Ornamental Horticulture
ISSN 2447-536X | WWW.ORNAMENTALHORTICULTURE.COM.BR
SBFPO Sociedade Brasileira de Floricultura e Plantas Ornamentais

ARTICLE

Control of leaf yellowing and postharvest longevity of Alstroemeria in different preservative solutions

Controle do amarelecimento de folhas e longevidade pós-colheita de Alstroemeria em diferentes soluções conservantes

Clery Paixão de Oliveira[1], Patrícia Paiva Duarte de Oliveira[1,*], Antonio Rodrigues da Cunha Neto[2], Sabrina de Souza Nascimento[1], Mariza Moraes Ponce[1], Diogo Pedrosa Côrrea da Silva[1] and Michele Valquíria dos Reis[1]

[1]Universidade Federal de Lavras, Escola de Ciências Agrárias, Lavras-MG, Brasil.
[2]Universidade Federal de Alfenas, Instituto de Ciências da Natureza, Alfenas-MG, Brasil.

Abstract: Alstroemeria faces a stressful condition during its postharvest phase, as the leaves tend to yellow before the senescence of the flowers. Therefore, this study aimed to evaluate and compare the efficacy of different solutions previously recommended for the postharvest conservation of *Alstroemeria hybrida* L. cv. Akemi. The preservatives solutions tested included Florissant 210® with chlorine, 1-methylcyclopropene, benzyladenine, cycloheximide, silver thiosulfate, salicylic acid, spermine, silver nanoparticles, calcium chloride, gibberellin, Florissant 210®, Crystal, along with two control treatments using tap water and artesian well water. The results indicated significant differences when comparing the different water sources used in preparing the solutions. An increase in microbial population was observed over time postharvest, with genera Pseudomonas spp. and Bacillus identified. When tap water was utilized, the most suitable solutions included the addition of benzyladenine, gibberellin, Florissant 210®, Crystal, and Florissant 210® with chlorine. These results inform producers about selecting preservatives and water sources to enhance postharvest longevity and quality.
Keywords: *Alstroemeria hybrida*, cut flowers, microbiology, preservative solutions.

Resumo: Alstroemeria apresenta um desafio durante sua fase pós-colheita, pois as folhas tendem a amarelar antes da senescência das flores. Portanto, este estudo teve como objetivo avaliar e comparar a eficácia de diferentes soluções previamente recomendadas para a conservação pós-colheita de *Alstroemeria hybrida* L. cv. Akemi. Os conservantes testados incluíram Florissant 210® com cloro, 1-metilciclopropeno, benziladenina, cicloheximida, tiossulfato de prata, ácido salicílico, espermina, nanopartículas de prata, cloreto de cálcio, giberelina, Florissant 210® e Crystal, juntamente com dois tratamentos de controle usando água da torneira e água de poço artesiano. Os resultados indicaram diferenças significativas ao comparar as diferentes fontes de água utilizadas na preparação das soluções. Foi observado um aumento na população microbiana ao longo do tempo pós-colheita, com os gêneros Pseudomonas spp. e Bacillus identificados. Quando uma estação de tratamento de água foi utilizada, as soluções mais adequadas incluíam a adição de benziladenina, giberelina, Florissant 210®, Crystal e Florissant 210® com cloro. Esses resultados informam os produtores sobre a seleção de conservantes e fontes de água para melhorar a longevidade e qualidade pós-colheita.
Palavras-chave: *Alstroemeria hybrida*, flores cortadas, microbiologia, soluções conservantes.

Introduction

Postharvest quality preservation is directly related to the maintenance of plant metabolism and the deceleration of the senescence process. Thus, enhancing the quality of flowers requires a thorough investigation of the physiological aspects related to this process to prolong postharvest longevity (Cunha Neto et al., 2023; Nogueira et al., 2023).

Alstroemeria (*Alstroemeria hybrida* L.), despite being one of the main cut flowers produced, still faces limitations in the postharvest stage. The flowers longevity is approximately eight days, but premature leaf yellowing can occur, leading to a loss of their ornamental value even when the flowers remain fresh (Galati et al., 2017; Langroudi et al., 2020a). This can be attributed to factors, such as inadequate storage conditions, internal cytokinin deficiency, exposure to ethylene, high levels of abscisic acid, and senescence processes (Langroudi et al., 2020a).

Alstroemeria, known for its longevity as a cut flower, faces the primary postharvest challenge of premature leaf yellowing, a sign of senescence. This flower is sensitive to ethylene, a hormone gas that accelerates the aging process (Chanasut et al., 2003). Alternatives such as hormonal treatments and refrigerated storage have been effective in reducing postharvest issues. Another technology under investigation is lighting, which positively influences postharvest quality by reducing ethylene production and increasing chlorophyll levels, contributing to a longer and healthier life for the cut flower (Pintos et al., 2023).

To ensure the quality and extend the lifespan of flowers, the use of preservative solutions and storage at low temperatures is recommended (Galati et al., 2017). It is equally important to monitor water quality, as high levels of salts, such as chlorine, can reduce the longevity of the stems (Costa et al., 2021). The composition of tap water can vary significantly between different regions or even within a single location, complicating the comparison of results between different preservative solutions (Costa et al., 2015).

The efficacy of preservative solutions with the addition of different products was tested for Alstroemeria, without a precise recommendation. Thus, growth regulators such as gibberellic acid (Yeat et al., 2012) and benzyladenine (Matak et al., 2017), preservative substances like salicylic acid (Maruri-López et al., 2019), and ethylene inhibitors such as 1-methylcyclopropene have been recommended (Galati et al., 2017).

Other senescence retardants have also been used, such as cycloheximide (Matak, 2017), calcium chloride (Galati et al., 2015), spermine (Langroudi et al., 2019), and silver thiosulfate (Chanasut et al., 2003). It is noteworthy that some senescence retardants, such as silver thiosulfate, silver nanoparticles, and chlorine, also possess antimicrobial properties (Naing and Kim, 2020).

