JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

Juice Quality of Two New Mandarin-like Hybrids (*Citrus clementina* Hort. ex Tan x *Citrus sinensis* L. Osbeck) Containing Anthocyanins

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Tacle and Clara [Monreal clementine (*Citrus clementina* Hort. ex Tan) x Tarocco orange (*Citrus sinensis* L. Osbeck)] are two new triploid citrus hybrids developed by the CRA-Istituto Sperimentale per l'Agrumicoltura (Acireale, Italy). The fruits are easy-peeling and juicy, have a pleasant taste like the Tarocco orange, and are sweet like the Monreal clementine. In addition, a distinctively attractive characteristic of these mandarin-like fruits is the red-pigmented flesh caused by the presence of anthocyanins. This study reports the juice quality attributes of fresh fruits harvested at different ripening stages and of cold-stored fruits kept for 104 days at 6 ± 1 °C and 90–95% relative humidity. Physicochemical analyses showed that the fresh-fruit juice yield ranged between 39 (Tacle) and 41% (Clara); these values were 11–14% lower after 104 days of storage. Vitamin C content in the Clara juice was decisively higher than that in the Tacle juice. Juice anthocyanins and other polyphenols increased during cold storage. These results show that low-temperature storage enhances the functional attributes of Tacle and Clara fruit juices.

KEYWORDS: Tarocco orange; Monreal clementine; pigmented fruit; flavonoids; phenolic acids; vitamin C

INTRODUCTION

The growing consumption of fruit juice in recent years is due mainly to the launching of new fruit juices or fruit-juice-based beverages, often enriched with vitamins, fiber, or other health-promoting additives. In line with consumer demand, elaborate drinks with less fruit juice compete with traditional 100% fruit juices. These enjoyable soft drinks are enhanced with biological additives such as vitamins, fiber, and so forth and contain vegetable juices or citrus juices (orange, mandarin, and lemon) alone or in combination with exotic-fruit or berry juices (papaya, mango, pineapple, strawberry, and blueberry). Consumer stimulation by fashionably fresh flavors has widened the search for new distinctive juices to make soft drinks more attractive and enjoyable. The production of new citrus-fruit juices for the beverage market or for minimally treated citrus juices falls within this framework. Therefore, it is important to study new products that respond to such demands.

In 1951, the CRA-Istituto Sperimentale per l'Agrumicoltura initiated a breeding program directed toward the improvement of extant blood (pigmented) oranges and the development of new pigmented citrus hybrids for the fresh fruit market and juice production, that are easy-peeling and larger and have new and original sensory characteristics (*1–3*).

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Recent studies on Tarocco-orange characterization have individuated the optimal fruit maturity of different clones and selected genotypes with the highest anthocyanin content, which were then used for processing (*4*). Other research has focused on juice and essential-oil composition of the new citrus hybrid Cami, a cross between the monoembrionic 50-15A-6 hybrid [Comune clementine (*Citrus clementina* Hort. ex Tan.) x Avana mandarin (*Citrus deliciosa* Ten.)], used as the female parent, and the Mapo tangelo (*C. deliciosa* Ten. x *Citrus paradisi* Macf.), used as the male parent (*5*). In addition, the essential oils of the pigmented hybrids OMO-6, OMO-12, OMO-15, and OMO-31, obtained by crossing Oroval clementine [(*C. clementina* Hort. ex Tan) x Moro orange (*C. sinensis* L. Osbeck)] (*6*), have been evaluated. Nonvolatile components with antioxidant properties such as vitamin C, flavanone glycosides, anthocyanins, and hydroxycinnamic acids were also determined in the OMO-31 hybrid and its parents to evaluate the heredity of such characteristics in their progeny (*7*).

