Acta Botanica Brasilica, 2023, 37: e20230100
doi: https://doi.org/10.1590/1677-941X-ABB-2023-0100

Original article

Exploring the impact of dry conditioning on the postharvest quality and longevity of torch ginger flower stems

Antonio Rodrigues da Cunha Neto[1], Patrícia Duarte de Oliveira Paiva[1*], Marina Romano Nogueira[1], Ângela Maria Pereira do Nascimento[2], Heloisa Oliveira dos Santos[1] and Michele Valquíria dos Reis[1]

Received: April 29, 2023
Accepted: September 19, 2023

ABSTRACT

Dry conditioning and sucrose pulsing are techniques used to improve the durability of flower stems. Dry conditioning helps to balance the osmotic potential of the flower stems and can be applied after harvest and transportation. The objective was to evaluate how different dry conditioning times followed by sucrose pulsing may affect the postharvest quality, durability, and physiological aspects of torch ginger flower stems. For this purpose, flower stems were collected and submitted to dry conditioning for different periods: 0-h, 3-h, 6-h, 12-h, and 24-h. Every 3 days, visual quality, percentage of true flowers, absorption rate, water content, fresh and dry weights, and colorimetric parameters were evaluated. The concentration of pigments, biochemistry of the antioxidant system, and macromolecules were analyzed. Dry conditioning for more than 12-h is not recommended as it leads to a loss of quality and durability in torch ginger flower stems and accelerates senescence. The absorption rate decreases and pigments break down after this period, while H_2O_2 and lipid peroxidation concentrations increase. Furthermore, sugar and protein reserves are consumed during senescence. It is recommended to hydrate harvested stems immediately to avoid the negative effects of dry conditioning on postharvest quality and durability.

Keywords: Antioxidant system; durability; *Etlingera elatior*; senescence; water stress.

Introduction

Postharvest practices encompass a series of procedures designed to uphold quality, enhance durability, and minimize losses of flower stems. Conditioning, when performed correctly, is a fundamental process for attaining these objectives (Carneiro *et al.* 2014; Malakar *et al.* 2023).

For the conditioning of torch ginger flower stems, it is recommended to harvest them early in the morning and promptly transport them for processing. Throughout this procedure, it is advisable to keep the stems immersed in water to maintain the hydration of the torch ginger (Nogueira *et al.* 2023). The most common conditioning method from harvest to commercialization involves

1 Universidade Federal de Lavras (UFLA), Escola de Ciências Agrárias, Departamento de Agricultura, Lavras, MG, Brazil.
2 Empresa de Pesquisa Agropecuária de Minas Gerais, São João Del Rei, MG, Brazil.

* Corresponding author: patriciapaiva@ufla.br

immersion in a solution. However, unlike dry conditioning, this method presents certain drawbacks that vary according to the species, including reduced postharvest quality and occupying a considerable amount of space within the cold chamber (Almeida *et al.* 2011; Cunha Neto *et al.* 2023).

Thus, dry conditioning has been investigated as an alternative for some species that tolerate water absence, such as the genus *Gladiolus*. Dry conditioning prevents flower opening, thereby prolonging stem durability. Upon hydration, flower opening begins. However, dry conditioning for a prolonged period, such as exceeding 36 hours for *Gladiolus*, can be detrimental, inducing physiological stress and injuries (Costa *et al.* 2017).

Dry conditioning can be employed for calla lilies for up to 6 days; nonetheless, pretreatment involving immersing the stems in sucrose or water for 1 hour is necessary (Almeida *et al.* 2011). Otherwise, for many species, dry conditioning is ineffective as wilting and senescence of flower stems are closely associated with water deficit. Continuous reductions in water uptake can lead to stress and alterations in the physiology of the flower stems (Costa *et al.* 2021).

Water stress due to water limitation occurs when the water absorption rate is lower than the transpiration rate of the stem. Consequently, there is low hydraulic conductance, microbial growth, the formation of air bubbles, deposition of suberin and lignin in the xylem vessels, and deposition of pectin and phenols. These factors significantly impact the postharvest quality of stems, thereby restricting their overall quality and durability (Costa *et al.* 2017; Sales *et al.* 2021).

Moreover, the process of harvesting ornamental plants can be costly due to the necessity of maintaining stem hydration consistently after cutting. Therefore, the present study aimed to evaluate the effects of dry conditioning for different periods of time on the quality and physiological aspects of torch ginger after harvest. Moreover, we aimed to elucidate whether the stems of this species are tolerant to periods without immersion in water, whether dry conditioning alters the physiology and biochemistry of floral stems, and whether these changes are related to stress conditions.

Material and methods

Evaluation of a dry conditioning period during flower stem storage

Flower stems of *Etlingera elatior* cv. 'Porcelain' were harvested at a semi-open stage in relation to the inflorescence aperture point, selecting those without true flowers (Mattos *et al.* 2018). The flower stems were obtained at the Federal University of Lavras, in the Ornamental Plants sector, responsible for cultivating tropical flowers. The average diameter of the stems was 1.2 cm +/- 2 mm, with a weight of 290 g. The flower stems were cleaned and standardized to 45 cm from the base of the stem to the beginning of the inflorescence. The treatments consisted of conditioning periods without water after harvest, which were 0 h (control), 3-h, 6-h, 12-h, and 24-h. After this period encompassing the tested treatments, the stems were placed in a 15% sucrose pulsing solution for 24-h and then transferred to fully sealed containers containing 1 L of distilled water, maintaining a temperature of 21 °C and 70% relative humidity.

Commercial quality of flower stems

The visual quality of torch ginger flower stems was assessed by three evaluators until all treatments scored a grade of 3, which represents the limit for commercialization, based on criteria described in Table 1 by Carneiro *et al.* (2014).

In addition to visual quality, the percentage of stems with emerged true flowers after harvest; flower stems absorption rate, the fresh mass (g) and dry mass (g) of torch ginger stems, and water content (%) were evaluated using a scale for analytical precision. The absorption rate was determined by measuring the volume of water consumed in mL/stem/day, while the water content (%) was calculated using equation 1 (Sales *et al.* 2021):

(Eq 1) water contents (%) = [(fresh weight (g) - dry weight (g))/fresh weight (g)] × 100%

Table 1. Criteria for assigning scores to evaluate the visual quality of torch ginger inflorescences.

Score	Rating	Description
4	Excellent	Stems and inflorescences are turgid, with bracts exhibiting brilliance and characteristic coloration.
3	Good	Beginning of turgor loss (only sensitive to touch), with or without the beginning of fading and/or wilting of the edges of the bracts and stems.
2	Regular	Decline in bracts due to a visible loss of turgor and brightness of the inflorescence and stem. Borders of the bracts with a wilted appearance.
1	Bad	Loss of pronounced turgor of bracts and/or stems; edges of bracts translucent; central part of the inflorescence softened.
0	No quality	Trash: bracts that are soft and/or dry, with a soggy appearance and rotting of the central part of the inflorescence, leading to abscission of the bracts.

Source: Carneiro *et al.* (2014).

Colorimetric analyses

The changes in color were also analyzed using a colorimeter (Konica Minolta®, CM-5, Osaka, Japan) at a 10 ° angle and illuminant D65 (daylight). Three fully expanded bracts of each inflorescence, located in the second outermost row, were measured with the colorimeter positioned in the middle portion of the bract. The parameters a* (dimensionless) for the red (positive values) and green (negative values) wavelengths; b* (dimensionless) representing the yellow (positive values) and blue (negative values) wavelengths, and L* (dimensionless) indicating the luminosity of the sample (the more positive the value, the lighter the sample; the more negative the value, the darker the sample) were measured. Chroma (dimensionless) corresponds to the color purity (the stronger and brighter the color, the more distant it is from the origin of the coordinates). Additionally, the Hue angle was calculated using equation 2, defining the color hue (Lago *et al.* 2020).