Due to these various results, producers still face uncertainties regarding the recommendation of the best senescence retardant product for the postharvest of Alstroemeria. Therefore, this study aimed to identify the most effective preservative solution to prolong the postharvest longevity of Alstroemeria stems, especially to prevent leaf yellowing. To achieve this goal, several key questions were established, such as which preservative solution provides the greatest efficacy in increasing the longevity of Alstroemeria stems? Among the preservative solutions analyzed, which maintains the most stable chlorophyll content in Alstroemeria leaves, thereby delaying the yellowing process? Can the use of preservatives with antimicrobial action also contribute to inhibiting bacterial proliferation during post-harvest? Does the source of water used in preparing preservative solutions influence the efficacy of the products tested?

Corresponding author: patriciapaiva@ufla,br | https://doi.org/10.1590/2447-536X.v30.e242753 | Editor: Claudia Fabrino Machado Mattiuz, Escola Superior de Agronomia "Luiz de Queiroz", Brasil | Received: May 03, 2024 | Accepted: Aug 01, 2024 | Available online: Aug 30, 2024 |

Materials and methods

For the postharvest analysis, floral stems of the Akemi cultivar of Alstroemeria (*Alstroemeria hybrida* L.) were used. The floral stems were harvested from a commercial area located at an altitude of 684 meters, latitude 23°58'56" south, and longitude 48°52'32" west, in a protected environment. Two distinct experiments were conducted:

The first experiment, conducted in the autumn with temperatures ranging from 17 °C to 19 °C, used artesian well water to prepare different preservative solutions. The second experiment, conducted in the spring with temperatures between 20 °C and 23 °C, used tap water for preparing various preservative solutions. The use of different water sources was justified to analyze the effect of water quality on the efficacy of the tested products.

After harvesting, the floral stems were transported to the laboratory in a climate-controlled vehicle. The stems were selected and standardized with the first flowers showing color, measuring 0.5 m in length, and having an average weight of 0.04 ± 0.005 kg. The stems were maintained in closed plastic containers containing 0.5 L of preservative solution according to each treatment. The stems remained immersed in the preservative solutions or water throughout the period, as per the treatments. Simulating procedures typically used in commercial production, the experiments were kept in a cold chamber at an average temperature of 4 °C for 3 days, and then transferred to an environment with a temperature of 20 ± 3 °C, without changing the solution.

Experiment 1: Different preservative solutions prepared in artesian well water.

The stems were arranged in treatments prepared with different preservative solutions and different application methods. In this experiment, the artesian well water from the flower-producing company was used for preparing the solutions and also served as the negative control.

a) Florissant 210® + Chlorine: The stems were placed in a commonly used preservative solution by flower producers, at a concentration of 0.05 mol L^{-1} of Florissant 210®, supplemented with 0.03 g L^{-1} of chlorine (sodium dichloroisocyanurate dihydrate, 56% active chlorine).

b) 1-Methylcyclopropene (1-MCP): Alstroemeria stems were placed in airtight chambers and exposed to gaseous 1-MCP, using the product in the form of a wettable powder (0.0005 g L^{-1}) for 6 hours. Subsequently, the stems were transferred to sealed containers containing water (Galati et al., 2017).

c) 6-Benzyladenine: The floral stems were completely sprayed with the solution at a concentration of 0.2 g L^{-1} and, after application, were placed in sealed containers with water (Matak et al., 2017).

d) Cycloheximide: The floral stems were completely sprayed with the solution at a concentration of 0.05 g L^{-1} and, after application, were placed in sealed containers with water (Matak et al., 2017).

e) Silver Thiosulfate (STS): The solution was prepared with 1.58 g L^{-1} of sodium thiosulfate and 1.70 g L^{-1} of silver nitrate, used as a pulsing treatment for 1 hour. Afterward, the stems were transferred to sealed containers containing water (Chanasut et al., 2003).

f) Salicylic Acid: The stems were maintained in a preservative solution prepared with 0.03 g L^{-1} of salicylic acid (Langroudi et al., 2020).

g) Spermine: The stems were maintained in a preservative solution prepared with 0.005 g L^{-1} of spermine (Langroudi et al., 2019).

h) Silver Nanoparticles: The stems were maintained in a preservative solution containing 0.003 g L^{-1} of silver nanoparticles (Langroudi et al., 2020b).

i) Calcium Chloride: The stems were maintained in a preservative solution containing 7.35 g L^{-1} of calcium chloride (Galati et al., 2015).

j) Gibberellic Acid (GA_3): The stems were maintained in a preservative solution prepared with 0.0346 g L^{-1} of GA_3 (Yeat et al., 2012).

k) Florissant 210®: The stems were maintained in a preservative solution prepared with 0.00005 g L^{-1} of this commercial product.

l) Crystal: The stems were maintained in a preservative solution containing 1 g L^{-1} of Floralife Crystal Clear® - Flower Food, a commercial product.

Experiment 2: Different preservative solutions prepared with tap water.

The second experiment was conducted with the same treatments as Experiment 1; however, the solutions were prepared with tap water from an urban water treatment station, which was also used as the negative control. The different water sources used during the experiment were analyzed to identify physicochemical parameters.

Physicochemical analyses

To assess the composition of the water used and identify possible influences on the quality of the prepared solutions, water samples were collected from the artesian well, representing the water used by the producer for stem preservation, and from the tap, representing the water from the treatment station. A composite sample collection with a final volume of 2 liters was carried out and analyzed according to the 'Standard Methods for Examination of Water and Wastewater', 22nd Edition, 2012 (APHA AWWA, WEF, 2012).

Determination of the solution's pH

The pH of all preservative solutions was measured at the beginning and the end of the experiment using a digital pH meter (HANNA, Brazil), previously calibrated with pH buffer solutions of 4.0 and 7.0. The pH meter's electrode was directly inserted into the sample, and after each reading, it was washed with distilled water to avoid any possibility of contamination.

Analysis of the quality and longevity of floral stems

To assess the visual quality of alstroemeria floral stems, daily scores were assigned until the loss of commercial value. These scores were determined by three evaluators, following the criteria established by Galati et al. (2015) (Table 1).

