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Post-harvest quality of safflower flower stems with different pre-cooling periods and preservative solutions

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Abstract

Safflower (*Carthamus tinctorius* L.) is still a relatively new crop In Brazil, this way, studies regarding the post-harvest of its floral stems are required. They present an ornamental character, because of their beauty, rusticity and versatility of use. The objective of this study was to assess the post-harvest quality and durability of safflower floral stems at different pre-cooling periods and conservative solutions. It was used a completely randomized design, organized in a 3x7 scheme (0; 12 and 24 h periods, and conservative solutions: control (distilled water (DW)); DW + 2% sucrose; DW + 2% sucrose + 2% sodium hypochlorite; DW + 20 mg L^{-1} of gibberellic acid; DW + 20 mg L^{-1} of citric acid; and DW+ 20 mg L^{-1} of salicylic acid). Each experimental unit consisted of five floral stems. Assessments were made on the average diameters of inflorescences and stems, as well as on vase life, which was measured by their durability with a healthy and marketable aspect. It was observed that the durability of safflower flower stems was favored by pre-cooling, and when combined with different preservative solutions, their vase life reaches up to 12 days. Thus, it is recommended the use of a preservative solution containing distilled water + 20 mg L^{-1} of citric acid and a pre-cooling period of 24 h, in order to preserve the durability of safflower floral stems.

Keywords: *Carthamus tinctorius* L., flower

Introduction

The floral stems of safflower (*Carthamus tinctorius* L.) have an ornamental character, due to their beauty, rusticity and versatility, and can be used as a fresh or dry cut flower (Emongor & Oagile, 2017). When used as a cut flower, its stems must have homogeneous bunches, with 95% uniformity in terms of length, stem thickness and opening point. The length of the stem may vary from 60 to 90 cm, divided into classes, with at least three inflorescences, and the central one must be starting to open (Bellé et al., 2012; Cooperativa Veiling Holambra, 2016).

Post-harvest is a technical procedure that aims to maximize the quality of flower stems and to reduce losses after harvest, providing longer shelf-life and a longer period for the commercialization of these products. Due to the high perishability of flower stems, specific pre- and post-harvest management is required to contribute favorably to their preservation. After the stems are cut, the physiological processes to maintain their metabolism intensify, due to the separation from the mother plant and the interruption of the supply of water and nutrients, resulting in the acceleration of senescence. Thus, understanding the preservation of flower stems is important to provide producers and consumers with products that suffer minimal changes in their aesthetics and qualitative aspects (Menegaes et al., 2018; Menegaes & Nunes, 2020).

Temperature and preservative solutions are among the main factors that determine the durability of cut plants. The first is aimed at reducing respiratory activity, which is directly related to vase life. Low temperatures tend to slow down breathing, reducing the production of ethylene and, consequently, delaying the degradation of sugar reserves or other substrates, prolonging the durability of flowers and foliage in preservation environments

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(Almeida et al., 2009; Menegaes et al., 2019a; b).

Preservative solutions are intended to provide cut flower stems and leaves with hydration, energy and phytosanitary substrates. Their composition provides energy to flower stems, preventing microbial development or ethylene synthesis; however, the ingredients used in preservative solutions may be beneficial for some species, but not for others (Nomura et al., 2014).

Preservative solutions are classified as strengthening or "pulsing", conditioning, maintenance, and floral inducting. Among these solutions, maintenance is the most used at points of sale, as it contains substances in its composition that may be used alone or mixed with others, contributing to the conservation of the quality of the cut stems. The ingredients used to make these solutions are, in general, sucrose, germicides, ethylene inhibitors, organic acids, antioxidants, plant regulators and essential oils, among others (Durigan et al., 2013; Bastos et al., 2016).

Thus, this study aimed to assess the quality and post-harvest durability of safflower flower stems subjected to different pre-cooling periods and preservative solutions.

