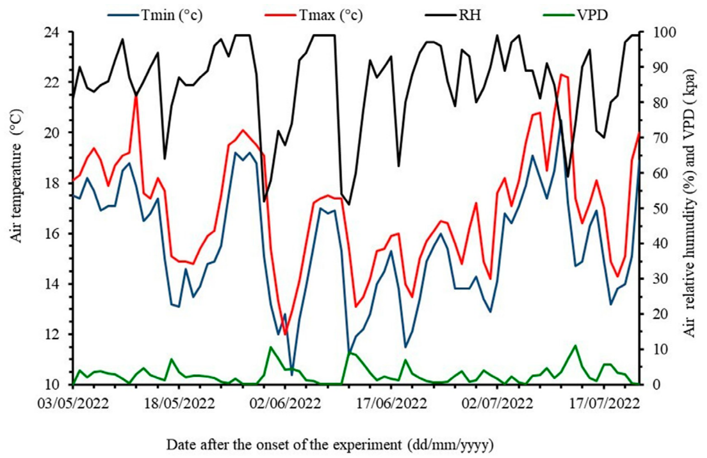

Fig. 1. Daily minimum (Tmin) and maximum (Tmax) air temperature, air relative humidity (RH) at 7 p.m., and air vapor pressure deficit (VPD) at 7 p.m. during the postharvest experiment with *Ornithogalum saundersiae* floral stems.

At the onset of the postharvest experiment, the diameters at these points ranged from 0.7 to 0.8 cm and 1.0 to 1.2 cm, respectively, with no significant differences among treatments (Table 1). These consistent measurements indicate a randomized selection of floral stems for the postharvest experiment.

Table 1. Stem diameter at the insertion of the inflorescence and diameter at the bottom of the stem of *Ornithogalum saundersiae* floral stems at the day of onset of the experiment with postharvest management treatments.

Treatment	Stem diameter at the insertion of the inflorescence (cm)	Diameter at the bottom of the stem (cm)
Static tap water	0.7 a	1.2 a
Tap water changed	0.8 a	1.0 a
Tap water changed and stem recut	0.7 a	1.1 a

A linear regression between NAF and DAE or ATT with an R^2 greater than 0.95 was observed in all treatments, indicating that the approach of estimating the anthochron as the inverse of the slope of the linear regression during the postharvest of floral stems in *Ornithogalum saundersiae* is appropriate (Streck and Schwab, 2016). An example of the strong relationship between NAF and DAE or ATT and how the anthochron was calculated for each replication (floral stem) is in Fig. 2. Overall, the R^2 was slightly higher for the regression between NAF and ATT (Fig. 1B) compared to the regression between NAF and DAE (Figure 1A). These results indicate that thermal time is a better descriptor of time for flower development than calendar days and that flower opening during postharvest in *Ornithogalum saundersiae* is highly driven by temperature, just as in gladiolus (Santos et al., 2021).

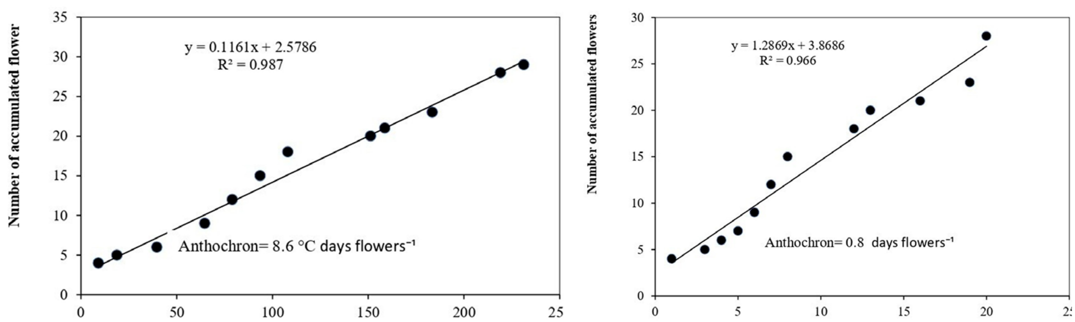

Fig. 2. Number of accumulated flowers as a function of (A) calendar time (DAE = days after the onset of the experiment) and (B) accumulated thermal time from the onset of the experiment (ATT) in a floral stem of *Ornithogalum saundersiae* during the experiment with postharvest management treatments. The equation is the linear regression with its coefficient of determination (R^2) and the anthochron is the inverse of the slope of the linear regression.