Tacle and Clara are new triploid hybrids obtained by crossing the diploid Monreal clementine (*C. clementina* Hort. ex Tan.), used as the female parent, with the tetraploid Tarocco orange (*C. sinensis* L. Osbeck), used as the male parent. Both are considerably diffuse in Italy (*8, 9*). Tacle is easy-peeling, tastes like Tarocco orange, and has an oblate form and an average weight of 150 g. The peel and flesh are dark orange with red streaks at maturity, which, in Italy, occurs in mid-February when anthocyanin levels in the flesh are the highest. Clara is large,

10.1021/jf072616e CCC: $40.75
Published on Web 02/26/2008

generally ovoid or slightly oblate to almost subglobose in shape, has an average weight of 170 g, and tastes like a mix between clementine and Tarocco orange. It ripens between mid-January and February (*10*).

In this work, the Tacle and Clara juice quality attributes of fresh fruits harvested at different ripening stages and of cold-stored fruits were studied to identify the optimal stage for fruit processing and to evaluate polyphenol evolution during cold storage.

MATERIALS AND METHODS

Materials. Tacle and Clara fruits were each collected from three trees at different ripening stages (January 5, February 2, February 23, and March 15 of 2005) at the Palazzelli experimental farm of the CRA-Istituto Sperimentale per l'Agrumicoltura (Acireale, Italy). A total of 20 randomly chosen fruits was harvested from each tree. Samples (each 100 kg ca.) of both hybrids collected on February 23 were cold-stored at 6 ± 1 °C and 90–95% relative humidity (RH) for 104 days. Triplicate samples of 20 fruits were analyzed every 20–30 days. The juice was obtained with an electric fruit juicer and strained with a 2 mm mesh sieve.

Chemical Analysis. Titratable acidity (TA), total soluble solids (TSS), and juice yield were determined according to conventional methods (*11*). Vitamin C was determined by the 2,6-dichloropheno-lindophenol titrimetric method, modified by Rapisarda and Intelisano (*12*). Total anthocyanins were determined spectrophotometrically by the pH differential method (*13*). Individual anthocyanin analysis was performed by HPLC by using a Waters 600-E liquid chromatograph (Waters, Milford, MA) equipped with a Waters 996 photodiode array detector (PDA), and the data was processed by Millenium 3.2 software. The column was a 250 mm × 4.6 mm i.d., 5 μm Hypersil ODS (Phenomenex, Torrance CA), and the solvent system was as follows: A, water:formic acid (85:15) and B, water:formic acid:acetonitrile (35:15:50). The percentage of B was increased linearly from 10 to 30% in 30 min at a flow rate of 1 mL/min. Elution was monitored at 520 nm, and the column temperature was maintained at 35 °C.

Flavanone glycosides were determined by HPLC (*14*). A sample of centrifuged juice was diluted at a ratio of 1:5 with the mobile phase, 0.45 μm filtered, and injected directly into the column. The eluent was water:acetonitrile:acetic acid (79.5:20:0.5), and the flow rate was 0.8 mL/min. The column effluent was monitored at 280 nm.

Hydroxycinnamic acids were extracted from the juice by solid phase extraction after the alkaline hydrolysis of hydroxycinnamic esters (*15*). A sample of 10 mL of centrifuged juice was added to 10 mL of 2N sodium hydroxide and stored at room temperature in the dark. Complete hydrolysis of bound hydroxycinnamic acids occurred in 4 h. The solution was then acidified with 2N chloridric acid (HCl) to pH 2.5 and passed through a C18 Sep-Pak cartridge (Waters). Hydroxycinnamic acids were eluted with 0.5% HCl in methanol. The alcoholic solution was 0.45 μm filtered, and 20 μL of the solution was analyzed by HPLC. The mobile phase consisted of water:acetic acid (98:2) (solvent A) and methanol (solvent B). The elution program was 95% of A and 5% of B (5 min), ramped down to 70% of A and 30% of B (35 min), and held until the end of the run (45 min) at a flow rate of 1 mL/min. The detection was performed at 300 nm.