Material and Methods

The experiment was conducted from April to August in 2020, at the Floriculture Sector in the Department of Plant Science at the Federal University of Santa Maria (UFSM), located in Santa Maria, RS, Brazil (29°43' S; 53°43' W and altitude of 95m). The climate in the region is humid subtropical (Cfa), according to the Köppen-Geiger classification, with an average accumulated annual precipitation of 1,769 mm, an average annual temperature near 19.2° C and average air humidity around 78.4% (Alvares et al., 2013).

The experimental design was completely randomized, organized in a 3x7 factorial scheme (three pre-cooling periods and seven preservative solutions), with four replications, and each experimental unit consisted of five safflower flower stems.

Pre-cooling periods were 0; 12 and 24 hours after collection and standardization of flower stems. The preservative solutions consisted of: PS1: Distilled water (control); PS2: distilled water + 2% sucrose; PS3: Distilled water + 2% sodium hypochlorite; PS4: Distilled water + 2% sucrose + 2% sodium hypochlorite; PS5: Distilled water + 20 mg L^{-1} gibberellic acid; PS6: Distilled water + 20 mg L^{-1} citric acid and PS7: Distilled water + 20 mg L^{-1} salicylic acid.

The cultivation of safflower (Lasting Orange cultivar) took place in the Floriculture Sector of UFSM, in a greenhouse: sowing took place on April 3rd, 2020, directly in the beds (previously prepared and fertilized), and harvest took place 120 days after sowing (DAS). Immediately after harvesting, the flower stems were standardized to 60 cm of stalk length and three inflorescences, the central one being partially open (Figure 1 B.a, B.b and B.c) according to market standards and classification criteria for safflower in cut flowers, determined by Cooperativa Veiling Holambra (2016). Subsequently, these stems were subjected to pre-cooling in a cold chamber at 5±2° C and stored in distilled water for the aforementioned periods (Reid & Jiang, 2012; Menegaes et al., 2018).

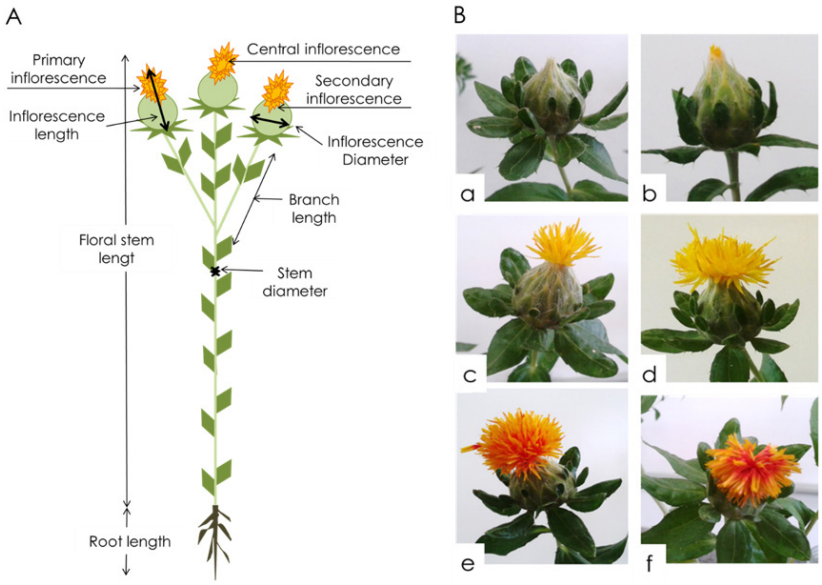

Figure 1. Carthamus tinctorius L. A - Illustration for the assessment of biometric parameters of floral stems. B - Flowering stages: appearance of color in the ligules on the bud (B.a), appearance of the visible stamens (B.b), stamens and ligules partially exposed (B.c), full flowering (B.d), end of flowering (B.e) and senescence of the inflorescence (B.f). Source/Photos: adapted from Menegaes et al. (2019).

