JOURNAL OF AGRICULTURAL AND FOOD CHEMISTRY

J. Agric. Food Chem. **2008,** *56,* 7091–7099 **7091**

Optimization of Color and Antioxidant Activity of Peach and Nectarine Puree: Scale-Up Study from Pilot to Industrial Plant

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The effects of an innovative process for the manufacture of peach and nectarine purees on the main quality indices, namely, color, consistency, carotenoid and phenolic content, and antioxidant activity, were studied using a peach cultivar that is optimal for nectar processing (cv. Redhaven) and peach and nectarine varieties that undergo a faster browning degradation. The innovative process, operating the pulping/finishing step at room temperature, was compared to the traditional process of hot pulping/finishing. The study comprised initial trials on a pilot plant scale and scaling up to industrial production of the puree and nectar. The quality of products was analyzed at the time of production and as a function of storage of both the puree and the nectar. With respect to the traditional process, the new process, scaled up to industrial levels, improved the color of peach and nectarine products (by increasing the L^* value and decreasing the a^* value), whatever the variety studied; maintained almost the same levels of carotenoids, hydroxycinnamates, flavan-3-ols, and flavonols; and reduced the level of cyanidin 3-*O*-glucoside. The presence of cyanidin 3-*O*-glucoside was correlated to an unstable and undesirable red hue of the products (even if its concentration was very low in all products), and the decreased level obtained by the innovative process was considered to be positive. On the basis of these results, new technology can be proposed for the processing of fruit varieties that are not suitable for puree production using traditional technology. This opens up two possibilities: (a) utilization of fresh market fruit surplus and (b) processing of selected fruit varieties that are rich in antioxidants but have a high browning potential, such as the Stark Red Gold nectarine. Furthermore, as the positive impact of the new technology is optimal at the beginning of storage, it is particularly suitable for fruit-based products with a short shelf life.

KEYWORDS: ***Prunus persica*; color; puree and nectar processing; phenolics; carotenoid; ascorbic acid; antioxidant activity**

INTRODUCTION

Peaches and nectarines (*Prunus persica*) contain significant amounts of secondary plant metabolites, including hydroxycinnamic acids, flavan-3-ols, flavonols, anthocyanins, procyanidins, and carotenoids (*1, 2*). These minor dietary compounds have been postulated to play a key role in vivo as antioxidants, by preventing reactions produced by oxygen and nitrogen species during the progression of different human pathologies (*3*). Supportive evidence to this hypothesis was provided by Ko et al. (*4*), who found that the uptake of 150 mL of peach juice effectively suppressed the generation of reactive oxygen species in human plasma within 30 min after consumption. Conversely, some phenolic compounds are degradation substrates, which lower the nutritive value and color of fruit juices, purees, and nectars and impair consumer preference.

Polyphenol oxidases (PPO) and peroxidases (POD), which occur in multiple forms in different fruits and vegetables, are the major catalysts involved in fruit degradation and browning. The common name PPO denotes two different enzymes. One enzyme catalyzes the hydroxylation of monophenols to *o*-dihydroxyphenols and the oxidation of *o*-dihydroxyphenols to *o*-quinones. The other enzyme oxidizes *o*- and *p*-dihydroxyphenols to quinones. The quinones formed are highly reactive and polymerize, forming brown pigments (*5*). The natural PPO substrate in peaches and nectarines is chlorogenic acid (*6*). POD decomposes hydrogen peroxide in the presence of a hydrogen donor. These enzymes are highly specific to hydrogen peroxide but have a low affinity toward the hydrogen donor substrate (*5*). Anthocyanase has been found in some fruits and may indirectly promote fruit

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10.1021/jf8008469 CCC: $40.75 © 2008 American Chemical Society
Published on Web 07/12/2008

browning. The enzyme catalyzes the hydrolysis of sugar molecules from anthocyanins. The anthocyanidin produced by this reaction is accessible to PPO and POD, whereas both enzymes have low affinities for anthocyanins (*7*).

Nonenzymatic routes also can lead to phenolic degradation and fruit browning. In model food systems, furfural and 5-hydroxymethyl furfural derived from sugar degradation by the Maillard reaction can react with anthocyanins to form brown compounds. However, it is unlikely that the low furfural and 5-hydroxymethyl furfural levels observed in fruit products would affect anthocyanin degradation (*5*). The association of anthocyanins with different fruit compounds may proceed to produce condensation products (*5*). In addition, the interaction between ascorbic acid and anthocyanin leads to mutual degradation (*8, 9*).

The color of peach and nectarine products is considered to be one of the main criteria affecting consumer preference. To improve the color of juices and purees, the use of antibrowning agents, adsorption processes, high hydrostatic pressure, and photochemical processes have been proposed (*10–13*). Peach and nectarine varieties are cultivated throughout the world and are well-appreciated in the fresh produce market. However, only a few varieties, characterized by a low browning potential, are currently used for fruit processing. During the harvesting season, these fruits are processed into stabilized purees that are then consumed directly or aseptically stored in tanks and processed throughout the year to produce jellies, jams, and mostly nectars.

