Influence of cold storage and shelf-life on quality of 'Salustiana' orange fruits

Antonio Piga[a]*
Salvatore D'Aquino[b]
Mario Agabbio[a]

[a] Dipartimento di Scienze Ambientali Agrarie e Biotecnologie Agro-Alimentari, Università degli Studi, Viale Italia 39, 07100 Sassari, Italy, pigaa@ssmain.uniss.it

[b] Istituto per la Fisiologia della Maturazione e della Conservazione del Frutto delle Specie Arboree Mediterranee, Via dei Mille, 48, 07100 Sassari, Italy

* Correspondence and reprints

Received 11 May 1999
Accepted 16 September 1999

Fruits, 2000, vol. 55, p. 37–44

Resumen Español, p. 44

Influence of cold storage and shelf-life on quality of 'Salustiana' orange fruits.

Abstract — Introduction. 'Salustiana' orange fruits (*Citrus sinensis* L. Osbeck) have been gaining increasing interest in the European market as fresh or processed. Moreover, although fruits show an early ripening, they keep well on the tree up to April. Nevertheless, lack of research on storage performance of this promising cultivar should be highlighted. In this paper, response to cold storage at two very different temperatures and to marketing conditions are shown. **Materials and methods**. Late harvested fruits were cold stored at 2 or 8 °C and 90–95 % relative humidity (RH) for 5, 10 and 15 weeks; after each cold storage period, an additional week of shelf-life conditions (SL) at 20 °C and 75 % RH was simulated. Determination of weight loss, decayed fruits, evolution of CO_2 and C_2H_4, main chemical parameters of the juice and assessment of overall visual appearance and chilling injury incidence were carried out at the above fixed intervals. **Results and discussion**. Fruits stored at 2 °C appeared to be resistant to chilling injury and stored better than those held at 8 °C, as the former resulted in lower weight loss and better appearance during storage and SL periods. On the other hand, a more pronounced loss of product due to rots was registered for 2 °C cold stored fruits, if compared to the other cold storage regime. The taste of fruits was always judged acceptable, with slight differences between the two treatments. Most of the chemical parameters were affected only by storage duration. In particular, the vitamin C content underwent a 15 % loss from harvest to the end of the trial. © Éditions scientifiques et médicales Elsevier SAS

***Citrus sinensis* / cold storage / chemicophysical properties / Italy**

Stockage au froid et durée de conservation des oranges « Salustiana » en relation avec le maintien de leur qualité.

Résumé — Introduction. Les oranges « Salustiana » (*Citrus sinensis* L. Osbeck) font l'objet d'un intérêt croissant en Europe tant en frais qu'en produit transformé. De plus, bien que les fruits mûrissent précocement, ils se maintiennent bien sur l'arbre jusqu'en avril. Néanmoins, les recherches sur les possibilités de stockage de ce cultivar prometteur font défaut. Le document expose des résultats obtenus à l'issue d'un stockage au froid effectué à deux températures bien différentes, suivi d'une période de simulation de la mise en marché. **Matériel et méthodes**. Des fruits récoltés en fin de saison ont été stockés à 2 °C ou 8 °C et 90–95 % d'humidité relative (HR) pendant 5, 10 et 15 semaines ; après chacune de ces périodes, la mise en marché a été simulée par une semaine de stockage à 20 °C et 75 % HR. La perte de poids, le nombre de fruits abîmés, l'évolution des taux de gaz carbonique et d'éthylène, les principales caractéristiques chimiques du jus et une évaluation de l'aspect du fruit et de l'incidence du froid ont été déterminés à l'issue des trois périodes de stockages définies. **Résultats et discussion**. Les fruits placés à 2 °C se sont révélés résistants aux effets du froid et ont mieux supporté le stockage que ceux entreposés à 8 °C ; ils ont perdu moins de poids et leur apparence a été meilleure pendant les différentes périodes de stockage. D'autre part, les pertes dues au pourrissement ont été plus prononcées pour ces fruits conservés à 2 °C que pour ceux placés à 8 °C. Le goût des fruits est toujours resté acceptable avec de faibles différences d'un traitement à l'autre. La plupart des caractéristiques chimiques n'ont été affectées que par la durée du stockage. En particulier, la teneur en vitamine C a diminué de 15 % entre la récolte et la fin de l'essai. © Éditions scientifiques et médicales Elsevier SAS