The mean diameters of the inflorescences and flower stems were measured through a digital caliper (accuracy of 0.001 mm) (Figure 1a). To check the durability of flower stems, after pre-cooling, they were placed in clear glass containers (1.2 L volume) containing 300 mL of preservative solutions (with a 7-cm water column) corresponding to the aforementioned solutions, with renewal every three days. Environmental conditions of the experimental room were maintained through air conditioning at an average temperature of 20° C and a constant average relative humidity of 65% (Menegaes et al., 2019a; 2020).

Vase life was assessed by the durability of flower stems with a healthy and marketable appearance until they reached a score of three (Table 1). The assessment on the quality of stems, according to the characteristics of leaves (regarding wilting, yellowing and necrosis) and inflorescences (regarding commercialization appearance and vase life), was carried out according to the grading scale in Table 1.

Table 1. Scoring to evaluate the longevity of post-harvest *Carthamus tinctorius* L. floral stems.

SCORE	Inflorescences					
	Position	Closed	50% open	Open	50% senescent	100% senescent
1	Central			X		
	First	X	X			
	Second	X				
2	Central				X	
	First			X		
	Monday		X	X		
3	Central				X	
	First				X	
	Second			X		
4	Central					X
	First					X
	Second				X	
5	Central					X
	First					X
	Second				X	X
SCORE	Leaves				Healthy and commercial aspect	
1	Green	X	Turgidity	X	Yes	
	50% yellow		50% turgid			
	Yellow		Dry			
2	Green	X	Turgidity	X	Yes	
	50% yellow		50% turgid			
	Yellow		Dry			
3	Green	X	Turgidity	X	Yes	
	50% yellow	X	50% turgid			
	Yellow		Dry			
4	Green		Turgidity	X	Yes, with removal	
	50% yellow	X	50% turgid	X		
	Yellow		Dry			
5	Green		Turgidity		No	
	50% yellow	X	50% turgid	X		
	Yellow	X	Dry	X		

Source: Menegaes et al. (2019a).

The relative dry mass (RDM) of floral stems pre- and post-storage was calculated according to the methodology by Schmitt et al. (2014), expressed in the Equation [$RDM_{(\%)} = (M_t \times 100)/M_{t=0}$], where: M_t = dry mass of stem (g), t =days after harvest, and $M_{t=0}$= fresh mass of stem (g) on the day of harvest.

The absorption of preservative solution (APS) by floral stems in post-storage was calculated with the methodology by Antes et al. (2009), expressed in the Equation [$ASC_{(mL\ day\text{-}1\ g\text{-}1\ of\ fresh\ mass)} = (V_{t-1} - V_t)/M_{t=24\ h}$], where: V_t = solution volume (mL) t days after harvest; V_{t-1} =solution volume (mL) on the previous day, and $M_{t=24\ h}$ =fresh mass of stem 24 h after harvest.

The assessment of floral stem mass, absorption of preservative solution, and scoring were made 3, 6, 9, 12, 15, 18 and 21 days from the beginning of the post-harvest process (PHP).

The data expressed in percentage were transformed with arc-sine $\sqrt{}$ (x/100). The analysis of data variance, comparison of qualitative averages was performed by the Scott-Knott test, and quantitative averages by regression, at the level of 5% error, were

performed with SISVAR (Ferreira, 2014). Furthermore, it was performed a comparison of progressive averages of quality scoring, absorption of preservative solutions, and dehydration of floral stems of safflower at 3, 6, 9, 12, 15, 18 and 21 days from the beginning of the post-harvest process by regression ($p<0.05$) (Menegaes et al., 2020).

Results and Discussion

The safflower flower stems were standardized after harvest as mentioned above; thus, it was observed that there was no significant difference for the parameters of initial fresh mass (IFM), fresh mass after pre-cooling (FMA), flower stem diameter (FSD) and inflorescence diameter (IFD). The overall averages of these parameters were 26.1 g (4.69% CV), 25.4 g (3.45% CV), 2.04 mm (3.57% CV) and 19.82 mm (3.14% CV) for IFM, FMA, FSD and IFD, respectively.

This standardization meets the commercial requirements of marketing standards and classification criteria for cut safflower determined by Cooperativa Veiling Holambra (2016). Our results corroborate the studies by Menegaes et al. (2019a, 2019b, 2020), who evaluated safflower flower stems harvested at different times of the year and subjected to different preservative solutions.

