Postharvest changes in weight loss and quality of cactus pear fruit undergoing reproductive bud thinning

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Received 2th April, 2009; Accepted 18th February, 2010

Abstract

Fruit is a biological material that starts deteriorating after harvest. The extent of deterioration depends on the fruit itself, but can be modified by pre–harvest management such as reproductive bud thinning (RBT). This research evaluated the effect of two methods of RBT on some fruit quality attributes of 'Cristalina' (*Opuntia albicarpa*) and 'Rojo Liso' (*Opuntia ficus–indica*) cvs. of cactus pear at harvest and after four weeks storage at room temperature. Two RBT experiments were conducted in 2004. In the first experiment, treatments were: no thinning (control) or retaining four, eight or twelve reproductive buds (RB) per mature cladode. In the second experiment, treatments were: no thinning (control, C), thinning every other bud (T1), or thinning two out of every three buds (T2) along the cladode. In the first experiment, at harvest or after storage, pulp–to–peel ratio was lower in 'Cristalina' when four RBs per cladode were retained compared with the other treatments. Total soluble solids concentration (TSSC) of 'Rojo Liso' fruit was the highest after storage when four RBs per cladode were kept. In the second experiment, fruit quality of 'Cristalina' was not modified by either RBT treatment. The highest TSSC was observed in T2 for 'Rojo Liso'. Fruit weight loss was *ca* 30% higher in 'Cristalina' than 'Rojo Liso' in both experiments. The maintenance of fruit quality for longer storage periods is possible through RBT, in particular for 'Rojo Liso'.

Key words: *Opuntia* spp., flesh firmness, pulp and peel weights, total soluble solids, dry matter concentration.

Resumen

La fruta es un material biológico que después de la cosecha inicia su deterioro. El grado de deterioro depende del fruto en sí mismo, pero pude ser modificado por el manejo en pre–cosecha tal como el raleo de yemas reproductivas (RYR). Esta investigación evaluó el efecto de dos métodos de RYR en algunos atributos de calidad de fruto en los cultivares de nopal tunero 'Cristalina' (*Opuntia albicarpa*) y 'Rojo Liso' (*Opuntia ficus–indica*) a la cosecha y después de cuatro semanas en almacenamiento a temperatura ambiente. Dos experimentos de RYR se condujeron en 2004. En el primer experimento, los tratamientos fueron: sin raleo (testigo) o reteniendo cuatro, ocho o doce yemas reproductivas (YR) por cladodio maduro. En el segundo experimento, los tratamientos fueron: sin raleo (testigo, T), raleo alternado a una (T1) o dos (T2) YR a través del cladodio. En el primer experimento, la relación pulpa–cáscara fue menor a la cosecha o después de almacenamiento en frutos de 'Cristalina' cuando se retuvieron cuatro YR por cladodio comparado con los otros tratamientos. La concentración de sólidos solubles totales (CSST) en la fruta de 'Rojo Liso' fue la más alta después del almacenamiento cuando se retuvieron cuatro YR. En el segundo experimento, la calidad de la fruta de 'Cristalina' no fue modificada por los tratamientos de RYR. La mayor

CSST se observó con T2 en la fruta de ‘Rojo Liso’. La pérdida de peso de la fruta fue aproximadamente 30% mayor en ‘Cristalina’ que en ‘Rojo Liso’ en ambos experimentos. La calidad de la fruta puede ser mantenida por periodos largos de almacenamiento a través del RYR, en particular en ‘Rojo Liso’.

Palabras Clave: *Opuntia* spp., firmeza, pesos de pulpa y cáscara, sólidos solubles totales, concentración de materia seca.

Introduction

Cactus pear is a Mexican fruit crop cultivated extensively (*ca* 51, 000 ha) in the semiarid highlands of Central and North–Central Mexico. It has gained economic importance in other countries of Europe, America, Asia, and Africa (Basile, 2001). In Mexico, cactus pear production has a high social impact, but low competitiveness compared to other commodities such as dry pepper, peach, and alfalfa (Rincón–Valdés *et al*., 2004). The high volumes exported during the last decade have alleviated, in part, the low crop competitiveness. Therefore, many Mexican growers now focus on producing export-sized fruit for long–distance markets in the United States, Canada, and Japan (Zegbe and Mena, 2010).

