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Effect of reduced irrigation on postharvest quality of pear (*Pyrus communis* L.) cv. Triumph of Vienna

Efecto de la reducción del riego en la calidad poscosecha de pera (*Pyrus communis L.*) de la variedad Triumph of Vienna

Javier Enrique Vélez-Sánchez[1], Helber Enrique Balaguera-López[1], Javier Giovanni Álvarez-Herrera[2].

[1.] Universidad Nacional de Colombia, Bogotá, Colombia, jevelezs@unal.edu.co, https://orcid.org/0000-0002-1361-8374; hebalagueral@unal.edu.co, https://orcid.org/0000-0003-3133-0355
[2.] Universidad Pedagógica y Tecnológica de Colombia, Tunja, Colombia, javier.alvarez@uptc.edu.co, https://orcid.org/0000-0002-1737-6325 (Correspondence)

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ABSTRACT

Pear (*Pyrus communis L.*) is a fruit species of significant economic importance worldwide. This study focused on reducing irrigation during the rapid growth stage of the pear cv. Triumph of Vienna, specifically during the period of lower rainfall in the Colombian tropics, and on the effect of slight water stress on postharvest behavior. Three irrigation treatments were applied during the 2014 and 2015 growing seasons. One control treatment (T0) was irrigated at 100% of crop evapotranspiration (ETc), and two regulated deficit irrigation (RDI) treatments (T1 and T2) were used. Trees under treatments T1 and T2 were irrigated at 100% ETc, except during the rapid fruit growth phase. During this phenological period, the T1 trees were irrigated at 74% and 48% ETc in 2014 and 2015, respectively, whereas the T2 trees were irrigated at 60% and 27% ETc. Pear fruits were stored at 1 °C and 90% relative humidity. Storage ended after 49 and 59 days for fruits evaluated in 2014 and 2015, respectively. The results showed that deficit irrigation did not alter important postharvest properties of pear, such as firmness, carotenoids, and color. However, titratable acidity, soluble solids, and respiration were more sensitive to deficit irrigation, showing differences compared to pears from well-watered trees and a tendency to accelerate maturation due to the mild stress that RDI can generate in trees. Therefore, in the Colombian tropics, irrigation can be significantly reduced without altering the main postharvest properties of pears.

Keywords: deciduous; deficit irrigation; fruit metabolism; fruit quality; water saving; water stress

RESUMEN

El peral (*Pyrus communis* L.) es una especie frutal de gran importancia económica a nivel mundial. Este estudio se enfocó en reducir el riego durante la fase de rápido crecimiento de la pera cv. Triunfo de Viena, concretamente durante el período de menor pluviosidad en el trópico colombiano, y evaluó el efecto de un ligero estrés hídrico sobre el comportamiento poscosecha. Se implementaron tres tratamientos de riego durante los años 2014 y 2015. Un tratamiento de control (T0) se regó al 100 % de la evapotranspiración del cultivo (ETc), y se utilizaron dos tratamientos de riego deficitario controlado (RDC) (T1 y T2). Los árboles sometidos a los tratamientos T1 y T2 se regaron al 100 % de la ETc, excepto durante la fase de rápido crecimiento del fruto. Durante este periodo fenológico, los árboles del tratamiento T1 se regaron al 74 % y al 48 % de la ETc en 2014 y 2015, respectivamente, mientras que los del T2 se regaron al 60 % y al 27 % de la ETc. Los frutos se almacenaron a 1 °C y con 90% de humedad relativa durante 49 y 59 días, respectivamente, para los frutos de 2014 y 2015. Los resultados mostraron que el riego deficitario no alteró parámetros poscosecha importantes de la pera, como la firmeza, los carotenoides y el color. No obstante, la acidez, los sólidos solubles, y la respiración mostraron ser más sensibles al RDC, presentando diferencias con respecto a las peras bien irrigadas, mostrando una tendencia hacia una maduración más acelerada debido al leve estrés inducido por el RDC en los árboles. Por lo tanto, en los trópicos colombianos, el riego puede reducirse significativamente sin alterar las principales propiedades poscosecha de las peras.

Palabras clave: ahorro de agua; caducifolio; calidad de fruto; estrés hídrico; metabolismo del fruto; riego deficitario

INTRODUCTION

The European pear (*Pyrus communis* L.) cv. Triumph of Vienna is cultivated in the tropical regions at altitudes between 1,800 and 2,800 m above sea level (Fischer *et al*., 2022). Pear fruits are healthy and confer benefits with regular consumption (Molina-Ochoa *et al*., 2015). In Colombia, the cultivated area has increased in recent years, from 1,229 to 1,601 ha between 2018 and 2022 (Agronet, 2024), for both fresh consumption and processing. This trend also highlights the importance of the country's production of deciduous fruit crops (Gutiérrez-Villamil *et al*., 2022).

