

ORIGINAL ARTICLE

Soil applications of NPK affect fruit quality and shelf-life of 'Cristalina' cactus pear

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Abstract – Introduction. Studies of NPK application in cactus pear have focused on their effects on fruit yield and quality at harvest. Their effects on fruit postharvest life have been neglected. Our objective was therefore to study the influence of soil-applied NPK on some fruit quality attributes after three or four weeks of storage at room conditions for 'Cristalina' cactus pear. **Materials and methods.** The experiment was carried out in a commercial orchard in 2004, 2005, and 2006. Application rates were: 0, 30, 60, and 90 kg N ha⁻¹; 0, 30, 45, and 60 kg P ha⁻¹, and 0, 30, and 60 kg K ha⁻¹. These rates were arranged in an incomplete factorial matrix in a randomised complete block design with three replications. Nine fruit per treatment (three per replication) were randomly harvested and stored for three or four weeks at room temperature. The measured fruit quality parameters were: weight, pulp to peel ratio, flesh firmness (FF), total soluble solids concentration (TSSC), dry matter concentration of pulp (DMCP), and fruit weight loss (FWL). **Results and discussion.** After storage, FF was the same among treatments for all years. The TSSC and DMCP were similar among treatments but tended to be lower with high rates of N. The rate of 90 kg N ha⁻¹ increased the FWL. **Conclusion.** NPK applications produced inconsistent results; therefore, further research is needed in order to address the fruit quality of cactus pear as key for marketing and for consumers' acceptance.

Keywords: Mexico / cactus pear / *Opuntia albicarpa* / firmness / fruit weight loss / shelf life

Résumé – L'application au sol de NPK affecte la qualité et la durée de vie des fruits des figues de barbarie cv. 'Cristalina'. Introduction. Les études de fertilisation NPK du figuier de Barbarie ont généralement porté sur leurs effets sur le rendement et sur la qualité des fruits à la récolte. L'impact sur la qualité des fruits post-récolte a été négligé. C'est pourquoi notre objectif était d'étudier l'influence de la fertilisation NPK appliquée au sol sur certains critères qualitatifs des fruits mesurés après 3 ou 4 semaines de stockage à température ambiante. **Matériel et méthodes.** L'expérience a été réalisée dans un verger commercial (cv. 'Cristalina') en 2004, 2005 et 2006. Les doses d'application correspondent à 0, 30, 60 et 90 kg N ha⁻¹ ; 0, 30, 45 et 60 kg P ha⁻¹ ; et 0, 30, et 60 kg K ha⁻¹. Ces doses ont été apportées selon un dispositif matriciel factoriel incomplet en blocs randomisés à trois répétitions. Neuf fruits par traitement (3 par répétition) ont été récoltés et stockés de façon aléatoire pendant 3 ou 4 semaines à température ambiante. Les paramètres suivants de qualité du fruit ont été mesurés : poids, rapport pulpe/peau, fermeté de la chair (FF), concentration en matières solubles (TSSC), teneur en de matière sèche de la pulpe (DMCP), et perte de poids des fruits (FWL). **Résultats et discussion.** Après stockage, FF était le même pour tous les traitements et quelque soit l'année. TSSC et DMCP étaient comparables entre traitements, mais avaient tendance à être plus faibles pour des doses de N élevées. La dose de 90 kg N ha⁻¹ a fortement augmenté la FWL. **Conclusion.** L'application de NPK sur les cultures de figues de Barbarie a produit des résultats incohérents ; des recherches supplémentaires doivent être menées afin de maîtriser les facteurs de la qualité des fruits du figuier de Barbarie, la composante-clé pour le développement du marché et de la consommation.

Mots clés : Mexique / figue de Barbarie / *Opuntia albicarpa* / fermeté / perte de poids / aptitude au stockage

1 Introduction

Cactus pear fruit (*Opuntia albicarpa*) is a native Mexican fruit also called 'tuna'. On average, 0.49 Mt are annually harvested in more than 55,000 ha in the semi-arid highlands

of central and north-central Mexico. This plant, adapted to arid and semi-arid environment, exhibits the crassulacean acid metabolism [1]. It is therefore, highly efficient in water use and biomass production [1–3]. As fodder, vegetable, and fruit, cactus pear is now cultivated in Europe, America, Asia, and Africa [4, 5].