Modern production chains for horticultural crops must not only satisfy the demands of consumers, but also increase both quality and postharvest–life of products (Wills *et al*., 1998). However, the harvested products are living biological material that starts deteriorating at harvest. The rate of deterioration depends on the horticultural product (fruit, vegetable, or ornamental) and on pre–harvest (Crisosto and Mitchell, 2007) and post–harvest handling and storage practices (Mpelasoka *et al*., 2000). Several reports have examined cactus pear horticultural practices, including the removal of reproductive buds (RRB) for fruit thinning (Barbera *et al*., 1991; Inglese *et al*., 1995; Inglese, 1995; Gugliuzza *et al*., 2002a), to assess the effect on yield, yield components, and final fruit size and quality (Inglese *et al*., 2002; Gugliuzza *et al*., 2002a,b). Other reports have shown the effect of pre-harvest nitrogen application (Ochoa *et al*., 2002), irrigation (Zegbe *et al*., 2006), and out–of–season production (Zegbe and Mena, 2008) on the post–harvest performance of cactus pear fruit. This research evaluated the effect of two methods of RBT on some fruit quality attributes of ‘Cristalina’ (*Opuntia albicarpa*) and ‘Rojo Liso’ (*Opuntia ficus–indica*) cactus pear at harvest and after four weeks storage at room temperature. The experiments focused only on the manipulation of reproductive buds (RB) number, on the assumption that the retained buds would differentially use the available carbon during the growing season for enhancing fruit postharvest–life.

Materials and methods

Experimental site, genetic material, and orchard management

This research was conducted from March to October, 2004 in a commercial orchard (Rancho ‘La Tunera’) in Jerez, Zacatecas (22º 32' N; 103º 03' W, elevation 1,976 masl). The average annual temperature is 25.7ºC; whereas 482 mm is the yearly mean precipitation, and 62% occurs between July and October. The orchard soil is a clay loam with 1.63% organic matter and soil pH of 7.1. Two cactus pear cultivars, planted in 2000, were used: ‘Cristalina’ (*Opuntia albicarpa*) and ‘Rojo Liso’ [*Opuntia ficus–indica* (L.) Mill.]. The former cultivar is late–maturing with white pulp, while the latter is early–maturing with red pulp. Tree spacing was 5 x 3 m and trees were trained to the open vase form. Except for RB thinning, trees received cladode pruning, fertigation, and pest control according to standard commercial practices in this region. Drip irrigation was provided weekly based on soil water balance. Trees were fertilized in the first four irrigation events with 90N–13.1P–24.9K. The first half of the N and all P and K were applied with the first four irrigations; the remaining N was supplied via fertigation four weeks after fruit harvest.

Experiment 1

This trial studied the effect of RB load per cladode as proposed by Inglese et al. (1995). Sixteen plots (four plots per treatment) for each cactus pear cultivar were chosen. Each plot had three uniform trees which were randomly allocated to one of the four RB thinning treatments. The treatments were: a control with no thinning (C) or retaining four, eight or twelve RBs (4RB, 8RB, and 12RB, respectively) per mature cladode.

Experiment 2

In this trial, 12 plots (three plots per treatment) for each cactus pear cultivar were used. Each plot had three uniform trees which were randomly allocated to one of the three RB thinning treatments. The treatments were: a control with no thinning (C), thinning every other bud (T1), and thinning two out of every three buds (T2) along of the cladode. Twin RBs were manually removed except in the control treatment. Then, one or two reproductive buds were thinned out alternately along of the cladode (Figure 1). In both experiments, RBs were hand–thinned 10 days before bloom, which occurred on 15 and 20 April for ‘Rojo Liso’ and ‘Cristalina’, respectively.