A typical dynamic flower development that occurred during the postharvest experiment is depicted in Fig. 3. After harvesting and entering the postharvest experiment, the number of opened flowers on the raceme increased to a maximum and then decreased to zero, when longevity of the floral stem ended. The number of senesced flowers started slowly at the bottom of the raceme and increased exponentially until the upper most flowers (final flower number - FFL) senesced. The FFL of the floral stem in Fig. 3 is 61 and indicates the number of primordia that differentiated into flowers on the raceme. The FFL did not differ among the postharvest management treatments, with an average of 44 flowers raceme^{-1}.

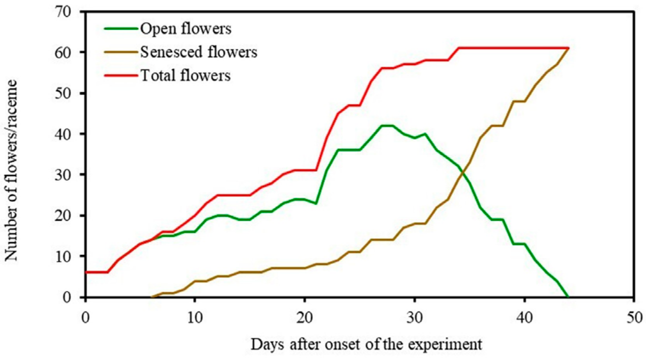

Fig. 3. Dynamics of flower development in a floral stem of *Ornithogalum saundersiae* during the experiment with postharvest management treatments.

The anthochron, both in days and in °C day, in *Ornithogalum saundersiae* floral stems did not differ among postharvest management treatments (Table 2), with an average of 0.9 day flower^{-1} and 9.4 °C day flower^{-1}, respectively. The anthochron in gladiolus floral stems during postharvest varied from 0.81 to 0.92 days flower^{-1} (Santos et al., 2021), and in field plants without harvesting the spikes the antochron of gladiolus varied from 0.65 to 2.07 days flower^{-1} (Schwab et al., 2014).

Table 2. Anthochron in *Ornithogalum saundersiae* floral stems as a function of postharvest management treatments.

Treatment	Anthochron	
	days flower^{-1}	°C day flower^{-1}
Static tap water	0.9 a	9.8 a
Water changed	1.0 a	9.9 a
Tap water changed and stem recut	0.8 a	8.5 a

The period from the day of harvest (DAY = 0) to the day the first flowers senesced (Fig. 4A and 4B), assumed as the period recommended for commercialization, did not differ among postharvest management treatments, being on average 11 days and 133 °C day, respectively. The number of opened flowers at the day when the first flowers senesced (Fig. 4B) did not differ among postharvest management treatments, with an average of 13 opened flowers on the raceme.

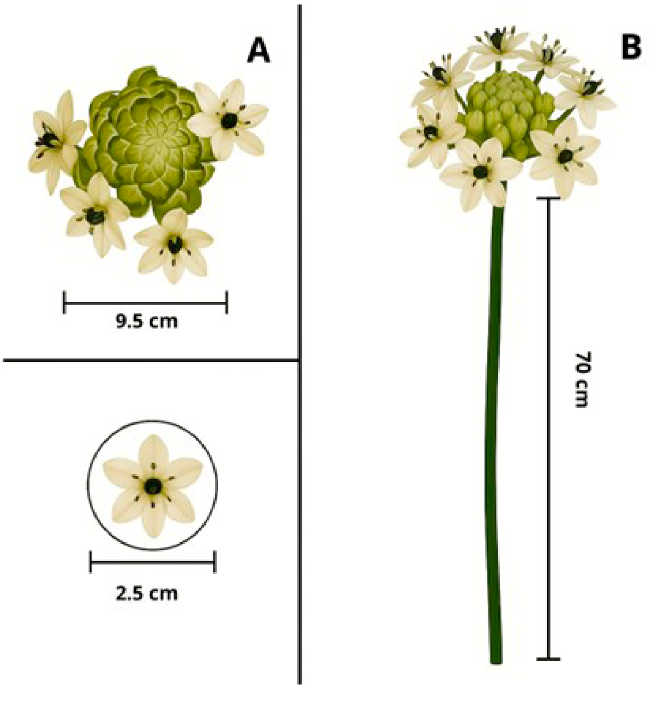

Fig. 4. A floral stem of *Ornithogalum saundersiae* during the period from (A) the day of harvest (DAY = 0) to (B) the day the first flowers senesced at the day.