The reduction in water resources is a major concern in agriculture, as it strongly affects the overall performance of fruit trees, including pear trees. One alternative to address this problem is regulated irrigation (Devin *et al*., 2023; Babaei *et al*., 2025). Regulated deficit irrigation (RDI) is an important technique for efficient use of irrigation, in which water is supplied in smaller amounts during certain development stages of the crop (non-critical periods), and applied at the necessary amount during the rest of the phenological cycle (critical periods) (Martínez-Nicolás *et al*., 2019; Blanco, Torres-Sánchez *et al*., 2019). RDI can help manage vegetative growth, improve fruit quality, reduce physiological disorders, and enhance water-use efficiency, as reported in various pear cultivars (Blanco *et al*., 2025). In pear trees of the cv 'Triumph of Vienna', the main variety cultivated in Colombia, the RDI has improved water-use efficiency, with a significant effect on fruit production and quality at harvest in two production cycles (Vélez-Sánchez *et al*., 2021; Vélez-Sánchez *et al*., 2022). It has even been reported that the RDI increased total soluble solids and organic acids (Díaz-Abril *et al*., 2016), without affecting volatile organic compounds (Vélez *et al*., 2019). However, there is limited information regarding its impact on postharvest behavior.

During the cultivation cycle of the pear tree in the Colombian tropics, rainfall is relatively high, except in January and February when pear fruits grow rapidly. That is to say, the rapid growth phase of pears in Colombia has the highest water demand, and several researchers have indicated that this phenological phase is critical from a productive point of view (Marsal *et al*., 2012; Galindo *et al*., 2018).

Therefore, this study aimed to evaluate the effects of reducing irrigation regimes during the rapid growth phase of the European pear (*Pyrus communis* L.), cv. Triumph of Vienna in the Colombian tropics and the effect of slight water stress on postharvest quality.

MATERIALS AND METHODS

Experimental site and plant material

This experiment was conducted during the 2013-2014 and 2014-2015 growing seasons of the European pear cv. Triumph of Vienna, on a farm in Sesquilé, Cundinamarca, with a clay-loam soil, which has an assimilable moisture retention capacity of 120 mm m^{-1} and an apparent density of 1.06 g cm^{-3}. Likewise, the moisture content at field capacity and the permanent wilting point is 27% and 15%, respectively; the pH is 4.6, with a potassium content of 78.2 ppm and phosphorus of 23.9 ppm, organic matter of 5.06%, and electrical conductivity of the soil and irrigation water of 1.7 and 2.0 dS m^{-1}. The trees of the Triumph of Vienna pear variety were planted in 1998 at a spacing of 4 m × 4 m. They were planted on a rootstock of the same material, drip-irrigated with six drippers with a flow rate of 8 L per plant, and had a shaded area of 44%. Edaphic fertilization was carried out twice a year, via irrigation system every fifteen days, from September to May. The total amount applied was 60, 44, and 100 kg ha^{-1} in 2014 and 63, 60, and 100 kg ha^{-1} in 2015 of N, P_2O_5, and K_2O, respectively.

Climatic Conditions and Water Requirements

Climatic data were recorded with a WS-GP1 portable station (ΔT devices, Cambridge, UK), positioned in the vicinity of the experimental plot. The mean temperature of the daily maximums was 21 and 16 °C in 2014 and 2015, respectively. The mean temperature of the daily minimums was 8 and 10 °C in 2014 and 2015, respectively. The mean daily temperatures were similar in both years (13 °C). The total precipitation (Pt) from November 2013 to April 2014 was 465.4mm, concentrated in November 2013 and February, March, and April 2014, and the Pt from September 2014 to March 2015 was 233.44 mm, concentrated in September and October 2014 and March 2015.

Irrigation Treatments and Experimental Design

The reference crop evapotranspiration (ETo), obtained using the Penman-Monteith method (Maskey, 2022), was 2.09- and 2.03-mm d^{-1} during the period between flowering and harvest, spanning 169 days in 2014 and 161 days in 2015. The crop evapotranspiration (ETc) was estimated as ETc = ETo x Kc, with Kc being the crop coefficient for each phenological stage.

During the experiment, 3 irrigation treatments were applied with 4 replicates each (12 plots, each with 16 or 20 trees), arranged in a randomized block design.

The irrigation period ranged from day 41 to 99 after flowering (59 days) in the 2013-2014 season and from day 53 to 114 (62 days) in the 2014-2015 season. The control (T0) trees were watered to meet the crop's water requirements. The T1 treatment trees were watered at 100% ETc, except during the period of rapid fruit growth, which had 74% ETc in 2013-2014 and 48% ETc in 2014-2015. During the same phenological phase, the T2 treatment trees were watered at 60 and 27% ETc in 2013-2014 and 2014-2015, respectively. These humidity levels in the treatments were selected from the results obtained by Molina-Ochoa *et al*. (2015), who tested treatments with RDIs of 67% and 55% of ETc in 2011 and 2012, with only a 12% difference in humidity, which may explain the lack of significant differences. During the irrigation period, trees in treatment T0 received 67.6 mm (2013-2014) and 48.3 mm (2014-2015), treatment T1 received 49.8 mm (2013-2014) and 23.3 mm (2014-2015), and treatment T2 received 40.9 mm (2013-2014) and 13.1 mm (2014-2015).