The lack of significance of fresh mass after pre-cooling (FMA) for periods of 0, 12 and 24 h after harvest indicates that pre-cooling helps to maintain the quality of these flower stems, regulating their metabolism in terms of moisture and heat. Menegaes et al. (2019a) observed that the use of cooling for 24 h after harvest favored the maintenance of the aesthetic quality of safflower flower stems. According to Paiva & Almeida (2014), for safflower flower stems, cooling is necessary to avoid premature deterioration.

According to Reid & Jiang (2012), cooling flower stems after harvesting serves to regulate the heat coming from the field and to reduce the respiratory rate and infection by pathogens. Menegaes et al. (2018) verified that the exposure of *Murraya paniculata* L. leaf stems to cold extended stem life span, preserving their ornamental and commercial qualities. Similarly, Álvares et al. (2010) concluded that pre-cooling reduced fresh mass loss, prolonging leaf turgidity and shelf life of parsley (*Petroselinum crispum* (Mill.) Nym).

It was found that the vase life of stems had an average durability of 9.2, 10.2 and 10.8 days for pre-cooling periods of 0, 12 and 24 h after collection, respectively (Table 2). It was observed that flower stems treated with solution PS6 (distilled water + 20 mg L^{-1} citric acid) reached a durability of 12.0 days of vase life.

According to Nowak et al. (1991), citric acid is used as a bactericide, but it also works as an antioxidant, preventing damage caused by the entry of oxygen into the vascular system, helping to reduce water pH. Despite being of little used in preservative solutions for maintenance, its use promotes good conditions for the maintenance of cut stems, as observed in this research.

Table 2. Vase life (LIFE; days) and accumulated absorption (ABS; mL g^{-1} fresh mass) of safflower (*Carthamus tinctorius L.*) flower stems.

Preservative solution	Pre-cooling period (h)							
	PR 0 h	PR 12 h	PR 24 h	MD	PR 0 h	PR 12 h	PR 24 h	MD
	LIFE (days)				ABS (mL g^{-1})			
PS1	9.6 *Bb	10.0 Ab	10.5 Ca	10.0	0.452 *Ab	0.469 Ba	0.470 Aa	0.464
PS2	8.8 Cb	9.5 Ba	9.5 Da	9.3	0.337 Cb	0.377 Da	0.347 Db	0.353
PS3	8.5 Cc	9.0 Bb	9.5 Da	9.0	0.395 Ba	0.337 Db	0.388 Ca	0.373
PS4	9.5 Bc	10.5 Ab	11.3 Ba	10.4	0.395Ba	0.399 Ca	0.380 Cb	0.392
PS5	10.5 Ab	11.2 Aa	11.8 Aa	11.2	0.454 Ab	0.485 Aa	0.475 Ab	0.472
PS6	10.1 Ab	10.6 Ab	12.0 Aa	10.9	0.393 Ba	0.367 Db	0.396 Ca	0.385
PS7	10.0 Ab	10.5 Ab	11.0 Ba	10.5	0.437 Aa	0.417 Cb	0.452 Ba	0.435
MD	9.6	10.2	10.8		0.409	0.407	0.415	
CV (%)	5.10				12.64			

*significant: interaction of factors. Test of means not followed by the same letter (uppercase in column and lowercase in rows) differ by the Scott-Knott test ($p<0.05$). MD: average. CV: coefficient of variation.

Pre-cooling periods were (PR) 0, 12 and 24 h after collection and standardization of flower stems. The preservative solutions consisted of: PS1: Distilled water (control); PS2: distilled water + 2% sucrose; PS3: Distilled water + 2% sodium hypochlorite; PS4: Distilled water + 2% sucrose + 2% sodium hypochlorite; PS5: Distilled water + 20 mg L^{-1} gibberellic acid; PS6: Distilled water + 20 mg L^{-1} citric acid and PS7: Distilled water + 20 mg L^{-1} salicylic acid.