A major requirement for the fruit industry is to process fresh market surplus into high quality purees and nectars. Processing of selected varieties with an enhanced antioxidant content also is a key area of development. The aim of this study was to evaluate the effects of an innovative process for the manufacturing of peach and nectarine purees on the main quality indices, namely, consistency, color, carotenoid and phenolic content, and antioxidant activity. The innovative process, operating the pulping/finishing step at room temperature, was compared to the traditional process of hot pulping/finishing. Fruit purees were produced from a peach cultivar that is optimal for nectar processing (cv. Redhaven) and from peach and nectarine varieties that undergo a faster browning degradation. The study was comprised of three steps: (a) evaluating the quality indices of traditional and innovative purees at the time of production on a pilot and industrial scale, (b) evaluation of the quality indices of traditional and innovative purees during 12 months of storage, and (c) evaluation of the quality indices of nectars industrially produced from traditional and innovative purees, as a function of the length of storage of both the puree and the nectar itself.

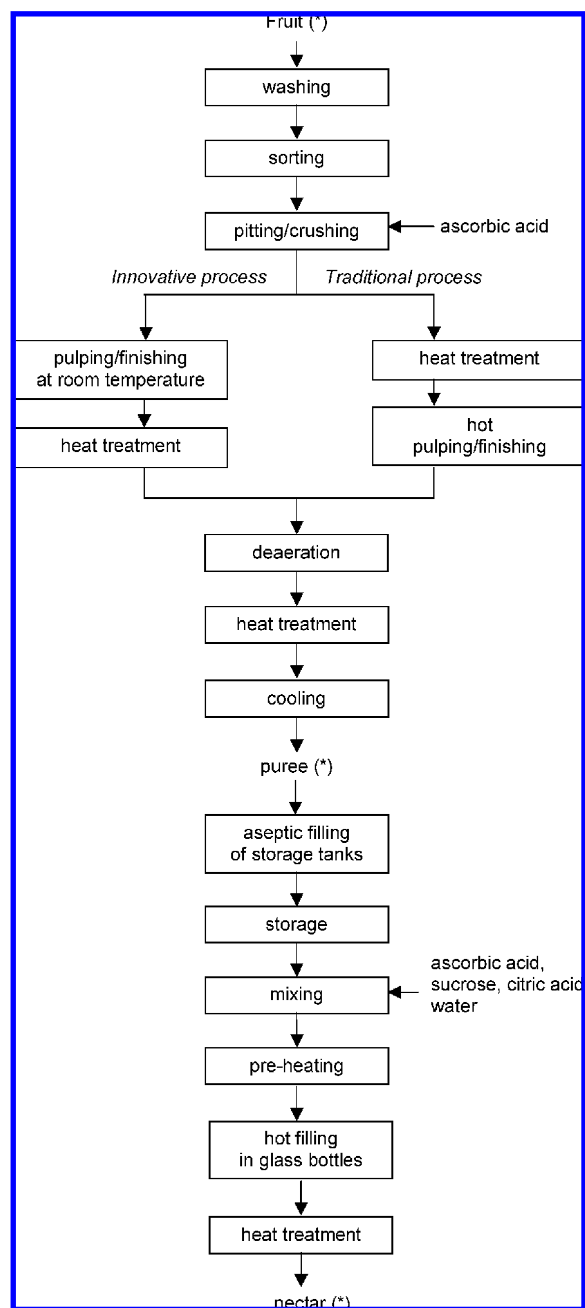

Figure 1. Flow diagram for production of peach and nectarine purees and nectars in the industrial plant operating an innovative pulping/finishing step, in parallel with the traditional processing line. The same processes also were carried out on a pilot plant scale. Asterisks indicate sampling points.

MATERIALS AND METHODS

Fruits. Peaches of Redhaven and Elegant Lady cultivars, nectarines of Stark Red Gold cultivar, and four peach mixtures were collected on different days at the full-ripe stage and processed separately on the same day of harvest. For analytical determinations, fresh fruits were frozen and stored at −20 °C.

Puree Production at Pilot Plant. Batches of Redhaven and Elegant Lady peaches and of Stark Red Gold nectarines were processed separately in the laboratory. Each fruit batch was divided into two homogeneous groups. Half of the fruits were treated by simulating the traditional puree manufacturing process. The remaining fruits were treated by simulating the new process.

The traditional process was simulated using a pilot plant as follows. Fruits (10 kg) were washed in cold water, rinsed, and manually pitted. Pitted fruits were transferred to a Malavasi Qbo 150 RoboQuo (Bologna, Italy), with ascorbic acid added at 0.5 g/kg fruits, pulped by rotating the cutter at 1000 rpm, and heated to 90 °C. The pulp was then transferred hot from the Malavasi Qbo 150 RoboQuo to a 0.5 mm screen pulper/finisher (Bertuzzi, Brugherio, Italy) to remove the peel. The pulping/finishing step was repeated 3 times. Afterward, the puree was transferred again into the Malavasi Qbo 150 RoboQuo, deaerated under vacuum for 9 min at 60 °C, and heated to 90 °C. The puree was hot-filled into glass bottles (125 mL). These were closed and heat treated in a water bath at 100 °C for 5 min. The new process was carried out using the same conditions as described previously, except that after being cut in the Malavasi Qbo 150 RoboQuo at room temperature, the pulp was directly transferred to the pulper/finisher for peel removal at room temperature.