From the fruits collected in each season of each treatment and replication, 20 were randomly selected and kept at a temperature of 1 °C and 90% relative humidity. The storage ended after 49 days for the fruits evaluated in 2014 and 59 days for those in 2015.

Fruit measurements

From the fruits collected in each season of each of the treatments and replication, 20 were randomly selected and stored at a temperature of 1 °C and 90% relative humidity, according to Rizzolo *et al*. (2015) for pear fruits. The evolution of the pear quality in each treatment during the postharvest storage was periodically determined by the following variables:

For each treatment, the postharvest duration of the fruits was determined, expressed in days after harvest (dah).

The fruits' weight loss (%) was determined using a precision electronic scale (Mettler Toledo, PB3001, Shanghai, China).

The soluble solids content (SS) was measured with a digital refractometer (Krüss Optronic, DR201-95, Germany). The titratable acidity (TA) was measured using a Titroline 6000 device (SI Analytics, Germany) with an alkaline solution in a 5 mL juice sample containing 2 to 3 drops of phenolphthalein. The TA expressed as % of malic acid.

The pulp firmness was measured at two opposite points on the equatorial zone of the fruit using a texturometer with a 6 mm diameter probe (METEK LS1 LLOYD). The total carotenoid content was determined using the procedure described by Vélez-Sánchez *et al*. (2021). Extracts were measured at 645 nm, using 80% acetone as the blank.

Fruit epidermis color was measured by reflection using a Chromameter CR400 device (Konica Minolta, Tokyo, Japan) on three points of the epidermis in the fruit's equatorial zone, according to the CIELab color space system (L*, a*, and b*).

Fruit respiration (mg CO_2 kg^{-1} h^{-1}) was measured using a CO_2 sensor (Vernier, Software & Technology, Beaverton, Oregon, USA) and LabQuest software. Measurements were recorded every 5 s for 900 s using two fruits per sample . The software calculates the respiration rate based on CO_2 emission per unit of weight and time.

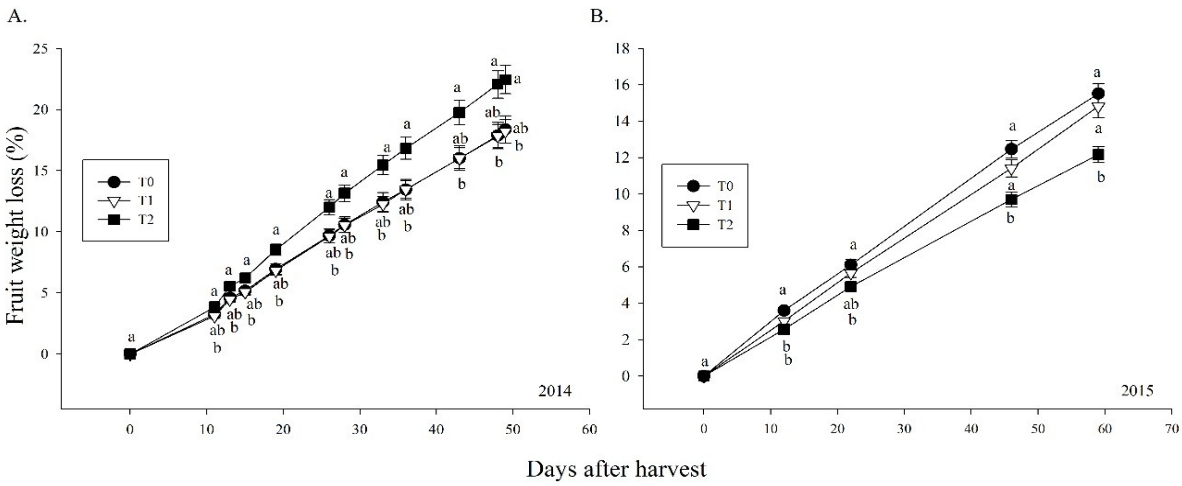
Statistical analysis

The information was analyzed using the SAS/STAT program (SAS Institute Inc., 2004). An analysis of variance (ANOVA) was carried out between irrigation levels each year. The irrigation treatments were compared using a post hoc Tukey test ($p < 0.05$).