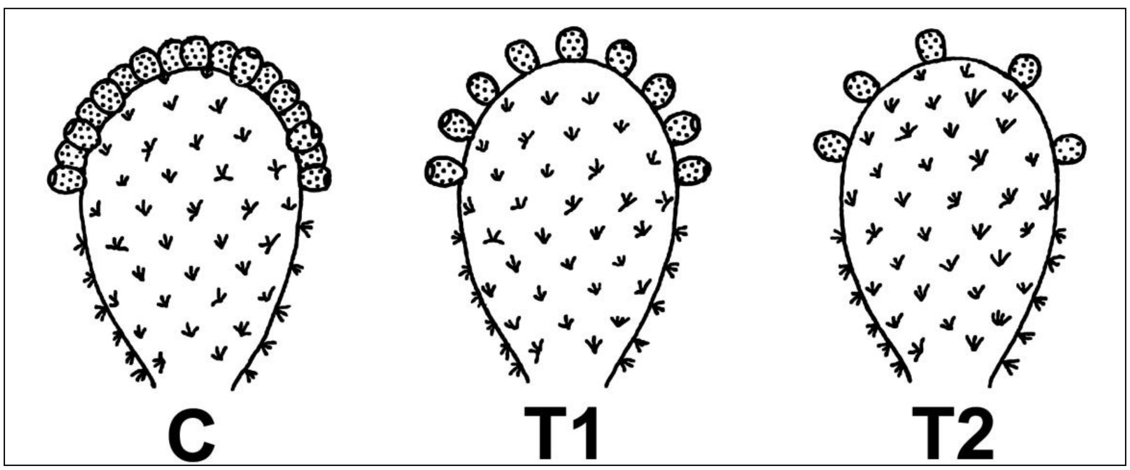

Figure 1. Reproductive bud thinning of two cactus pear cultivars (*Opuntia* spp.) during Experiment 2, carried out in Jerez, Mexico, during 2004. The treatments were: control with no thinning (C), thinning every other bud along the cladode (T1), and thinning two out of every three buds along the cladode (T2).

The experiments were conducted in a completely randomized design. Treatments were repeated four times. The minimum number of replications for detecting significant differences ($p<0.05$) among treatments was determined according to Petersen (1994).

Fruit quality

Fruit quality assessment was done at harvest on 12–fruit sets per treatment on 26 July (104 days after full bloom, DAFB) and on 27 August (130 DAFB) for ‘Rojo Liso’ and ‘Cristalina’, respectively. In both cultivars, fruits were picked at export harvest maturity, when peel color broke from green to red or yellow for ‘Rojo Liso’ or ‘Cristalina’, respectively. Another set of 12 fruits per treatment was collected at the same sampling dates for fruit quality determinations after four weeks of storage on 27 August (135 DAFB) for 'Rojo Liso' and on 24 September (158 DAFB) for 'Cristalina'.

Fruit quality determinations

Fruit quality indicators evaluated at harvest and after storage included flesh firmness, total soluble solids concentration, peel and pulp weights, pulp–to–peel ratio (P:P), and dry matter concentration of fruit. After removing the fruit skin, two flesh firmness determinations were done on two opposite sides of the equatorial plane of each fruit using a press–mounted Wagner penetrometer (model FT 327, Wagner Instruments, Greenwich, CT, USA) with an 11.1–mm tip. Total soluble solids concentration was measured with a digital refractometer with automatic temperature compensation (model PR–32α, Atago, Co., ltd., Tokyo, Japan) by mixing several drops from each side of the fruit. The peel and pulp were separated and weighed to assess P:P. Dry matter concentration was determined using a 25-g composite sample of fresh cortical tissue that was oven–dried to constant weight. Weight loss was evaluated at harvest and at 1–week intervals for four weeks by weighing each fruit individually with a precision scale (Mettler PE11, Mettler Instrumente, Greifensee–Zurich, Switzerland). Fruit weight loss was calculated as percent reduction from original weight. Both cultivars were stored at 20 ± 2 ºC and 40 ± 4% relative humidity. These storage conditions were similar to those used by commercial growers.

Statistical analysis

The data were analyzed by a completely randomized model using the ANOVA procedure of SAS software (version 9.1, SAS Institute, Cary, NC, USA). Treatment means were separated by the Fisher's protected Least Significant Difference (LSD) procedure at $p \leq 0.05$.

Results and discussion

Experiment 1

Fruit quality attributes

In 'Cristalina', the only fruit quality attribute affected by RBT at harvest was P:P (Table 1). The lowest P:P ($p \leq 0.05$) was observed when four RBs (4RB) per cladode were retained. This trend remained after storage ($p \leq 0.05$) (Table 1). The decrease in P:P means that the peel was higher than the edible tissue of fruit. The edible portion of the fruit is developed from the funiculi and the funicular envelopes of the seed (Weiss *et al*., 1993). Therefore, carbohydrate allocation in the other sink organs such as peel must have occurred, because after four weeks in storage, peel fruit weight was consistently higher in the 4RB treatment than in the remaining treatments. Corrales–García and Hernández–Silva (2005) found a positive strong correlation between fruit weight, peel thickness, and flesh firmness, which they associated with long–term storability. However, in this experiment fruit weight did not correlate with flesh firmness either at harvest ($r=0.16$; $p=0.30$) or after storage ($r=0.03$; $p=0.82$). Therefore, other factors, not studied here, determine the duration of the post–harvest life of cactus pear fruit. Alternatively, post–harvest life may be genetically determined as demonstrated in apples (Mann *et al*., 2008).