(Eq 2) °h = tangent-1(b*/a*)

Quantification of carotenoids and anthocyanins

The carotenoid concentration (μg g^{-1} MF) was quantified by extracting 0.2 g fresh mass samples in 80% acetone. The concentration of carotenoids was determined from the extracts using a spectrophotometer at absorbance wavelengths of 470, 646.8 and 663.2 nm based on the equation 3 (Lichtenthaler & Wellburn 1983):

(Eq 3) Total carotenoids = [1000ABS470-1.82 (12.25ABS663.2-2.79ABS646.8) - 85.02 (21.50ABS646.8-5.10ABS663.2)] 198

Where ABS = absorbance

For the extraction of anthocyanins, 1 g of the sample was weighed and ground, and then 30 mL of the extraction solution (95% ethanol + 1.5 N HCl) was added at a ratio of 85:15. The samples were homogenized and filtered, and the readings were taken at 535 nm following equation 4 (Francis 1982):

(Eq 4) Anthocyanin = (ABS535 x dilution factor)/98.2

Where ABS = absorbance

Hydrogen peroxide and lipid peroxidation quantification

Samples of fully expanded bracts, located in the second outermost row of each inflorescence, weighing 0.2 g, were macerated in liquid nitrogen with 20% polyvinylpyrrolidone (PVP) (m/v), homogenized in 1.5 mL of 0.1% (w/v) trichloroacetic acid (TCA), and centrifuged at 12,000 × g for 15 minutes at 4 °C. The concentration of hydrogen peroxide (H_2O_2) was determined by measuring the absorbance at 390 nm in a reaction medium containing 100 mM potassium phosphate buffer at pH 7.0 and 1 M potassium iodide (Velikova *et al.* 2000).

Lipid peroxidation was determined by quantifying the reactivity of species to thiobarbituric acid (TBA), as described by Buege and Aust (1978). Samples weighing 0.2 g were macerated in liquid nitrogen supplemented with 20% PVP (w/v) and homogenized in 1.5 mL of 0.1% TCA (w/v). The homogenate was centrifuged at 12,000 × g for 15 minutes at 4 °C. Aliquots of the supernatant (250 μL) were added to the reaction medium, which included 0.5% TBA (w/v) and 10% TCA (w/v), and then incubated at 95 °C for 30 minutes. Rapid cooling on ice halted the reaction, and the absorbance readings were taken at 535 nm and 600 nm using a spectrophotometer.

Analysis of superoxide dismutase and catalase

Using electrophoresis, the expression of the enzymatic activities of superoxide dismutase (SOD) and catalase (CAT) was determined by extracting 1 g of fresh matter (FM) in 0.2 M Tris-HCl buffer at pH 8.0 with 0.1% beta-mercaptoethanol for SOD and CAT. The material was vortexed and refrigerator for 12 hours, followed by centrifugation at 14,000 rpm for 30 minutes at 4 °C. The electrophoretic run was conducted using a polyacrylamide gel system with a discontinuous setup, consisting of a 7.5% separating gel and a 4.5% stacking gel. Tris-glycine running buffer with a pH of 8.9 was used. A volume of 60 μL of the sample supernatant was applied to the gel, and the electrophoretic run was performed at 150 V for 5 hours. After the run, the gels were used to detect the activities of SOD and CAT enzymes, following the methods described by Silva Neta *et al.* (2020).

Concentration of total soluble sugars, reducing sugars, and proteins

To assess the macromolecules associated with primary metabolism, 0.2 g of dry mass was extracted using 0.1 M potassium phosphate buffer (pH 7.0) and incubated in a water bath at 40 °C for 30 minutes. Then, the extract was centrifuged at 10,000 G for 20 minutes, and the supernatant was collected. Additional buffer was added, and the centrifugation process was repeated. The collected supernatant was promptly stored at -80 °C. Total soluble sugars, reducing sugars, and proteins were quantified using the Anthrone, Dinitrosalicylic acid (DNS), and Bradford spectrophotometric methods, respectively, following the protocols by Yemm and Willis (1954) and Miller (1959) and Bradford (1976), with some modifications.

Statistical analyses

The experiment was replicated twice using a completely randomized design with three repetitions, with 3 stems per plot, in a double factorial scheme (5 treatments x 5 evaluations). As treatment, we considered five dry conditioning periods, with five evaluations performed on different days. The results were obtained from the means of the two replicates, and the data were tested for normality using ANOVA and subjected to regression analysis. For the parameters of visual quality and absorption rate, the Skott-Knott test was performed using Sisvar software, version 5.6 (Ferreira 2019).

Results and discussion

According to the senescence scale, inflorescences with a score below 3 do not possess the optimal qualitative characteristics for commercialization and should be discarded. Therefore, all the selected flower stems had scores higher than "4". Among the various dry conditioning periods, the flower stems that remained dry for 24 hours exhibited a decrease in visual quality compared to those that maintained a maximum score (Fig. 1, Fig. 2).

On the 5th day of evaluation, all the stems remained suitable for commercialization with a score higher than 3. The control treatment exhibited the highest score, followed by the flower stems subjected to dry conditioned for 3-h, 6-h , and 12-h. The flower stems that underwent 24-h of dry conditioning received a score of 3, indicating the lowest score on the evaluation day.

On the 8th day, the flower stems in the control treatment obtained the highest score, followed by those in the treatments where the stems underwent dry conditioning for 3-h, 6-h, and 12-h. These stems received scores of 3, indicating their continued suitability for commercialization. The stems that were subjected to 24-h of dry conditioning received a score of 2, rendering them unsuitable for sale.

On the 11th day, all the stems had a score of less than 3, and the stems in the control treatment and those that underwent dry conditioning for 3-h, 6-h, and 12-h had similar scores, ranging from 2 to 2.5. The stems that received 24-h of dry conditioning obtained a score of 1 due to the high degree of senescence.

Observing the stages of senescence in flower stems and quantifying them using grades enables us to standardize the characteristics of commercial quality, thereby enhancing cultivation, harvesting, and distribution processes, while considering transportation time (Mattos *et al.* 2020). The results indicated that torch ginger stems could tolerate up to 12-h of dry conditioning. Nevertheless, the highest quality was achieved by keeping the stems continuously immersed in water.

The torch ginger stems were collected at the recommended opening stage, as described by Mattos *et al.* (2020), with no presence of fully bloomed flowers. Prior to the sucrose pulsing treatment, conducted two days after harvest, there were no flowering true flowers observed. However, following this period, the stems underwent 24-h of dry conditioning were the first to exhibit true flowers, appearing on 20% of the stems. By the 5th day, true flowers began to bloom on the stems subjected to all other treatments, with 20% of the stems displaying true flowers. Among the stems that received the 24-hour dry treatment, this percentage increased to 60% (Fig. 3).

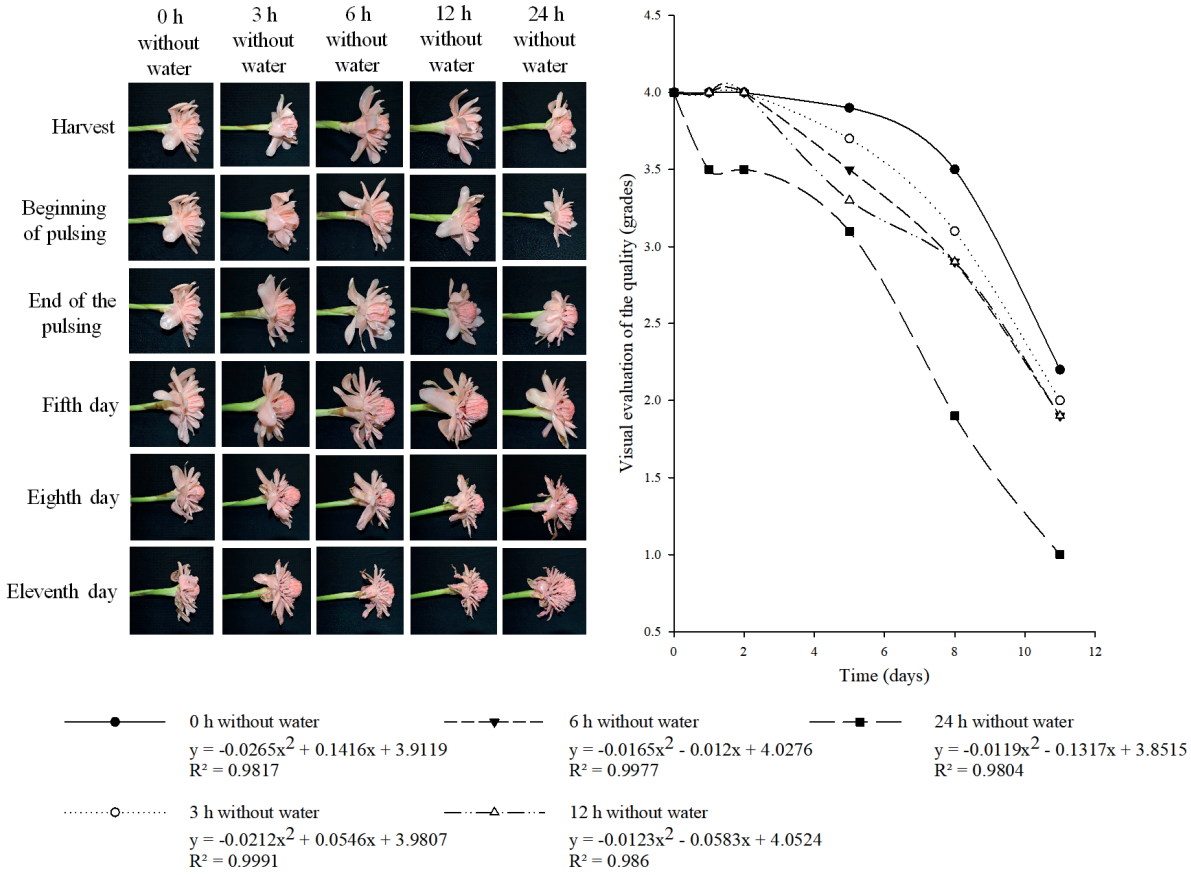

Figure 1. Visual assessment of the quality (grades) of torch ginger flower stems exposed to various postharvest dry conditioning periods.