***Citrus sinensis* / stockage au froid / propriété physicochimique / Italie**

1. introduction

'Salustiana' orange cultivar is reported to be originated through a vegetative mutation from the Spanish cv. 'Cadenera' [1]. Fruits are medium to large in size, almost seedless and are characterized by high juice and sugar content, thus they can be consumed as fresh or destined to the juice processing industry [2]. The 'Salustiana' cultivar has recently gained considerable interest from the commercial standpoint, being considered the most promising of the blond oranges in the European market. Fruits ripen early in the season, but harvesting is possible up to April, as they store very well on the tree. If late harvested fruits have a good postharvest response to cold storage, they may be marketed until the beginning of the summer season. Nevertheless, very little research has so far been conducted on storage performance of this cultivar and on postharvest response to different temperature regimes. In 1973, Caro carried out a storage trial at 2 and 4 °C with different combination of pre-treatments and reported that: a) pathological breakdown can be minimised at 2 °C by using controlled atmosphere plus ozone on fruits treated with ortophenyl-phenate; b) discarded fruits for physiological disorders and quality loss were less at 2 °C at normal atmosphere (data for the other combinations temperature-treatments are incomplete) [3]. Thus, apart from the fair benefits that have been so far attributed to controlled atmosphere on keeping quality of citrus fruits [4], no references are available on the postharvest response of this fruit cultivar to very different storage temperatures and to conditions for fresh fruit consumption.

Considering the above features and with the aim to extend the marketing season of citrus fruits, we studied the performance of late harvested 'Salustiana' orange fruits both during cold storage at two temperatures and following simulated market conditions.

2. materials and methods

2.1. fruit

'Salustiana' orange fruits were harvested the first week of April at the experimental research station of the National Research Council (CNR) located in Oristano (central western Sardinia, 39°55' N) from 12 year-old trees grafted on sour orange and promptly transported to the laboratory. A total of 2 520 fruits (60 fruits were used for chemical analyses at harvest), without any external defect, were selected, weighed and divided in two lots of 1 260 fruits.

2.2. storage and inspections

The two lots of fruits were placed in plastic boxes (70 fruits per box) and put in cold storage either at 2 or 8 °C and 95 % relative humidity (RH). At 5, 10 and 15 weeks, 420 fruits were removed from each storage room, half of them used for quality inspection and the remaining transferred to simulated marketing conditions at 20 °C and 75 % RH for an additional week. No fungicide was applied on fruit prior to storage.

2.3. assessments and determinations

At each inspection time, 50 fruits free of any visual alteration were re-weighted with an accuracy of 0.01 g and weight losses calculated as percentage. The incidence of decayed fruits (%) was also recorded. Fruits were rated by five trained panellists for overall appearance and chilling injury (CI) symptoms. The former was scored according a scale ranging from 1 to 5, where 1 = very aged, 2 = aged, 3 = acceptable (limit of marketability), 4 = fresh and 5 = very fresh (fruit at harvest). CI was evaluated with a weighted average on the basis of the severity of the symptoms, being 0 = nil, 1 = slight, 2 = moderate and 3 = severe chilling injury damage. Thirty fruits of each lot were peeled and evaluated for overall acceptability of taste by panellists on a scale from 1 to 5, where 5 = very good taste, 4 = good, 3 = limit of edibility, 2 = poor and 1 = very poor taste. Evolution of CO_2 and ethylene (C_2H_4) production were determined on 10 fruits individually closed in 1 litre-jars for 2 h both inside storage rooms for cold stored oranges and at 20 °C for fruits held in shelf-life conditions (SL). Samples of 20 and 2 mL of headspace gases were withdrawn with disposable syringes for CO_2 and C_2H_4 determinations and analysed with

a coupled infrared/paramagnetic detector (Servomex 1450B3, O_2/CO_2 analyser) or flame ionisation detector (FID) gas-chromatography (Varian 3300), respectively, as reported in a previous paper [5]. Three replications of 10 fruits for each treatment were squeezed and juice centrifuged at 3 000 × *g* for 5 min. Total soluble solids (TSS) and pH were measured in the juice with a hand refractometer and a pH-meter, respectively. Total acidity was calculated as % of citric acid after titrating 10 mL of juice against 0.1 N NaOH to end point (8.2). Percent juice and maturity index (TSS / titratable acidity) were also calculated. Ascorbic acid content (mg·100 mL^{-1}) of the juice was determined volumetrically by the 2–6 dichlorophenol-indophenol method [6].

