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Research article

Effect of a cold quarantine treatment on physiological disorders and quality of cactus pear fruit

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Abstract: Despite Italy is second only to Mexico for fresh production of cactus pears worldwide, postharvest handling and treatments are quite simply, being fruit immediately marketed after harvest. However, as the demand for fresh fruit beyond the harvesting period is constantly growing, in the next future the cactus pear industry likely will have to adopt postharvest treatments and technologies that can widen the marketable window. Yet, the potential exploitation of new markets in countries where the introduction of pests like Mediterranean fruit fly are considered risky, can be achieved only if fruit are subjected to approved quarantine protocols. Of the three main cultivated varieties ('Bianca', 'Gialla' and 'Rossa') limited studies concerning cold storage have been done mainly on fruit of cv 'Gialla', while knowledge on response to cold quarantine treatments lacks for all cultivars. Thus this study was undertaken to get knowledge on postharvest behavior of the three main Italian cultivated cactus pears varieties, i.e. 'Bianca', 'Gialla' and 'Rossa' subjected to a cold quarantine treatment followed by either a week of simulated marketing conditions at 20 ℃ or by two additional weeks of storage at 8 ℃ before transfer to simulated marketing conditions at 20 ℃ for three days. These storage conditions so far are not practiced by packing houses as fruit are directly marketed after harvest, but could be a typical protocol in case fruit should be sold in countries that require approved cold quarantine treatments.

Results showed an abnormal increase in respiratory activity and ethylene production rates following transfer from cold storage to 20 ℃, especially after the two additional weeks of storage at 8 ℃. Peel disorders and decay incidence were slight at the end of storage at 2 ℃ or 8 ℃, but severe peel disorders developed when fruit were moved to 20 ℃. Peel injury, decay incidence, the loss of overall appearance upon transfer to 20 ℃ were more severe in fruit stored for two additional weeks at 8 ℃. Among the three cultivars, susceptibility to chilling injury and decay was higher in cv

‘Bianca’. Nevertheless, cold storage seems not to affect the chemical and sensory quality of fruit, whose changes were similar in all cultivars.

Keywords: cactus pear; ethylene production; physiological disorders; juice acidity; respiratory activity; weight loss

1. Introduction

In Italy cactus pear [*Opuntia ficus indica* (L) Mill] is mainly grown in Sicily on a surface that exceeds 3500 ha [1]. Most of the production is marketed in Italy, while the remaining part is exported to European countries and Canada, where it is delivered by airfreight. Fruit are marketed immediately after harvest, and postharvest treatments and handling procedures are quite simple. Upon arrival to the packinghouse, fruit are dumped onto packing lines and moved across a series of brushes in dry conditions to remove the glochids (despination) and increase peel shine by rubbing on epicuticular wax [2]. Fruit are then sorted and hand-packed in one-layer tray liners allocated into plastic or cardboard boxes and are ready for marketing. Despite the high perishability and susceptibility to chilling injury [3,4], fruit maintain a good freshness and losses for decay are insignificant thanks to the short interval of time between harvest and consumption.

However, the demand for fresh cactus pears is constantly increasing, especially after the harvest season [5]. Thus, to meet the out-of-season demand of fresh fruit in the next future, the cactus pear industry needs to develop suitable postharvest treatments and technologies to mitigate chilling injury in fruit destined for long term storage. Yet, to increase volume of sales into new markets, quarantine measures to prevent the entry and spread of economically important pests, such as the Mediterranean fruit fly (*Ceratitis capitata* Wiedemann), need to be accomplished when required.

The Italian cactus pear varieties most grown are ‘Gialla’ or ‘Sulfarina’, ‘Bianca’ or ‘Muscaredda’ and ‘Rossa’ or ‘Sanguigna’ [6]. The ‘Gialla’ cultivar is the most widespread due to its high productivity and good adaptability to intensive cultivation methods; the cultivar ‘Bianca’ is appreciated for its peculiar flavor, while the cultivar ‘Rossa’ is particularly attractive for the deep red-purple color of its peel and flesh conferred by the high levels of betaxantins and betacyanins [7]. Although the cultivation of cv ‘Gialla’ prevails, the tendency of farmers is to grow the three cultivars in the same orchard, whereas the packinghouses frequently put in the same trays fruit of ‘Gialla’ and some of ‘Bianca’ and ‘Rossa’ to supply the market with a product of great chromatic impact.

Despite the economic importance of these three cultivars, cactus pears postharvest studies in Italy have been focused mainly on cv ‘Gialla’ [8–10] and at temperature regimes typical of cold storage protocols for fresh produce, but not as low as those required for cold quarantine treatments.

The objective of this study was to compare the postharvest behavior of the three main grown Italian cactus pear cultivars (i.e. ‘Bianca’, ‘Gialla’ and ‘Rossa’) under a cold-quarantine treatment of three weeks at 2 ℃ and two additional weeks of cold storage at 8 ℃. The quarantine conditions were chosen since they are the habitual conditions to send fruits like citrus fruit to countries where the Mediterranean fruit fly is considered as a quarantine pest. Treatment B was introduced in the experimental plan since at arrival in overseas markets, before distribution, normally fruit are cold stored for a short period before distribution.