With the period recommended for commercialization of 133 ºC day, the estimated period recommended for commercialization in days as a function of temperature followed a negative power equation y = 1078(x)$^{-1.57}$ (Fig. 5). From this power function, the estimated period recommended for commercialization at 10 ºC, 15 ºC, 20 ºC, and 25 ºC is 29 days, 15 days, 9 days, and 6 days, respectively. The practical application of these results is that, from harvesting, growers and garden centers have up to these days at those temperatures to sell the *Ornithogalum saundersiae* floral stems to the final consumers. This is a long time and very important when the flowers have to be transported at long distances to the final market.

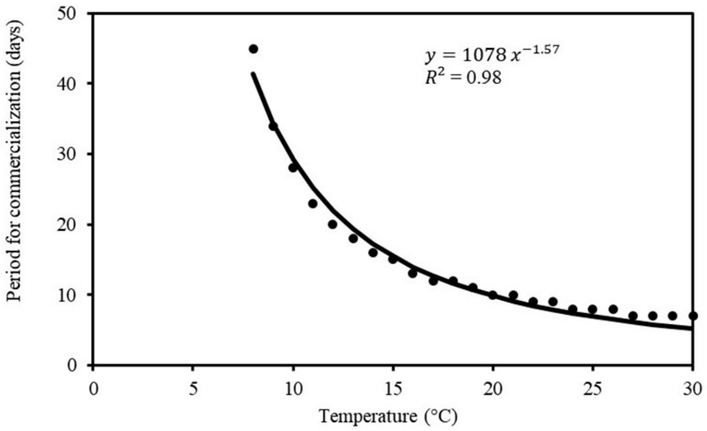

Fig. 5. Period recommended for commercialization of floral stems of *Ornithogalum saundersiae* as a function of temperature. The dots were estimated from a longevity of 133 ºC day and the curve is the fitted power equation given in the graphic.

The longevity of floral stems in *Ornithgalum saundersiae* was not affected by the postharvest management treatments (Table 3), with an average longevity of 45 days and 497 ºC day. This longevity is greater that the longevity of 23 to 34 days previously reported (Andżelika, 2018). No symptoms like rotting, wilting, yellowing or bent necking in the floral stems were observed in any of the treatments, indicating neither the need of replacing the water nor cutting the base of the floral stem. These results confirm that floral stems of *Ornithgalum saundersiae* have a longer longevity than other cut flowers such as roses (Hashemabadi et al., 2021; Ha et al., 2024; Kim et al., 2024), gypsophyla (Tilahun et al., 2024), alstroemeria (Oliveira et al., 2024), calla lily (Sales et al., 2021; Janowska and Andrzejak, 2022), amaryllis (Brito et al., 2023), chrysanthemum, gerbera, carnation, ranunculus, lisianthus and lily (Kalinowski and Dole, 2024**)**.

Table 3. Longevity of *Ornithogalum saundersiae* floral stems as a function of postharvest management treatments.

Treatment	**Longevity**	
	Days	**°C day**
Static tap water	43 a	472.7 a
Water changed	45 a	506.1 a
Tap water changed and stem recut	47 a	512.2 a

With the longevity of 497 ºC day obtained in the experiment, the estimated longevity of floral stems in days as a function of temperature followed a negative power equation y = 5229(x)$^{-1.68}$ (Fig. 6). From this power function, the estimated longevity at 15 ºC, 20 ºC, 25 ºC, and 30 ºC is 55 days, 34 days, 23 days, and 17 days, respectively, indicating that *Ornithogalum saundersiae* is a long-lasting cut flower.

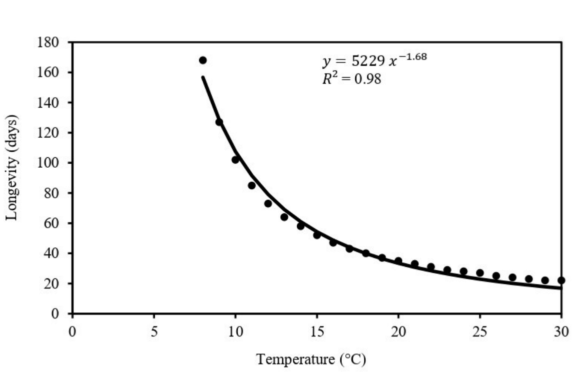

Fig. 6. Longevity of floral stems of *Ornithogalum saundersiae* as a function of temperature. The dots were estimated from a longevity of 497 ºC day and the curve is the fitted power equation given in the graphic.