Puree Production at Industrial Plant. The peach mixture and Stark Red Gold nectarines (the same as those processed in the laboratory) were processed separately at an industrial plant. The fruit was washed, sorted, and fed into a continuous puree processing line (**Figure 1**). The first step consisted of pitting/crushing in the presence of ascorbic acid (0.5 g/kg). Afterward, a new pulper/finisher was set up online, in parallel

with the traditional line. A portion of the pulp was processed following the traditional steps, namely, heating to 100 °C by steam injection, passing hot through a 0.5 mm screen pulper/finisher, and deaerating under vacuum. Another part of the pulp was passed through the innovative 0.5 mm screen pulper/finisher at room temperature, heated to 100 °C by steam injection, and deaerated under vacuum. The purees obtained both from the traditional and from the new process were then heated to 115 °C for 40 s using a tubular heat exchanger, cooled to 15 °C, and aseptically stored in tanks under nitrogen. The innovative process did not influence the yield of the products as compared to the traditional process. Traditional and innovative purees obtained from the peach mixture and from nectarine Stark Red Gold were analyzed immediately after production. For analytical determinations, purees were withdrawn from the tanks, heated to 90 °C, and poured into glass bottles (125 mL). These bottles were closed and heat treated in a water bath at 100 °C for 5 min.

Nectar Production at Industrial Plant. Three batches of purees, obtained from peach mixtures in the traditional and innovative production lines and the puree obtained from the Redhaven variety under traditional conditions, were processed to nectars immediately after production, after 2.5 months, and after 4 months of storage in a tank at room temperature. Purees were blended with water (50% w/w), ascorbic acid (300 mg/kg final), and sucrose (14.5 °Bx final). Citric acid was added to adjust the pH in the range of 3.5−3.7. The mixture was homogenized, heated to 90 °C, and poured into glass bottles (125 mL). These bottles were closed and heat treated in a water bath at 100 °C for 5 min.

Storage Study. Industrially processed purees and nectars were stored in the dark, in 125 mL glass bottles for 12 months. Storage temperatures were room temperature and 37 °C for the purees and room temperature for the nectars. Analyses were carried out at scheduled times.

Soluble Solids, pH and Acidity, and Bostwick Consistency. Soluble solids were measured at 20 °C using a RFM 340 refractometer (Bellingham and Stanley Ltd., Tunbridge Wells, U.K.) and expressed as °Brix (g sucrose/100 g (on a fresh wt basis)).

The pH was determined with a PB-20 pH meter (Sartorius, Ravenna, Italy). Purees were diluted with water (1:10 v/v), and the mixture was titrated in the presence of phenolphthalein with 0.1 M NaOH. Results were expressed as grams of citric acid per 100 g of fresh product. Consistency was determined by measuring the distance (in cm) over which the puree flowed in a Bostwick consistometer (LS 100, Labo-Scientifica, Parma, Italy) at 20 °C for 30 s.

Color. Color was measured with a SL-2000 chromameter (Labo Scientifica, Parma, Italy) and expressed as the Hunter L^*, a^*, and b^* coordinates, representing lightness and darkness (L^*), redness ($+a^*$), greenness ($-a^*$), yellowness ($+b^*$), and blueness ($-b^*$). The chromameter was calibrated with a red standard (No. 482, Bureau Communitaire de Reference: $L^* = 25.6$, $a^* = 33.5$, and $b^* = 14.7$). To study the variation in color during time, ΔE is generally calculated using the initial a^*, b^*, and L^* values of the sample as a reference (*13, 24, 25*). In this study, the colorimetric parameters of the puree and nectar obtained from the Redhaven cultivar (a^*_{RH}, b^*_{RH}, and L^*_{RH}), analyzed immediately after processing in traditional conditions, were taken as a reference to evaluate the color of the purees and nectars obtained from all the other fruits, by calculating ΔE_{RH} according to the equation

$$\Delta E_{RH} = ((a^* - a^*_{RH})^2 + (b^* - b^*_{RH})^2 + (L^* - L^*_{RH})^2)^{1/2} \quad (1)$$

According to the internal industrial standard, the colorimetric parameters of the puree and nectar obtained from the Redhaven cultivar represent the best color for these products. Using eq 1, the effects of both time and genetic factors on color were taken into consideration.

Extraction and Analysis of Ascorbic Acid. Purees (5 g) were diluted with water to 200 mL, and 5 mL of 30% metaphosphoric acid in glacial acetic acid was added. The mixture was titrated with 2,6-dichlorophenol-indophenol (*14*). Ascorbic acid was quantified from a calibration curve built with a pure standard (Sigma, Milan, Italy) and expressed as mg/kg (on a fresh wt basis).