Total carotenoids were determined spectrophotometrically by extracting carotenoid pigments with hexane:acetone:ethanol (50:25:25) and expressed as mg/L of β-carotene, according to the method described by Lee et al. (*16*).

Statistical elaboration of the physico-chemical results was conducted with the MSTAT WIN 10 program. Data were analyzed by variance analysis, and mean separation was determined by Tukey's test.

RESULTS AND DISCUSSION

Fresh Fruits. Data in **Tables 1** and **2** show the juice quality of Tacle and Clara fresh fruits harvested in January−March. Juice yield decreased during ripening, reaching minimum values at the end of February. Subsequently, yield rose significantly, possibly because of an increase in the activity of endogenous enzymes such as pectinmethylesterase, which play a crucial role in cell-wall degradation and juice release from vesicles (*17*).

TSS, which provide an estimate of the juice sugars, were comparable in both hybrids, and they remained constant during ripening. At all ripening stages, the TA of the Tacle was always higher than that of the Clara. This underlines the influence of Tarocco-orange parentage in the Tacle and clementine parentage in the Clara (*10*). However, a gradual decrease in TA was observed during ripening in both hybrids.

Table 1. Evolution of the Physico-chemical Parameters of Tacle Hybrid Juice during Fruit Ripening[a]

	harvest date			
	Jan 5	Feb 2	Feb 23	Mar 15
juice yield (%)	39.14 A	39.60 A	34.10 B	37.28 A
TSS (%)	11.47 ns	11.67 ns	11.81 ns	12.48 ns
TA (%)	1.45 a	1.21 b	1.30 ab	1.23 b
TSS/TA	7.92 D	9.63 B	9.08 C	10.18 A
vitamin C (mg/100 mL)	49.92 B	57.97 A	50.82 B	45.43 B
total anthocyanins (mg/L)	0.00 B	1.72 B	13.36 A	13.56 A
cyanidin-3-glucoside (%)[b]	0.00 C	14.82 B	33.82 A	18.76 B
cyanidin-3-(6″-malonyl)-glucoside (%)[b]	0.00 C	30.24 A	31.85 A	25.03 B
total flavanones (mg/L)	94.18 C	172.80 B	216.05 A	89.47 C
narirutin (mg/L)	5.79 C	12.13 AB	15.61 A	8.99 BC
hesperidin (mg/L)	81.65 B	150.79 A	182.00 A	77.58 B
total hydroxycinnamic acids (mg/L)	73.46 b	79.74 b	75.18 b	89.41 a
caffeic acid (mg/L)	8.57 b	8.66 b	10.15 ab	11.27 a
p-coumaric acid (mg/L)	12.97 B	17.46 B	15.42 B	28.24 A
ferulic acid (mg/L)	47.86 ns	48.97 ns	44.39 ns	44.15 ns
sinapic acid (mg/L)	4.05 B	4.65 AB	5.22 AB	5.75 A
total carotenoids (mg/L)	4.34 C	39.61 B	33.33 B	54.24 A

[a] Means in the same row followed by different letters are significantly different: capital letter, $p \leq 0.01$; lowercase letter, $p \leq 0.05$; ns, not significant. [b] Relative percentage of anthocyanins was based on HPLC peak areas.

Table 2. Evolution of the Physico-chemical Parameters of Clara Hybrid Juice during Fruit Ripening[a]