RESULTS

Weight loss

In 2014 and 2015, the irrigation treatments showed statistically significant differences in weight loss, with a clear tendency towards a progressive increase postharvest. In 2014, the greatest weight loss was observed in fruits with 60% ETc (T2); fruits with 100% and 74% ETc (T1) did not differ statistically (Figure 1A). In 2015, 27% of ETc (T2) generated the least weight loss in the fruits (Figure 1B).

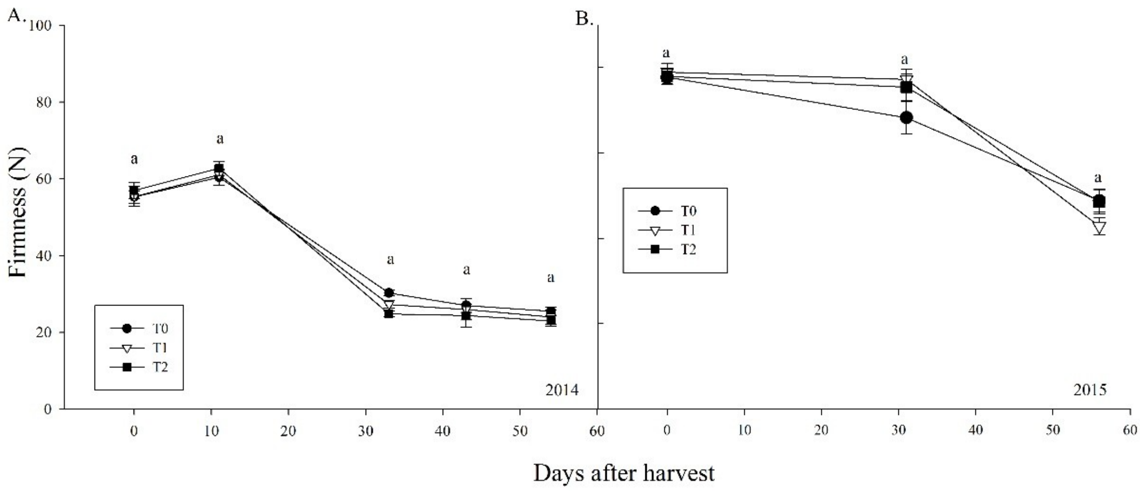


Note. Treatments followed by the same letter for each sampling point were not different according to the Tukey test ($p < 0.05$). Vertical bars indicate standard error (n=4). For 2014, T0, Control- 100% ETc; T1- 74% of ETc, and T3- 60% of ETc. For 2015, T0, Control- 100% of ETc; T1- 48% of ETc, and T2- 27% of ETc.

Figure 1. *Effect of regulated deficit irrigation on postharvest weight loss of pear fruit during the 2014 (A) and 2015 (B) seasons.*

Firmness

Pears in the three irrigation treatments showed a clear decrease in firmness during postharvest storage in 2014 and 2015, with no statistically significant differences among irrigation levels. However, during the first 11 days of 2014, there was a slight increase (Figure 2A). In this study, pear fruits showed similar dry matter contents across different irrigation levels, as previously observed for a harvest cycle in the cv. Triumph of Vienna (Vélez-Sánchez *et al*., 2021). The decrease in pulp firmness begins even before fruit harvest. Firmness stabilization was observed during a distinct period in the first days of storage in 2014 (10 days), which was longer in 2015 (30 days) (Figure 2B). This difference was observed across all treatments and was attributed to the fact that, in 2015, all fruits had higher firmness at the beginning of postharvest storage than the fruits of the previous year.