Extraction and Analysis of Phenolics. Frozen fruits were cut into pieces and pitted, and 100 g of frozen pulp was added to 120 mL of 5% formic acid in methanol. The mixture was homogenized with a model 17106 Omni-mixer (Sorvall Du Pont Instrument, Newton, CN) at 8000 rpm for 3 min. Liquid nitrogen was flushed to facilitate deaeration of the mixture, and 600 mL of 5% formic acid in water was added. The mixture was then centrifuged at 16 000*g* for 10 min at 15 °C. Puree extracts were obtained by adding 5 g to 10 mL of 5% formic acid in a water/methanol ratio of 80:20. The mixture was stirred for 1 min and centrifuged at 16 000*g* for 10 min at 15 °C.

The phenolic content of the fruit and puree extracts was analyzed using a model 600 HPLC pump coupled to a model 2996 photodiode array detector, operated by Empower Software (Waters, Vimodrone, Italy). A reversed phase C_{18} Symmetry column (250 mm × 4.6 mm i.d.; particle size 5 μm) (Waters, Vimodrone, Italy) equipped with a Symmetry C_{18} precolumn was used. Chromatographic separation was carried out according to the method of Tomas-Barberan et al. (*1*). In brief, formic acid (5%) was added to both methanol and water before preparing the following mobile phase: 95% water + 5% methanol (A); 88% water + 12% methanol (B); 20% water + 80% methanol (C); and methanol (D). The gradient elution was 0−5 min, 100% A; 5−10 min linear gradient to reach 100% B; 10−13 min 100% B; 13−35 min linear gradient to reach 75% B and 25% C; 35−50 min linear gradient to reach 50% B and 50% C; 50−52 min linear gradient to reach 100% C; 52−57 min 100% C; and 57−60 min 100% D. The injection volume was 20 μL, and the flow rate was 1 mL/min.

Phenolic compounds were identified by their UV−vis spectra and retention times and were quantified by calibration curves built with external standards, namely, catechin at 280 nm, cyanidin 3-*O*-glucoside at 510 nm, chlorogenic acid at 330 nm for the hydroxycinnamic acids, and rutin at 350 nm for the flavonols (all these standards were by Extrasynthese, Lyon, France). Concentrations were expressed as mg/kg (on a fresh wt basis).

Extraction and Analysis of Procyanidins. Frozen fruits were cut into pieces and pitted, and 100 g of frozen pulp was added to 200 mL of cooled methanol. The mixture was homogenized with a model 17106 Omni-mixer (Sorvall Du Pont Instrument) at 8000 rpm for 3 min. Liquid nitrogen was flushed to facilitate deaeration of the mixture, and 600 mL of methanol was added. The mixture was centrifuged at 16 000*g* for 10 min at 15 °C. Puree extracts were obtained by adding 0.9 g to 10 mL of methanol, and the mixture was stirred for 1 min and centrifuged at 16 000*g* for 10 min at 15 °C.

Reaction mixtures were prepared by adding 1 mL of fruit or puree extract in methanol, 5.7 mL of a solution of *n*-butanol containing concentrated HCl (95:5, v/v), 0.340 mL of 1.16% $NH_4Fe(SO_4)_2 \cdot 12H_2O$ dissolved in concentrated HCl, and 0.085 or 0.123 mL of water (for purees or fruits, respectively). The same water content was achieved in all samples since the yield of cyanidin is affected by small amounts of water (*15*). Hydrolysis was carried out in screw-capped glass tubes at 95 °C for 40 min. The solutions were cooled, and the absorbance was recorded at 550 mm. A calibration curve was built using procyanidin B1 (Extrasynthese, Lyon, France). Procyanidin content was expressed as cyanidin equivalents (extinction coefficient at 550 nm was 35 000 M^{-1} cm^{-1}).

Extraction, Saponification, and Analysis of Carotenoids. The extraction was based on that of Wright and Kader (*16*). Frozen fruits were cut and pitted, and 50 g of frozen pulp or puree was added to 100 mL of cooled ethanol. The mixture was homogenized with a model 17106 Omni-mixer (Sorvall Du Pont Instrument) at 8000 rpm for 3 min and then with a model T25 Ultra-Turrax (JK GmBH, Staufen, Germany) at 8000 rpm for 2 min, before 80 mL of hexane was added. The mixture was centrifuged for 5 min at 16 000*g*, and the carotenoid bearing hexane layer was transferred to a volumetric flask. To the residue, 50 mL of saturated sodium chloride solution was added. Hexane was added again (80 mL), and the mixture was centrifuged as described previously. The second hexane extract was combined with the first, and the volume was brought up to 200 mL with hexane.

Saponification was carried out as described by Kimura et al. (*17*). In brief, 15 mL of hexane extract was transferred into a Pyrex bottle and added to 15 mL of 10% methanolic potassium hydroxide, flushed with nitrogen, sealed, and wrapped in aluminum foil to exclude light. The reaction was carried out at room temperature for 16 h, with gentle shaking. The mixture was then transferred to a separatory funnel and

washed to remove potassium hydroxide, first with 50 mL of 10% NaCl and then with deionized water until the rinse had a neutral pH. The water phase was extracted with 10 mL of hexane, and the combined hexane extracts were evaporated under nitrogen to dryness and then redissolved in the mobile phase.