Pre-cooling periods were (PR) 0, 12 and 24 h after collection and standardization of flower stems. The preservative solutions consisted of: PS1: Distilled water (control); PS2: distilled water + 2% sucrose; PS3: Distilled water + 2% sodium hypochlorite; PS4: Distilled water + 2% sucrose + 2% sodium hypochlorite; PS5: Distilled water + 20 mg L^{-1} gibberellic acid; PS6: Distilled water + 20 mg L^{-1} citric acid and PS7: Distilled water + 20 mg L^{-1} salicylic acid.

The mean accumulated absorptions (ABS) were 0.409, 0.407 and 0.415 mL g^{-1} of fresh mass for pre-cooling periods of 0, 12 and 24 h after harvest, respectively (Table 2), corresponding to a daily average of solution

consumption of 0.019 mL day^{-1} g^{-1} of fresh mass. Among the preservative maintenance solutions, the one with the highest average absorption was PS5 (distilled water + 20 mg L^{-1} of gibberellic acid) with 0.472 mL g $^{-1}$, while the one with the lowest average was PS2 (distilled water + 2% sucrose) with 0.415 ml g $^{-1}$.

According to Brackmann et al. (2005), and Chitarra & Chitarra (2005), the use of gibberellic acid in preservative solutions delays the yellowing of leaves in cut flower stems by inhibiting the degradation of chlorophyll. During this study, plants treated with PS5 solution were the last to visibly show leaf yellowing. For Sonego & Brackmann (1995), sucrose acts in the preservative solution as an exogenous energy source, with the purpose of replacing depleted carbohydrates in the respiratory process, thus maintaining the integrity of the membrane, improving the water balance and helping to slow down the production and action of ethylene.

In Figure 2, it was observed, in general, that the absorptions of solutions decreased at 3, 6, 9, 12, 15, 18 and 21 days after collection, this process taking place for all pre-cooling periods. In Figure 2a, containing only distilled water (PS1; control), it was visually observed that the absorption on the evaluated days was greater for the 24-hour pre-cooling period. This indicates that cooling helped to regulate the breathing rate. Similar results were observed by Menegaes et al. (2019a), who used 24-hour cooling for safflower flower stems as a post-harvest methodology.