The longevity of floral stems is the result of a complex interaction among preharvest, harvest, and postharvest management factors. For instance, preharvest factors include crop management practices, fertilization, time of the year of the cultivation and genotype (Verdonk et al., 2023) while harvest factors include time of the day (Ahmad et al., 2014) and developmental stage of the flower (Sales et al., 2021), and postharvest management factors include periodically replacing the water, cutting the base of the floral stems and use of preservative solutions (Dias et al., 2005; Shokouhi et al., 2024). In order to understand the longevity of flower stem during the postharvest, a detailed understanding of the dynamics of flower development is essential. In this study, we described the dynamics of daily flower opening and senescence during posthasrvest (Fig. 3) and first used the anthochron in floral stems of *Ornithogalum saundersiae* using (Fig. 2). This approach is unique and novel as the concept of anthochron was proposed (Streck and Schwab, 2016) and validated (Schwab et al., 2014; Santos et al., 2021) for gladiolus floral stems and has never before been applied to *Ornithogalum saundersiae* floral stems.

The canonical approach to describe time for the longevity of floral stem has been in calendar days (Santos et al., 2021; Oliveira et al., 2024; Sukpitak et al., 2024), but it is well known that longevity is highly dependent on temperature (Dias et al., 2005). To our knowledge, this is the first time thermal time is used to quantify the longevity of floral stems during post-harvest, another novelty in this study. In using thermal time, we proposed a model to estimate both the period recommended for commercialization and the longevity of floral stems during postharvest of *Ornithogalum saundersiae* as a function of temperature (Figs. 5 and 6). The assumption in using the model is that the water or the preservative solution fully prevent rotting, wilting, yellowing or bent necking. The practical application of the model is that farmers, garden centers, flower shops and final consumers can have an estimate on how much time the floral stems can last at temperatures that they can control. For instance, the storage of the stems at 10 °C pretty much stops their development as the estimated period recommended for commercialization is 29 days and longevity are 109 days. However, further studies are needed to validate the power model in Figs. 5 and 6 with independent data at different temperatures where preservative solutions or management practices may contribute to maintain longevity at its potential.

Finally, the results indicated that using tap water with no need of replacing the water nor cutting the base of the floral stem maintain the longevity of floral stems of *Ornithogalum saundersiae*. These results and the long longevity of floral stems are very important for practical applications to farmers, garden centers, flower shops and final consumers. Furthermore, the results confirm the success of this cut flower crop among farmers of the Flowers for All Project in different regions of Brazil (Streck and Uhlmann, 2021; Fonseca et al., 2024) who highlight the longevity of the floral stem as the main trait to attract consumers.

Conclusions

The findings in this study indicate that none of the postharvest management treatments influence the postharvest performance of *O. saundersiae* floral stems, with an anthochron of 0.9 days flower^{-1} and 9.4 °C day flower-1. Notably, the number of accumulated flowers showed a strong correlation with the accumulated thermal time (ATT), suggesting that temperature plays a pivotal role in flower development and opening rates. The floral stems had a longevity of 45 days or 497 °C day, underscoring their substantial vase life. Based on the results, the commercialization of *O. saundersiae* floral stems can occur up to a 30-day period post-harvest at 10 °C to ensure optimal quality and customer satisfaction.

Acknowledgments

This study was conducted during the 13th phase of the Flowers for All Project, which provided management practices throughout the experiment.

Author Contribution

NAS: Conceptualization, Investigation, Methodology, Data Collection, Data Analysis, Writing – Original Draft, Writing – Review & Editing, Supervision, Formal Analysis, Project Administration. **MLS:** Conceptualization, Data Analysis, Writing – Review & Editing. **MESF:** Conceptualization, Data Analysis, Writing – Review & Editing. **GHB:** Data Analysis. **LOU:** Investigation, Supervision, Writing – Review & Editing. **LLB:** Investigation, Supervision, Writing – Review & Editing**. TH:** Investigation, Data Collection. **LGOS:** Investigation, Data Collection.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement

All the research data is contained in the manuscript.

Declaration of generative AI and AI-assisted technologies in the writing process

The authors declare that the use of AI and AI-assisted technologies was not applied in the writing process.

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