2. Materials and methods

2.1. Plant material

Cactus pears (*Opuntia ficus-indica*) cvs 'Bianca', 'Gialla, and 'Rossa', were harvested on August 20th from Agris Sardegna research station located in Bari Sardo, South-Est Sardinia (Lat. 39°50' N, Long. 9° 38' E). Fruit were harvested using a knife, leaving a little piece of cladode at the stem end and gently placed in carton boxes. Within two hours from harvest, fruit were transported to ISPA-CNR laboratory in Sassari where they were conditioned overnight at room temperature. The day after, sound and uniform fruit weighing 150–180 g were selected and divided into plastic boxes in number of 25 per box; each box represented a replication.

2.2. Storage conditions

The fruit was divided into two groups: group A was stored at 2 ℃ and 90–95 % RH for 3 weeks and then transferred to 20 ℃ and 60–65 % RH for 7 d to simulate marketing conditions (SMC) and group B (treatment B) was stored at 2 ℃ for 3 weeks, 2 weeks at 8 ℃ and finally transferred to 20 ℃ for 3 d to SMC. For each treatment and storage time for boxes were used.

2.3. Respiratory activity and ethylene production rate

Respiratory activity and ethylene production rates were determined at the beginning of the experiment and after 1 and 3 weeks at 2 ℃, after 1 and 7 d at 20 ℃ in group A and after 1day and 2 weeks at 8 ℃ and 1 and 3 d at 20 ℃ in group B as previously described [11]. In brief, fruit were individually closed in 1 L jars whose lids were fitted with two silicon septa to allow gases sampling. Initially and in SMC fruit were incubated for 2 h at 20 ℃, whereas the incubation time was increased to 5 h while fruit were in storage at the same temperature of storage (2 or 8 ℃). For each treatment/cultivar combination, measurements were always carried out on the same lot of fruit (ten fruit) chosen at harvest. As among fruit, respiratory activity may show a large variability, initially we chose fruit with similar activity in order to minimize sampling error. Precisely, at harvest a preliminary test for respiration was conducted using several fruits, among whom twenty fruits for each treatment/cultivar combination showing a respiratory activity of 10 ± 0.5 mL CO_2 kg^{-1} h^{-1} were chosen. All fruits were numbered but subsequent determinations were only carried out on the first ten of each treatment/cultivar combination; the remaining ten were used to replace the fruits of the first ten that would decay over the experiment time.

For ethylene analysis, the headspace air was agitated ten times with a 20 mL syringe and a 2 mL sample from each jar was withdrawn. Ethylene was determined by a 3300 Varian gas chromatograph fitted up with a flame ionization detector (FID) and a packed column (Unibeds®, Alltech, Milan). Helium was used as carrier gas at a flow rate of 7 mL s^{-1}. The temperatures of the injector, oven, and detector were 150, 60, and 200 ℃, respectively. Carbon dioxide was determined soon after ethylene sampling using a combined CO_2/O_2 analyzer (Combi Check 9800-1, PBI-Dansensor A/S, Denmark). The analyzer was connected to each jar by two tubes,

each tube ending with a needle inserted in one of the two septa, in order to form a closed system. An incorporated-analyzer-pumped headspace air through the inlet tube until readings of CO_2 were fairly constant (about 60 s). Respiratory activity was expressed as milliliters CO_2 per kilogram per hour, while ethylene production rate was expressed as microliters C_2H_4 per kilogram per hour.

2.4. Fruit weight loss, decay, peel alterations and overall appearance

In treatment A, weight loss was determined at the end of cold storage at 2 ℃ and after 7 d of SMC, whilst in treatment B, it was determined at the end of cold storage at 2 and 8 ℃ and after 3 d of SMC. For each treatment and cultivar, 30 fruits were weighed at the beginning of the experiment marking initial weight on the peel and were re-weighted at the end of each storage time and SMC Weight loss was expressed as percentage reduction of the initial weight.

One hundred fruits (4 replications of 25 fruits each) per treatment per storage time per cultivar were used to assess peel alterations, overall appearance and decay (soft rot). At each inspection time, fruit were first checked for decay, expressed as percentage of decayed fruit. The remaining fruit were evaluated for peel alterations, which included any injury of the peel caused by abiotic origin (low temperature, mechanical stress, punctures by glochids), on a subjective scale ranging from 1 to 5 (1 = none, 2 = slight, 3 = moderate, 4 = severe, and 5 = very severe), while overall appearance was scored on a 9-point hedonic scale, where: 1 = very poor, 3 = poor, 5 = good (limit of marketability), 7 = very good, and 9 = excellent.

2.5. Chemical analyses and sensory assessments

Chemical analyses were conducted on three replicates, combining the juice of ten fruits per replicate. Total soluble solids (TSS) were measured by a digital refractometer (Mod. PR- 101, Atago, Tokyo, Japan) and expressed as percent; pH was measured using an automatic titrator (Titritino 702, Metrohm, Swiss); titratable acidity (TA) was determined by titrating aliquots (10 mL) of juice samples to an endpoint of pH 8.2 with 0.1 N NaOH and expressing the result as gram citric acid per 100 mL.

The sensory evaluation was performed by five experienced technicians. Ten fruits per cultivar were used at each sampling time. Fruit were peeled and divided into six pieces by one transversal cut and two longitudinal cuts. Each panelist first smelled the samples and then ate five to six pieces of each cultivar and evaluated the fruit for off-flavor, texture (overall impression of hardness to bites), and overall acceptability. All sensory assessments were based on a 9-point scale, according to the intensity of the attributes. For texture and overall acceptability, a score of 5 was established as the limit of acceptability for eating; while the limit of acceptability for off-flavour was a score higher than 5.