	harvest date			
	Jan 5	Feb 2	Feb 23	Mar 15
juice yield (%)	40.87 B	39.96 B	38.31 B	48.59 A
TSS (%)	11.52 ns	12.37 ns	11.90 ns	13.28 ns
TA (%)	1.24 a	1.15 ab	0.97 b	0.88 b
TSS/TA	9.29 D	10.82 C	12.29 B	15.08 A
vitamin C (mg/100 mL)	57.81 b	63.56 ab	77.02 a	68.91 ab
total anthocyanins (mg/L)	0.00 D	0.98 C	1.70 B	2.66 A
cyanidin-3-glucoside (%)[b]	0.00 C	10.13 B	25.68 A	25.61 A
cyanidin-3-(6″-malonyl)-glucoside (%)[b]	0.00 C	17.02 B	37.41 A	35.54 A
total flavanones (mg/L)	182.17 B	186.78 B	328.65 A	333.87 A
narirutin (mg/L)	9.38 B	8.66 B	11.51 B	15.61 A
hesperidin (mg/L)	164.62 B	171.27 B	306.74 A	309.17 A
total hydroxycinnamic acids (mg/L)	30.80 B	39.14 B	81.06 A	96.77 A
caffeic acid (mg/L)	3.85 B	4.75 B	7.30 A	7.33 A
p-coumaric acid (mg/L)	4.95 B	6.94 B	14.95 A	15.90 A
ferulic acid (mg/L)	20.45 B	24.99 B	48.40 A	54.94 A
sinapic acid (mg/L)	1.54 C	2.46 C	10.41 B	18.60 A
total carotenoids (mg/L)	28.73 ns	30.10 ns	34.33 ns	31.42 ns

[a] Means in the same row followed by different letters are significantly different: capital letter, $p \leq 0.01$; lowercase letter, $p \leq 0.05$; ns, not significant. [b] Relative percentage of anthocyanins was based on HPLC peak areas.

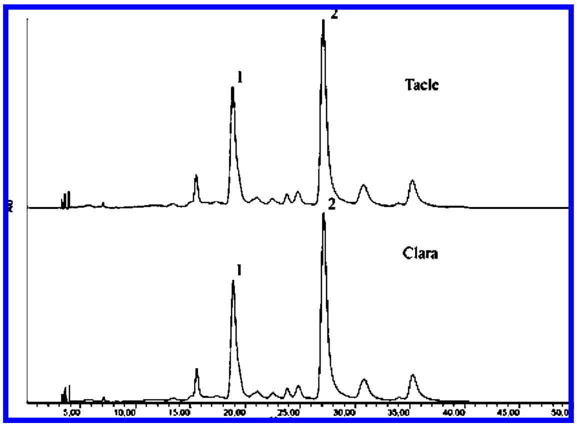

Figure 1. HPLC-PDA profile of Tacle and Clara fresh fruit anthocyanins at 520 nm. Peaks: 1, cyanidin-3-glucoside; 2, cyanidin-3-(6″-malonyl)-glucoside.

The TSS/TA ratio represents an important quality index for citrus juice, because it correlates with the ripening and sensory characteristics of the fruits. During ripening, the increase of the TSS/TA ratio of the Tacle was lower than that of the Clara. The Tacle reached values around 10.18 only by mid-March, whereas the Clara rose to 12.29 by the end of February. Such a difference between the two hybrids is due to juice acidity. Although the Clara resembles the orange morphologically, its acidity is closer to that of the clementine, hence its higher TSS/TA ratio.

Vitamin C content in the Clara was decisively higher than that in the Tacle. At full ripeness, the values of this component in the former hybrid were comparable to those in the Tarocco orange, which is the orange variety that is the richest in vitamin C (*12*). Thus, it is possible to affirm that orange parentage enhanced vitamin C in the Clara hybrid. The level of vitamin C was significantly lower in the Tacle hybrid; it was similar to that of clementine juice (*7*). During ripening, the maximum value of vitamin C was reached on February 2 in Tacle juice and on February 23 in Clara juice.