The patterns observed on the 8th and 11th days of evaluation were similar, with 100% of the stems included in the 12-h and 24-h dry treatments exhibiting true flowers. In contrast, the maximum percentage of stems with true flowers observed in the remaining treatments was 60%.

With an extended dry conditioning period followed by rehydration during post-harvest, the stems absorbed a greater amount of water, consequently facilitating the opening of the true flowers and maintaining fresh mass through cell turgidity. Water supply is one of the factors influencing anthochron, which is the time interval between successive flower openings in inflorescences, as it can impact water stress and the translocation of stem sugars during flowering (Schwab *et al.* 2014).

Anthochron is a factor that influences commercial quality as it measures the rate of flower opening. A faster anthochron leads to quicker mobilization of reserves to sustain floral stem metabolism, consequently accelerating senescence. In both gladiolus and torch ginger flower stems, the sequential opening of flowers was faster among stems receiving lower water supply and slower among those receiving higher water supply (Santos *et al.* 2021).

These findings indicate that the postharvest opening of flower stems is closely linked to water availability and significantly influenced by the rehydration process following dry conditioning (Santos *et al.* 2021). This correlation is observed in torch ginger stems, where rehydration after extended dry conditioning periods (12-h and 24-h) promotes the accelerated opening of true flowers, resulting in more rapid quality deterioration.

Regarding water absorption (Fig. 4A), the dry conditioning treatments of 6-h, 12-h, and 24-h exhibited the lowest rates. By the 8th day, the absorption rates decreased for all the treatments compared to the previous evaluation. Stems subjected to 3-h and 6-h dry conditioning displayed similar values, while lower absorption rates were observed for the 12-h and 24-h treatments. The same patterns observed on the 8th persisted during the 8th day evaluation.

Dry conditioning can induce stress due to water deficit, which accelerates the senescence process, depletes reserves, and triggers stomatal closure, resulting in reduced transpiration and increased CO_2 accumulation. Consequently, these factors lead to a decrease in water absorption rate (Piroli *et al.* 2020), as observed in torch ginger stems. Stems subjected to longer dry conditioning periods, specifically 12-h and 24-h, experienced greater reductions in absorption rates and water content and, ultimately affecting their quality, even after rehydration through sucrose pulsing.

The torch ginger stems exhibited a water content of 93% immediately after harvest (Fig. 4B). Following dry conditions, a similar pattern of reduction in water content was observed across all stems, indicating water loss and a decrease in the percentage of their moisture content. When comparing the different treatments groups, the control stems maintained the highest water content, reaching 90% on the 11th day of evaluation. This was followed by the 3-h and 6-h treatment stems, which had a water content of 86%. In contrast, the stems that underwent 12-h and 24-h of dry conditioning exhibited lower water content, measuring below 84%.

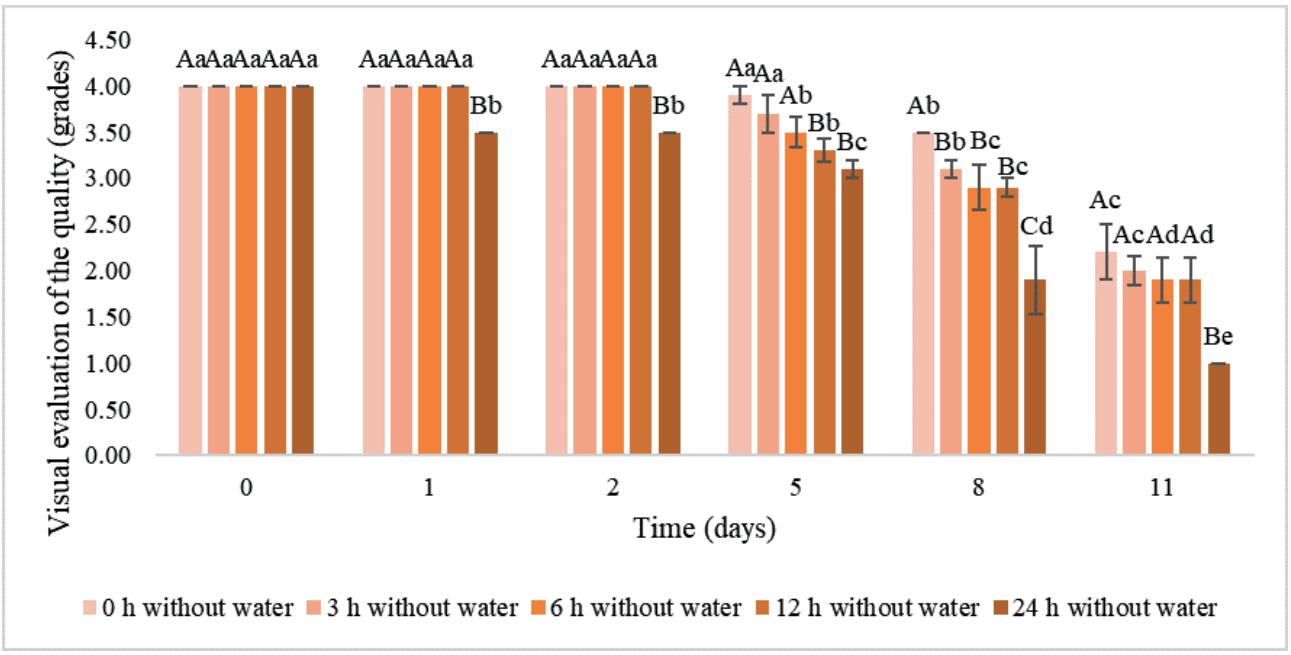

Figure 2. Visual assessment of the quality (grades) of torch ginger flower stems exposed to various postharvest dry conditioning periods. Means sharing the same uppercase letter (Treatment comparison within the same time) and lowercase letters (Comparison between times within the same treatment) indicate no significant difference based on the Scott-Knott test, with a 5% error probability. The bars represent the standard errors.

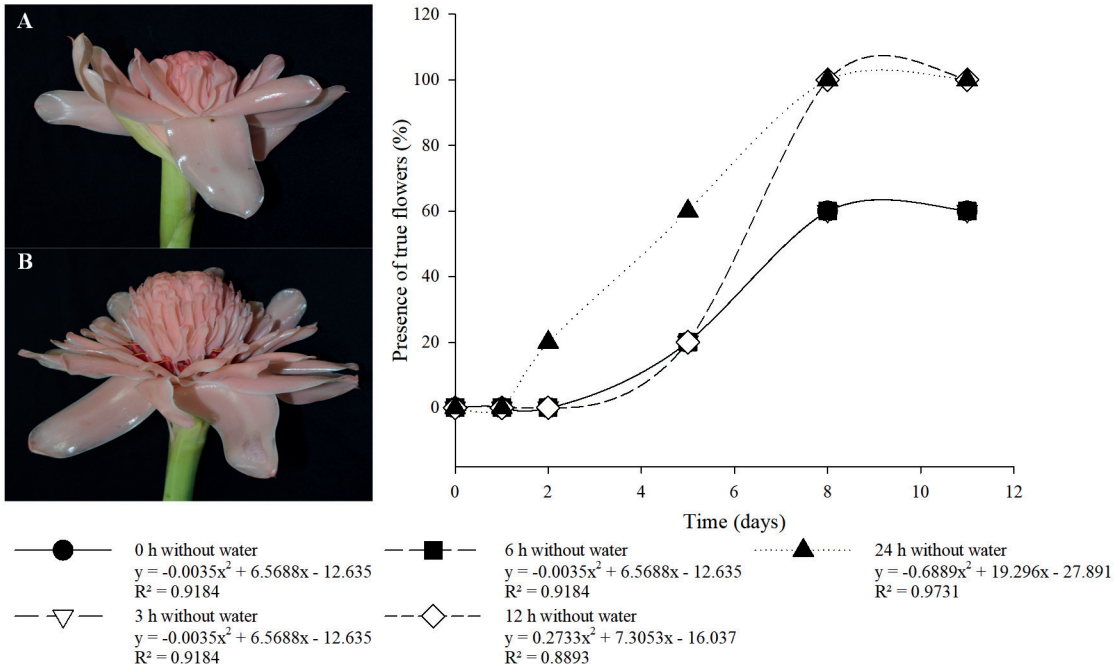

Figure 3. Presence of true flowers (%) on torch ginger stems subjected to various postharvest dry conditioning durations. (**A**) Representative stem harvested without the presence of a true flower. (**B**) Floral stem illustrating the occurrence of a true flower in the treatments.