2.6. Statistical Analysis

Data were subjected to analyses of variance. Means separation was accomplished by Duncan's multiple range test at $P < 0.05$. The work-package Statgraphics Centurion XV software (StatPoint Inc., Herdan, Virginia) statistical program was used.

3. Results and Discussion

3.1. Respiration and ethylene production rate

Initially, respiratory activity was 10 ± 0.5 mL CO_2 kg^{-1} h^{-1} and declined to 1.5–2 mL CO_2 kg^{-1} h^{-1} (Figure 1A, 1B) during storage at 2 ℃. In treatment A, after one day at 20 ℃, respiratory activity in 'Gialla' and 'Rossa' increased to 15.4–16.9 mL CO_2 kg^{-1} h^{-1}, then declined to around 12 mL CO_2 kg^{-1} h^{-1} after one week (Figure 1A). In contrast, in 'Bianca' after one day at 20 ℃ respiration was significantly higher than in the other two cultivars (above 22 mL CO_2 kg^{-1} h^{-1}) and continued to increase during the week of SMC (Figure 1A).

In treatment B, one day after transfer from 2 ℃ to 8 ℃, respiration doubled, while after 1 d of SMC at 20 ℃, values were in all cultivars higher than in treatment A (Figure 1A, 1B), and continued to increase, with rates after 3 d even higher than 50 mL CO_2 kg^{-1} h^{-1} in cv 'Bianca, and around 30 CO_2 kg^{-1} h^{-1} in 'Gialla' and 'Rossa'.

Ethylene rates, which initially were around 0.3 μL C_2H_4 kg^{-1} h^{-1}, decreased below the limit of detectability while fruit was exposed to 2 ℃, and slightly increased when moved to 8 ℃ (Figure 1C, 1D). In contrast, upon transfer to SMC, the rates increased dramatically in fruit of both treatments, with a trend similar to that detected for respiration. Specifically, fruit of treatment A showed significantly lower rates than those of treatment B after 1 d at 20 ℃ and their rates decreased after 1 week of SMC (Figure 1C), while in treatment B, after 3 d of SMC their rates increased further (Figure 1D).

In cactus pears as in other chilling sensitive species, respiratory activity is greatly stimulated following transfer from chilling temperatures to warm temperatures. In sound fruit this burst is transient and the rates gradually return to levels of fruit held continually at warm temperatures [12–14]. In injured fruit respiration remains high or even increases. In this study, in treatment A, the slight decline in respiration detected in cvs 'Gialla' and 'Rossa' over the week of SMC but with values 20–30 % higher than rates of harvest time, could be expression of localized damages of the peel. In contrast, the higher respiratory activity of cv 'Bianca' and its increasing trend during the week of SMC is a clear physiological response to severe injuries. The close relationship between the severity of chilling injury and the increasing rates of respiratory activity and ethylene production is further supported by results of treatments B, where the additional two weeks of storage at 8 ℃ led to an overall dramatic increase in respiration and ethylene rates when fruit were moved to SMC and further more after three days. The constantly higher rates in respiration and ethylene production occurring in cv 'Bianca' compared to the other cultivars denote its higher susceptibility to chilling injury. Similar results were previously reported by D'Aquino et al. [11,15].

3.2. Decay and peel disorders

As previously reported for cactus pears and other tropical fruit [16–18], decay developed slowly while fruit where in storage, ranging between 2 and 4 % after three weeks at 2 ℃ and between 3 and 5 % in treatment B at the end of storage at 8 ℃, but increased sharply when fruit of both treatments were moved to SMC (Figure 2A, 2B). After 3 d of SMC, in treatment A decay incidence was 17 % in cv 'Bianca', 9 % in 'Gialla' and 7 % in 'Rossa' and the losses increased to 22, 11 and 12 % after 7 d, respectively (Figure 2A). Significantly higher losses occurred in treatment B, where decay incidence was 31 % in cv 'Bianca' and around 15 % in cvs 'Gialla'

and ‘Rossa’ after 3 d of SMC. In all cases, fruit of cv ‘Bianca’ resulted more susceptible to decay than those of the other two cultivars.