Anthocyanins are an important class of flavonoids responsible for the various shades of red and blue in many fruits. These compounds are present in the red-flesh orange varieties called blood oranges and in some of their mandarin-like hybrids such as OMO-31 (*7*), OMO-6, and OMO-12 (*6*). Anthocyanin biosynthesis was very low in the Clara, with only a few pigmented juice sacs, whereas there was a more intense pigmentation in the fully ripe fruits of the Tacle. Maximum concentration was reached in both hybrids in March with values of 13.56 mg/L in the Tacle and 2.66 mg/L in the Clara. These concentrations are by far lower than those in Tarocco oranges, the anthocyanin of which generally ranged between 40 and 100 mg/L (*13*). Cyanidin-3-glucoside and cyanidin-3-(6″-malonyl)-glucoside are the major red pigments present in Tarocco oranges (*18*). The same anthocyanin pattern was found in the Tacle and the Clara (**Figure 1**). During fruit ripening, both anthocyanins increased until February; then, they remained constant in Clara and slightly decreased in Tacle fruits.

Oranges and clementines mainly accumulate the tasteless flavanones rutinoside, narirutin, and hesperidin (*19*). These substances are potentially beneficial to human health because of their antioxidant activity (*20*). Extensive in vivo and in vitro studies have demonstrated anticancer, antiviral, and anti-inflammatory activities (*21*). The major flavanone glycoside found in both hybrid fruits was hesperidin, representing 88–96% of total flavanones. The hybrid which was the richest in flavanone glycosides was the Clara; its level of flavanone glycosides reached 328.65 mg/L in February and remained constant during final ripening. The Tacle also reached its highest flavanone level in February, but a subsequent decrease was observed.

Hydroxycinnamic acids (ferulic, *p*-coumaric, caffeic, and sinapic) are a class of secondary plant metabolites involved in the ripening and defense processes of fruits and vegetables (*22*). Hydroxycinnamic acid esters and glycosides are present in citrus fruits (*23*) and are mainly derived from ferulic acid (*15*). In Tacle and Clara fruit juices, ferulic acid was always the most abundant phenolic acid. The concentration of total hydroxycinnamic acids in Tacle juice remains unchanged during ripening until the end of February. It subsequently increases, mainly because of a consistent increase in *p*-coumaric acid concentration. During early ripening, total hydroxycinnamic acids in Clara juice were lower than those in Tacle juice, whereas the values were similar during final ripening because of the development of sinapic and ferulic acids. However, total hydroxycinnamic acids in the Clara increased 3-fold during ripening, whereas a lower increase (∼17%) was observed in the Tacle.

Citrus fruits of various shades of yellow, orange, and red are the most important carotenogenic fruits (*24*). In particular, some citrus varieties such as mandarin and mandarin-like hybrids are rich in some classes of carotenoids that the human organism is able to convert into vitamin A (*25*). The concentrations of total carotenoids found in Tacle and Clara juices are comparable to those generally found in mandarin juice (*26*). In Clara juice, the content of pigments remained relatively constant during ripening. Instead, in Tacle juice, there was a sharp rise between the first (January 5) and second (February 2) samplings, the highest value being reached in mid-March (54.24 mg/L).

Cold-Stored Fruits. Although the respiration rate of ripe citrus fruits is relatively low, post-harvest storage can produce internal quality changes (*27*). Recent studies have shown that increases in health-promoting substances such as anthocyanins and hydroxycinnamic acids occur in blood oranges during cold storage (*28*). Additionally, an increase in TSS and a simultaneous decrease in TA have been observed.

The storage of Tacle and Clara fruits for 104 days at 6 ± 1 °C and 90–95% RH (**Tables 3** and **4**) reduced juice yield and TA but slightly increased TSS. The decrease in acid content of cold-stored citrus fruits may be due to the use of organic acids for energy production and alcoholic fermentation (*29*). During storage, the TSS/TA ratio ranged from 10.49 to 16.20 in Tacle juice and from 11.82 to 17.37 in Clara juice. A similar trend was also observed in cold-stored Tarocco, Hamlin, and Valencia orange varieties and grapefruits (*28, 30, 31*).

No relevant changes in vitamin C content were observed during cold storage in both the Tacle and Clara hybrids. At the end of treatment, vitamin C levels (42.21 and 65.27 mg/100 mL) in both hybrids did not result in an excessive reduction of the fruits' antioxidant defense (*32*).