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For fruit production cactus pear needs management practices such as pest, disease, and weed control; pruning, thinning, irrigation, and organic/mineral nutrition [6, 7]. Organic and mineral nutrition research has focused on effects on yield, fruit size, fruit quality [2, 8–13], and off-season fruit yield [14–18]. Some reports have shown no effect of soil applications of NPK (nitrogen, phosphorous and potassium) either on yield [8, 10, 12] or on some fruit quality attributes at harvest [10, 12]. Fruit sugar concentration has been an exception [10]. The latter authors found higher sugar concentration in fruit from NPK-fertilized plants than from unfertilized ones. They concluded that cladode magnesium concentration significantly influences fruit sugar concentration.

In stone fruit, the influence of orchard management practices, especially irrigation and mineral nutrition, have had strong influence on postharvest fruit quality [19, 20]. However, little [21] or no attention has been paid to the effect of soil application of NPK on fruit quality after storage period for this fruit. For instance, several N fertilization rates (from 0 to 300 kg ha⁻¹) were studied for their effect on postharvest fruit quality of ‘Amarilla sin espinas’ [21]. The latter authors found that fruit firmness decreased and fungal damage increased after 14 days in storage at room conditions as N fertilization rates increased. To our knowledge, there is no more information on this topic which is important for its implication on fruit storability potential, shipment to distant markets, and consumer acceptance. The objective of this research was to study the influence of soil-applied NPK on some fruit quality attributes after three or four weeks of storage at room conditions for ‘Cristalina’ cactus pear. We expected that at least some of the NPK rates could delay fruit weight loss and therefore, would maintain fruit quality.

2 Materials and methods

2.1 Experimental site, plant material, and orchard management

The study was carried out in a commercial orchard established in a semi-arid region of north central México (lat. 22°32’N, long. 103°03’W, elevation 1,976 m asl). The annual mean temperature, cumulative precipitation, and pan evaporation were 25.7 °C, 482 mm, and 2245 mm, respectively, with most of the rainfall (62%) falling in summer [22]. The soil is classified as Fluvisol [23], and it has a sandy-loam to loam texture with a pH from 6.1 to 7.4, organic matter content from 1.00 to 1.56%, and cation exchange capacity from 13.8 to 26.5 meq 100 g⁻¹ soil. Soil fertility analysis, before the fertilizers were applied, indicated a total concentration of 0.71 mg kg⁻¹ inorganic-N and a total-N of 10 mg kg⁻¹. The concentration range for some other macronutrient elements was: 2.0–3.2 mg P kg⁻¹, 520–1,173 mg K kg⁻¹, 1,834–4,440 mg Ca kg⁻¹, and 213–334 mg Mg kg⁻¹ soil.

The orchard of 4-year-old cactus pear plants (*Opuntia albicarpa* Scheinvar) cv. ‘Cristalina’, a late-maturing and white-pulped cultivar, was planted in rows separated at 4 m and 3 m between plants and trained to an open vase system. Tilling between rows and by hand pulling and hoe cultivation around

Table I. Mineral nutrition treatments applied to ‘Cristalina’ cactus pear plants for three consecutive growing seasons from 2004 to 2006 in Jerez, Zacatecas, Mexico.

Treatment number	Mineral nutrient rates (kg ha ⁻¹)		
	Nitrogen	Phosphorus	Potassium
1	0	0	0
2	0	30	30
3	30	30	30
4	60	30	30
5	90	30	30
6	60	45	30
7	60	60	30
8	60	30	0
9	60	30	60
10	90	60	60

trees controlled weeds. Cultural practices used in cactus pear local production included cladode pruning, furrow irrigation, and pest control. Size and uniformity of fruit was promoted by manual fruit thinning (24). In dry season (April to June) irrigation water was applied 4 to 5 times and an additional one 2 weeks after harvesting (September or October) for applying the second half of the nitrogen dose as explained below.