Table 1. Flesh firmness (FF) in Newtons (N), peel and pulp weights, pulp–to–peel ratio (P:P), total soluble solids (TSSC), and dry matter concentration (DMC) by fresh weight (FW) of ‘Cristalina’ cactus pear fruit with different fruit loads per cladode at harvest and after four weeks of storage . Treatment values are the mean ± standard error.

Treatments (fruit/cladode)	FF (N)	Weight (g) Peel	Weight (g) Pulp	P:P ratio	TSSC (%)	DMC (mg g^{-1} FW)
	At harvest					
Control	40.3 ± 3.5	81.6 ± 2.1	106.9 ± 6.1	1.3 ± 0.1	10.6 ± 0.4	177.6 ± 4.5
12	32.8 ± 1.4	79.6 ± 3.5	122.8 ± 4.8	1.6 ± 0.05	10.7 ± 0.3	171.6 ± 3.9
8	39.5 ± 4.2	83.6 ± 2.5	114.7 ± 5.0	1.4 ± 0.06	10.7 ± 0.3	173.4 ± 2.2
4	34.1 ± 2.7	88.7 ± 1.9	106.8 ± 4.6	1.2 ± 0.05	09.2 ± 0.5	185.5 ± 6.7
	After storage					
Control	29.3 ± 1.0	61.4 ± 2.4	121.3 ± 4.8	2.0 ± 0.08	10.4 ± 0.3	152.0 ± 1.6
12	31.0 ± 1.4	61.0 ± 2.0	121.0 ± 3.5	2.0 ± 0.05	10.3 ± 0.2	152.0 ± 2.8
8	31.2 ± 1.2	62.0 ± 1.8	124.6 ± 3.3	2.0 ± 0.08	10.4 ± 0.2	152.0 ± 6.0
4	30.5 ± 1.4	70.2 ± 3.5	122.5 ± 5.8	1.8 ± 0.1	10.1 ± 0.3	146.7 ± 5.9

In ‘Rojo Liso’, the fruit quality indicators were the same among treatments (Table 2). However, treatment 4RB tended to increase total soluble solids concentration (TSSC), and this response was significant ($p \leq 0.05$) after four weeks in storage. Our results suggest that there was an increased influx of carbohydrate to the fruit (as sink organ) during fruit development (Wardlaw, 1990) that was influenced by thinning. However, there was a reduction in both fruit dry matter concentration (DMC) and TSSC by 25.1% and 9.8%, respectively, during the four weeks of storage. This was also true for DMC in ‘Cristalina’. Cactus pear fruit is considered non climacteric, with low respiration rates (Cantwell, 1995; Schirra *et al*., 1999). We did not measure respiration rates, but the reduction in TSSC and DMC indicates that carbohydrates were metabolized during storage (Lakshminarayana and Estrella, 1978).

Fruit water loss

Fruit weight loss (FWL) during storage was the same in both cactus pear cultivars (Figure 2A). However, FWL tended to be greater in the 8RB and 12RB treatments than in the control and 4RB treatment in ‘Cristalina’ trees. The greater FWL is associated with fruit size (Mpelasoka et al., 2000) and cuticle alterations (Crisosto *et al*., 1994; Maguire et al. 1999). The average fruit sizes (LSD = 29.0 g) were 206.4, 199.4, 198.0, and 190.1 g for the 12RB, 8RB, and 4RB treatments, respectively. Our data indicates no association between FWL and fruit size ($r=-0.2$; $p=0.159$). Further investigation may determine whether cuticle alterations exist, and if so, what mechanism is responsible. In contrast, the extent of RBT did not affect FWL in the ‘Rojo Liso’ cultivar. However, FWL tended to be lower in fruit from the thinned treatments than from the control (Figure 2B). For cactus pear fruit, a FWL of ~ 8% was established as the threshold to observe shrivel symptoms (Cantwell, 1995), which did not occur in either cultivar. The FWL rate was ~ 0.2% and 0.12% per day for ‘Cristalina’ and ‘Rojo Liso’, respectively, at 20 ºC and 40% relative humidity [vapor pressure deficit (VPD) ~ 1.35 kPa]. Thus, low FWL rates are commercially important for long–term storage and long–distance transport to markets (Schirra *et al*., 1999).