Table 1. Postharvest quality evaluation parameters for alstroemeria floral stems.

Score	Classification	Description	
		Flower	Leaves
5	Excellent	Flowers 100% closed or fully turgid	100% green
4	Good	25% loss of turgor	25% yellow
3*	Fair	50% loss of turgor	50% yellow
2	Poor	75% loss of turgor	75% yellow
1	Bad	100% loss of turgor	100% yellow

*End of vase life

Water absorption rate

The water absorption rate was calculated based on the determination of the consumed volume measured at the beginning and at the end of the experiment, as described by Sales et al. (2021) and Nogueira et al. (2023).

Chlorophyll analysis

To quantitatively monitor the visual changes occurring in the leaves and compare them with the results of visual evaluations, a total chlorophyll sensor (CM-500, Chlorophyll Meter, Solfranc, Spain) was used. Measurements were taken every four days on one leaf per stem in a non-destructive manner. The readings were consistently made on the same predefined middle portion of the leaves at the start of the experiment. The portable sensor provided chlorophyll data based on the plant's absorbance at 660 and 940 nm (Souza et al., 2021).

Microbiological Analysis of Solutions

The determination of the microbial population in the preservative solutions of each vase was conducted through six stages of collection for analysis: the preservative solution of the stems on the first day of contact, after 3 days in the cold chamber, the solution after 5 hours at room temperature, and after a 7-day interval until reaching a score of 3 for the floral stems. For each treatment, 0.005 liters of solution was collected for microbiological analysis.

The analysis was conducted through serial decimal dilution of each preservative solution, followed by triplicate plating using the spread plate method on Brain Heart Infusion (BHI) agar. The BHI medium is composed of: Peptone mixture 10 g L^{-1}; Bovine heart infusion 10 g L^{-1}; Calf brain infusion 7.5 g L^{-1}; Dextrose 2.0 g L^{-1}; Disodium phosphate 2.5 g L^{-1}; Sodium chloride 5.0 g L^{-1} and Bacteriological agar 15 g L^{-1}.

The plates were incubated at 30 °C for 24 hours for colony counting and morphological characterization. Subsequently, the isolates were purified, and the identity of each isolate was confirmed using the MALDI-TOF MS technique (Bruker Daltonics; Bremen, Germany), following the method described by Chen et al. (2023).

Experimental design and statistical analysis

The experimental design used was completely randomized, in split plots over time, with 5 stems each, characterizing the repetitions in a simple factorial scheme. The experiments were thus delineated: 12 treatments x 5 replicates. All data collected in each experiment were subjected to analysis of variance, followed by regression tests and absolute frequency analysis, using Sisvar software version 5.6 (Ferreira, 2019).

Results and discussion

From the physicochemical analysis of different water sources used for preparing the solutions, it was identified that the water obtained directly from the floral company's artesian well had a total solids occurrence of 0.297 g L^{-1}, while the water from the treatment station recorded 0.082 g L^{-1} (Table 2).

The accumulation of total solids in aquatic ecosystems is related to the presence of various impurities found in the water. High concentrations of total solids can result from insufficient dilution and extended weathering time, contributing to changes in pH and electrical conductivity (Costa et al., 2020).

Although the total solids values are significantly different between the two water sources, the pH values were very similar, and the electrical conductivity was the same in both sources. This indicates that the differences in total solids content were not sufficient to cause significant changes in pH and electrical conductivity.

The water from the artesian well showed a lower chloride concentration than tap water. Public service water typically undergoes filtration processes using chlorine-based chemicals. Chlorine can be one of the factors affecting the postharvest senescence of flowers due to its generated toxicity (Malakar et al., 2023).

Tab. 2. Physico-chemical analysis of different water sources used for the preparation of preservative solutions.

Parameters	Artesian well water	Tap water
ph	5.0	5.4
Chlorides (g L^{-1})	0.014	0.017
Biochemical Oxygen Demand (g L^{-1})	0.001	0.002
Chemical Oxygen Demand (g L^{-1})	0.0045	0.0045
Electrical Conductivity (mS cm^{-1})	0.150	0.150
Total Nitrogen (g L^{-1})	< 0.0028	< 0.0028
Total Solids (g L^{-1})	0.297	0.082

*Analyses conducted according to the 'Standard Methods for the Examination of Water and Wastewater', 22nd Edition, 2012.

Analyzing the pH of the preservative solutions, these were influenced by the various chemicals used in their composition (Fig. 1). The control solution, in addition to the preservatives, exhibited a neutral pH, while the other preservative solutions showed an acidic pH. At the end of the evaluation period, when the last stems were no longer suitable for commercialization (after 24 days), the pH of all preservative solutions decreased.

Some solutions exhibited a more alkaline pH, starting from 7.8, such as the one prepared with Florissant 210® (Fig. 1B). Among the tested solutions, those prepared with Crystal exhibited a more acidic pH, reaching 2.8 (Fig. 1A) or 3.3 (Fig. 1B), depending on the water used. As it is a commercial product, the specific composition is not disclosed by the manufacturer, although they are typically composed of sugars, biocides, and acidifying substances.

To optimize the postharvest life of cut flowers, it is recommended that the preservative solution maintain an acidic pH to inhibit the proliferation of microorganisms and, consequently, prolong the longevity of the floral stems (Sales et al., 2021). On the other hand, alkaline preservative solutions have the opposite effect, reducing mobility in the vascular conduits of the floral stems compared to acidic solutions, thus reducing the longevity of the flowers (Malakar et al., 2023).

Stems preserved only in water maintained maximum visual quality until the 16th day, recommended for disposal on the 21st day. The preservative solution containing Florissant 210® + chlorine was recommended for disposal on the 22nd day. Solutions with Florissant 210® or gibberellin showed a reduction in commercial quality on the 23rd day, while stems preserved with silver thiosulfate lost commercial quality on the 24th day (Fig. 2).