2.4. data analysis

Data were analysed for each period with the MSTAT-C software (Michigan State University, 1991) by one way analysis of variance.

3. results and discussion

3.1. physiological parameters

A marked decrease in respiration rate was observed at the end of the first period of storage, with respect to harvest values (*figure 1A*). The pattern was similar after 10 weeks, while a slight increase was registered at the end of cold storage. Fruit stored at 2 °C showed a significant lower CO_2 production, than those at 8 °C throughout the whole trial. The transfer to shelf-life conditions resulted in a burst in respiration activity and followed the same pattern of cold storage. Similar results either in cold storage or in retail conditions have been reported for other orange cultivars [7], grapefruits [8] and mandarins [5]. The respiration activity of fruit held in shelf-life conditions was quite the same as fruit previously cold stored at 2 and 8 °C. Previous findings on other citrus fruits revealed that lemons [9] and grapefruits [10] stored at chilling temperatures showed a higher respiration even after a week in shelf-life conditions, if compared to those stored at non chilling ones, due to an irreversible metabolic imbalance of these chilling sensitive species. In our case, thus, it seems that no symptoms of CI could be associated to the respiration metabolism response, as fruit

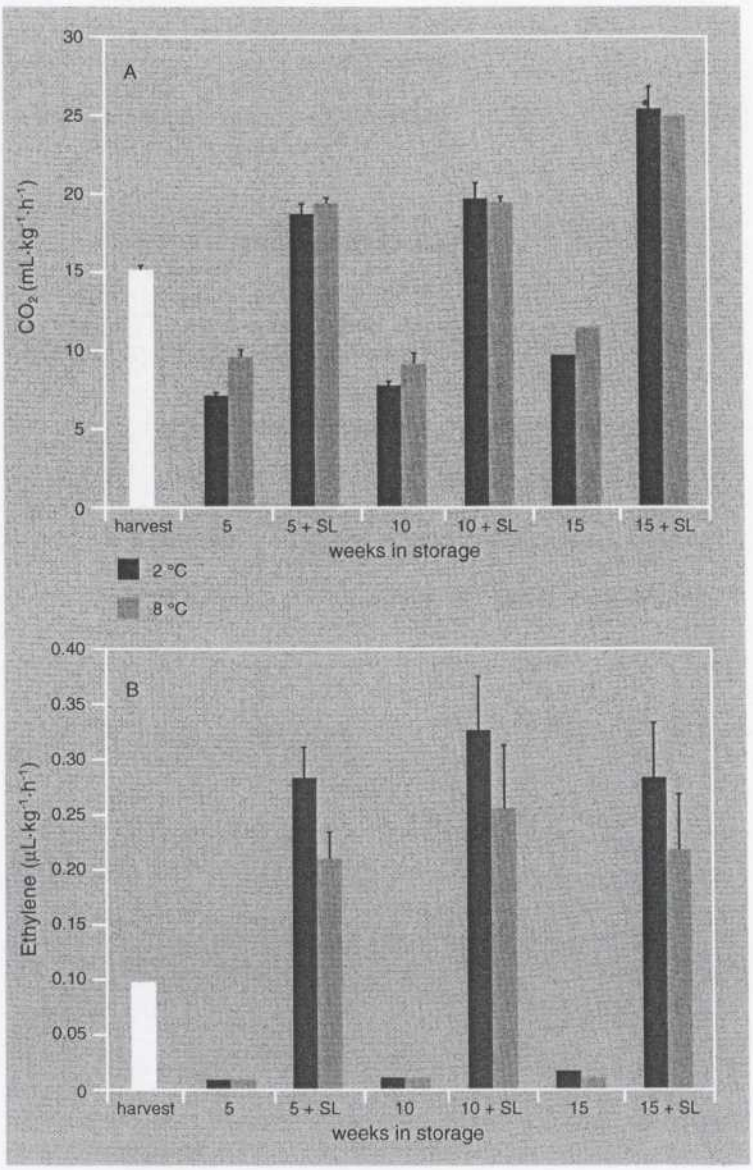

Figure 1.
Influence of different storage temperature on respiration rate (A) and ethylene production (B) of 'Salustiana' orange fruits during 5, 10 and 15 weeks of cold storage plus one additional week of simulated marketing conditions at 20 °C and 75 % of relative humidity. Means are the average of 10 determinations. Vertical bars indicate standard error. * indicates results significantly different at $p \leq 0.01$.