Carotenoid content was analyzed by HPLC as described previously (*18*). In brief, a Vydac 201TP54 C18 column (250 mm × 4.6 mm), equipped with a C_{18} precolumn, was used. Chromatographic separation was performed with 95:5 methanol/tetrahydrofuran stabilized by the addition of 0.1% butylated hydroxytoluene (2,6-di-*t*-butyl-*p*-cresol) as the eluent under isocratic conditions, 1.0 mL/min flow rate, at room temperature. The UV−vis detector was set at 454 nm. β-Carotene was quantified from a calibration curve built with a pure β-carotene standard (Extrasynthese, Lyon, France) and expressed as mg/kg (on fresh wt basis).

Antioxidant Activity. This assay was performed as described previously (*19*). Briefly, 1 mL of different dilutions of the fruit or puree extracts in water/methanol (80:20) containing 5% formic acid was added to 2 mL of a 25 mg/L methanolic solution of 2,2-diphenyl-1-(2,4,6-trinitrophenyl)hydrazyl (DPPH, Sigma, Milan, Italy). The decrease in absorbance was determined at 515 nm after 30 min (when a constant value was reached) by a Jasco UVDEC-610 spectrophotometer (Jasco Europe, Cremella, LC).

The percentage decrease of DPPH concentration was calculated with respect to the initial value after 30 min of reaction. A dose−response curve was constructed, and the amount of product required to lower the initial DPPH concentration by 50%, I_{50}, was interpolated. 6-Hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox, Sigma, Milan, Italy) was used as a reference antioxidant, and the antioxidant activity was expressed as Trolox equivalents. Trolox equivalents are the ratio of I_{50} of Trolox (nmol) to I_{50} of the sample (mg, fresh wt).

Statistical Analysis. For each process (traditional or innovative) and each fruit batch, three bottles were analyzed at each sampling time. 2-D regression of data and analysis of variance were conducted using the Statgraphics 5.1 software (STCC Inc., Rockville, MD); Fisher's least significant difference (LSD) procedure ($p < 0.05$) was used to discriminate among the means. 3-D regression of data was carried out with TableCurve 3D (Jandel Scientific, Chicago, IL).

RESULTS AND DISCUSSION

Effect of Innovative and Traditional Processes Applied in Pilot and Industrial Plants on Quality of Purees. The quality of purees was evaluated immediately after processing. The soluble solid content, pH, titratable acidity, and consistency of the purees produced by traditional and innovative processes are shown in **Table 1**. For all purees tested, the soluble solid content, pH, and titratable acidity were in the range of those of fully ripe fresh fruits (*1, 2*), indicating that all fruit batches were processed at optimal maturity.

Peach and nectarine purees are mostly utilized for nectar production. For this use, puree consistency is critical: it decreases markedly upon fruit pulping if the pectinolytic enzymes are not promptly deactivated. Puree consistency was determined by measuring the distance over which the puree flowed in a Bostwick consistometer at 20 °C for 30 s. Therefore, the higher the value is in **Table 1** (flow rate), the lower the consistency is. According to an internal industrial standard, the flow rate must be lower than 13 cm in 30 s for an acceptable consistency. Initial laboratory studies on a pilot plant scale showed that all the purees obtained by the innovative process had a much lower consistency with respect to the corresponding purees obtained by the traditional process and that none of the innovative purees had an acceptable consistency. This effect was likely dependent on the delayed thermal inactivation of the enzymes during the innovative process (**Figure 1**). However, the purees obtained on industrial scale, by both the traditional and the innovative processes, had good consistency values. It can be hypothesized that this result was achieved due to the high rate of the industrial process and the shorter length of time for enzymes to act on the pectins.

Table 1. Soluble Solid Content, Titratable Acidity, pH, and Bostwick Consistency of Peach and Nectarine Purees Obtained from Traditional and Innovative Processes in Pilot and Industrial Plants[a]

		process applied			
		pilot scale		industrial scale	
quality index	peach/nectarine	traditional	innovative	traditional	innovative
soluble solids (°Bx)	RH p.	11.5[a]	11.3[a]		
	EL p.	13.5[a]	12.9[a]		
	SRG n.	12.4[a]	11.9[a]	12.2[a]	12.6[a]
	M p.			8.6[a]	8.2[a]
acidity (% citric acid)	RH p.	0.66[a]	0.62[a]		
	EL p.	0.74[a]	0.82[b]		
	SRG n.	0.93[b]	0.84[a]	0.87[ab]	0.91[b]
	M p.			0.60[a]	0.57[a]
pH	RH p.	3.70[a]	3.68[a]		
	EL p.	3.68[b]	3.55[a]		
	SRG n.	3.64[a]	3.63[a]	3.62[a]	3.79[b]
	M p.			3.80[a]	3.83[a]
consistency (cm in 30 s)	RH p.	12.8[a]	15.5[b]		
	EL p.	12.0[a]	15.0[b]		
	SRG n.	12.5[c]	20.5[d]	9.3[b]	8.5[a]
	M p.			11.5[a]	11.5[a]

[a] RH p.: Redhaven peach; EL p.: Elegant Lady peach; SRG n.: Stark Red Gold nectarine; and M p.: mixture of different peach varieties. Different letters within the same row indicate significant differences (LSD; $p < 0.05$).