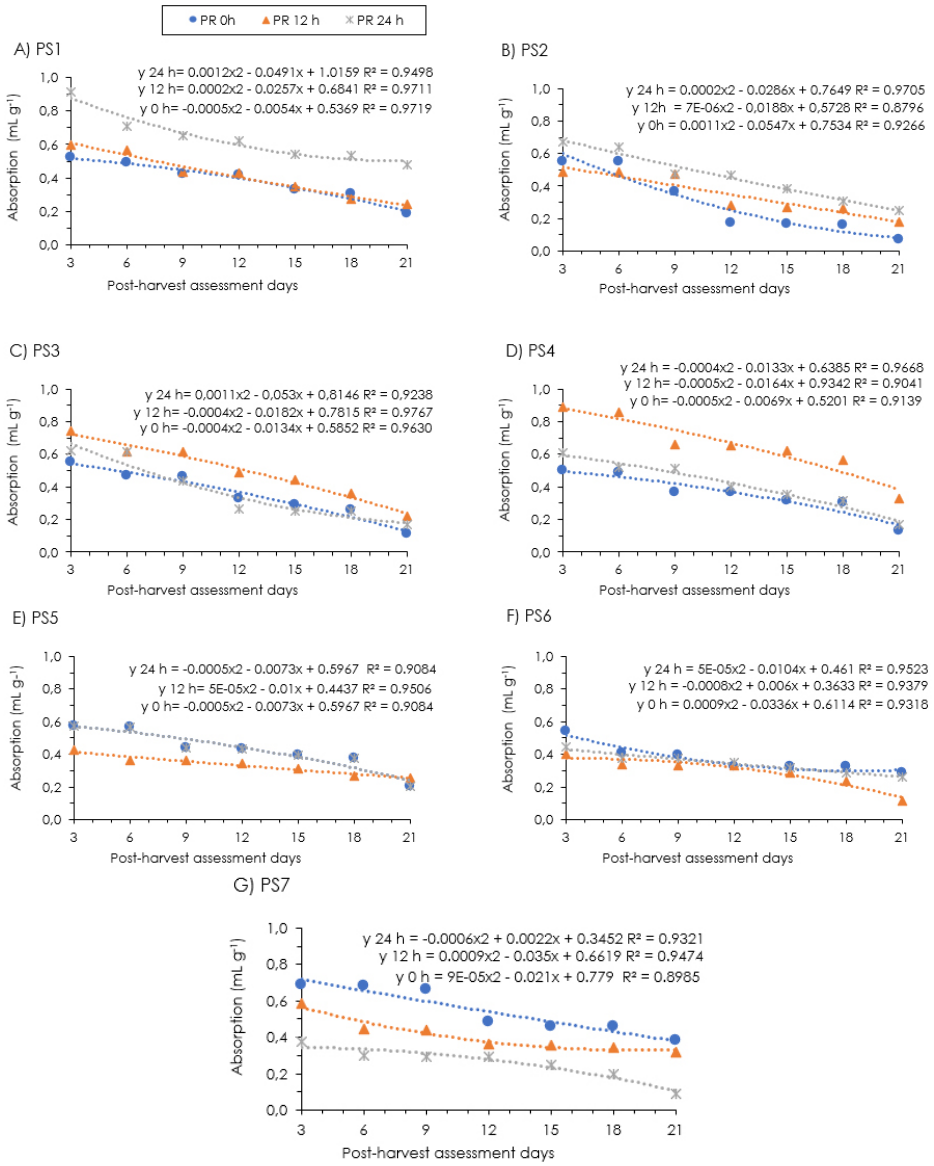

Figure 2. Progressive means of absorption of preservative solutions from safflower (*Carthamus tinctorius* L.) flower stems in post-harvest, evaluated 3, 6, 9, 12, 15, 18 and 21 days after harvest. Pre-cooling periods were (PR) 0, 12 and 24 h after collection and standardization of flower stems. The preservative solutions consisted of: PS1: Distilled water (control); PS2: distilled water + 2% sucrose; PS3: Distilled water + 2% sodium hypochlorite; PS4: Distilled water + 2% sucrose + 2% sodium hypochlorite; PS5: Distilled water + 20 mg L^{-1} gibberellic acid; PS6: Distilled water + 20 mg L^{-1} citric acid and PS7: Distilled water + 20 mg L^{-1} salicylic acid.

In Figure 3, it can be seen that the progressive means of dehydration of safflower flower stems, in all preservative solutions and pre-cooling periods, were 4.5%, 17.8%, 24.6%, 32.6%, 35.3%, 36.6% and 39.2%, for evaluations performed on days 3, 6, 9, 12, 15, 18 and 21 days after collection. In visual observation, the stems submitted to 0 h of pre-cooling showed faster dehydration in relation to the other pre-cooling periods. For Nomura et al. (2014) and Sales et al. (2015), dehydration is the main process that accelerates the senescence of cut plants, with the depletion of its reserves immediately following detachment from the mother plant.