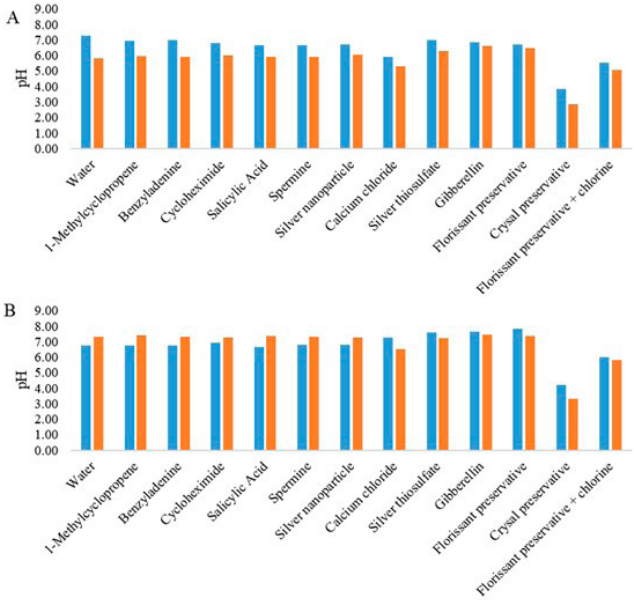

Fig. 1. Evaluation of the pH of different preservative solutions for alstroemeria floral stems prepared with (A) artesian well water, (B) tap water.

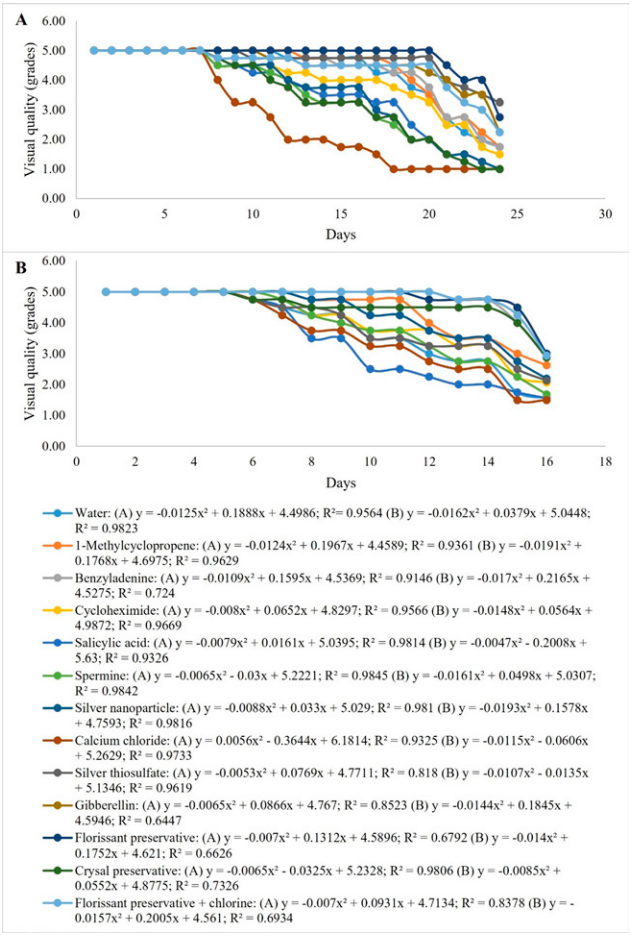

Fig. 2. Evaluation of the visual quality of different preservative solutions for alstroemeria floral stems prepared with (A) artesian well water and (B) tap water.

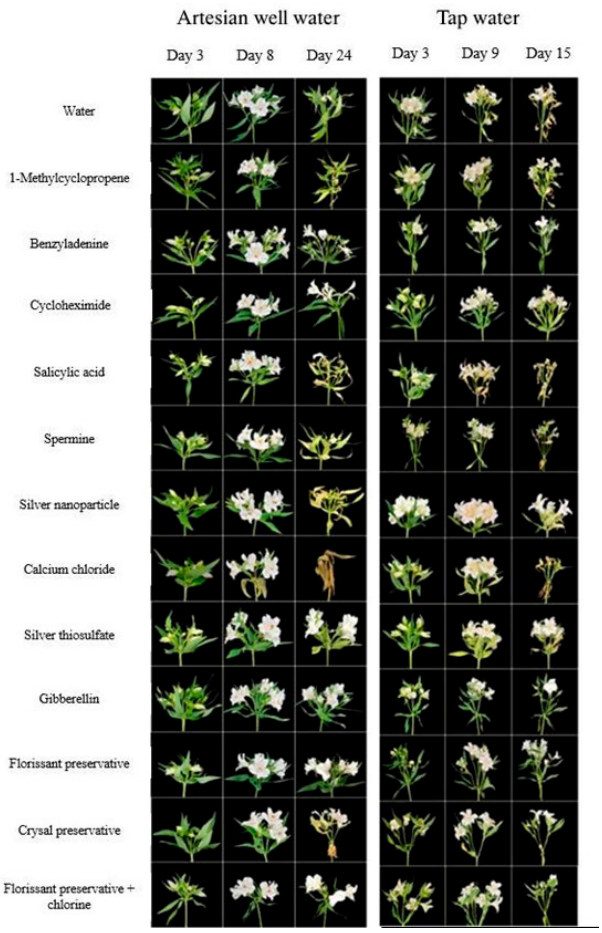

Fig. 3. Senescence process of alstroemeria stems with different preservative solutions prepared with (A) artesian well water and (B) tap water water.

There were no significant visual differences in stem quality during the first 6 days of postharvest evaluation when various products diluted in water from the treatment station were used. Stems stored in a preservative solution containing salicylic acid became unsuitable for commercial purposes on the 8th day, while those in a calcium chloride solution lost commercial viability and were recommended for disposal on the 10th day. Stems preserved only in water were downgraded on the 11th day, as were those subjected to a solution containing spermine. The Florissant 210® preservative solution was downgraded on the 15th day, along with solutions containing benzyladenine, gibberellin, crystal, or Florissant 210® with chlorine. No significant differences in post-harvest longevity were observed among these different preservative solutions (Fig. 2B).