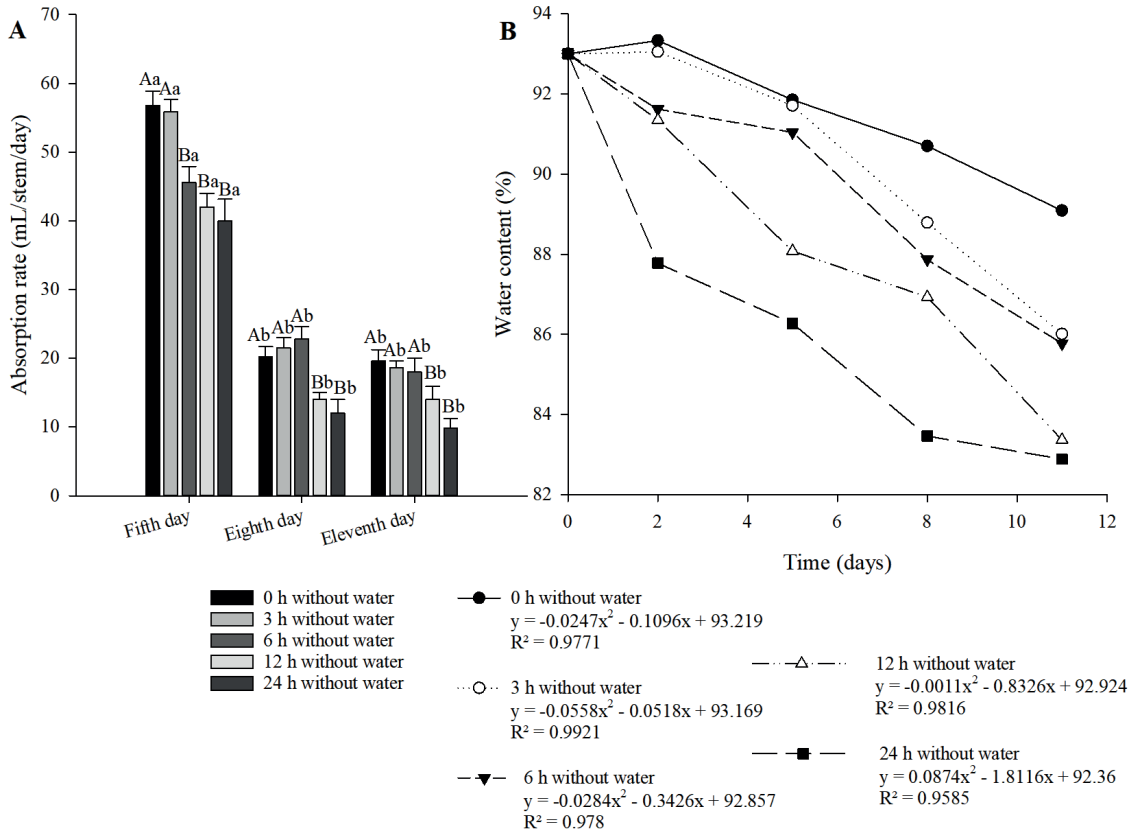

Figure 4. (**A**) Absorption rate (mL/stem/day) and (**B**) water content (%) of the torch ginger flower stems subjected to various postharvest dry conditioning durations. Means sharing the same uppercase letter (Treatment comparison within the same time) and lowercase letters (Comparison between times within the same treatment) indicate no significant difference based on the Scott-Knott test, with a 5% error probability. The bars represent the standard errors.

The turgor of a flower stem is contingent upon the equilibrium between absorption and transpiration rates, as well as various physiological processes governing water transport, loss, and tissue water retention – all factors affecting water content. Mass loss can be attributed to transpiration, which diminishes water absorption. This reduction may arise from xylem obstruction caused by microorganisms and air bubbles, or it may be influenced by genetically determined factors (Santos *et al.* 2021).

When evaluating the fresh and dry weights of the stems (Fig. 5A), similar patterns were observed between these two parameters. The control treatment and the 3 hours dry conditioning treatment exhibited the highest mass, while the stems subjected to 24-h of dry conditioning had the lowest fresh weights. It is worth noting that the greatest mass loss in all treatments occurred between the conclusion of sucrose pulsing and the 5th day of evaluation, particularly in the stems that underwent dry conditioning for durations exceeding 6 hours.

In contrast to fresh weight, dry weight (Fig. 5B) exhibited the most significant reduction for all treatments between harvest and the conclusion of sucrose pulsing. Regarding the different treatments, the stems in the control and 3-h dry conditioning groups displayed higher dry weights. The stems submitted to the 24-h dry condition had the lowest dry weights in all evaluations.

Studies indicate that, similar to torch ginger stems, there is a decline in fresh and dry masses of flower stems within the initial days following harvest. This decline is attributed to natural transpiration and reductions in absorption rates due to hydraulic conductance limitations in the xylem. This process is intensified in stems that undergo dry

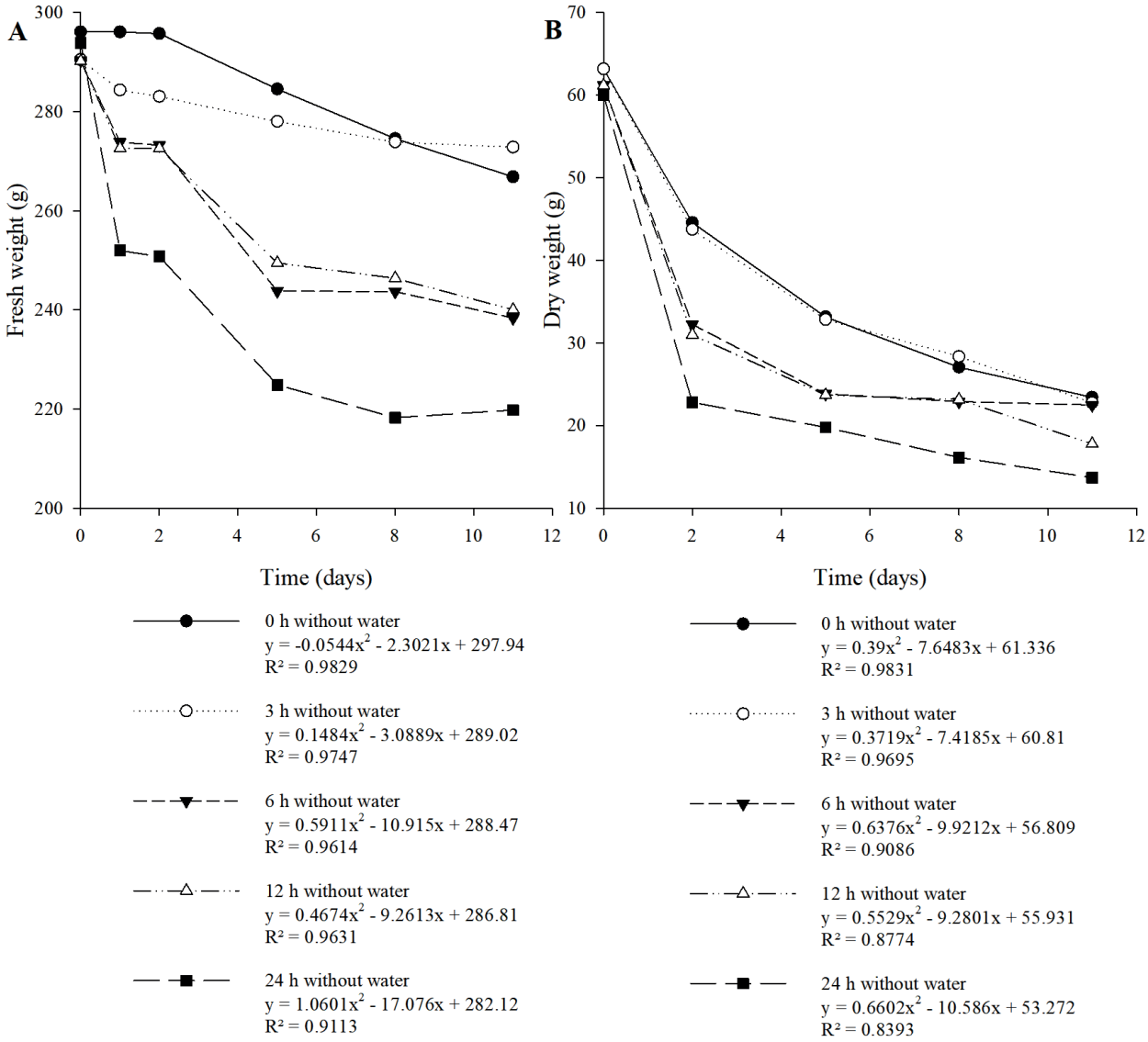

Figure 5. (**A**) Fresh weight (g) and (**B**) dry weight (g) of torch ginger flower stems subjected to various postharvest dry conditioning durations.

conditioning, which is one of the primary causes of turgor loss contributing to product deterioration, as observed through visual quality analysis (Santos *et al.* 2021).