During cold storage, a marked increase in anthocyanin concentration was observed in the Tacle and the Clara. The pigment levels after 104 days of storage were 3- and 9-fold higher than those of the fresh fruits before storage, respectively. Individual pigment analysis for both hybrids showed an increase in cyanidin-3-glucoside until the 42nd day of storage, whereas the highest level of cyanidin-3-(6″-malonyl)-glucoside was reached on the 72nd day of storage.

Flavanone glycoside content increased in both hybrids, reaching 406.98 mg/L in the Tacle and 370.15 mg/L in the Clara. This change was due to the doubling of the narirutin concentra-

Table 3. Physico-chemical Parameters of Tacle Hybrid Juice Obtained from Fruits Stored at 6 ± 1 °C and 90–95% RH[a]

	storage days				
	0	23	42	72	104
juice yield (%)	33.33 AB	34.92 A	32.30 AB	31.52 AB	29.57 B
TSS (%)	11.35 C	10.99 D	12.09 AB	11.85 B	12.20 A
TA (%)	1.08 A	1.06 AB	0.99 AB	0.84 AB	0.75 B
TSS/TA	10.49 D	10.33 D	12.25 C	14.05 B	16.20 A
vitamin C (mg/100 mL)	46.96 ns	46.40 ns	49.22 ns	49.09 ns	42.21 ns
total anthocyanins (mg/L)	12.89 D	20.87 C	31.70 B	33.70 B	38.63 A
cyanidin-3-glucoside (%)[b]	32.93 b	34.29 ab	37.05 a	36.76 ab	28.90 c
cyanidin-3-(6″-malonyl)-glucoside (%)[b]	30.96 C	33.59 C	48.63 B	59.13 A	57.58 A
total flavanones (mg/L)	205.93 D	238.48 CD	248.73 C	313.08 B	406.98 A
narirutin (mg/L)	10.17 D	13.07 CD	15.96 BC	18.12 B	23.91 A
hesperidin (mg/L)	183.70 C	205.27 BC	232.77 BC	269.51 B	340.04 A
total hydroxycinnamic acids (mg/L)	73.23 B	119.93 A	134.95 A	133.67 A	138.33 A
caffeic acid (mg/L)	7.35 C	9.45 BC	10.45 AB	13.36 A	10.40 AB
p-coumaric acid (mg/L)	19.72 C	29.19 BC	34.95 B	39.29 B	53.89 A
ferulic acid (mg/L)	42.47 B	77.59 A	80.76 A	72.38 A	61.19 A
sinapic acid (mg/L)	3.69 C	3.71 C	8.79 B	8.64 B	12.85 A
total carotenoids (mg/L)	41.11 B	39.64 B	41.01 B	55.02 A	54.54 A

[a] Means in the same row followed by different letters are significantly different: capital letter, $p \leq 0.01$; lowercase letter, $p \leq 0.05$; ns, not significant. [b] Relative percentage of anthocyanins was based on HPLC peak areas.

Table 4. Physico-chemical Parameters of Clara Hybrid Juice Obtained from Fruits Stored at 6 ± 1 °C and 90–95% RH[a]