2.2 Mineral nutrient treatments, experimental design, and fertilization program

The NPK fertilization was applied in 10 different combinations (treatments) arranged as an incomplete factorial matrix (table I). The rates (in kg ha⁻¹) were: 0, 30, 60, and 90 N; 0, 30, 45, and 60 P; and 0, 30, and 60 K. In the field, treatments were applied in a randomised complete block design with three replicates. Every experimental unit had 5 consecutive plants in a row. Half of the N and all of the P and K of every fertilization treatment were applied with the irrigation water at the beginning of the blooming stage, on 6 April 2004, 19 April 2005, and 21 April 2006. The remaining dose of N was applied 2 weeks after fruit harvest with watering on 19 October in both 2004 and 2005 and on 22 September in 2006. The sources for N, P, and K were ammonium sulphate, triple superphosphate, and potassium chloride, respectively.

2.3 Fruit data collection

The fruits were collected at export harvest maturity (yellowish-green) from the two central plants of each plot. To assess fruit quality after storage conditions, 9 uniformly sized fruits per treatment (3 per replication) were randomly picked at the fourth harvesting time from the outer part and around the plants. This was done on 5 October 2004, 15 September 2005, and 21 August 2006. Fruit quality assessment was recorded after 3 to 4 weeks of storage at room temperature and relative humidity conditions, mimicking growers’ commercial storage. These assessments were done on 3 November 2004, 7 October 2005, and 18 September 2006.

Table II. Effect of mineral nutrition treatments (MNT) on final fruit weight and weight loss after 3 to 4 weeks of storage at room conditions for ‘Cristalina’ cactus pear in Jerez, Zacatecas, Mexico. Values of vapour pressure deficit for 2004, 2005, and 2006 were ≈ 1.3 , 0.9, and 0.8 kPa, respectively. Mean separations within a column were by Tukey’s minimum significant difference (MSD) at $P \leq 0.05$ ($n = 9$).

MNT	Mineral nutrient rates (kg ha ⁻¹)			Fruit weight (g)			Fruit weight loss (%)		
	N	P	K	2004	2005	2006	2004	2005	2006
	1	0	0	0	162.6b	178.8a	182.4a	6.0a	11.8a
2	0	30	30	184.5b	165.3a	201.4a	6.2a	8.80a	4.2b
3	30	30	30	190.3ab	174.3a	201.9a	4.6a	12.3a	4.6ab
4	60	30	30	221.4ab	178.3a	188.7a	4.5a	11.7a	4.7ab
5	90	30	30	250.6a	187.4a	187.7a	4.3a	10.0a	6.3a
6	60	45	30	218.2ab	192.8a	195.1a	4.7a	9.90a	4.6ab
7	60	60	30	218.1ab	177.5a	211.7a	5.5a	11.1a	4.8ab
8	60	30	0	211.4ab	196.6a	185.1a	5.0a	9.40a	4.3b
9	60	30	60	220.8ab	181.9a	187.1a	5.0a	11.8a	4.4ab
10	90	60	60	206.3ab	171.6a	191.4a	7.1a	12.0a	5.1ab
<i>Significance</i>				<i>0.01</i>	<i>0.1</i>	<i>0.7</i>	<i>0.3</i>	<i>0.2</i>	<i>0.04</i>
<i>MSD</i>				<i>64.1</i>	<i>35.4</i>	<i>58.0</i>	<i>4.3</i>	<i>3.7</i>	<i>1.8</i>

2.4 Fruit quality assessment

Several fruit quality attributes were measured after storage: flesh firmness (FF), total soluble solids concentration (TSSC), pulp and peel weights, and dry matter concentration of pulp (DMCP) [25]. Briefly, fruits were individually weighed and after removing fruit skin, two FF measurements (in N) were performed on 2 opposite sides in the middle of each fruit using a press-mounted penetrometer (FT 327, Wagner Instruments, Greenwich, CT, USA). The TSS concentration (in ° Brix) was measured using a digital refractometer (PR-32 α , Atago, CO., Ltd., Tokyo, Japan) calibrated before each reading. For each fruit, pulp and peel were separated and distinctly weighed (Mettler PE11, Mettler Instrumente, Greifensee-Zurich, Switzerland). The DMCP (in mg g⁻¹ fresh weight) was determined from 25-g composite samples of fresh pulp from 3 fruits (per replicate) and oven-dried at 65 °C to constant weight.