Regarding the colors of the bracts, among the parameters evaluated by the colorimeter, the hue angle (h°) determines the color quadrant in which a sample is located. Values between 0° to 90° fall within the red spectrum. The torch ginger stems obtained an average hue angle of 40.50°, which justifies the analysis of parameter a*. The analysis of parameter b* did not identify any differences between treatments over time (value of 20.90). This analysis corresponds to the blue range for negative values and yellow range for positive values. The parameter C* had an average value of 27.05, indicating that there were no significant differences between treatments.

Positive values of the parameter a* were observed for the torch ginger stems (Fig. 6A), which indicate the intensity of the red color. These values increased as the conditioning time progressed, indicating the occurrence of senescence. The stems kept in the control and the 3 hours treatment exhibited similar behavior, with slight changes in the red color. The stems subjected to the 12-h and 24-h dry conditioning treatments showed the most pronounced change in the red color, especially between the 5th and 8th days of evaluation, indicating the progress of the senescence process.

The parameter L* (Fig. 6B) quantifies the quality of light and brightness in numerical values. Consequently, the torch ginger stems, regardless of the treatment, exhibited similar behavior until the 8th evaluation, maintaining consistent values since the harvest period. Distinctions began to emerge on the 11th day of evaluation when the values decreased significantly, and greater reductions were observed in the conditioned stems.

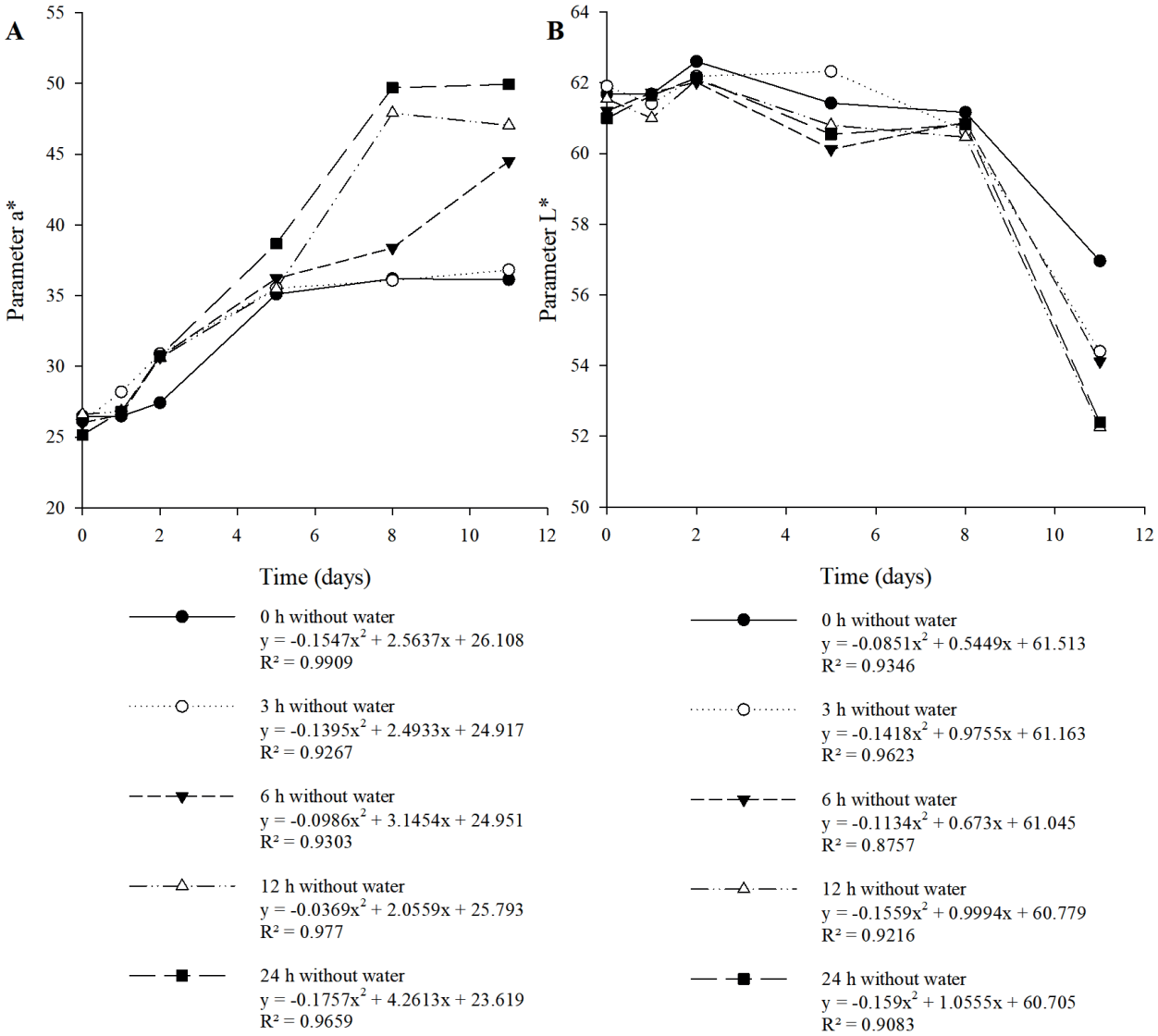

Figure 6. The parameters (**A**) a* (dimensionless) and (**B**) L* (dimensionless) were assessed for the torch ginger flower stems that underwent various postharvest dry conditioning durations.

It is possible to establish a correlation between the parameters analyzed by the colorimeter and the scores related to visual quality. Noticeable changes in the parameters a* and L* took place on the 5th and 8th evaluation days, respectively, corresponding to periods when the visual quality declined, receiving the lowest scores.

Changes in color can indicate the stage of senescence. The intensification of red color is linked to the oxidation process of the bracts, as it is associated with the breakdown of molecules, such as sugars, through reactions with oxygen (Endo *et al.* 2007). The utilization of a colorimeter reinforces and improves the accuracy of visual quality evaluations (Mattos *et al.* 2020).

The reduction in the L* parameter of the torch ginger stems initiated on the 8th day after harvest, signifying a decrease in brightness and an increase in bract browning caused by stress-induced injuries and senescence. Darkening and loss of brightness can occur due to water loss, as evidenced by parameters such as absorption rate, water content, and fresh mass. These factors lead to cellular disruption and the presence of anthocyanin, the pigment responsible for the red color, which undergoes color changes due to oxidative enzymes (Mattos *et al.* 2020).

The concentration of carotenoids (Fig. 7B) and anthocyanins (Fig. 7C) did not undergo any changes during the period between harvest and the completion of sucrose pulsing. However, a notable shift in both pigments occurred between the end of sucrose pulsing and the 5th day post-harvest, with an increase in carotenoid concentration and a decrease in anthocyanin concentration. In addition, no significant difference was observed in the concentration of anthocyanin, whereas higher concentrations of carotenoids were found in the stems subjected to 24-h of dry conditioning.