Table 2. Hunter *a**, *b**, and *L** Colorimetric Parameters, at the Time of Production, of Peach and Nectarine Purees Obtained from Traditional and Innovative Processes in Pilot and Industrial Plants[a]

		process applied			
		pilot scale		industrial scale	
color index	peach/nectarine	traditional	innovative	traditional	innovative
*a**	RHp.	0.91[b]	−4.86[a]		
	ELp.	13.62[b]	0.85[a]		
	SRGn.	9.62[d]	−0.34[a]	8.96[c]	2.07[b]
	Mp.			9.56[b]	5.10[a]
*b**	RHp.	23.12[b]	23.00[a]		
	ELp.	16.69[a]	22.41[b]		
	SRGn.	19.52[c]	18.59[a]	18.81[b]	20.32[d]
	Mp.			16.67[a]	18.07[b]
*L**	RHp.	48.4[a]	48.7[b]		
	ELp.	38.9[a]	46.8[b]		
	SRGn.	39.9[b]	39.8[a]	40.3[c]	43.6[d]
	Mp.			38.8[a]	42.4[b]

[a] RH p.: Redhaven peach; EL p.: Elegant Lady peach; SRG n.: Stark Red Gold nectarine; and M p.: mixture of different peach varieties. Different letters within the same row indicate significant differences (LSD; $p < 0.05$).

The colorimetric data of the purees, evaluated immediately after production, are shown in **Table 2**. Laboratory trials in pilot scale plants showed that both the genotypic factors and the process applied greatly affected the color of the purees. As expected, the optimal colorimetric parameters (i.e., lowest a^* value and highest b^* and L^* values) were found in purees obtained from the Redhaven peach, whatever the process applied. With respect to the traditional process, the innovative process decreased the a^* value of all purees and increased the L^* value in most cases.

This improvement in color was confirmed by the scale-up study. With respect to the traditional process, by applying the innovative process, a^* values decreased from 8.96 to 2.07 in the Stark Red Gold nectarine puree and from 9.56 to 5.10 in that of the mixture of peaches; b^* values increased from 18.81

Table 3. Antioxidant Content and Antioxidant Activity of Peach and Nectarine Fruits and Purees Obtained from Traditional and Innovative Processes in Pilot and Industrial Plants, Analyzed at Time of Production[a]

			puree			
			pilot scale		industrial scale	
quality index	peach/nectarine	fruit	traditional	innovative	traditional	innovative
ascorbic acid (mg/kg)	RH p.		355[b] (29)	55[a] (89)		
	EL p.		445[b] (11)	265[a] (47)		
	SRG n.		380[c] (24)	40[a] (92)	370[c] (26)	170[b] (66)
	M p.				330[b] (34)	235[a] (53)
neochlorogenic acid (mg/kg)	RH p.	65[c]	49[b] (25)	39[a] (40)		
	EL p.	53[c]	42[b] (20)	38[a] (27)		
	SRG n.	152[d]	57[b] (63)	26[a] (83)	67[c] (56)	70[c] (54)
	M p.	70[b]			28[a] (61)	26[a] (63)
chlorogenic acid (mg/kg)	RH p.	72[c]	69[b] (4)	47[a] (35)		
	EL p.	105[c]	96[b] (9)	79[a] (24)		
	SRG n.	272[d]	75[b] (73)	17[a] (94)	105[c] (61)	100[c] (63)
	M p.	71[c]			47[b] (34)	42[a] (40)
catechin (mg/kg)	RH p.	40[b]	45[b]	21[a] (47)		
	EL p.	41[c]	37[b] (10)	28[a] (33)		
	SRG n.	52[d]	25[b] (52)	7[a] (87)	37[c] (29)	36[c] (30)
	M p.	49[c]			22[b] (55)	18[a] (63)
procyanidins (mg cyanidin equiv/kg)	RH p.	211[b]	253[b]	181[a] (14)		
	EL p.	320[c]	197[b] (38)	161[a] (50)		
	SRG n.	287[e]	163[b] (43)	47[a] (84)	203[d] (29)	182[c] (37)
	M p.	177[b]			134[a] (24)	127[a] (28)
quercetin 3-*O*-glycosides (mg rutin equiv/kg)	RH p.	12[b]	13[b]	7[a] (42)		
	EL p.	22[b]	23[b]	17[a] (24)		
	SRG n.	27[d]	26[cd]	8[a] (70)	24[c] (10)	18[b] (33)
	M p.	13[a]			15[a]	15[a]
cyanidin 3-*O*-glucoside (mg/kg)	RH p.	5.5[c]	3.7[b] (32)	1.2[a] (78)		
	EL p.	17.3[c]	17.0[b] (2)	3.1[a] (82)		
	SRG n.	32.7[e]	11.6[d] (64)	1.5[a] (95)	8.2[c] (75)	4.4[b] (87)
	M p.	30.3[c]			11.6[b] (62)	7.5[a] (75)
β-carotene (mg/kg)	RH p.	2.6[b]	1.3[a] (48)	1.4[a] (47)		
	EL p.	3.1[c]	1.4[b] (54)	1.1[a] (65)		
	SRG n.	2.1[c]	1.4[b] (33)	1.2[a] (41)	1.4[b] (32)	1.4[b] (32)
	M p.	2.3[b]			1.3[a] (43)	1.3[a] (43)
antioxidant activity (mmol TE/kg)	SRG n.	3.9[c]			3.6[b]	2.8[a]
	M p.	2.4[a]			2.8[b]	2.4[a]