Table 2. Flesh firmness (FF) in Newtons (N), peel and pulp weights, pulp–to–peel ratio (P:P), total soluble solids (TSSC), and dry matter concentration (DMC) by fresh weight (FW) of 'Rojo Liso' cactus pear fruit with different fruit loads per cladode at harvest and after storage for four weeks. Treatment values are the mean ± standard error.

Treatments (fruit/cladode)	FF (N)	Weight (g)		P:P ratio	TSSC (%)	DMC (mg g^{-1} FW)
		Peel	Pulp			
			At Harvest			
Control	35.8 ± 2.1	64.3 ± 2.6	61.5 ± 1.6	0.96 ± 0.03	10.9 ± 0.3	197.2 ± 3.6
12	33.2 ± 1.5	60.3 ± 2.3	61.7 ± 1.9	1.04 ± 0.04	11.2 ± 0.3	198.8 ± 5.4
8	31.7 ± 1.3	65.0 ± 1.8	66.8 ± 2.5	1.03 ± 0.04	11.1 ± 0.3	198.1 ± 4.4
4	32.8 ± 1.4	65.1 ± 1.9	66.1 ± 2.8	1.02 ± 0.04	12.1 ± 0.2	202.8 ± 4.1
			After storage			
Control	28.4 ± 1.3	50.8 ± 1.7	75.3 ± 3.3	1.5 ± 0.07	9.6 ± 0.3	150.2 ± 6.5
12	26.9 ± 0.9	49.9 ± 1.6	72.4 ± 2.3	1.5 ± 0.07	10.2 ± 0.2	147.1 ± 9.6
8	27.3 ± 0.8	47.6 ± 2.2	77.5 ± 1.8	1.7 ± 0.07	10.4 ± 0.2	146.8 ± 9.5
4	28.0 ± 1.3	51.0 ± 2.2	77.0 ± 3.4	1.5 ± 0.04	10.6 ± 0.2	152.9 ± 4.5

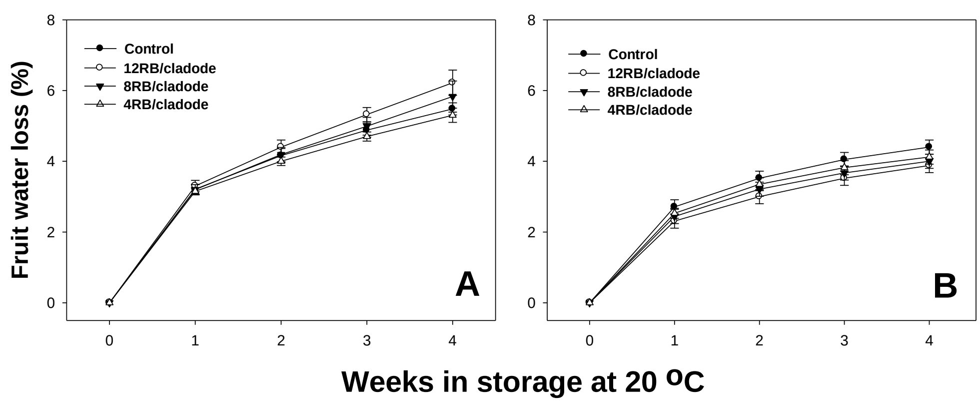

Figure 2. Cumulative fruit weight loss as percentage of original weight during storage for 'Cristalina' (**A**) and 'Rojo Liso' (B) cactus pear fruits thinned to 12, eight, or four reproductive buds (RB) per cladode. The vertical bar at each sampling date represents the mean ± standard error.

Experiment 2

Fruit quality attributes

Thinning of half (T1) or two thirds (T2) of the reproductive buds did not modify any fruit quality attribute of 'Cristalina' either at harvest or after four weeks in storage (Table 3), which had not been reported before under this thinning criterion. The lack of response to RB manipulation could be, in part, associated with better carbohydrates distribution between fruits and the other plant organs during fruit development period as reflected in no measurable changes of dry matter concentration at harvest or after storage.