stored at 2 °C and 8 °C showed quite the same carbon dioxide productions.

Ethylene production was 0.1 $\mu L \cdot kg^{-1} \cdot h^{-1}$ at harvest (*figure 1B*). During the cold storage trial, it was scarcely detected, as it never exceeded 0.015 $\mu L \cdot kg^{-1} \cdot h^{-1}$. On the other hand, a sharp rise in ethylene production was recorded after 1 week of shelf-life conditions following each cold storage period and fruits that have been cold stored at 2 °C showed higher, but not significantly different, ethylene production than those stored at 8 °C.

3.2. chilling injury

Chilling injury appeared as a pitted area on the peel of orange fruits. CI incidence was quite low throughout the whole trial, especially in cold storage conditions (*table I*). In particular, after the first 10 weeks of cold storage, CI was negligible, with no fruit being affected by severe damage, while, at the end of the cold storage conditions, fruit no more marketable due to CI external symptoms were 4.5 and 1 % for 2 and 8 °C cold stored fruits, respectively (data not shown). Thus it seems that, for this orange cultivar, the time needed for CI to occur at chilling conditions is more than 10 weeks. These values are in agreement with those reported by Caro [3]. Statistical analysis revealed that there were no significant differences in CI index between the two cold storage temperatures. The general trend was a rise of the CI index on transfer to shelf-life conditions and this resulted in a maximum loss of 6 % at the end of the trial

Table I.
Effect of different storage temperatures on overall appearance, chilling injury, overall acceptability and incidence of decay on 'Salustiana' oranges during 5, 10 and 15 weeks of cold storage plus one additional week of simulated marketing conditions at 20 °C and 75 % of relative humidity.

Treatment	Overall appearance[1] (index number)		Chilling injury[2] (index number)		Overall acceptability[3] (index number)		Decay[4] (%)	
	At transfer to 20 °C	After 1 week at 20 °C	At transfer to 20 °C	After 1 week at 20 °C	At transfer to 20 °C	After 1 week at 20 °C	At transfer to 20 °C	After 1 week at 20 °C
Harvest	5.0	–	–	–	4.8	–	–	–
5 weeks								
at 2 °C	4.36	3.71	0.01	0.18	4.50	4.40	1.5	3.8
at 8 °C	3.74	3.22	0.01	0.12	4.20	4.20	6.1	9.0
Significance	*	*	ns	ns	ns	ns	*	*
10 weeks								
at 2 °C	3.41	3.03	0.11	0.30	4.40	4.20	8.8	14.3
at 8 °C	2.89	2.68	0.09	0.30	4.20	4.00	0.9	1.1
Significance	*	*	ns	ns	ns	ns	*	*
15 weeks								
at 2 °C	3.01	2.78	0.39	0.57	3.6	3.4	13.0	13.8
at 8 °C	2.61	2.47	0.29	0.46	3.2	3.0	3.5	4.5
Significance	*	*	ns	ns	ns	ns	*	*

ns, * Non significant or significant at $P \leq 0.01$, respectively.
[1] Overall appearance was evaluated on a scale from 1 to 5, where 5 = fruit fresh as at harvest, 3 = limit of marketability and 1 = very aged fruit.
[2] Chilling injury external symptoms were scored according to a scale ranging from 0 to 3, where 0 = nil, 1 = slight, 2 = medium and 3 = severe. The CI index was calculated multiplying the fruits of each CI rating by the defined index and taking a weighted average.
[3] The overall acceptability of taste was rated with a scale ranging from 1 to 5, where 5 = very tasteful fruit, 3 = limit of edibility and 1 = very poor taste.
[4] Decay was computed as percentage of rotten fruit of the total number of fruit for each treatment.