Fruit weight loss (in %) was evaluated at weekly intervals for 3 to 4 weeks by weighing fruit individually with a precision scale (Mettler PE11, Mettler Instrument, Greifensee-Zurich, Switzerland). In 2004 the storage conditions at room temperature were 20.0 \pm 1.0 °C and relative humidity 44 \pm 7% [vapour pressure deficit (VPD) \approx 1.3 kPa]. The corresponding values in the same order for 2005 and 2006 were 15.0 \pm 1.0 °C and 47 \pm 10% (VPD \approx 0.9), and 15.0 \pm 0.8 °C and 53 \pm 3% (VPD \approx 0.8), respectively.

2.5 Data analysis

The data were analysed through a randomised complete block model using the GLM procedure of SAS software (version 9.2; SAS Institute, Cary, NC). The NPK combinations were analysed as treatments. Treatment means were separated by the Tukey’s studentised range test at $P \leq 0.05$. Main effect of N, P or K was analysed separately.

The use of an incomplete matrix of factor levels is a statistical strategy to reduce the dimensions of the experiment.

However, this technique cannot be used to test the null hypothesis over the interaction among factor levels [26]. Therefore, the data on each quality parameter was firstly analysed as treatments. Secondly, when some significant difference was detected, the main effect of N, P or K was explored separately to establish its particular relevance over each quality attribute.

3 Results and discussion

3.1 Fruit weight loss as main treatment effect

In 2004, after 4 weeks of storage at room conditions, there was a significant treatment effect on fruit size in terms of fruit weight ($P \leq 0.05$). Treatment 5 (90N-30P-30K) and control (0N-0P-0K) produced the highest and the lowest fruit weight respectively. However, fruit size was the same among the treatments in 2005 and 2006 (table II). These results were consistent with those observed at harvest in this experiment [25]. The effect can be attributed to a competition for assimilates among fruit [27]. At the start of the 2004 experiment there was lesser amount of fruit in all treatments compared with 2005 and 2006 growing seasons. Therefore, a higher fruit sink strength, partitioning of assimilates among fruits resulted in more uniform sized-fruit in all treatments.

After harvest, fruit weight loss (FWL) is the major cause of fruit deterioration during storage [28]. This is because cactus pear fruit continue to transpire resulting in shrivelling and loss of marketability [29]. However, the final size and shelf life of cactus pear fruit depend on orchard management practices during the growing season [19,20] and post-harvest handling [30]. In our experiment, after 3 to 4 weeks of storage at room conditions, FWL was not affected by the treatments in 2004 and 2005. In cactus pear the FWL should be higher than 8% for shrivel symptoms to be observed [30]. This only occurred in 2005 due to a severe fungi attack that could speed up FWL; in fact, the fruit could not be stored for more than three weeks. In 2006, Treatment 5 (90N-30P-30K) increased FWL by $\approx 38\%$

Table III. Main effect of nitrogen, phosphorous, and potassium on final fruit weight loss (in %) after 3 to 4 weeks of storage at room conditions for ‘Cristalina’ cactus pear in Jerez, Zacatecas, Mexico. Values of vapour pressure deficit for 2004, 2005, and 2006 were \approx 1.3, 0.9, and 0.8 kPa, respectively. Mean separations within a column were by Tukey’s minimum significant difference (MSD) at $P \leq 0.05$.

Fertilization rates	Fruit weight loss (%)		
	2004	2005	2006
Nitrogen (kg ha ⁻¹)			
0	6.3a	10.4a	4.4b
30	4.6a	12.3a	4.6b
60	4.9a	10.8a	4.6b
90	5.7a	11.0a	5.7a
<i>Significance</i>	0.08	0.07	0.002
<i>MSD</i>	2.1	2.0	0.7
Phosphorus (kg ha ⁻¹)			
0	6.5a	11.8a	4.6a
30	4.9a	10.7a	4.8a
45	4.7a	09.9a	4.6a
60	6.3a	11.5a	4.9a
<i>Significance</i>	0.52	0.39	0.88
<i>MSD</i>	5.5	3.6	1.9
Potassium (kg ha ⁻¹)			
0	5.7a	10.6a	4.4a
30	5.0a	10.7a	4.9a
60	5.0a	11.9a	4.8a
<i>Significance</i>	0.20	0.35	0.41
<i>MSD</i>	2.0	3.0	1.1

($P \leq 0.05$) compared with the control and Treatments 2 and 8. The other treatments had an intermediate FWL (*table II*). To minimize FWL during storage is commercially important for long-term storage and long-distance transport to markets [28].