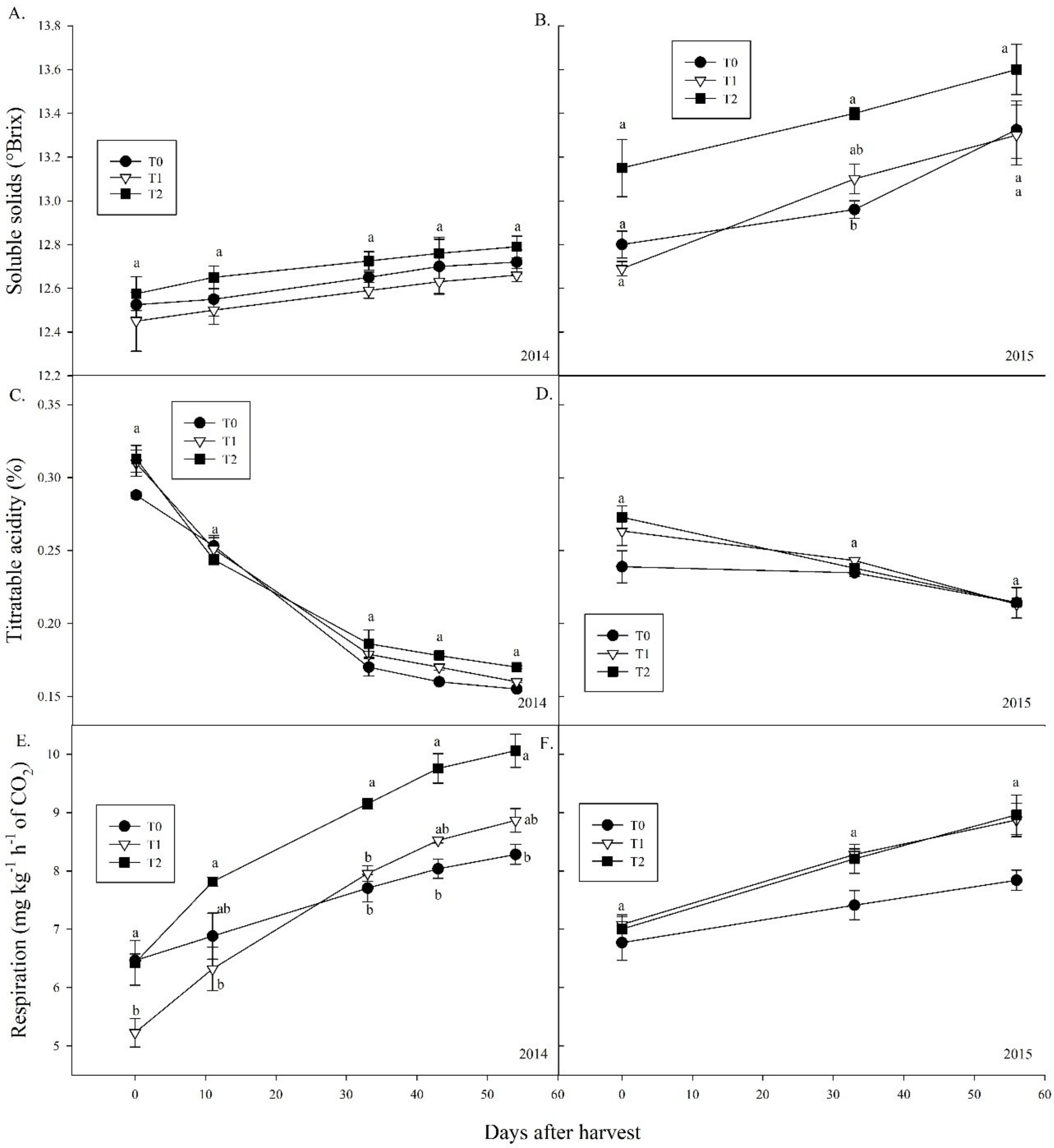


Note. Treatments followed by the same letter for each sampling point were not different according to the Tukey test ($p < 0.05$). Vertical bars indicate standard error (n=4). For 2014, T0, Control- 100% ETc; T1- 74% of ETc, and T3- 60% of ETc. For 2015, T0, Control- 100% of ETc; T1- 48% of ETc, and T2- 27% of ETc.

Figure 2. *Effect of regulated deficit irrigation on postharvest firmness of pear fruit, during the 2014 (A) and 2015 (B) seasons.*

Soluble solids (SS)

In all treatments, the SS content showed a clear tendency to increase with storage time (Figures 3A and 3B). In the 2014 season, there were no statistical differences between treatments, but the SS values in fruits with 48% ETc (T1) tended to be higher during the 2015 evaluation, with statistical differences at 33 days after harvest. The values found are slightly lower than those reported by Rizzolo *et al*. (2015), who reported that the SS of pear fruits averages 13.6±0.26%.



Note. Soluble solids (A and B), total titratable acidity (C and D), and respiration rate (E and F) for each year, respectively.

*Treatments followed by the same letter for each sampling point were not different according to the Tukey test ($p < 0.05$). Vertical bars indicate standard error (n=4). For 2014, T0, Control- 100% ETc; T1- 74% of ETc, and T3- 60% of ETc. For 2015, T0, Control- 100% of ETc; T1- 48% of ETc, and T2- 27% of ETc.

Figure 3. *Effect of regulated deficit irrigation on postharvest behavior of pear fruit during the 2014 and 2015 seasons.*

Titratable Acidity (TA)