Table 3. Flesh firmness (FF) in Newtons (N), peel and pulp weights, pulp–to–peel ratio (P:P), total soluble solids (TSSC), and dry matter concentration (DMC) by fresh weight (FW) of 'Cristalina' cactus pear fruit at harvest and after storage for four weeks in response to reproductive bud thinning (RBT). The treatments were: control with no thinning, C; thinning every other bud along the cladode, T1; and thinning two out of every three buds along the cladode, T2.

RBT	FF (N)	Weight (g) Peel	Weight (g) Pulp	P:P ratio	TSSC (%)	DMC (mg g^{-1} FW)
			At harvest			
Control	31.4 ± 3.5	84.7 ± 3.4	118.5 ± 3.9	1.4 ± 0.06	10.8 ± 0.2	164.4 ± 10.9
T1	36.2 ± 2.5	81.8 ± 2.5	116.9 ± 3.0	1.4 ± 0.04	10.1 ± 0.2	171.9 ± 4.5
T2	31.0 ± 3.0	87.0 ± 2.6	119.7 ± 4.4	1.4 ± 0.05	10.5 ± 0.4	169.0 ± 4.9
			After storage			
Control	26.5±1.5	60.7±3.2	125.2±7.3	2.1±0.06	10.8±0.2	157.2±5.4
T1	27.8±0.8	60.8±1.1	127.3±5.3	2.1±0.08	10.2±0.1	154.1±5.7
T2	27.2±0.9	66.0±3.2	127.6±6.2	2.0±0.08	10.5±0.3	156.4±9.6

In contrast, 'Rojo Liso' fruit from the T2 treatment had the highest TSSC both at harvest ($p \leq 0.05$) and after storage ($p \leq 0.01$, Table 4). The other quality attributes examined were not modified by RBT treatments. The high TSSC induced by T2 treatment is indicative that either the 'Rojo Liso' fruits were more active in attracting carbohydrates or that their allocation was higher due to less inter–organ competition (Zegbe and Mena, 2009). We observed an almost two–fold reduction of TSSC and DWC during postharvest storage (Table 4). This reduction confirms that carbohydrates are used in other metabolic pathways during storage, reducing the sweetness of the fruit. After storage, flesh firmness, pulp and peel weights, pulp–to–peel ratio, and dry matter concentration of fruit showed no measurable changes (Table 4). In fact, there was no association between pulp and peel weights, probably due to the anatomical origins of these organs (Weiss *et al*., 1993).

Fruit water loss

Changes in weight of 'Cristalina' fruit, as percentage of FWL, during the first three weeks of storage were greater in the unthinned control fruit than in fruit undergoing T1 treatment. At week four, FWL was the same among treatments (Figure. 3A). 'Rojo Liso' fruit showed a similar trend (Figure 3B), which is consistent with earlier reports (Zegbe and Mena, 2009). Fruit water loss was less than 8% in both cactus pear cultivars. Additionally, FWL per day was lower in thinned fruit of 'Rojo Liso' than in control fruit. The FWL values for 'Cristalina' were 0.24%, 0.23%, and 0.24% for C, T1, and T2, respectively. The values for 'Rojo Liso' were 0.15%, 0.14%, and 0.13% for C, T1, and T2 fruit, respectively. There was only a weak association between peel weight and FWL ($r=-0.37$, $p=0.03$), indicating that no anatomical alterations are induced in the cuticle by the RB treatments. The glochids were not removed from the fruit, so these structures might have contributed to the low FWL in both cultivars (Cantwell, 1995). This indicates that RB manipulation is a feasible way to increase post–harvest life of fruits from both cactus pear cultivars that are destined for transport to distant markets, storage, and retail handling.

Table 4. Flesh firmness (FF) in Newtons (N), peel and pulp weights, pulp–to–peel ratio (P:P), total soluble solids (TSSC), and dry matter concentration (DMC) by fresh weight (FW) of ‘Rojo Liso’ cactus pear fruit at harvest and after storage for four weeks in response to reproductive bud thinning (RBT). The treatments were: control with no thinning, C; thinning every other bud along the cladode, T1; and thinning two out of every three buds along the cladode, T2.