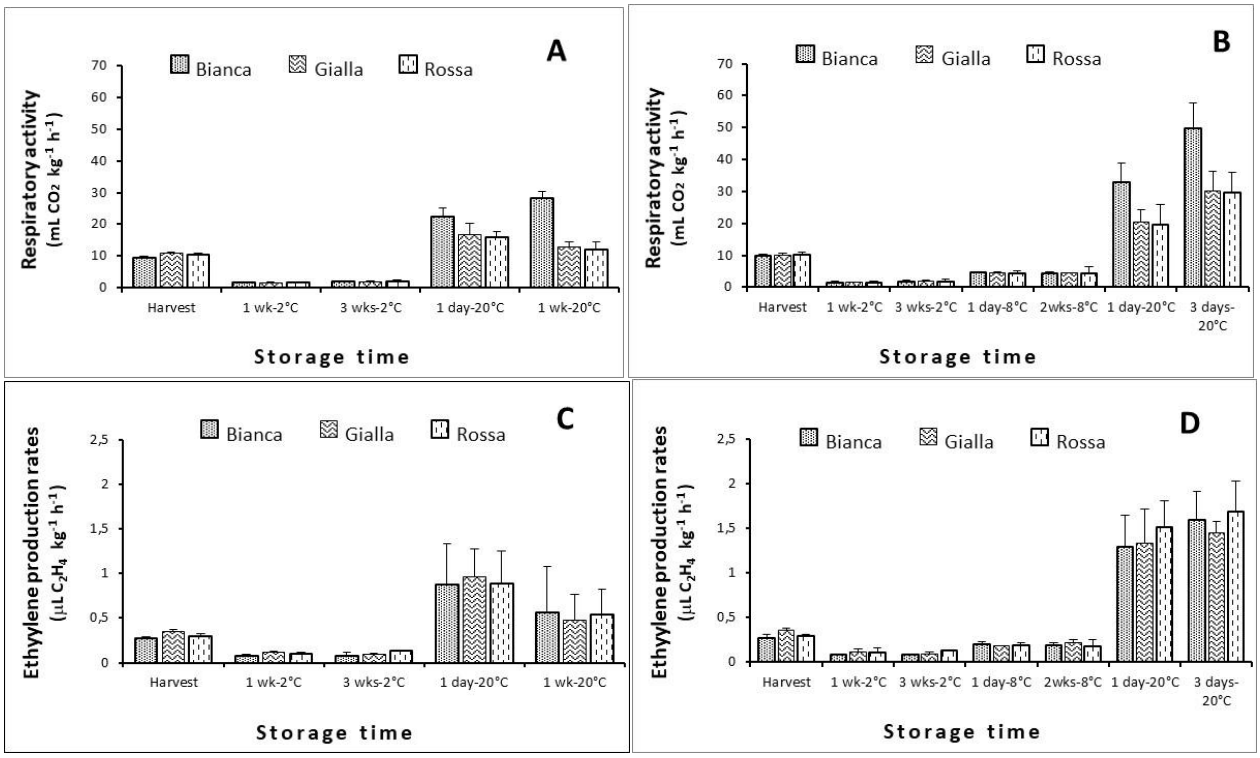

Figure 1. Respiratory activity (A, B) and ethylene production rates (C, D) of cactus pears stored for 3 weeks at 2 ℃ plus 1 week at 20 ℃ (A, C) or stored for 3 weeks at 2 ℃ and 2 weeks at 8 ℃ plus 3 d at 20 ℃ (B, D). For each storage time, means with different letters are significantly different according to Duncan’s multiple range test ($P \leq 0.05$). Vertical indicate the standard deviation (N = 10).

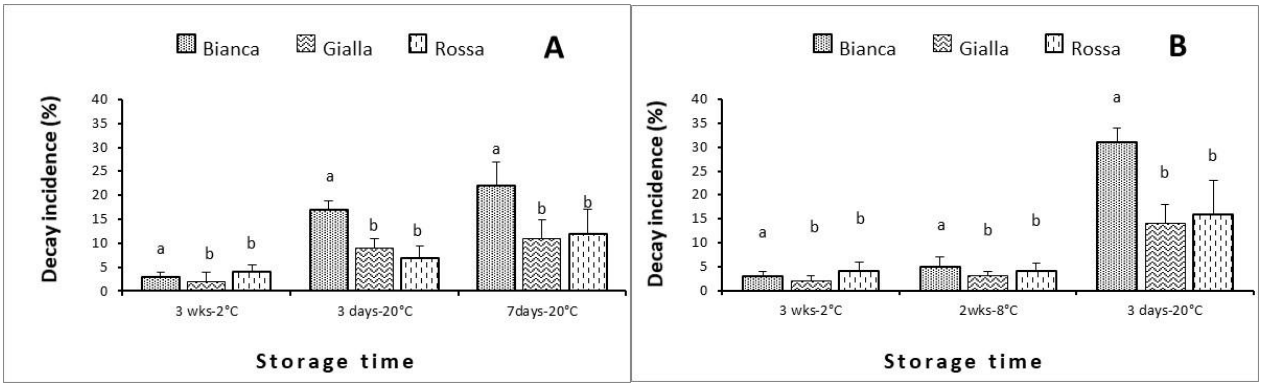

Figure 2. Decay incidence in cactus pears stored for 3 weeks at 2 ℃ plus 1 week at 20 ℃ (A) or stored for 3 weeks at 2 ℃, 2 weeks at 8 ℃ plus 3 d at 20 ℃ (B). For each storage time, means with different letters are significantly different according to Duncan’s multiple range test ($P \leq 0.05$). One hundred fruit were used for each treatment divided into 4 replicates of 25 fruit each. Vertical bars indicate the standard deviation (n = 4).

Peel disorders in cactus pears are very frequent; they develop for bruises occurring during harvest and handling, but also for micro-wounds inflicted by glochids as well as chilling injury [2,4]. When pre-storage mechanical stresses and micro-wounds are slight or moderate, damages become visible after several days. As a result, peel disorders developing in cold storage frequently are the combination of different causes, making it difficult to discern between disorders caused by chilling temperatures and pre-storage mechanical injuries, whose expression however is exacerbated by low temperatures [20,21]. In this study, regardless of the cultivar and treatment considered, peel disorders developed slowly during the storage period, but, as it normally happens in most chilling sensitive species, symptoms developed rapidly when fruit were moved to SMC, especially in fruit of cv 'Bianca'. At the end of storage at 2 °C most fruit of cvs 'Gialla' and 'Rossa' were still free of defects and were still sound or slightly injured after the two additional weeks of storage at 8 ℃, while in cv 'Bianca' most of the fruit developed slight peel alterations which become severe at the end of storage at 8 ℃ (Figure 3A, 3B). The disorders developed dramatically when fruit from 2 ℃ and even more from 8 ℃ were transferred to SMC. In treatment A, 41 % (data not shown) of cv 'Bianca' showed moderate or severe injury and at the end of the week of SMC and only occasionally some fruit still free of disorders was detected. Less disorders developed in cvs 'Gialla' and 'Rossa', which even after 7 d of SMC had 31 and 38 % of fruit still free of injuries (data not shown) and an index number of 1.6 and 1.48, respectively (Fig. 3A).