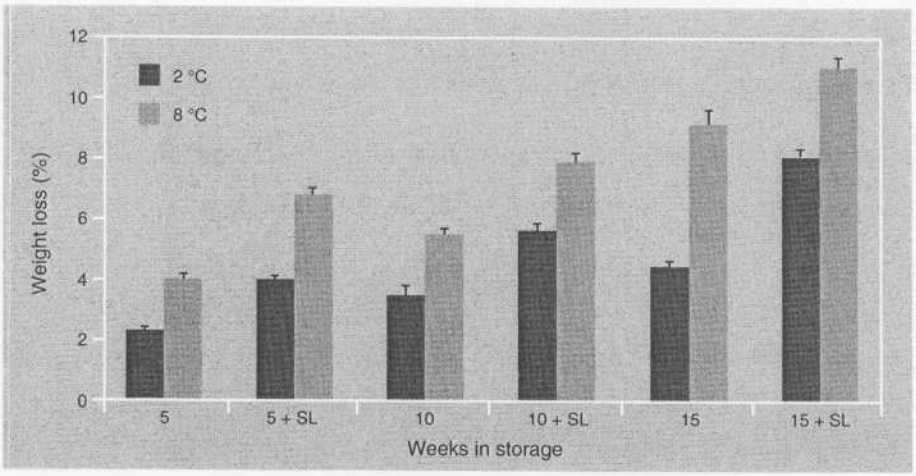

Figure 2.
Effect of different storage temperature on weight loss of 'Salustiana' orange fruits during 5, 10 and 15 weeks of cold storage plus one additional week of simulated marketing conditions at 20 °C and 75 % of relative humidity. Vertical bars indicate standard error.
* indicates results significantly different at $p \leq 0.01$*.

for fruit stored at 2 °C (data not shown). Water loss from the peel has been related to CI increase in citrus and other fruit species, as it favours the extent of the peel damage of chilled tissues [11, 12]. The transfer from cold storage to shelf-life conditions enhanced the moisture loss from the peel, thus increasing the CI incidence.

3.3. weight loss and overall quality

Weight loss was strongly influenced by temperature and, as expected, by time in storage (*figure 2*). In fact, after 15 weeks, weight loss of fruit stored at 2 °C was quite the same (4.2 %) to that of fruit stored for 5 weeks at 8 °C (4.0 %). The rate in loss of weight was more pronounced in the beginning of storage. In fact, at the end of the first cold storage period (5 weeks), it was about half of the whole loss and showed a decreasing trend over the other cold storage periods. The same results were obtained when fruits were transferred to shelf-life conditions. Our data show that this orange cultivar has a very low loss of weight during cold storage conditions both at 2 and 8 °C.

Overall appearance changed notably in relation to time and storage temperature (*table I*). The latter had a relevant effect on esthetical aspect of fruits. In fact, fruit cold stored at 2 °C got significant higher scores than those stored at 8 °C during cold and shelf-life condition periods. In particular, minimum acceptability was gained by fruit stored at 2 °C along cold storage and shelf-life condition periods, if we except the shelf-life conditions following 15 weeks of cold storage, while 8 °C cold stored fruit had a score less than 3 (limit of marketability) since after 10 weeks. The main signs of overall quality degradation were shrivelling of the peel and loss of brightness. External deterioration of citrus fruits depends highly on transpiration [13]. A more pronounced weight loss in fruit stored at 8 °C, with respect to those stored at 2 °C, may help in explaining the above cited difference.

The overall acceptability of taste decreased during storage, but was judged acceptable by the panellists throughout the entire trial, with minimum differences between the two cold storage temperatures, if we except the end of storage and shelf-life conditions (*table II*). In particular, a marked decrease of taste was registered from the second to the third cold storage and following shelf-life condition periods. Anyway, panellists did not detect any off-flavour on the juice.

3.4. pathological breakdown

Decay incidence was significantly lower at 2 °C only at the end of 5 weeks of cold storage, as compared to 8 °C (*table I*). Contrary to what was expected, the percentage of rots was notably less for fruit stored at 8 °C after the other two cold storage peri-

Table II.
Effect of different storage temperatures on chemical parameters of 'Salustiana' oranges during 5, 10 and 15 weeks of cold storage plus one additional week of simulated marketing conditions at 20 °C and 75 % of relative humidity. Means were not significantly different at $p \leq 0.01$.