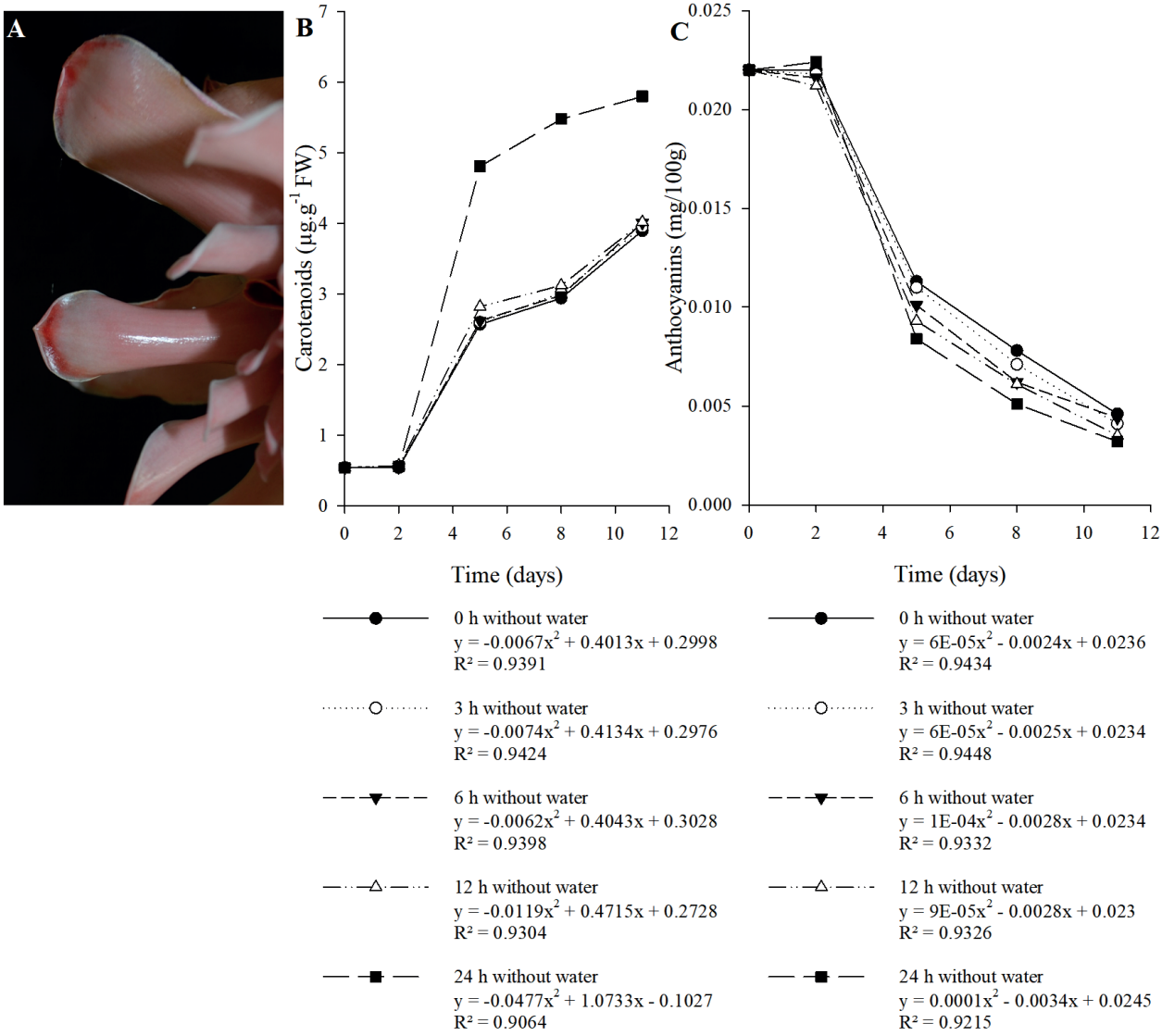

Figure 7. (**A**) Detailed view of color alterations occurring at the edges of the stems following 24 hours of dry conditioning. (**B**) Concentration of carotenoids and (**C**) anthocyanins in the torch ginger flower stems treated with different postharvest dry conditioning times.

The increase in carotenoid concentration in the torch ginger stems was found to be correlated with the rise in red color quantified by the colorimeter. This pigment is responsible for mitigating damage caused by stress to the photosynthetic apparatus. Increasing the concentration of this pigment can be a strategy to dissipate excess light energy under water deficit conditions, in which carotenoids play a photoprotective role (Silva *et al.* 2016).

The degradation of anthocyanins observed in the torch ginger stems is linked to the increase in H_2O_2 levels (Fig. 8). This flavonoid act as a non-enzymatic antioxidant that is essential for the homeostasis of flower stems, and its production helps mitigate intracellular oxidative stress (Moustaka *et al.* 2020).

The torch ginger stems that underwent 12-h and 24-h of dry conditioning demonstrated a higher concentration of H_2O_2 production (Fig. 8A) compared to the stems in the other treatments. The concentration of H_2O_2 increased gradually over time, showing a correlation with the senescence of the stems.

A similar pattern was observed for lipid peroxidation (Figure 8B). The torch ginger stems that underwent 12-h and 24-h of dry conditioning displayed a higher concentration of peroxidation compared to the other stems, and this phenomenon intensified upon rehydration. In terms of the duration of dry condition, the stems in the control, 3-h and 6-h treatments exhibited an increase in lipid peroxidation, indicating the onset of senescence in the stems on the 8th day.

The rise in hydrogen peroxide levels in the torch ginger stems treated with 12-h and 24-h of dry conditioning is linked to water stress and senescence. This oxidative process occurs because hydrogen peroxide is one of the reactive oxygen species that causes oxidative damage to the cell's lipid membrane (Bhattacharjee 2005).

The senescence of flower stems and the occurrence of stress may be linked to the concentration of malondialdehyde (MDA), which serves as an indicator of lipid peroxidation. The increase in MDA begins upon the cutting of the floral stem and continues throughout the vase life (Pourzarnegar *et al.* 2020).

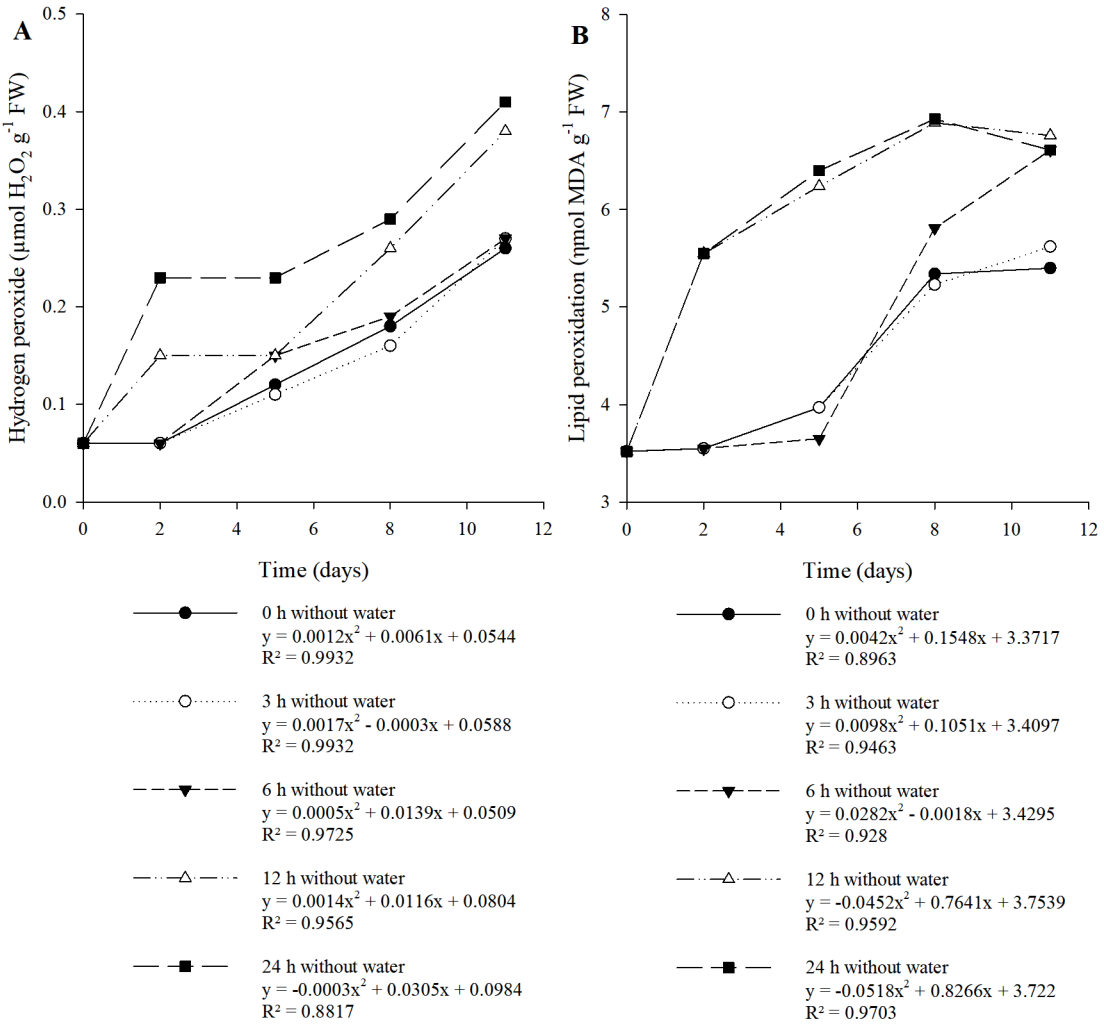

Figure 8. (**A**) Hydrogen peroxide and (**B**) lipid peroxidation in the torch ginger flower stems exposed to various postharvest dry conditioning durations.