Alstroemeria stems were subjected to three days at low temperatures in a cold chamber, and during this phase, they received the highest quality rating. This cooling process resulted in a significant reduction in the mobilization of reserves, affecting the action of their metabolites (Fig. 3). Conditioning the stems under refrigeration provided an extended vase life and delayed petal fall in Alstroemeria (Almeida et al., 2008).

The preservative solution containing calcium chloride resulted in low stem longevity, corroborating previous observations in calla lilies (Almeida et al., 2008). On the other hand, the Florissant 210® preservative solution demonstrated high stem longevity, as did the combination of Florissant 210® with chlorine. The specific compositions of floral preservative formulations are often not provided by manufacturers, but typically, these formulations include sugars, basic preservative substances, and adjuncts such as acidifying agents or ethylene inhibitors (Chanasut et al., 2003).

It can be inferred that the prolonged longevity of alstroemerias maintained in the Florissant 210® floral preservative was due to the concentration of auxiliary preservative substances and sugars, considering that the presence of a microbial population in the preservative solution of all treatments was detected from the beginning. The addition of chlorine aids in maintaining water quality and delays microbial infections in the flower's vascular system (Menegaes et al., 2019), as observed in the solution containing Florissant 210® + chlorine.

In the experiment using artesian well water for solution preparation, pulsing with the preservative silver thiosulfate demonstrated a three-

day extension in alstroemeria longevity compared to the control. This effect was also previously observed in studies with alstroemeria. Silver thiosulfate acts by blocking the activity of ethylene (C_2H_4), competing for binding sites at the ethylene receptor (Chanasut et al., 2003).

The use of a preservative solution containing Crystal with a lower pH did not result in a significant extension of the vase life of alstroemeria stems. However, the use of substances that maintain a low pH, between 3.0 and 4.0, is recommended to inhibit the proliferation of microorganisms and, consequently, increase the longevity of the flowers (Sales et al., 2021).

In another study conducted with calla lilies using Crystal as the preservative solution, no significant improvements in post-harvest flower quality were observed, and floral opening was accelerated. Regarding gerberas, it was found that the pH of the preservative solution also had no significant influence on the longevity of the floral stems (Almeida et al., 2008).

The water absorption rate of stems conditioned in different preservative solutions with tap water was measured, resulting in the following values: 0.185 L for solutions containing cycloheximide and benzyladenine, 0.17 L for the Crystal solution, and 0.155 L for the control group. This increase in water uptake can be attributed to a positive water balance, indicating that the amount of water absorbed by the stems was greater than their consumption (Matak et al., 2017). This phenomenon contributed to delaying the senescence of the floral stems (Fig. 4).

The water absorption rate of alstroemeria stems maintained in a preservative solution with artesian well water containing benzyladenine was 0.27 L, showing the highest consumption among the tested groups. As previously observed in studies with alstroemeria cultivar Aurantiaca, the preservative solution containing benzyladenine increased water absorption compared to the control, resulting in a delay in stem senescence. Benzyladenine has a retarding effect on the senescence process and stabilizes the respiratory rate of the flowers (Matak et al., 2017).

Floral stems subjected to a preservative solution with artesian well water exhibited a higher water absorption rate, resulting in a longer vase life. In contrast, stems maintained in preservative solutions with tap water absorbed less water. The increased longevity of floral stems is generally related to high levels of tissue hydration. Chlorine, when present in prolonged concentrations, can harm floral stems by affecting the absorption of the preservative solution (Durigan et al., 2013). Tap water had a chloride concentration of 0.017 g L^{-1}, which may have led to reduced water absorption by the stems, accelerating the senescence of the flowers.

Similarly, to Alstroemeria stems, chrysanthemum floral stems exhibited significantly higher water absorption when conditioned in tap water. The quality of the water in which the floral stems are placed has a direct influence on the shelf life of the flowers. Chlorine treatment can affect the mobility of absorbed water in the stem's vascular conduits, in addition to inhibiting the growth of microorganisms due to the use of this preservative (Costa et al., 2021; Chen et al., 2023).

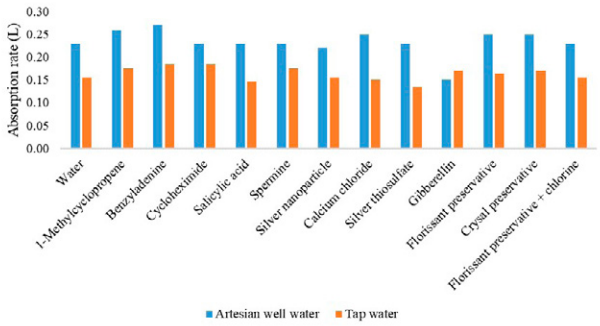

Fig. 4. Water absorption rate of alstroemeria floral stems maintained in different preservative solutions with artesian well water and treatment station water.

Alstroemeria stems maintained in preservative solutions containing benzyladenine, Florissant 210®, and gibberellin exhibited a delay in chlorophyll degradation compared to the control group. In studies with *Alstroemeria aurantiaca* stems, the preservative containing benzyladenine also demonstrated a delay in the senescence process. Cytokinins, such as benzyladenine, act as senescence retardants by inhibiting chlorophyll degradation (Fig. 5). Similarly, the use of gibberellin delays chlorophyll degradation, prolonging the green coloration in alstroemeria stems (Yeat et al., 2012).