Treatment	Juice (%)		pH		Acidity (% of citric acid)		Total soluble solids (° Brix)		Vitamin C (mg·100 mL^{-1})		Maturity index (°Brix / acidity)	
	At transfer to 20 °C	After 1 week at 20 °C	At transfer to 20 °C	After 1 week at 20 °C	At transfer to 20 °C	After 1 week at 20 °C	At transfer to 20 °C	After 1 week at 20 °C	At transfer to 20 °C	After 1 week at 20 °C	At transfer to 20 °C	After 1 week at 20 °C
Harvest	47.27	–	3.63	–	0.86	–	11.2	–	66.80	–	13.00	–
5 weeks												
at 2 °C	46.41	48.83	3.63	3.70	0.83	0.78	11.6	11.3	63.40	66.06	13.97	14.48
at 8 °C	46.06	49.02	3.62	3.73	0.82	0.77	11.3	11.1	65.45	63.14	13.78	14.41
10 weeks												
at 2 °C	48.47	51.22	3.79	3.82	0.78	0.75	11.3	11.7	62.37	68.80	14.48	15.60
at 8 °C	48.69	48.89	3.78	3.85	0.76	0.74	11.6	11.6	63.44	68.50	15.26	15.67
15 weeks												
at 2 °C	47.94	46.27	3.83	3.88	0.74	0.69	11.4	11.3	65.66	56.94	15.40	16.37
at 8 °C	46.78	44.35	3.90	3.95	0.70	0.67	11.3	11.1	63.56	58.50	16.14	16.57

ods. Very low chilling temperatures, such as 2 °C, may favour the development of microlesions on the peel, thus enhancing pathogen penetration and growth [14]. As expected moulds increased after transfer to shelf-life conditions. The most prevailing pathogen was *Penicillium digitatum* Sacc., that accounted for over 90 % of total decay.

3.5. chemical parameters

Changes of chemical parameters were registered only during the trial course, while cold storage temperatures had a negligible effect (*table II*). Juice content declined from about 47 % at harvest to 44 % at the end of the trial, with an increase during the second storage period. The pH value increased from 3.73 to about 4.00, being mirrored by a concomitant decrease of acidity from 0.86 to about 0.7 % at the end of the last shelf-life condition period. Total soluble solids, instead, remained quite constant and this led the maturity index to increase. Vitamin C, which was 66.80 mg·100 mL at harvest, showed a loss of about 15 % at the end of the trial.

4. conclusion

This study seems to support in part the findings of Caro [3], as late harvested 'Salustiana' orange fruits show a good postharvest performance even at chilling temperatures. In fact, fruits proved to be very resistant to physiological disorders, if we consider that oranges stored at 2 °C underwent a total loss of about 6 %, due to severe pitting. Contrary to what was expected, decay was less pronounced on 8 °C cold stored fruits. Anyway, the best result was gained at 2 °C, as fruits lost less weight than at 8 °C, thus maintaining a good external aspect for almost 4 months of cold storage.

If we consider that we harvested fruit in early April, we can make available this citrus cultivar until the mid-summer, at least in the Italian area. Moreover, the use of film wrapping, that generally results in positive effects in keeping quality of citrus fruits, and appropriate fungicides applications could allow a further extension of the market life of this orange.

references

[1] Spina P., Russo F., Geraci G., Martelli S., Schede per il registro varietale dei fruttiferi: 1 – Arancio e Mandarino, 1980, 56–57.

[2] Hodgson R.W., Horticultural varieties of citrus fruits, In: Reuther W., Webber H.J., Batchelor L.D. (Eds.), The Citrus Industry, Univ. of California, Division of Agricultural Sciences, USA, 1967, pp. 431–591.

[3] Caro J., El ozono y las atmósferas artificiales como coadyuvantes del frio, en la conservación frigorífica de las principales variedades de naranja y mandarina españolas, In: Carpena O. (Ed.), Proc. I Congreso Mundial de Citricultura, Murcia-Valencia, Spain, 29 April–10 May, 1973, pp. 249–270.