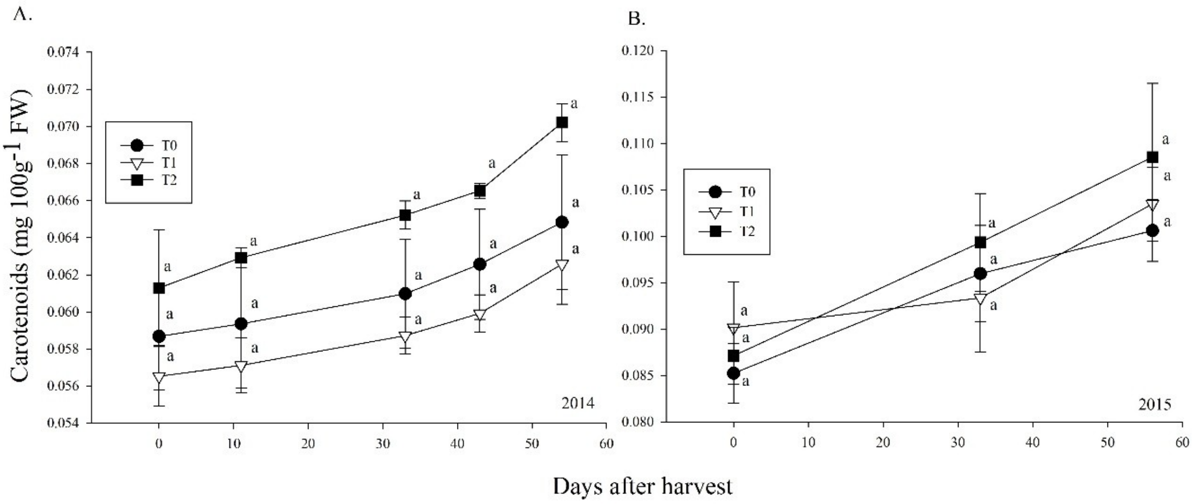
There was a clear decrease in TA levels during storage in all irrigation treatments. In the 2015 season, no statistical differences were observed, but differences were noted in 2014, when the highest acidity at the end of storage was observed in fruits with 60% ETc (T2) (Figure 3C and D).

Respiratory rate (RR)

The respiration values in 2014 and 2015 at harvest had some differences during postharvest. Specifically, in 2014, the pears with 60% of ETc (T2) had higher RR values. In 2015, the irrigation treatments did not differ statistically (Figures 3E and 3F).

Total Carotenoids

The ripening process of pears during postharvest conservation did not show marked differences in carotenoid content among the treatments. However, a tendency to increase fruit contents was observed in the most deficient treatment (T2) (Figure 4).