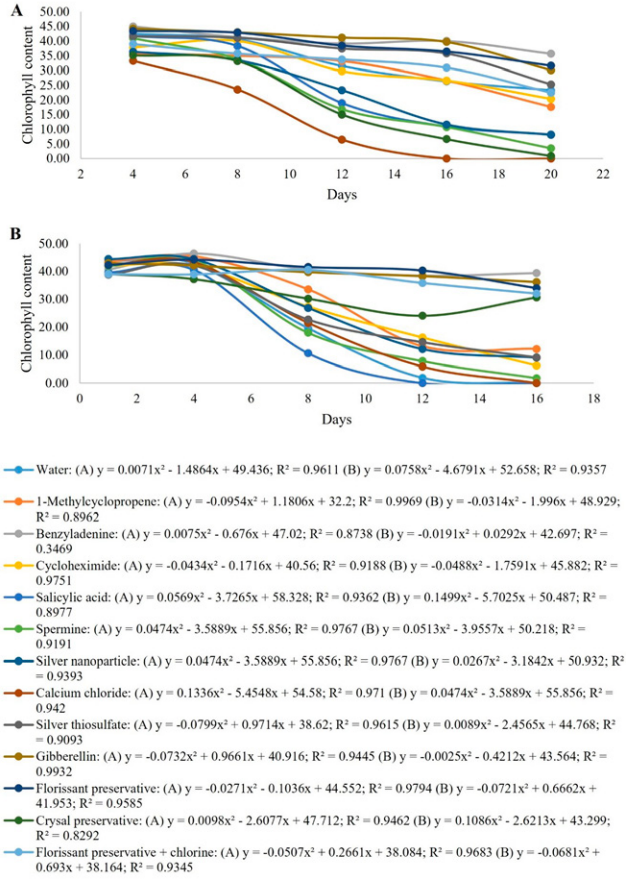

Fig. 5. The chlorophyll content of floral stems of alstroemeria with different preservative solutions prepared with (A) artesian well water and (B) water from a treatment plant.

Research conducted with gibberellin (GA_3) as a component of the preservative solution revealed a significant delay in the yellowing of alstroemeria leaves (Yeat et al., 2012). Furthermore, studies involving acidic lemon fruits treated with gibberellic acid showed a more attractive aesthetic preservation, keeping them with a greener and more beautiful appearance (Barbara and Ferro, 2021).

In stems maintained in preservative solutions containing Florissant 210® or gibberellin, an increase in water consumption, a delay in chlorophyll degradation, and a consequent increase in longevity compared to the control group were observed.

On the day of the experiment setup, different microbial populations were observed in the various preservative solutions. The solution containing Florissant 210® had the highest microbial population, with 36 CFU L^{-1} and a pH of 6.7, while the solution containing Florissant 210® + chlorine had the lowest population, with 0.0003 CFU L^{-1} and a pH of 5.54. The solution containing Crystal had a microbial population of 0.0047 CFU L^{-1}, with a more acidic pH of 3.83 (Table 3).

Table 3. Evaluation of microbial growth (CFU L^{-1}) from the preservative solutions in which alstroemeria stems were maintained during the post-harvest period.

Preservative solutions	1ª collection CFU L^{-1}	2ª collection CFU L^{-1}	3ª collection CFU L^{-1}	4ª collection CFU L^{-1}	5ª collection CFU L^{-1}	6ª collection CFU L^{-1}
Water	0.006	0.0053	0.003	0.2	70	48
^{1}-Methylcyclopropene	0.018	0.22	0.016	78	88	340
Benzyladenine	0.032	0.019	0.014	100	70	60
Cycloheximide	0.011	0.014	0.074	0.1	49	30
Salicylic acid	0.007	0.003	0.0017	90	60	48
Spermine	0.0017	0.009	0.0027	330	130	8,6
Silver nanoparticle	0.0077	0.00667	0.016	140	88	40
Calcium chloride	0.056	0.12	27	270	47	34
Silver thiosulfate	0.0077	0.0023	0.013	210	160	27
Gibberellin	0.054	0.009	0.35	57	170	0.67
Florissant 210®	0.36	3500	1700	880	100	2.6
Crystal preservative	0.0047	0.03	0.0087	0.39	4.9	8.3
Florissant 210® + chlorine	0.0003	0.003	0.0007	0.0067	84	830

It is important to highlight that the preservative solution containing Crystal had the most acidic pH, consequently inhibiting the proliferation of microorganisms. No reduction in microbial population was observed with the use of Crystal, as the microbial population on the day of experiment setup was 0.0047 CFU L^{-1}, while the solution containing Florissant 210® + chlorine recorded 0.0003 CFU L^{-1}. These results are in line with previous studies on alstroemerias, where a reduction in microbial population occurred with the use of chlorine (Jowkar, 2015).

The microbial population showed a significant increase over time, resulting in considerably higher final growth. This increase was especially observed in the solution prepared with Florissant 210® + chlorine, whose effectiveness decreased over time, allowing for the growth of the microbial population. Similar results were observed with the use of preservative solutions containing silver thiosulfate and silver nanoparticles, which have antimicrobial properties but also showed an increase in microbial population over time (Table 3).

It was observed that in solutions prepared with artesian well water, the addition of Florissant 210®, Crystal, or gibberellin resulted in solution turbidity. A similar effect was also observed with treated water in the solution containing Crystal. The turbidity observed in solutions containing only water, Florissant 210®, Crystal, and calcium chloride was confirmed by the microbial population count, suggesting the presence of bacterial exudates (Durigan et al., 2013).

Although the preservative solution containing Florissant 210® presented whitish exudate, this preservative still proved effective in prolonging stem longevity without interfering with quality assessment scores. On the other hand, the solution containing Crystal developed an odor at the end of the experiment, characteristic of bacterial proliferation. These results suggest that the presence of bacterial exudates may occur in some preservative solutions but does not always affect the quality and longevity of alstroemeria stems.

In the alstroemeria cultivar Akemi, it was possible to observe that stems maintained in solutions containing Crystal or calcium chloride showed a change in coloration in the area in contact with the solution, drying when submerged in the calcium chloride solution. These effects were also observed in other species, such as Alstroemeria cv. Vanilla, where stem bleaching was reported (Jowkar, 2015).

Microbial identification revealed the presence of the genus Pseudomonas ssp in all solutions prepared with artesian well water. Pseudomonas bacteria are known to promote plant growth, producing antimicrobial compounds, hydrolytic enzymes, and volatiles that can inhibit phytopathogens or induce systemic resistance, contributing to disease reduction in plants (Gu et al., 2020).