In treatment B peel disorders developed very rapidly upon transfer to SMC, especially in cv 'Bianca,' where 59 % of the fruit showed severe or very severe disorders after 3 d (data not shown); less disorders developed in cvs 'Gialla' and 'Rossa', with 95 % and 98 % fruit showing slight or moderate damages (data not shown) and an index number of 1.23 and 1.12, respectively (Fig. 3B).

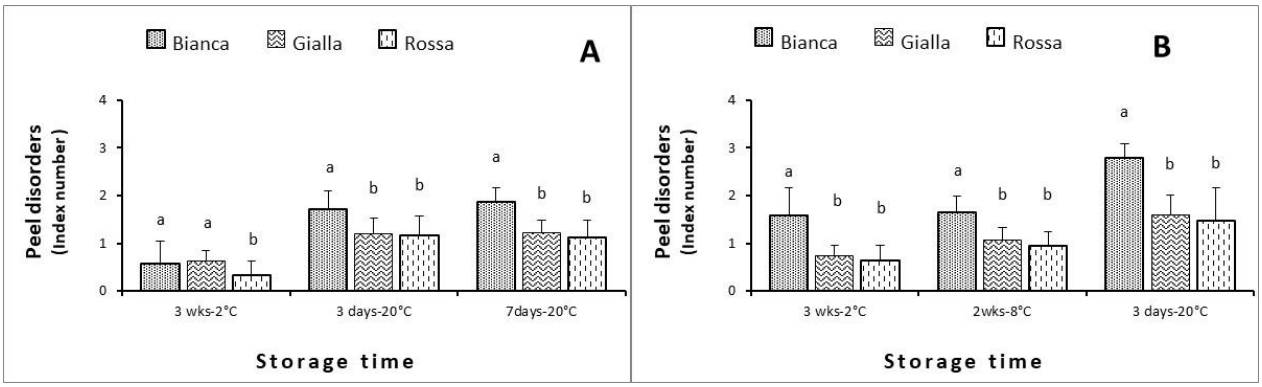

Figure. 3 Peel disorders in cactus pears stored for 3 weeks at 2 ℃ plus 1 week at 20 ℃ (A) or stored for 3 weeks at 2 ℃, 2 weeks at 8 ℃ plus 3 d at 20 ℃ (B). For each storage time, means with different letters are significantly different according to Duncan's multiple range test ($P \leq 0.05$). Vertical bars indicate the standard deviation ($n = 4$).

3.3. Weight loss overall appearance

After 3 weeks at 2 ℃ weight loss was just above 3 % in all cultivars and approximately doubled after 2 weeks at 8 ℃, with no significant difference among cultivars (Tables 1 and 2). Weight loss increased at a higher rate when fruit were moved to SMC, especially in fruit of treatment B, which

lost after only 3 d (Table 2) more weight than fruit of treatments A had lost after 7 d (Table 1). The highest losses occurred in cv 'Bianca', with a peak of 9.6 %, while in cvs 'Gialla' and 'Rossa' the losses never exceeded 8.7 %.

Table 1. Weight loss and overall appearance in cactus pears stored for 3 weeks (wks) at 2 ℃ plus 1 week (wk) at 20 ℃.

	Bianca	Gialla	Rossa
	Weight loss (%)		
3 wks at 2 ℃	3.22 b A	3.33 b A	3.15 b A
2 wks at 2 ℃ plus 1 wk at 20 ℃	8.12 a A	7.22 a B	7.09 a B
	Overall appearance (Index number)		
Harvest	9 a	9 a	9 a
3 wks at 2 ℃	8.2 b A	8.3 b A	8.6 b A
2 wks at 2 ℃ plus 3 d at 20 ℃	5.8 c C	7.1 B	7.7 A
2 wks at 2 ℃ plus 1 wk at 20 ℃	5.4 d B	6.3 d A	6.6 d A

[1] Means in columns followed by unlike lowercase letters and in rows followed by unlike uppercase letters are significantly different at $P < 0.05$ according to Duncan's multiple range test.

Table 2. Weight loss and overall appearance in cactus pears stored for 3 weeks (wks) at 2 ℃ and 2 weeks at 8 ℃ plus 3 d (d) at 20 ℃.

	Bianca	Gialla	Rossa
	Weight loss (%)		
3 wks at 2 ℃	3.22 c A	3.33 c A	3.15 c A
2 wks at 2 ℃ plus 2 wks at 8 ℃	6.39 b A	6.10 b B	6.23 b AB
2 wks at 2 ℃ plus 2 wks at 8 ℃ plus 3 d at 20 ℃	9.60 a A	8.60 a B	8.70 a B
	Overall appearance (Index number)		
Harvest	9 a	9 a	9 a
3 wks at 2 ℃	8.2 b B	8.3 b B	8.6 b A
2 wks at 2 ℃ plus 2 wks at 8 ℃	6.5 c B	7.4 c A	7.6 c A
2 wks at 2 ℃ plus 2 wks at 8 ℃ plus 3 d at 20 ℃	5.2 d B	6.2 d A	6.4 d A

[1] Means in columns followed by unlike lowercase letters and in rows followed by different uppercase letters are significantly different at $P < 0.05$ according to Duncan's multiple range test.