	storage days				
	0	23	42	72	104
juice yield (%)	37.84 A	34.53 AB	34.46 AB	34.57 AB	32.42 B
TSS (%)	11.79 bc	11.23 c	12.30 b	12.46 b	13.37 a
TA (%)	0.99 a	0.96 ab	0.87 ab	0.83 ab	0.77 b
TSS/TA	11.82 C	11.72 C	14.13 B	14.93 B	17.37 A
vitamin C (mg/100 mL)	71.12 ns	70.19 ns	69.22 ns	68.57 ns	65.27 ns
total anthocyanins (mg/L)	1.83 D	5.43 C	9.94 B	11.77 B	17.00 A
cyanidin-3-glucoside (%)[b]	26.77 C	34.05 BC	45.32 A	37.66 AB	38.20 AB
cyanidin-3-(6″-malonyl)-glucoside (%)[b]	36.73 B	40.36 B	41.17 B	58.83 A	54.57 A
total flavanones (mg/L)	322.28 ns	316.07 ns	319.86 ns	362.97 ns	370.15 ns
narirutin (mg/L)	9.37 C	11.40 C	10.31 C	17.38 B	23.22 A
hesperidin (mg/L)	300.30 ns	295.37 ns	295.38 ns	329.58 ns	323.14 ns
total hydroxycinnamic acids (mg/L)	64.61 B	87.43 AB	94.17 A	96.33 A	98.47 A
caffeic acid (mg/L)	5.79 B	9.58 A	8.83 A	9.44 A	9.16 A
p-coumaric acid (mg/L)	12.12 C	19.53 AB	19.23 B	23.09 AB	25.95 A
ferulic acid (mg/L)	38.71 b	50.46 a	51.51 a	51.78 a	49.01 ab
sinapic acid (mg/L)	7.99 B	7.86 B	14.60 A	12.03 AB	14.34 A
total carotenoids (mg/L)	33.33 ns	31.70 ns	29.71 ns	33.40 ns	32.82 ns

[a] Means in the same row followed by different letters are significantly different: capital letter, $p \leq 0.01$; lowercase letter, $p \leq 0.05$; ns, not significant. [b] Relative percentage of anthocyanins was based on HPLC peak areas.

tion and a relevant increase in hesperidin concentration in the Tacle hybrid only.

Cold storage of the Tacle and the Clara significantly influenced the level of hydroxycinnamic acids. These results agree with those recently reported by Rapisarda et al. (*28*) on polyphenol change during cold storage of two different varieties of blood oranges. In the Tacle hybrid, the main contributor to the increase in total hydroxycinnamic acids was ferulic acid during early storage; later, caffeic, *p*-coumaric, and sinapic acids increased. A marked increase in the total and individual hydroxycinnamic acids was also observed in Clara fruits.

Anthocyanins, flavanones, and hydroxycinnamic acids were the three phenolic classes which increased during cold storage of Tacle and Clara fruits. The high levels of these components may be attributable to the activation of the enzymes involved in phenylpropanoid metabolism induced by low temperatures, according to other reports which found that cold storage stimulates polyphenol biosynthesis in different fruit species (*33*).

The effect of temperature on post-harvest carotenoid development in citrus fruits has been exstensively studied (*27*). Previous work established that cold storage improves the external color of Valencia oranges, but no change was observed in flesh color (*34*). No significant variations were found in Clara fruit juice pigments during the entire storage period. In the Tacle, however, total carotenoids increased on the 72nd day of storage and leveled off until the end of storage.

In conclusion, the chemical composition of Tacle and Clara fresh fruits at different stages of ripening showed that the optimal period for fruit processing is February, when there is a suitable TSS/TA ratio, high vitamin C values, and good anthocyanin, flavanone, and total hydroxycinnamic acid concentrations. Thus, it is possible to obtain new juices with a notable antioxidant component, which could be blended with commercial citrus juices or used for new beverages. Likewise, fruit storage further improved juice quality, even though low TA values in both hybrid juices after 72 days of storage may negatively affect their taste. Nevertheless, anthocyanin development in fruits during 104 days of cold storage may positively influence the sensory quality of processed products. In addition, the increase in flavanones and hydroxycinnamic acids and the preservation of vitamin C during cold storage suggest that consumption of these fruits or juices can play a significant role in human-health promotion.

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Received for review September 4, 2007. Revised manuscript received December 27, 2007. Accepted January 15, 2008. This work was supported by a grant from the Ministero delle Politiche Agricole Alimentari e Forestali (Mi.P.A.A.F.), Italy, and carried out under the Innovazioni per il raggiungimento della qualità globale in agrumicoltura project (Pub. N. 3).

JF072616E