In the different preservative solutions containing artesian well water, the bacterium Bacillus amyloliquefaciens was identified in some of them, such as benzyladenine, cycloheximide, silver nanoparticles, silver thiosulfate, gibberellin, and crystal. The genus Bacillus has been associated with xylem vessel plugging and stem breakage in some varieties of gerbera, such as cv. Provence. These bacteria can grow under a wide range of environmental conditions and may dominate preservative solutions, which can influence the quality and longevity of alstroemeria stems during the post-harvest period (Jowkar, 2015).

Conclusions

The water quality plays a crucial role in the longevity of the floral stems of the alstroemeria cultivar Akemi. The effectiveness of post-harvest preservatives used is influenced by the quality of the water employed. When floral stems of the Akemi alstroemeria cultivar are kept in artesian well water, the use of silver thiosulfate, Florissant 210®, and gibberellin provides greater longevity. On the other hand, when tap water was used, solutions prepared with benzyladenine, gibberellin, Florissant 210®, crystal, and Florissant 210® + chlorine were more efficient in prolonging stem longevity. However, the use of floral preservatives with antimicrobial action, such as chlorine, silver nanoparticles, and silver thiosulfate, was not able to prevent bacterial proliferation. Additionally, the yellowing of leaves in alstroemeria floral stems was delayed when kept in a preservative solution containing benzyladenine, gibberellin, and Florissant 210®.

Acknowledgments

The authors are thankful to the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) - APQ-02575-21, and to the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

Author contribution

COP: data curation; formal analysis; investigation; methodology; writing - original draft. **PDOP**: conceptualization; funding acquisition; project administration; resources; supervision; writing - review & editing. **ARCN**: data curation; formal analysis; investigation; methodology; writing - original draft; writing - review & editing. **SSN**: data curation; formal analysis; methodology. **MMP**: data curation; formal analysis; methodology. **DPCS**: conceptualization; investigation. **MVR**: conceptualization; funding acquisition; project administration; resources; supervision; writing - review & editing.

Declaration of interest statement

On behalf of the authors, the corresponding author declares that, by their knowledge, there is no relevant competing interest for the present manuscript.

Data Availability Statement

Data will be available on request.

References

APHA AWWA, WEF. Standard Methods for examination of water and wastewater. 22nd ed. Washington: American Public Health Association, 2012. 1360p.

ALMEIDA, E.F.A.; PAIVA, P.D.O.; LIMA, L.C.O.; RESENDE, M.L.; FONSECA, J.; TAVARES, T.S. Calla lily postharvest: effect of different commercial preservative solutions and cold storage. **Ciência e Agrotecnologia**, v.32, p.1189-1194, 2008. https://doi.org/10.1590/S1413-70542008000400023

BARBARA, G.; FERRO, D.A.M. Tecnologia de aplicação de ácido giberélico na manutenção da coloração esverdeada do fruto lima ácida 'Tahiti' (*Citrus latifolia*). **Unifunec Científica Multidisciplinar**, v.10, n.12, p.1-8, 2021. https://doi.org/10.24980/ucm.v10i12.3563

CHANASUT, U.; ROGERS, H.J.; LEVERENTZ, M.K.; GRIFFITHS, G.; THOMAS, B.; WAGSTAFF, C.; STEAD, A. D. Increasing flower longevity in Alstroemeria. **Postharvest Biology and Technology**, v.29, n.3, p.325-333, 2003. https://doi.org/10.1016/S0925-5214(03)00048-6

CHEN, Y.H.; MILLER, W.B.; HAY, A. Postharvest bacterial succession on cut flowers and vase water. **Plos One**, v.18, n.10, p.e0292537, 2023. https://doi.org/10.1371/journal.pone.0292537

COSTA, K.A.D.; BENJAMIM, J.K.F.; AGUIAR NETO, S.A.; FERREIRA, T.M.C.; PHILIPPSEN, H.K.; ROSAS, J.C.F.; SERRA, I.S.D.; SILVA, J.M.S.; LOPES, M.S.B.; SOUZA, C.M.N. Avaliação da qualidade das Águas da Baia do Guajará para consumo humano. **Revista Ibero-Americana de Ciências Ambientais**, v.11, n.6, p.150-159, 2020.

COSTA, L.C.; ARAÚJO, F.F.; MENDES, T.D.C.; FINGER, F.L. Influence of electrical conductivity on water uptake and vase life of cut gladiolus stems. **Ornamental Horticulture**, v.21, n.2, p.221-226, 2015. https://doi.org/10.14295/aohl.v21i2.673

COSTA, L.C.; ARAUJO, F.F.; RIBEIRO, W.S.; SANTOS, M.N.S; FINGER, F.L. Postharvest physiology of cut flowers. **Ornamental Horticulture**, v.27, p.374-385, 2021. https://doi.org/10.1590/2447-536X.v27i3.2372

CUNHA NETO, A.S.; PAIVA, P.D.O.; PONCE, M.M.; CALVELLI, J.V.B.; BARBOSA, S. Meta-analysis of new technologies in post-harvest of tropical flowers. **Ornamental Horticulture**, v.29, n.2, p.224-237, 2023. https://doi.org/10.1590/2447-536X.v29i2.2643

DURIGAN, M.F.B.; MATTIUZ, B.H.; RODRIGUES, T.D.J.D.; MATTIUZ, C.F.M. Uso de soluções de manutenção contendo ácido cítrico, cloro ou 8-HQC na conservação pós-colheita de flores cortadas de gérbera 'Suzanne'. **Ornamental Horticulture**, v.19, n.2, p.107-116, 2013. https://doi.org/10.14295/rbho.v19i2.352

FERREIRA, D.F. SISVAR: A computer analysis system to fixed effects split plot type designs. **Brazilian Journal of Biometrics**, v.37, n.4, p.529-535, 2019. https://doi.org/10.28951/rbb.v37i4.450

GALATI, V.C.; MARQUES, K.M.; MUNIZ, A.C.C.; SILVA, J.P.; GUIMARÃES, J.E.R.; MATTIUZ, C.F.M.; MATTIUZ, B.H. Use of calcium chloride in postharvest treatment of Alstroemeria cut flowers. **Acta Horticulturae (ISHS)**, v.1104, n.41, p.267-272, 2015. https://doi.org/10.17660/ActaHortic.2015.1104.41