Overall appearance was markedly affected by peel disorders, firmness, weight loss and shriveling. In treatment A, overall appearance changed slightly during storage at 2 ℃, while worsened at a faster rate in SMC (Table 1). Precisely, in cv 'Bianca' after three days all fruit were still quite good and marketable, with an average score of 6.5, but after 7 d about 40 % of fruit were rated less than 5, the limit of marketability, while the remaining 60 % although still marketable were rated at the limit of marketability. In contrast a better appearance was detected in cvs 'Gialla' and 'Rossa', being all fruit still marketable after 1 week of SMC (Table 1).

In treatment B fruit appearance was strongly altered by the end of the two additional weeks of storage at 8 ℃ and when transferred to SMC fruit deteriorated very rapidly: after only three days about 30 % of fruit in cv 'Bianca' were unmarketable, while in cvs 'Gialla' and 'Rossa' despite

almost all fruit were still marketable, only 41 and 32 % were still graded as "very good", respectively, while from day 3 overall appearance declined dramatically and most fruit decayed, regardless the cultivar (Table 2).

3.4. Chemical parameters and taste analysis

The results of the chemical analyses are reported in Tables 3 and 4. At harvest chemical parameters of the three cultivars were similar, resulting in pH levels ranging from 5.30 to 5.46, a TA value of 0.061 g citric acid/ 100 mL juice in cv 'Bianca' and of 0.075 and 0.077 g citric acid/ 100 mL juice in 'Rossa' and 'Gialla', respectively and quite high percentages of TSS (Tables 3 and 4). Over storage as well as during the SMC, TSS changed slightly, while pH and TA underwent marked changes, especially during the first three weeks of storage at 2 ℃ (Tables 3 and 4).

Table 3. Changes of pH, titratable acidity (TA) and total soluble solids in cactus pears stored for 3 weeks (wks) at 2 ℃ plus 1 week (wk) at 20 ℃.

	Bianca	Gialla	Rossa
	pH		
Harvest	5.30 b C[1]	5.46 b A	5.38 b B
3 wks at 2 ℃	6.03 a AB	6.09 a A	5.98 a B
2 wks at 2 ℃ plus 1 wk at 20 ℃	6.03 a B	6.10 a A	6.02 a B
	Titratable acidity (TA) (g/100 mL)		
Harvest	0.061 a A	0.077 a A	0.075 a A
3 wks at 2 ℃	0.036 b B	0.045 b A	0.046 b A
2 wks at 2 ℃ plus 1 wk at 20 ℃	0.034 b A	0.039 c A	0.035 c A
	Total soluble solids (TSS) (%)		
Harvest	14.2 a A	14.3 a A	14.5 a A
3 wks at 2 ℃	14.5 a A	14.4 a A	14.4 a A
2 wks at 2 ℃ plus 1 wk at 20 ℃	13.3 b B	14.3 a A	14.5 a A

[1] Means in columns followed by unlike lowercase letters and in rows followed by different uppercase letters are significantly different at $P < 0.05$ according to Duncan's multiple range test. (n=3).

The results from sensory analyses (Tables 5 and 6) revealed a dramatic decline of texture, particularly upon transfer to SMC, while off-flavors, barely detected over the storage time, increased slightly in SMC but never at a level that could affect the sensory quality. Nevertheless, the liking score for overall acceptability at the end of storage in treatment B (Table 6) and even more during the SMC of both treatments dropped at a point that the fruit were barely acceptable to eat.

For sensory analysis as well as for chemical parameters changes occurring over the storage time and the subsequent periods of SMC were quite similar for all cultivars, and even when significant differences were detected, results were inconsistent over time.

From comments of assessors and in accordance with previous findings [22,23], the decline of eating quality was mainly due to the high loss in firmness and sourness. These changes as well as those detected for chemical parameters are normal to occur during the postharvest life of cactus pear [24], even in those cases when the fruit are stored at temperatures higher than those tested in this study. So, despite the fact that the outer tissues of the fruit were severely affected by the stringent experimental

conditions, both for the visible damages and the high susceptibility to pathogens' growth, the inner tissues were barely injured by the chilling temperatures.

Table 4. Changes of pH, titratable acidity (TA) and total soluble solids in cactus pears stored for 3 weeks (wks) at 2 ℃ and 2 weeks at 8 ℃ plus 3 d at 20 ℃.