Analyzing the activity of the enzymes superoxide dismutase (SOD) and catalase (CAT), no expression was detected, even in the stems that underwent the dry conditioning process. The absence of these enzyme activities, coupled with lipid peroxidation and the rise in H_2O_2 levels, contributes to understanding the effects of dry conditioning on the quality and durability of torch ginger stems. Dry conditioning induces an increase in reactive oxygen species (ROS), and the enzymes are degraded by anthocyanins, thereby accounting for the reduction in this pigment.

The enzymes of the antioxidant system, such as SOD and CAT, play a crucial role in protecting plant tissues against stress-induced damage during growth, development, and senescence. Studies have shown that a high concentration of activity of these antioxidant enzymes is associated with greater post-harvest longevity in floral stems (Ren *et al.* 2017). In contrast, Nogueira *et al.* (2023) investigated the antioxidant system of floral stems from the torch ginger species cv "Red Torch" and observed the absence of expression of the SOD and CAT enzymes, which may justify the low post-harvest longevity of this species. However, the authors found that the peroxidase enzyme remained active during the senescence of post-harvest stems.

The protein, total soluble sugars, and reducing sugars reserves in the torch ginger stems were reduced when exposed to dry conditioning. Initially, the stems conditioned for 0 and 3 hours did not exhibit reduced protein concentrations (Fig. 9A). The depletion of these reserves commenced on the 5th day, coinciding with the onset of senescence. In the stems subjected to the other treatments, the consumption of reserves began on the first day of evaluation, with the most substantial reduction occurring between the completion of sucrose pulsing and the 5th day of evaluation.

The concentrations of reducing sugars (Fig. 9B) and total soluble sugars (Fig. 8C) in the reserves decreased prior to the pulsing process and immediately after harvest when the stems were subjected to dry conditioning. The sugar concentration was maintained until the end of pulsing in the stems of the control treatment. The duration of dry

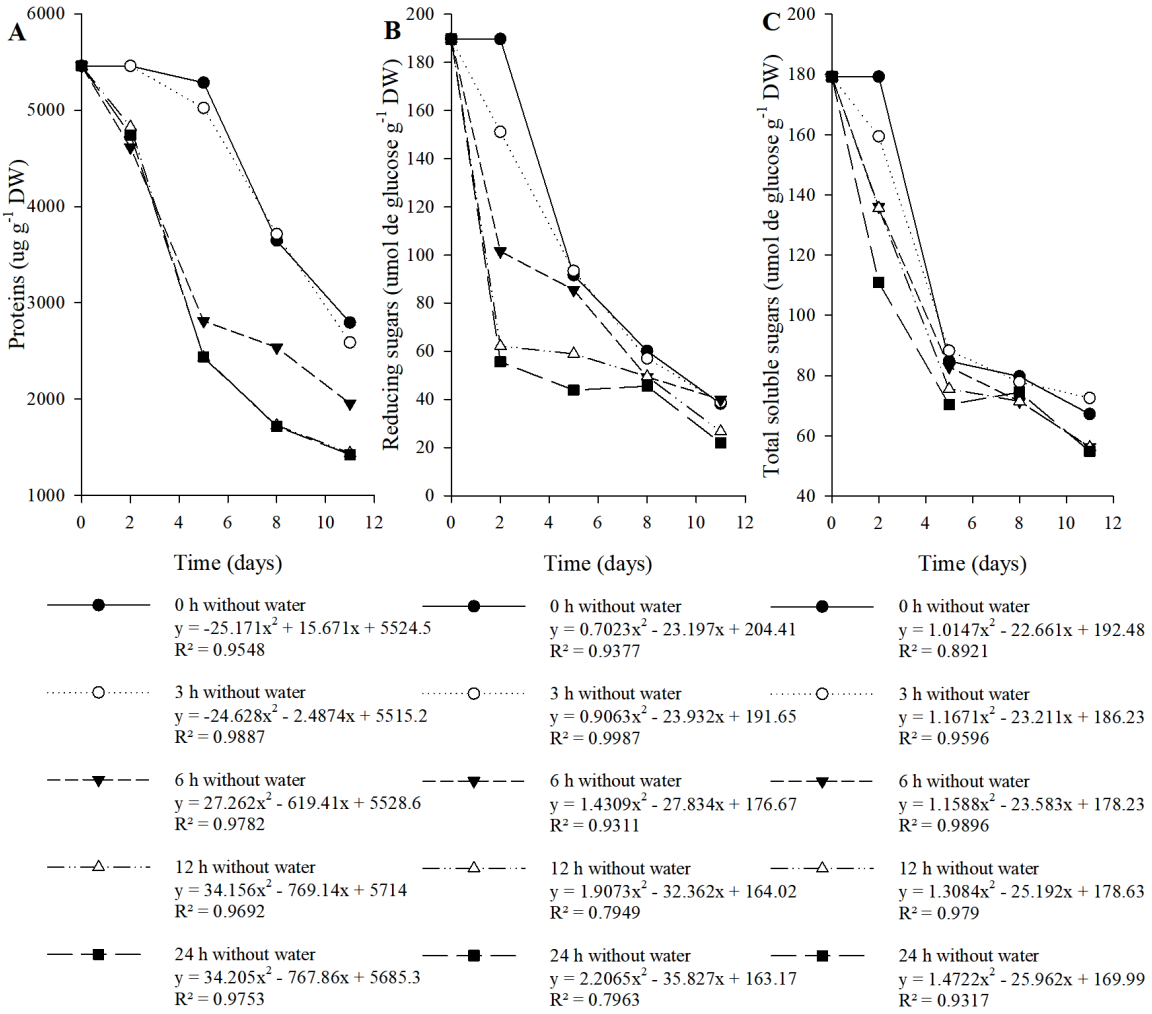

Figure 9. (**A**) Proteins, (**B**) reducing sugars and (**C**) total soluble sugars in torch ginger flower stems exposed to various postharvest dry conditioning durations.

conditioning is related to the depletion of sugars, as longer conditioning times are associated with a higher utilization of these reserves. In addition, among the available reserves for the torch ginger stems, the initial consumption of sugars was greater than that of proteins.

There is a correlation between protein concentration and senescence since, during the senescence process, there is an increase in proteolytic activity in the bracts and petals of flower stems. The breakdown of proteins depends on the species analyzed and the organ where the reserve is located (Rabiza-Świder *et al.* 2019), and in the case of torch ginger flower stems, protein breakdown begins after the 8th day from harvest, following the breakdown of sugars.

After harvest, the sugar reserves in the stems are no longer utilized for cell expansion and are translocated as an energy source to be used in cellular respiration. Due to the water stress caused by dry conditioning, the presence of sugar reserves leads to an influx of water, reducing the absorption rate, and consequently decreasing the fresh weight of the stems. In addition, it also induces floral opening, accelerating senescence and consequently reducing the quality (Sales *et al.* 2018).

Given the results, dry conditioning for more than 12-h is not recommended because it results in a loss of quality and durability and accelerates the senescence process in torch ginger stems. After this period, reductions become apparent in the absorption rate and pigment breakdown. In addition, it is evident that the stems experienced water stress due to dry conditioning, as indicated by increases in the concentration of H_2O_2 and lipid peroxidation. Another finding related to senescence and the stress induced by dry conditioning is the depletion of sugar and protein reserves, necessary for metabolic and respiratory processes.

Conclusions

Dry conditioning can cause several physiological alterations in torch ginger stems, including a reduction in absorption rates, water content, fresh and dry weights, as well as protein and sugar concentrations. Additionally, dry conditioning for 12-h and 24-h resulted in an increase in hydrogen peroxide concentration and lipid peroxidation in the stems, indicating water stress. Although the stems can tolerate up to 12-h of dry conditioning, their shelf life under these conditions was only eight days. Therefore, it is recommended to hydrated the stems immediately after harvest to preserve their post-harvest quality and durability.