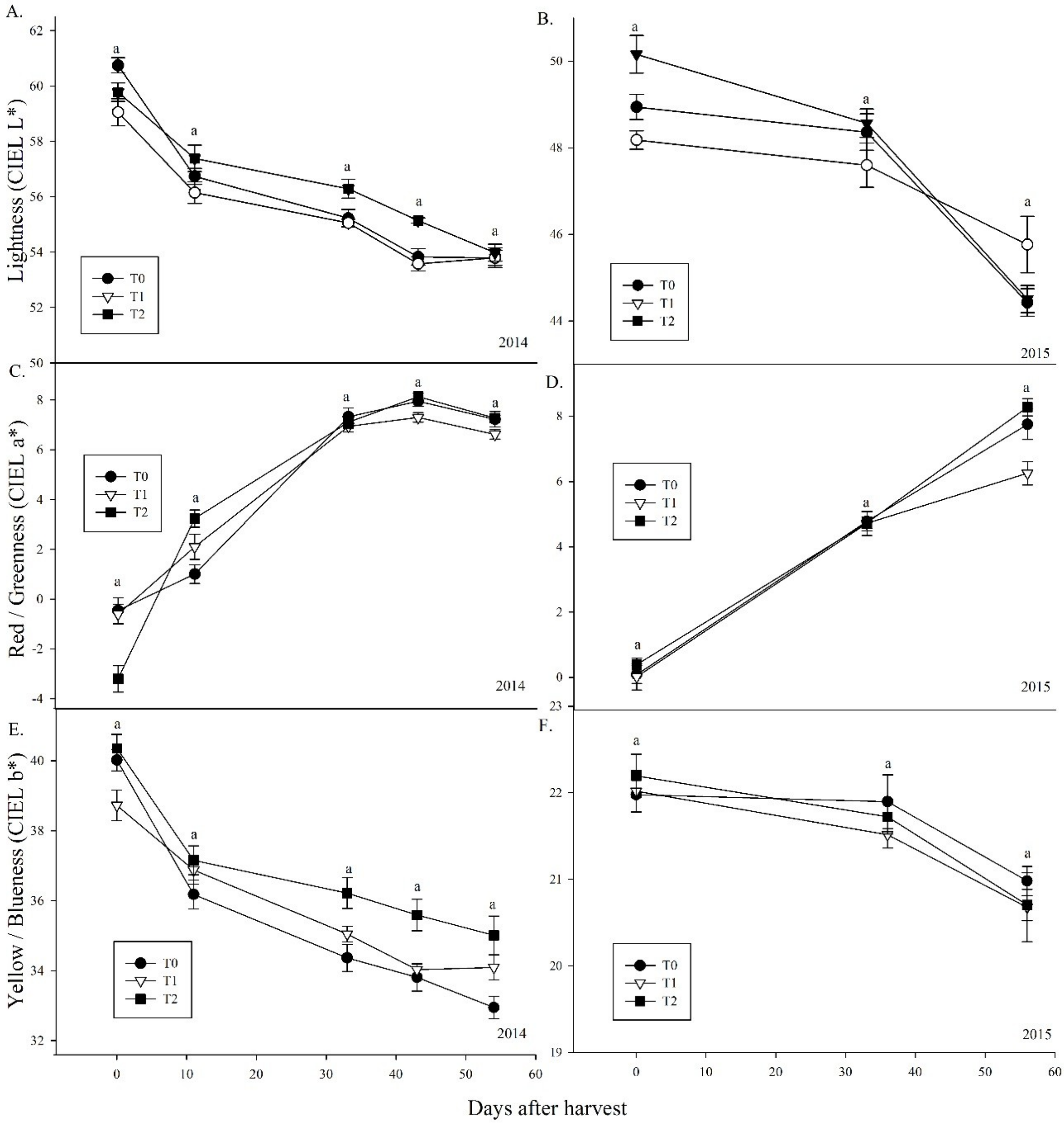


Note. Treatments followed by the same letter for each sampling point were not different according to the Tukey test ($p < 0.05$). Vertical bars indicate standard error (n=4). For 2014, T0, Control- 100% ETc; T1- 74% of ETc, and T3- 60% of ETc. For 2015, T0, Control- 100% of ETc; T1- 48% of ETc, and T2- 27% of ETc.

Figure 4. *Effect of regulated deficit irrigation on total carotenoids of pear fruit during postharvest in 2014 (A) and 2015 (B) seasons.*

Color

The color parameters of the CIEL*a*b* system (Figure 5) were not significantly affected by the irrigation levels. During storage, a reduction in greenish color was observed in pears, in favor of the evolution of more reddish tones (increases in a* and C*), less yellowish tones (decreases in b*), and darker tones (decreases in L*). This behavior is well known because luminosity and pigment content are inversely related: as pigment content increases, more light is absorbed, and luminosity decreases (L*) (Fialho *et al*., 2021).



Note. Lightness (A and B), the value of a* (C and D), and the value of b* (E and F) for each year, respectively.
*Treatments followed by the same letter for each sampling point were not different according to the Tukey test (p < 0.05). Vertical bars indicate standard error (n=4). For 2014, T0, Control- 100% ETc; T1- 74% of ETc, and T3- 60% of ETc. For 2015, T0, Control- 100% of ETc; T1- 48% of ETc, and T2- 27% of ETc.

Figure 4. *Effect of regulated deficit irrigation on postharvest behavior of pear fruit during the 2014 and 2015 seasons.*

DISCUSSION

Weight Loss

The change in the rate of weight loss observed in this study could have been due to a decrease in the skin thickness and/or changes in its properties that promote greater water loss through transpiration, without fruit deterioration in any of the treatments, as reported in fruit crops with water stress (Collado-González *et al*., 2013). Similarly, Lopez *et al*. (2011) mentioned that the difference in weight loss between water-deficient and well-watered plants could be due to differences in the structure and/or composition of the epidermis or epicuticular waxes.

Firmness

Regarding firmness, Lu (2022) found that water deficit resulted in lower postharvest firmness loss in apples due to higher dry matter content. The absence of differences in values among the irrigation treatments led to the conclusion that water savings were achieved without affecting this quality parameter, indicating that irrigation can be reduced under similar conditions. The decrease in pulp firmness is largely due, according to Álvarez-Herrera *et al*. (2022), to the action of hydrolytic enzymes that degrade starch and to the conversion of protopectins and pectins into other water-soluble compounds. In contrast to the results obtained in this study, previous reports indicate that fruits subjected to water stress tend to have lower water content and, consequently, higher firmness (Wu et al., 2013), as observed in pear fruits cv. Conference under water deficit followed by storage at 0 °C and 90% relative humidity (Lopez *et al*., 2011). Conversely, fruits with a water deficit experience a clear acceleration of ripening, with a notable decrease in firmness.

Soluble Solids (SS)

For soluble solids, it is known that a water deficit favors an increase in the SS of fruits (Vélez-Sánchez *et al*., 2021; Rodríguez *et al*., 2018). In the pear fruit cv 'conference', the RDI strategy supplied during ripening generated the highest SS at harvest (14.2 °Brix) compared with the control (13.9 °Brix), which is attributed to the fact that as water stress increases, the fruit may present partial dehydration, which increases the concentration of SS (Lopez *et al*., 2011). At first glance, there may appear to be a concentration effect resulting from a decrease in fruit moisture at 27% ETc (T2), which may be related to a lower osmotic potential, as reported by Volschenk (2020). However, the fact that the weight losses were very similar across treatments (Figure 1) reduces the possibility that this factor was a determinant for the observed behavior. On the other hand, the transformation of organic acids into sugars has been reported as a possible cause (Rodríguez *et al*., 2018; Silveira *et al*., 2020), possibly via gluconeogenesis.