[a] Different letters within the same row indicate significant differences (LSD; $p < 0.05$). Values in parentheses are percent losses calculated with respect to amounts present in fresh fruits for carotenoids and phenolics and to amounts added during the pulping/finishing step for ascorbic acid. RH p.: Redhaven peach; EL p.: Elegant Lady peach; SRG n.: Stark Red Gold nectarine; and M p.: mixture of different peach varieties.

to 20.32 in the Stark Red Gold nectarine puree and from 16.67 to 18.07 in that of the mixture of peaches; and L^* values increased from 40.3 to 43.6 in the Stark Red Gold nectarine puree and from 38.8 to 42.4 in that of the mixture of peaches.

The ascorbic acid content of fresh peaches and nectarines ranged from 50 to 140 mg/kg (*2*). In all peach and nectarine batches, we found negligible amounts of ascorbic acid (lower than 50 mg/kg) with respect to the amount that was added during the pitting/pulping step of puree manufacturing (500 mg/kg). The percentages of loss during processing were calculated with respect to the amount added during the pulping/finishing step. As shown in **Table 3**, the ascorbic acid content of the purees, determined immediately after production in the pilot scale plants, decreased by 11−29% under traditional processing conditions and by 47−92% under innovative conditions. In the scale-up study, the loss of ascorbic acid during the traditional and innovative processes was 26−34 and 53−66%, respectively.

In a previous study, the genotypic variation in phenolic composition was evaluated using 20 peach and nectarine cultivars at the fully ripe stage. The concentration ranges were 38−349 mg/kg (flesh) and 112−547 mg/kg (peel) hydroxycinnamic acids (chlorogenic and neochlorogenic acids), 13−551 mg/kg (flesh) and 93−744 mg/kg (peel) flavan-3-ols (monomers, dimers, and trimers), 0−20 mg/kg (flesh) and 32−119 mg/kg (peels) quercetin glycosides (glucoside and rutinoside), and 0−23 mg/kg (flesh) and 49−312 (peel) anthocyanins (mainly cyanidin 3-*O*-glucoside) (*1*). With respect to these ranges, the fresh fruits considered in the present study showed intermediate phenolic contents, except those of the Stark Red Gold nectarine cultivar, which showed an especially high content of hydroxycinnamic acids and quercetin glycosides. Procyanidin oligomers, monomers through undecamers, previously were identified in peaches (*20*). However, the genotypic variations of the total amount and molecular weight distribution of procyanidins in these fruits are still unknown.

Initial studies carried out on the purees obtained on a pilot scale showed that the innovative process caused greater losses of all phenolic compounds in all varieties tested as compared to the traditional process (**Table 3**). Furthermore, these losses were cultivar-dependent. This result is most likely consistent with varying levels of PPO and POD among different cultivars (*21*), with cultivar-dependent distributions of phenolics between the peel and the flesh tissues (*1*) and with a reduced extraction efficiency of the innovative process. The greatest losses were observed in the purees obtained from the Stark Red Gold nectarine.

The scale-up study, carried out in industrial plants, showed that the traditional and innovative processes had, in general, similar effects on phenolic contents in both fruit batches. Although the industrially processed purees, both traditional and innovative, showed some statistically significant differences in the levels of phenolic compounds, these differences were small,