Disclosure statement

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

Funding

The authors thank the govenmental agencies Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES – Brazil) and "CAPES/BRASIL PDPG-POSDOC No. 2930/2022", Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG – Brazil), and the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq – Brazil) for finantial support and scholarships

Author contributions

AR Cunha Neto: Data curation; Formal analysis; Investigation; Methodology; Writing - original draft. PDO Paiva: Conceptualization; Data curation; Funding acquisition; Project administration; Writing - review & editing. MR Nogueira: Data curation; Formal analysis; Investigation; Methodology. AMP Nascimento: Data curation; Formal analysis; Investigation; Methodology; Writing - original draft. HO Santos: Data curation; Writing - review. MV Reis: Conceptualization; Data curation; Project administration; Writing - review & editing.

Data Availability

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

Almeida EFA, Paiva PDO, Lima LCO, Silva FC, Fonseca J, Nogueira DA. 2011. Calla lily inflorescences postharvest: Pulsing with different sucrose concentrations and storage conditions. Ciência e Agrotecnologia 35: 657-663. doi: 10.1590/S1413-70542011000400003

Bhattacharjee S. 2005. Reactive oxygen species and oxidative burst: Roles in stress, senescence and signal transducation in plants. Current Science 89: 1113-1121.

Bradford MM. 1976. Um método rápido e sensível para a quantificação de quantidades de microgramas de proteína utilizando o princípio da ligação proteína-corante. Analytical Biochemistry 72: 248-254.

Buege JA, Aust SD. 1978. [30] Microsomal lipid peroxidation. Methods in Enzymology 52: 302-310. doi: 10.1016/S0076-6879(78)52032-6

Carneiro DNM, Paiva PDO, Carneiro LF, Rodrigues RS, Lima LCO, Dias GMG, Pedroso RGAV. 2014. Estádios de abertura floral e condicionamento em inflorescências de bastão-do-imperador. Ornamental Horticulture 20: 163-170. doi: 10.14295/RBHO.V20I2.578

Costa LC, de Araujo FF, Ribeiro WS, de Sousa Santos MN, Finger FL. 2021. Fisiologia pós-colheita de flores de corte. Ornamental Horticulture 27: 374-385. doi: 10.1590/2447-536X.V27I3.2372

Costa LC, de Araújo FF, Santos MNS, Lima PCC, Pereira AM, Finger FL. 2017. Vase life and rehydration capacity of dry-stored gladiolus flowers at low temperature. Ciência Rural 47: 2. doi: 10.1590/0103-8478CR20160139

Cunha Neto AR, Paiva PDDO, Ponce MM, Calvelli JVB, Barbosa S. 2023. Meta-analysis of new technologies in post-harvest of tropical flowers. Ornamental Horticulture 29: 224-237. doi: 10.1590/2447-536X.v29i2.2643

Endo É, Borges SV, Daiuto ÉR, Cereda MP, Amorim E. 2007. Avaliação da vida de prateleira do suco de maracujá (*Passiflora edullis* f. flavicarpa) desidratado. Food Science and Technology 27: 382-386. doi: 10.1590/S0101-20612007000200029

Ferreira DF. 2019. SISVAR: A computer analysis system to fixed effects split plot type designs. Brazilian Journal of Biometrics 37: 529-535. doi: 10.28951/RBB.V37I4.450

Francis FJ. 1982. Analysis of anthocyanins. In: Markakis P (ed.). Anthocyanins as food colors. New York, Academic Press. p. 192-207.

Lago RC, Oliveira ALM, Cordasso Dias M *et al*. 2020. Obtaining cellulosic nanofibrils from oat straw for biocomposite reinforcement: Mechanical and barrier properties. Industrial Crops and Products 148: 112264. doi: 10.1016/J.INDCROP.2020.112264

Lichtenthaler HK, Wellburn AR. 1983. Determinations of total carotenoids and chlorophylls a and b of leaf extracts in different solvents. Biochemical Society Transactions 11: 591-592. doi: 10.1042/bst0110591

Malakar M, Paiva PDDO, Beruto MI, Cunha Neto AR. 2023. Review of recent advances in post-harvest techniques for tropical cut flowers and future prospects: Heliconia as a case-study. Frontiers in Plant Science 14: 1221346. doi: 10.3389/fpls.2023.1221346

Mattos DG, Paiva PDO, Mundim AS, Reis MV, Nery EM, Araújo NAF, Silva DPC. 2020. Digital images and in-person evaluation of Anthurium 'Tropical' postharvest quality. Ornamental Horticulture 26: 166-176. doi: 10.1590/2447-536X.V26I2.2123

Mattos DG, Paiva PDO, Elias HHDS, Boas EVDBV, Rodrigues LF, Lago RC. 2018. Starch and total soluble sugar content in torch ginger postharvest. Ornamental Horticulture 24: 435-442. doi: 10.14295/OH.V24I4.1205

Miller GL. 1959. Use of dinitrosalicylic acid reagent for determination of reducing sugar. Analytical Chemistry 31: 426-428. doi: 10.1021/ac60147a030

Moustaka J, Tanou G, Giannakoula A, Adamakis IDS, Panteris E, Eleftheriou EP, Moustakas M. 2020. Anthocyanin accumulation in poinsettia leaves and its functional role in photo-oxidative stress. Environmental and Experimental Botany 175: 104065. doi: 10.1016/J.ENVEXPBOT.2020.104065

Nogueira MR, Paiva PDO, Cunha Neto AR, Reis MV, Nascimento AMP, Timoteo CO. 2023. Starch-based films for Red Torch ginger inflorescences postharvest conservation. Ciência e Agrotecnologia 47: e015722. doi: 10.1590/1413-7054202347017822

Piroli J, Peiter M, Robaina AD, Ferreira L. 2020. Crop coefficient of cut gerbera with water supplementation in a protected environment Pró-África: Agricultura familiar conservacionista e segurança alimentar View project. Revista Brasilieira de Ciências Agrárias 15: e7652. doi: 10.5039/agraria.v15i1a7652

Pourzarnegar F, Hashemabadi D, Kaviani B. 2020. Nitrato de cério e ácido salicílico na vida de vaso, peroxidação lipídica e atividade de enzimas antioxidantes em flores cortadas de lisianthus. Ornamental Horticulture 26: 658-669. doi: 10.1590/2447-536X.V26I4.2227

Rabiza-Świder J, Skutnik E, Jedrzejuk A. 2019. The effect of a sugar-containing preservative on senescence-related processes in cut clematis flowers. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 47: 432-440. doi: 10.15835/NBHA47211379

Ren PJ, Jin X, Liao WB *et al.* 2017. Effect of hydrogen-rich water on vase life and quality in cut lily and rose flowers. Horticulture, Environment, and Biotechnology 58: 576-584. doi: 10.1007/S13580-017-0043-2

Sales TS, Paiva PDO, Manfredini GM, Nascimento AMP, Reis MV. 2021. Water relations in cut calla lily flowers maintained under different postharvest solutions. Ornamental Horticulture 27: 126-136. doi: 10.1590/2447-536X.V27I2.2235

Sales TS, Paiva PDO, Siqueira HH, Manfredini GM, Lima LCO. 2018. Preservative solutions on quality and biochemical aspects of calla lily flowers. Ciência e Agrotecnologia 42: 176-185. doi: 10.1590/1413-70542018422020717

Santos JJS, Pêgo RG, Couto BRM, Martins RCF, Carvalho DF. 2021. Pós-colheita e antocrono de hastes florais de gladíolo produzidas em casa de vegetação sob diferentes épocas e níveis de irrigação. Ciência e Agrotecnologia 45: e009321. doi: 10.1590/1413-7054202145009321

Schwab NT, Streck NA, Langner JA, Ribeiro BSMR, Uhlmann LO, Becker CC. 2014. Applicability of the term anthochron for representing the speed rate of flower opening on the inflorescence. Pesquisa Agropecuária Brasileira 49: 657-664. doi: 10.1590/S0100-204X2014000900001

Silva ARA, Bezerra FML, Lacerda CF, Sousa CHC, Chagas KL. 2016. Pigmentos fotossintéticos e potencial hídrico foliar em plantas jovens de coqueiro sob estresses hídrico e salino. Revista Agro@mbiente On-line 10: 317-325. doi: 10.18227/1982-8470ragro.v10i4.3650

Silva Neta IC, Von Pinho VRÉ, Abreu VM *et al.* 2020. Gene expression and genetic control to cold tolerance during maize seed germination. BMC Plant Biology 20: 188. doi: 10.1186/s12870-020-02387-3

Velikova V, Yordanov I, Edreva A. 2000. Oxidative stress and some antioxidant systems in acid rain-treated bean plants: Protective role of exogenous polyamines. Plant Science 151: 59-66. doi: 10.1016/S0168-9452(99)00197-1

Yemm EW, Willis AJ. 1954. The estimation of carbohydrates in plant extracts by anthrona. The Biochemical Journal 57: 508-514. doi: 10.1042/bj0570508