Titratable Acidity (TA)

Concerning total acidity, the rise observed in 2014 may be attributed to the increase in organic acid metabolism due to water stress, and to the osmotic adjustment mechanism that also increases SS, and is related to fruit flavor that implies greater acceptance by the consumers, as reported for peach fruit (Conesa *et al*., 2021). Similar results in TA were reported by Lopez *et al*. (2011) in the pear cv. Conference. For apples Ambrosia™, the water deficit caused minor degradation and maintained the highest acidity (Lu, 2022). According to Volschenk (2020), water deficits cannot affect or increase acidity. In grapes cv. Chardonnay, to increase berry acidity, full irrigation is recommended (Prats-Llinàs *et al*., 2019).

Respiration Rate (RR)

For respiratory rate, it is known that fruits have internal regulation mechanisms that maintain a constant or adjusted RR in response to changes in water supply, and that for the respiratory rate of the fruits to be affected, the water stress must be severe (Seleiman *et al*., 2021). The deficit affected the RR of the fruits in storage in specific cases, resulting in higher values. This is typical behavior in climacteric fruits that produce a greater number of characteristic compounds with intense aromas during ripening (Vélez *et al*., 2019), coinciding with high ethylene production and high respiration rate, which produce several changes due to degradation that occurs in cell walls, along with pigmentation and thickening of the epidermis that becomes permeable. The higher sugar content in the deficit treatments could have been due to a lower water supply or an osmotic adjustment induced as a response mechanism to stress, which generated a greater conversion of reserve carbohydrates into soluble sugars used in the respiration process for the decomposition of polysaccharides and oxidation of sugars to organic acids, CO_2, water, and energy (Álvarez-Herrera *et al*., 2022).

Total Carotenoids

Regarding total carotenoids, Sun *et al*. (2022) report that carotenoids are compounds that plants can synthesize from precursors available in the soil and in the air. Therefore, differences in irrigation do not significantly affect the plant's ability to absorb the nutrients necessary to produce carotenoids, which is similar to Vélez-Sánchez *et al*. (2021), who also did not find significant differences in the carotenoid content in pear fruits subjected to different water levels. In contrast, Mossad *et al*. (2020) found that a water deficit stimulates carotenoid accumulation and suggested that the evolution of color reflects the characteristic physiological process during ripening, driven by the degradation of chlorophyll and the synthesis of carotenoids.

Color

For color, the results are consistent with those reported for pomegranate fruits, where the RDI did not significantly affect the color parameters L*, a*, and b* during cold storage (Fialho *et al*., 2021), and in the pear fruit cv. Triumph of Vienna did not affect the color index of the epidermis and pulp during cold storage (Bayona-Penagos *et al*., 2017). In apples, the color is water-dependent (Lu, 2022). However, water deficits affecting fruit quality parameters result in changes in epidermal color due to their implications for fruit ripening. Additionally, reduced vegetative growth under water deficit conditions may increase fruit exposure to sunlight (Conesa *et al*., 2021), with no changes in pear fruit epidermal coloration during cold storage, as observed for total carotenoids. This result can also be attributed to storing pears at 1°C, which reduces ethylene synthesis and its effects in all fruits. It is well known that ethylene is involved in the color change of the fruits. In cherry, the RDI did not affect fruit color during storage at 2°C for 20 days and during the subsequent shelf-life period (Blanco, Martínez-Hernández *et al*., 2019).

The absence of differences between the results found in the different irrigation levels for the 2015 season led to the conclusion that the water deficits reduced irrigation and provided significant water savings without causing differences or effects on the postharvest quality and crop yield, as compared to the fruits in the control (100% of ETc, T0).

CONCLUSIONS

The results showed minimal differences in pear behavior among the three irrigation levels, with a similar postharvest duration for all fruits in both 2014 and 2015. In the Colombian tropics, significant water savings may be achieved in soils with similar characteristics using the two deficit irrigation treatments, without altering key fruit properties during postharvest cold storage, such as firmness, carotenoids, and skin color. However, some of the parameters studied, including soluble solids, titratable acidity, and respiration rate were more sensitive to deficit irrigation, showing differences compared with pears from well-watered trees.

AUTHOR CONTRIBUTIONS

Conceptualization, JEV-S, HEB-L, and JGA-H.; Methodology, JEV-S.; Software, JEV-S, HEB-L, and JGA-H.; Formal Analysis, JEV-S, HEB-L, and JGA-H.; Investigation, JEV-S.; Writing—Original Draft Preparation, JEV-S, HEB-L, and JGA-H; Writing—Review & Editing, JEV-S, HEB-L, and JGA-H.; Visualization, JEV-S, HEB-L, and JGA-H.; Supervision, JEV-S.; Project Administration. All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST

The authors state no conflict of interest.

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