RBT	FF (N)	Weight (g)		P:P ratio	TSSC (%)	DMC (mg g^{-1} FW)
		Peel	Pulp			
	At harvest					
Control	36.0 ± 1.1	55.0 ± 2.4	61.9 ± 2.3	1.14 ± 0.05	11.2 ± 0.3	182.0 ± 7.3
T1	38.2 ± 0.9	61.3 ± 1.4	61.0 ± 2.6	0.99 ± 0.04	11.5 ± 0.2	191.7 ± 3.2
T2	36.5 ± 1.3	58.0 ± 1.7	65.5 ± 1.7	1.13 ± 0.03	12.3 ± 0.1	195.5 ± 4.2
	After storage					
Control	28.6 ± 1.3	48.2 ± 2.1	72.9 ± 3.0	1.5 ± 0.04	09.9 ± 0.2	136.9 ± 3.8
T1	30.8 ± 1.0	51.1 ± 1.3	72.1 ± 2.3	1.4 ± 0.05	10.2 ± 0.2	153.9 ± 7.7
T2	27.8 ± 1.0	46.6 ± 1.8	74.6 ± 2.1	1.6 ± 0.05	10.7 ± 0.2	145.4 ± 2.3

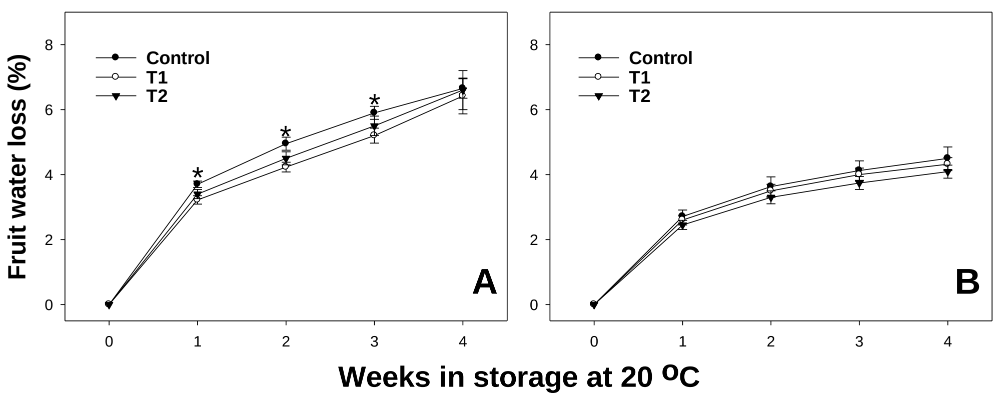

Figure 3. Cumulative fruit weight loss during storage as the percentage of the original weight for ‘Cristalina’ (A) and ‘Rojo Liso’ (B) cactus pear undergoing reproductive bud thinning treatments. The treatments were: control with no thinning; thinning every other bud along the cladode, T1; and thinning two out of every three buds along the cladode, T2. Vertical bars at each sampling date represent the means ± standard error. The asterisks represent significant differences at $p<0.05$.

Conclusions

Fruit quality of both cactus pear cultivars was differentially modified by the fruit thinning treatments. Furthermore, in the second experiment the total soluble solids concentration of ‘Rojo Liso’ fruit was enhanced by reproductive bud thinning, an important quality measure for those growers who are interested in exporting fruit. Additionally, fruit weight loss (FWL) was less than 8% in ‘Rojo Liso’ in both experiments while FWL of ‘Cristalina’ reached this level between two and three weeks of storage in the first experiment. Therefore, ‘Rojo Liso’ fruit may have better attributes for post–harvest handling and can be transported to more distant markets than ‘Cristalina’ fruit. The storage conditions closely resembled those in commercial use, so the optimum temperature and relative humidity for longer storage periods needs to be studied in both cultivars and in other marketable varieties.

Acknowledgements

The authors thank Mr. Miguel and Mr. Valentín Nava Félix, the owners of the orchard 'Rancho La Tunera', where this study was conducted. We also thank Sirs Manuel González Solís, Guadalupe de la Cruz Rodríguez, Salvador Rosas Gallegos, and Miguel Juárez Aguilar for their field assistance. We are grateful to Dr. Mario Domingo Amador Ramírez, M. Sc. Agustín F. Rumayor Rodríguez (both from INIFAP), Mrs. Barbara Gunn (University of California at Davis), and Mrs. Mary Lou Mendum for their critical comments on the manuscript. This research was partially supported by the 'Fundación Produce Zacatecas A.C.', No. Ref.: 02/FPZ/2001 and the CONACYT, No. Ref.: 0007–2005–1_12448. The Sabbatical Leave for the first author at the University of California at Davis was funded by the CONACYT (No. Ref.: 94173), the INIFAP México, and the Universidad Autónoma de Zacatecas.

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