GALATI, V.C.; MUNIZ, A.C.C.; GUIMARÃES, J.E.R.; INESTROZA-LIZARDO, C.O.; MATTIUZ, C.M.F.; MATTIUZ, B.H. Postharvest conservation of alstroemeria 'ajax'using 1-methylcyclopropene. **Ciência e Agrotecnologia**, v.41, p.181-190, 2017. https://doi.org/10.1590/1413-70542017412032816

GU, Y.; MA, Y.N.; WANG, J.; XIA, Z.; WEI, H.L. Genomic insights into a plant growth promoting Pseudomonas koreensis strain with cyclic lipopeptide mediated antifungal activity. **MicrobiologyOpen**, v.9, n.9, p.e1092, 2020. https://doi.org/10.1002/mbo3.1092

JOWKAR, M.M. Effects of chlorination and acidification on postharvest physiological properties of alstroemeria, cv. 'Vanilla'and on microbial contamination of vase solution. **Horticulture, Environment, and Biotechnology**, v.56, p.478-486, 2015. https://doi.org/10.1007/s13580-015-0022-4

LANGROUDI, M.E.; HASHEMABADI, D.; KALATEJARI, S.; ASADPOUR, L. Effects of pre-and postharvest applications of salicylic acid on the vase life of cut Alstroemeria flowers (*Alstroemeria hybrida*). **Journal of Horticulture and Postharvest Research**, v.3, p.115-124, 2020a. https://doi.org/10.22077/jhpr.2019.2409.1053

LANGROUDI, M.E.; HASHEMABADI, D.; KALATEJARI, S.; ASADPOUR, L. Effect of silver nanoparticles, spermine, salicylic acid and essential oils on vase life of alstroemeria. **Revista de Agricultura Neotropical**, v.6, n.2, p.100-108, 2019. https://doi.org/10.32404/rean.v6i2.2366

LANGROUDI, M.E.; HASHEMABADI, D.; KALATEJARI, S.; ASADPOUR, L. Effects of silver nanoparticles, chemical treatments and herbal essential oils on the vase life of cut alstroemeria (Alstroemeria 'Summer Sky') flowers. **The Journal of Horticultural Science and Biotechnology**, v.95, n.2, p.175-182, 2020b. https://doi.org/10.1080/14620316.2019.1657786

MALAKAR, M.; PAIVA, P.D.O.; BERUTO, M.; CUNHA NETO, A.R.D. Review of recent advances in post-harvest techniques for tropical cut flowers and future prospects: Heliconia as a case-study. **Frontiers in Plant Science**, v.14, p.1221346, 2023. https://doi.org/10.3389/fpls.2023.1221346

MARURI-LÓPEZ, I.; AVILES-BALTAZAR, N.Y.; BUCHALA, A.; SERRANO, M. Intra and extracellular journey of the phytohormone salicylic acid. **Frontiers in Plant Science**, v.10, p.455069, 2019. https://doi.org/10.3389/fpls.2019.00423

MATAK, S.A.; HASHEMABADI, D.; KAVIANI, B. Changes in postharvest physio-biochemical characteristics and antioxidant enzymes activity of cut *Alsteroemeria aurantiaca* flower as affected by cycloheximide, coconut water and 6-benzyladenine. **Bioscience Journal**, v.33, n.2, p.321-332, 2017. https://doi.org/10.14393/BJ-v33n2-34381

MENEGAES, J.F.; LIDÓRIO, H.F.; BELLÉ, R.A.; LOPES, S.J.; BACKES, F.A.A.L.; NUNES, U.R. Post-harvest of safflower flower stems harvested at different times and submitted to different preservative solutions. **Ornamental Horticulture**, v.25, p.87-96, 2019. https://doi.org/10.14295/oh.v25i1.1989

NOGUEIRA, M.R.; PAIVA, P.D.O.; CUNHA, A.R.D.; REIS, M.V.D.; NASCIMENTO, Â.M.P.; TIMOTEO, C.D.O. Starch-based films for Red Torch ginger inflorescences postharvest conservation. **Ciência e Agrotecnologia**, v.47, p.e017822, 2023. https://doi.org/10.1590/1413-7054202347017822

NAING, A.H.; KIM, C.K. Application of nano-silver particles to control the postharvest biology of cut flowers: A review. **Scientia Horticulturae**, v.270, p.109463, 2020. https://doi.org/10.1016/j.scienta.2020.109463

PINTOS, F.; NICO, A.; RODONI, L.; CIEZA, R.; HASPERUÉ, J. Postharvest illumination of alstroemeria: Effect of light quality on flower metabolism and shelf life. **Postharvest Biology and Technology**, v.201, p.112346, 2023. https://doi.org/10.1016/j.postharvbio.2023.112346

SALES, T.S.; PAIVA, P.D.O.; MANFREDINI, G.M.; NASCIMENTO, Â.M.P.D.; REIS, M.V.D. Water relations in cut calla lily flowers maintained under different postharvest solutions. **Ornamental Horticulture**, v.27, p.126-136, 2021. https://doi.org/10.1590/2447-536X.v27i2.2235

SOUZA, R.R.; PAIVA, P.D.O.; SOUZA, A.R.; SILVA, R.R.; SILVA, D.P.C.; REIS, M.V.; PAIVA, R. Morpho-anatomical changes and antioxidant enzyme activity during the acclimatization of *Genipa americana*. **Acta Physiologiae Plantarum**, v.43, p.1-10, 2021. https://doi.org/10.1007/s11738-021-03263-9

YEAT, C.S.; SZYDLIK, M.; ŁUKASZEWSKA, A.J. The effect of postharvest treatments on flower quality and vase life of cut alstroemeria 'Dancing Queen'. **Journal of Fruit and Ornamental Plant Research**, v.20, n.2, p.147-160, 2012. https://doi.org/10.2478/v10290-012-0024-6