	Bianca	Gialla	Rossa
	pH		
Harvest	5.30 c C[1]	5.46 c A	5.38 c B
3 wks at 2 ℃	6.03 b AB	6.09 b A	5.98 b B
2 wks at 2 ℃ plus 2 wks at 8 ℃	6.06 ab A	6.12 b B	6.05 ab A
2 wks at 2 ℃ plus 2 wks at 8 ℃ plus 3 d at 20 ℃	6.10 a B	6.24 a A	6.09 a B
	Titratable acidity (TA) (g/100 mL)		
Harvest	0.061 a A	0.077 a A	0.075 a A
3 wks at 2 ℃	0.036 b B	0.045 b A	0.046 b A
2 wks at 2 ℃ plus 2 wks at 8 ℃	0.031 c B	0.036 c A	0.037 c A
2 wks at 2 ℃ plus 2 wks at 8 ℃ plus 3 d at 20 ℃	0.037 b bB	0.037 c B	0.043 b A
	Total soluble solids (TSS) (%)		
Harvest	14.2 a A	14.3 a A	14.5 a A
3 wks at 2 ℃	14.5 a A	14.4 a A	14.4 a A
2 wks at 2 ℃ plus 2 wks at 8 ℃	13.5 b B	14.1 ab A	14.0 b A
2 wks at 2 ℃ plus 2 wks at 8 ℃ plus 3 d at 20 ℃	13.6 b B	13.8 b AB	14.2 ab A

[1] Means in columns followed by unlike lowercase letters and in rows followed by different uppercase letters are significantly different at $P < 0.05$ according to Duncan's multiple range test. (n=3).

Table 5. Sensory evaluation of cactus pear fruit stored for 3 weeks at 2 ℃ plus 1 week at 20 ℃ or stored for 3 weeks at 2 ℃ and 2 weeks at 8 ℃ plus 3 d at 20 ℃.

	Bianca	Gialla	Rossa
	Texture (index number)		
Harvest	8.2 a A[1]	7.9 a A	8.0 a A
3 wks at 2 ℃	6.4 b A	6.1 b A	6.2 b A
2 wks at 2 ℃ plus 1 wk at 20 ℃	5.1 c A	5.3 c A	5.5 c A
	Off-flavor (index number)		
Harvest	1.0 b A	1.0 b A	1.0 b A
3 wks at 2 ℃	1.2 b A	1.1 b A	1.4 b A
2 wks at 2 ℃ plus 1 wk at 20 ℃	2.9 a A	2.4 a B	2.7 a AB
	Overall acceptability		
Harvest	8.2 a A	8.1 a A	8.2 a A
3 wks at 2 ℃	7.7 b B	7.5 b B	7.9 b B
2 wks at 2 ℃ plus 1 wk at 20 ℃	5.4 c B	6.1 c A	6.2 c A

[1] Means in columns followed by unlike lowercase letters and in rows followed by different uppercase letters are significantly different at $P < 0.05$ according to Duncan's multiple range test. (n=5).

Table 6. Sensory evaluation of cactus pear fruit stored for 3 weeks (wks) at 2 ℃ and 2 weeks at 8 ℃ plus 3 d at 20 ℃.

	Bianca	Gialla	Rossa
	Texture (index number)		
Harvest	8.2 a A[1]	7.9 a A	8.0 a A
3 wks at 2 ℃	6.4 b A	6.1 b A	6.2 b A
2 wks at 2 ℃ plus 2 wks at 8 ℃	5.5 c AB	5.7 c A	5.1 c B
2 wks at 2 ℃ plus 2 wks at 8 ℃ plus 3 d at 20 ℃	3.6 d A	3.4 d A	3.4 d A
	Off-flavor (index number)		
Harvest	1.0 c A	1.0 b A	1.0 c A
3 wks at 2 ℃	1.2 c A	1.1 b A	1.4 bc A
2 wks at 2 ℃ plus 2 wks at 8 ℃	1.6 b AB	1.3 b B	1.8 b A
2 wks at 2 ℃ plus 2 wks at 8 ℃ plus 3 d at 20 ℃	2.1 a B	2.2 a B	2.6 a A
	Overall acceptability		
Harvest	8.2 a A	8.1 a A	8.2 a A
3 wks at 2 ℃	7.7 b B	7.5 b B	7.9 b B
2 wks at 2 ℃ plus 2 wks at 8 ℃	6.2 c A	5.9 c AB	5.8 c B
2 wks at 2 ℃ plus 2 wks at 8 ℃ plus 3 d at 20 ℃	4.7 d B	5.1 d AB	5.3 d A

[1] Means in columns followed by unlike lowercase letters and in rows followed by different uppercase letters are significantly different at $P < 0.05$ according to Duncan's multiple range test. (n=5).

4. Conclusion

The results showed that 'Bianca' cactus pears are much more susceptible to chilling temperatures than 'Gialla' and 'Rossa' ones. In contrast, 'Gialla' and 'Rossa' fruit showed a good tolerance and despite when moved to SMC developed typical symptoms of chilling injury and were easily subjected to decay, maintained a fair appearance over the week of SMC. However, when fruit were subjected to two additional weeks of cold storage at 8 °C, despite again 'Gialla' and 'Rossa' showed a better performance of 'Bianca', after three days at 20 °C all fruit showed damages and evident signs of ageing and a high incidence of decay. Based on these results only 'Gialla' and 'Rossa' cactus pears seem able to stand a cold quarantine treatment, but fruit soon after should immediately be marketed, while it is not feasible even for 'Gialla 'and 'Rossa' tolerate further exposure to chilling temperatures. Further studies testing postharvest treatments able to mitigate chilling injury before cold quarantine treatments need be carried out to clarify if damages and susceptibility to decay when fruit are moved to warm temperatures may be reduced.

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Conflict of interest

The authors declare no conflict of interest.