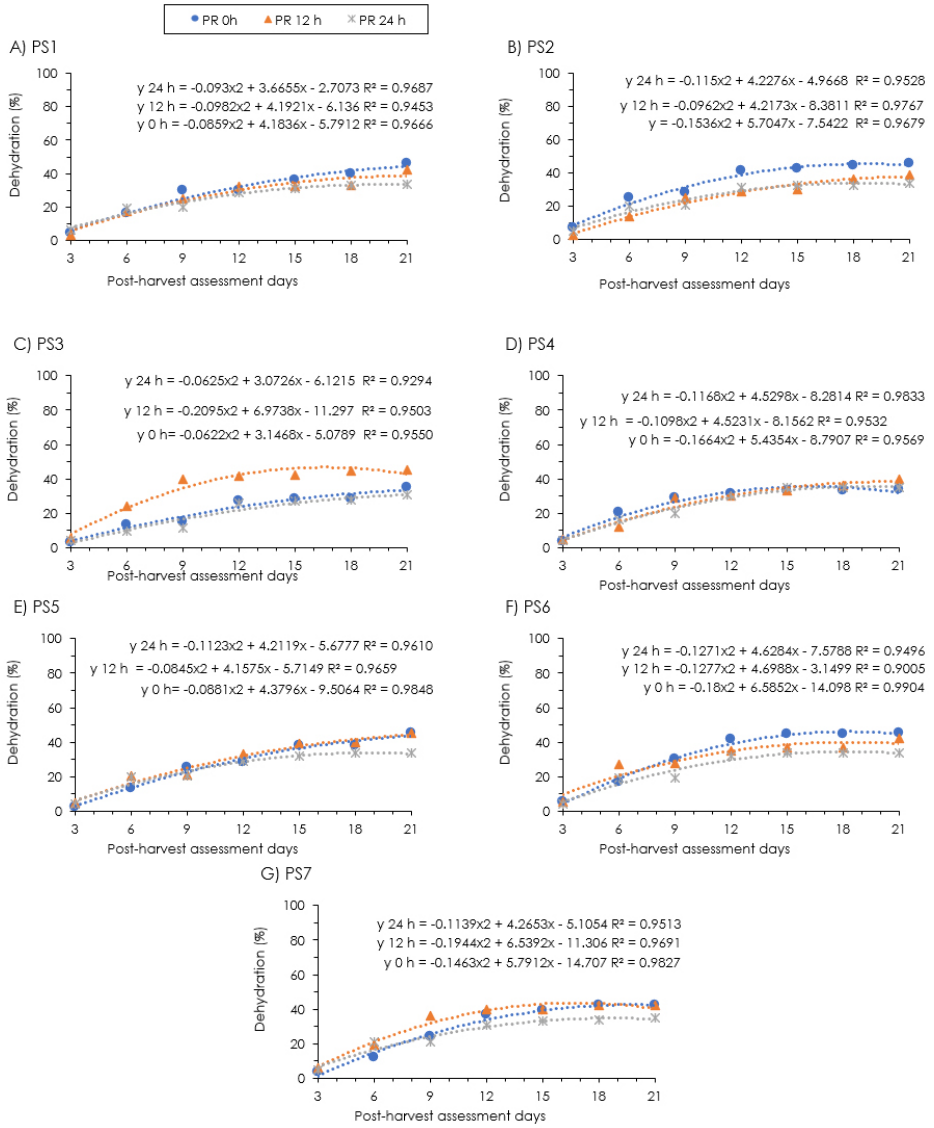

Figure 3. Progressive means of dehydration of safflower (*Carthamus tinctorius* L.) flower stems in post-harvest, evaluated 3, 6, 9, 12, 15, 18 and 21 days after harvest. Pre-cooling periods were (PR) 0, 12 and 24 h after collection and standardization of flower stems. The preservative solutions consisted of: PS1: Distilled water (control); PS2: distilled water + 2% sucrose; PS3: Distilled water + 2% sodium hypochlorite; PS4: Distilled water + 2% sucrose + 2% sodium hypochlorite; PS5: Distilled water + 20 mg L^{-1} gibberellic acid; PS6: Distilled water + 20 mg L^{-1} citric acid and PS7: Distilled water + 20 mg L^{-1} salicylic acid.

According to Silva et al. (2008) and Menegaes et al. (2018), the use of preservative solutions combined with pre-cooling is a valid practice, aiming to prolong the postharvest durability of gladiolus flower stems (*Gladiolus* x *hortulanus*) and murraia leaf stems.

Conclusion

Combining the use of preservative solutions with pre-cooling improves the maintenance of fresh safflower (*Carthamus tinctorius* L.) flower stems in post-harvest, with an average vase life of up to 12.0 days using a solution composed of distilled water + 20 mg L^{-1} citric acid (PS6) combined with a 24-hour pre-cooling period.

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