[4] Hardenburg R.E., Watada A.E., Wang C.Y., The commercial storage of fruits, vegetables, and florist and nursery stocks, Agriculture Handbook No. 66, USDA, Washington DC, USA, 1986.

[5] Agabbio M., D'Aquino S., Piga A., Molinu M.G., Agronomic behaviour and postharvest response to cold storage of 'Malvasio' mandarin fruits, Fruits 54 (1999) 103–114.

[6] Ting S.V., Rousseff R.L., Vitamins, In: Ting S.V., Rousseff R.L. (Eds.), Citrus fruits and their products: analysis and technology, Marcel Dekker, New York, USA, 1986, pp. 121–136.

[7] Eaks I.L., Effect of chilling on the respiration and volatiles of oranges and lemons, Proc. Am. Soc. Hortic. Sci. 87 (1965) 181–186.

[8] Schirra M., Chessa I., Valencia late oranges: shelf-life response to storage conditions, Agr. Med. 120 (1990) 58–65.

[9] Eaks L.I., Effect of chilling on respiration and volatiles of California lemon fruits, J. Am. Soc. Hortic. Sci. 105 (6) (1980) 865–869.

[10] Schirra M., Behaviour of 'Star Ruby' grapefruits under chilling and non-chilling temperature, Postharv. Biol. Technol. 2 (1992) 315–327.

[11] Brooks C., McColloch L.P., Some storage diseases of grapefruit, J. Agric. Res. 52 (1936) 319–351.

[12] Purvis A.C., Relationship between chilling injury of grapefruit and moisture loss during storage: amelioration by polyethylene shrink film, J. Am. Soc. Hortic. Sci. 110 (3) (1985) 385–388.

[13] Ben-Yehoshua S., Gas exchange, transpiration, and the commercial deterioration in storage of orange fruit, J. Am. Soc. Hortic. Sci. 94 (5) (1969) 524–528.

[14] Saltveit M.E. Jr., Morris L.L., Overview on chilling injury of horticultural crops, In: Wang C.Y. (Ed.), Chilling injury of horticultural crops, CRC Press Inc, Boca Raton, Florida, USA, 1992, pp. 1–15.

Almacenamiento en frío y duración de conservación de naranjas 'Salustiana' con relación al mantenimiento de su calidad.

Resumen — Introducción. Las naranjas 'Salustiana' (*Citrus sinensis* L. Osbeck) interesan cada vez más en Europa, tanto frescas como en productos transformados. Además, aunque los frutos maduran precozmente, se mantienen bien en el árbol hasta abril. Sin embargo, escasean las investigaciones sobre las posibilidades de almacenamiento de este prometedor cultivar. El documento expone los resultados obtenidos tras un almacenamiento frío a dos temperaturas bastante diferentes, seguido de un periodo de simulación de puesta en mercado. **Material y métodos**. Se almacenaron frutos, cosechados al final de la temporada, a 2 °C ó 8 °C y 90–95 % de humedad relativa (HR) durante 5, 10 y 15 semanas; tras cada uno de dichos periodos, se simuló la puesta en mercado mediante una semana de almacenamiento a 20 °C y 75 % HR. Al final de los tres periodos de almacenamiento definidos, se determinó la pérdida de peso, número de frutos dañados, evolución del índice de gas carbónico y etileno, principales características químicas del jugo, evaluación del aspecto del fruto e incidencia del frío. **Resultados y discusión**. Los frutos colocados a 2 °C se mostraron resistentes a los efectos del frío y soportaron mejor el almacenamiento que los que se situaron a 8 °C; perdieron menos peso y conservaron un mejor aspecto durante los diferentes periodos de almacenamiento. Por otro lado, las pérdidas por podredumbre fueron más altas en los frutos conservados a 2 °C que en los conservados a 8 °C. El sabor de los frutos permaneció siempre aceptable con pocas diferencias entre ambos tratamientos. La mayor parte de las características químicas sólo se vio afectada por la duración de almacenado. En particular, la vitamina C disminuyó un 15 % entre la cosecha y el final del ensayo.

***Citrus sinensis* / almacemiento en frío / propiedades fisicoquímicas / Italia**