The main effects of N, P, and K were also separately studied. The application rates of P and K did not alter FWL over the 3 cropping seasons while those of N did ($P = 0.002$) in 2006 (*table III*). The rate of 90 kg N ha⁻¹ increased significantly FWL in relation to 0, 30 and 60 kg N ha⁻¹. In apple, fruit water loss is positively correlated with their size and surface area [31]. Here, the FWL arcsine-transformed data did not correlate with the weights of fruit ($r = -0.16$; $P = 0.14$), peel ($r = -0.18$; $P = 0.09$), and pulp ($r = -0.01$; $P = 0.93$). The removal of glochids (spines) from cactus pear fruit increases FWL during storage [30]. We did not remove spines from the fruit. Then, some cuticular alterations might have been induced at the highest N rate leading to increase FWL. However, further epicuticular studies are needed for confirmation.

3.2 Fruit firmness poorly related to N and P

After 3 to 4 weeks of storage fruit firmness was maintained without measurable changes among treatments in all years (*table IV*). This is in contrast to another study on mineral nutrition of cactus pear [21]. In the first two years of this study, pulp to peel ratio (PPR) was similarly maintained among treatments along the storage period. In 2006 however, PPR was significantly higher in Treatment 8 (60N-30P-0K) and 10 (90N-60P-60K) than in the control. Except for the main

effects of N ($P = 0.05$) and P ($P = 0.05$), K ($P = 0.6$) did not influence PPR. The main effect of N revealed a trend to increase PPR as the rate of N increased. The PPR values (minimum significant difference (MSD) = 0.431; $P = 0.05$) were 1.5, 1.5, 1.8, and 1.8 for 0, 30, 60, and 90 kg N ha⁻¹, respectively. On the other hand, the main effect of P pointed out that 45 kg P ha⁻¹ was higher than the control. The PPR values (MSD = 0.4; $P = 0.04$) were 1.3, 1.7, 1.8, and 1.7 for 0, 30, 45, and 60 kg P ha⁻¹, respectively. Although peel thickness was not measured, higher PPR could be due to decreases in peel thickness, in terms of weight; hence higher PPR in the rates of N and P.

3.3 Total soluble solids and dry matter concentrations of fruit

Total soluble solids concentration (TSSC) showed an inconsistent response after 3 to 4 weeks of storage under room conditions. In 2004, control fruit maintained higher TSSC compared with other treatments (*table IV*). Although not significant, a similar trend was observed in 2005. In contrast, Treatment 4 (60N-30P-30K) and control and Treatment 7 (60N-60P-30K) registered the highest and lowest values of TSSC, respectively while the other treatments had an intermediate response in 2006 (*table IV*). The main effect of P revealed that the rates (kg ha⁻¹) 30 and 45 maintained higher TSSC values compared with those of 0 and 60. The TSSC values (MSD = 1%; $P = 0.02$) were 10.0, 11.1, 11.2, and 10.5 for 0, 30, 45, and 60 kg P ha⁻¹, respectively. Cactus pear fruit exhibit a non-climacteric respiration pattern [32]. However, in similar storage conditions to ours, significant reduction of both TSSC and dry matter concentration of pulp (DMCP) after storage has been observed [33]. In the present experiment, on average, the reduction of TSSC (from harvest to after storage) was 27%, 13.0%, and 6.1% for 2004, 2005, and 2006, respectively. This last trend has been observed in other cactus pear cultivars such as ‘Rojo Liso’ [33] and ‘Amarilla Olorosa’ and ‘Cristalina’ [34] undergoing thinning and irrigation treatments, respectively. Therefore, all these findings might confirm that other unknown metabolic pathways are using the soluble sugars.