References

1. Ochoa MJ, Barbera G (2017) History and economic and agro-ecological importance, In: Inglese P, Mondragon C, Nefzaoui A, et al., *Crop Ecology, Cultivation and Uses of Cactus Pear*, Rome: The Food and Agriculture Organization of the United Nations and the International Center for Agricultural Research in the Dry Areas, 1–11.
2. Potgieter J, D'Aquino S (2017) Fruit production and post-harvest management, In: Inglese P, Mondragon C, Nefzaoui A, et al., *Crop Ecology, Cultivation and Uses of Cactus Pear*, Rome: The Food and Agriculture Organization of the United Nations and the International Center for Agricultural Research in the Dry Areas, 51–72.
3. Cantwell M (1995) Post-harvest management of fruits and vegetable stems, In: Barbera G, Inglese P, Pimienta Barrios E, et al., *Agro-ecology, cultivation and uses of cactus pear*, Rome: FAO Plant Production and Protection Paper No. 132, 120–141.
4. Yahia EM, Saenz C (2011) Cactus pear (Opuntia species), In: Yahia EM, *Postharvest biology and technology of tropical and subtropical fruits Vol. 2*, Cambridge: Woodhead Publishing, 290–329.
5. Liguori G, Inglese P (2015) Cactus pear (O. ficus-indica (L.) Mill.) fruit production: ecophysiology, orchard and fresh−cut management. *Acta Hortic* 1067: 247–252.
6. Inglese P, Basile F, Schirra M (2002) Cactus pear fruit production, In: Nobel PS, *Cacti: Biology and uses*, Berkeley: University of CaliforniaPress, 163–184.
7. Patel S (2013) Reviewing the prospects of Opuntia pears as low cost functional foods. *Rev Environ Sci Biotechnol* 12: 223–234.
8. Schirra M, Barbera G, D'Aquino S, et al. (1996) Hot dips and high-temperature conditioning to improve shelf quality of late-crop cactus pear fruit. *Tropical Science* 36: 159–165.
9. Schirra M, Agabbio M, D'Aquino S, et al. (1997) Postharvest heat conditioning effects on early ripening 'Gialla' cactus pear fruit. *Hortscience* 32: 702–704.
10. Piga A, D'Aquino S, Agabbio M, et al. (1996). Storage life and quality attributes of cactus pears cv 'Gialla' as affected by packaging. *Agricoltura Mediterranea* 126: 423–427.
11. D'Aquino S, Chessa I, Inglese P, et al. (2017) Increasing cold tolerance of cactus pear fruit by high-temperature conditioning and film wrapping. *Food Bioprocess Technol* 10: 1466–1478.
12. Lyons MJ, Breidenbach RW (1990) Relation of chilling stress to respiration, In: Wang CY, *Chilling injury of horticultural crops*, Boca Raton: CRC Press, 223–233.
13. McCollum TG, McDonald RE (1991) Electrolyte leakage, respiration, and ethylene production as indices of chilling injury in grapefruit. *HortScience* 26: 1191–1192.
14. Wang CY (2010) Alleviation of chilling injury in tropical and subtropical fruits. *Acta Hortic* 864: 264–273.
15. D'Aquino S, Chessa I, Schirra M (2014) Heat Treatment at 38 ℃ and 75–80 % Relative Humidity Ameliorates Storability of Cactus Pear Fruit (*Opuntia ficus-indica* cv 'Gialla'). *Food Bioprocess Technol* 7: 1066–1077.
16. D'Aquino S, Palma A, Schirra M, et al. (2015) Decay control of cactus pear by pre- and post-cold storage and water at 50 ℃. *Acta Hortic* 1067: 119–125.
17. Pantastico EB, Soule J, Grierson W (1968) Chilling injury in tropical and subtropical fruits: II. limes and grapefruit. *Amer Soc Hort Sci Caribbean Reg Proc* 12: 171–183.
18. Jackman RL, Yada RY, Marangoni A, et al. (1988) Chilling injury: a review of qualitative aspects. *J Food Qual* 11: 253–278.

19. Schirra M, Brandolini V, Cabras P, et al. (2002) Thiabendazole uptake and storage performance of cactus pear [Opuntia ficus-indica (L.) Mill. Cv Gialla] fruit following postharvest treatments with reduced doses of fungicide at 52 ℃. *J Agric Food Chem* 50: 739–743.
20. Cantwell M (2016) Prickly pear, In: Gross KC, Wang CY, Saltveit M, *The commercial storage of fruits, vegetables, and florist and nursery stocks*, USDA, ARS, Agricultural Handboob 66. Washington DC., 511–513.
21. Wang CY (2016). Chilling and Freezing Injury, In: Gross KC, Wang CY, Saltveit M, *The commercial storage of fruits, vegetables, and florist and nursery stocks*, USDA, ARS, Agricultural Handboob 66. Washington DC., 62–67.
22. Palma A, Continella A, La Malfa S, et al. (2018) Changes in physiological and some nutritional, nutraceuticals, chemical-physical, microbiological and sensory quality of minimally processed cactus pears cvs 'Bianca', 'Gialla' and 'Rossa' stored under passive modified atmosphere. *J Sci Food Agric* 98: 1839–1849.
23. Pimienta-Barrios E (1994) Prickly Pear (*Opuntia* spp.): a valuable fruit crop for the semi-arid lands of Mexico. *J Arid Environ* 28: 1–11.
24. Kyriacou MC, Emmanouilidou MG, Soteriou GA (2016) Asynchronous ripening behavior of cactus pear (*Opuntia ficus-indica*) cultivars with respect to physicochemical and physiological attributes. *Food Chem* 211: 598–607.

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