After 4 weeks of storage, DMCP was similar among mineral nutrient treatments in 2004. For the years 2005 and 2006, Treatment 5 (90N-30P-30K) had the lowest DMCP values (*table IV*). The main effect analysis of N revealed significant influence on DMCP only in 2005. Values of DMCP were reduced with the higher application rates of these nutrients. The DMCP values (mg g⁻¹ fresh weight, MSD = 10.1; $P = 0.001$) were 178.8, 172.7, 170.2, and 161.8 for 0, 30, 60, and 90 kg N ha⁻¹, respectively. The DMCP values (MSD = 9.5; $P = 0.05$) were 174.8, 171.2, and 164.1 for 0, 30, and 60 kg K ha⁻¹. We explored the possibility of a dilution effect due to higher pulp weight in fertilised treatments, but a non-significant and weak correlation between DMCP and pulp weight ($r = -0.13$; $P = 0.05$) was found. Similar to TSSC, on average, a reduction of DMCP after storage was observed over the years of this experiment. The values were 14.4%, 8.5%, and 13.3% for 2004, 2005, and 2006, respectively. Although cactus pear fruit is non-climacteric, the reduction of DMCP

Table IV. Effect of mineral nutrition treatments (MNT) on flesh firmness (FF), pulp to peel ratio (PPR), total soluble solids concentration (TSSC), and dry matter concentration of pulp (DMCP) after storage at room conditions for ‘Cristalina’ cactus pear in Jerez, Zacatecas, Mexico. Vapour pressure deficit for 2004, 2005, and 2006 was \approx 1.3, 0.9, and 0.8 kPa, respectively. Mean separations within a column were by Tukey’s minimum significant difference (MSD) at $P \leq 0.05$ ($n = 9$).

MNT	Mineral nutrition rates (kg ha ⁻¹)			FF (N)			PPR (gg ⁻¹)			TSSC (° Brix)			DMCP (mg g ⁻¹ fresh weight)		
	N	P	K	2004	2005	2006	2004	2005	2006	2004	2005	2006	2004	2005	2006
1	0	0	0	27.4a	26.7a	37.8a	1.5a	1.6a	1.3b	9.4a	11.0a	10.0b	157.9a	180.0a	162.7ab
2	0	30	30	29.0a	25.5a	35.4a	1.4a	1.5a	1.6ab	8.3ab	10.0a	11.3ab	162.4a	177.5a	166.7ab
3	30	30	30	29.2a	23.4a	30.0a	1.5a	1.8a	1.5ab	8.3ab	10.7a	10.6ab	159.3a	172.7ab	155.1ab
4	60	30	30	28.2a	23.6a	30.8a	1.6a	1.9a	1.8ab	7.6ab	10.4a	11.6a	165.8a	174.2ab	169.5a
5	90	30	30	31.4a	22.2a	27.6a	1.4a	2.1a	1.8ab	6.9b	10.6a	10.8ab	156.1a	158.9b	146.0b
6	60	45	30	31.9a	26.4a	28.2a	1.4a	1.9a	1.8ab	6.8b	9.9a	11.2ab	150.0a	169.4ab	153.6ab
7	60	60	30	29.6a	26.0a	35.4a	1.6a	1.8a	1.6ab	7.5ab	9.7a	9.9b	153.5a	174.4ab	149.3ab
8	60	30	0	26.3a	30.2a	29.9a	1.6a	1.8a	1.9a	7.6ab	9.9a	11.3ab	147.3a	169.6ab	162.1ab
9	60	30	60	28.6a	26.0a	26.5a	1.5a	1.9a	1.7ab	7.1b	10.1a	10.9ab	161.5a	163.5ab	154.7ab
10	90	60	60	27.3a	25.1a	29.8a	1.5a	1.9a	1.9a	6.8b	10.4a	11.1ab	157.4a	164.7ab	156.0ab
<i>Significance</i>				0.4	0.3	0.06	0.3	0.2	0.03	0.01	0.2	0.01	0.06	0.005	0.03
<i>MSD</i>				8.4	10.0	12.6	0.4	0.7	0.5	2.3	1.7	1.4	21.0	16.6	22.4

indicates that part of the carbohydrates was consumed during the storage period, what still needs to be assessed.

4 Conclusion

After three years of postharvest evaluations, the effect of mineral nutrition treatments on some quality attributes of cactus pear fruit is still not clear. Fruit weight was maintained higher in Treatment 5 (90N-30P-30K) than in the other treatments only in 2004. In 2006, fruit weight loss increased with 90 kg N ha⁻¹ but P and K did not influence fruit weight loss. Fruit firmness was the same among treatments in the three years of this experiment. Mixed results were shown for treatment effects on pulp to peel ratio, total soluble solids concentration, and dry matter concentration of pulp. Further studies on cactus pear are needed to understand the metabolic processes affecting fruit quality at harvest and after storage.

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