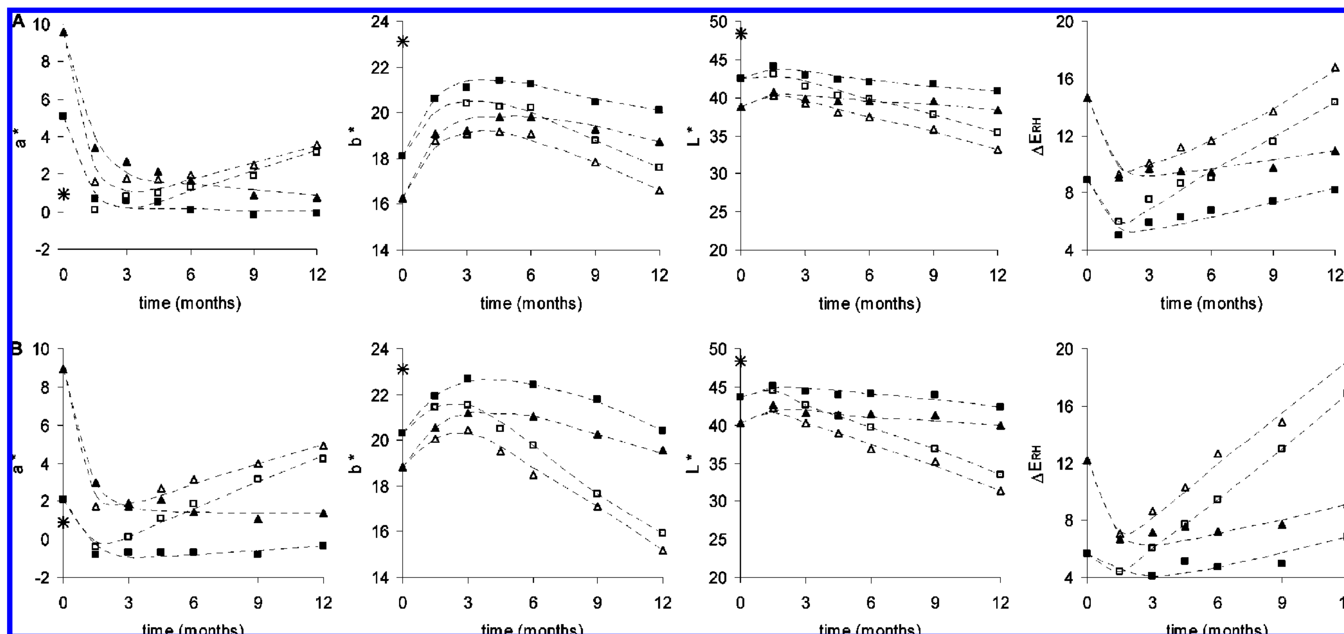

Figure 2. Time course of variations of colorimetric parameters a^*, b^*, L^*, and ΔE_{RH} in purees during storage at room temperature (■ and ▲) and at 37 °C (□ and △). Purees were processed in innovative (■ and □) and traditional (▲ and △) industrial plants. Asterisks indicate a^*, b^*, and L^* values of the puree of the Redhaven variety processed under traditional conditions and immediately analyzed. These parameters were used as a reference in the calculation of ΔE_{RH}. (**A**) Mixture of different peach varieties and (**B**) Stark Red Gold nectarine. Coefficients of variation for a^*, b^*, L^*, and ΔE_{RH} were <1%.

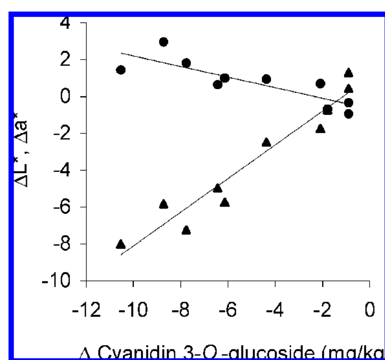

Figure 3. Variations in colorimetric parameters a^* and L^* as a function of the variation in cyanidin 3-*O*-glucoside content in peach and nectarine purees. Δa^* (▲), ΔL^* (●), and changes in cyanidin 3-*O*-glucoside content were calculated as the difference between the value after 1.5 months of storage in the dark at 37 °C and the initial value. Coefficients of variation were <1% for a^* and L^* and <5% for cyanidin 3-*O*-glucoside.

except for the cyanidin 3-*O*-glucoside content. For instance, in the purees obtained from the Stark Red Gold nectarine, from the traditional and innovative processes applied in the industrial plants, the final phenolic concentrations were 105 and 100 mg/kg chlorogenic acid, 67 and 70 mg/kg neochlorogenic acid, 37 and 36 mg/kg catechin, 203 and 182 mg/kg procyanidins (as cyanidin equiv), 24 and 18 mg/kg quercetin glycosides, and 8.2 and 4.4 mg/kg cyanidin 3-*O*-glucoside. Interestingly, the concentrations of hydroxycinnamic acids, catechin, and quercetin glycosides in the purees produced from the Stark Red Gold nectarine, from both the traditional and the innovative processes, were much higher than those found in 10 commercial purees by Bengoechea et al. (*22*) and those found in 40 commercial purees by Trifirò et al. (*23*). This consideration emphasizes the interest in processing this nectarine variety.

A previous study showed that β-carotene is the main carotenoid in peaches and nectarines, ranging from 1.86 to 3.79 mg/kg in the peels and from 0.56 to 1.68 mg/kg in the flesh of yellow fruits (*2*). The Elegant Lady variety showed the highest β-carotene content among the fruits considered. Puree manufacturing on a pilot plant scale decreased the β-carotene content in all varieties by 33−65%. As observed for phenolics, the decrease was variety-dependent and was in general higher during the innovative process than during the traditional one. In the scale-up study, it was found that β-carotene contents in the purees obtained by innovative and traditional processes were the same. For the Stark Red Gold nectarine, the final β-carotene content was 1.4 mg/kg, whereas for the mixture of peaches, it was 1.3 mg/kg. As a general rule, the extraction of puree at room temperature on a pilot plant scale resulted in a greater decrease in the content of most of the individual antioxidants of the purees than hot-extraction, whatever the variety studied. However, in the scale-up study, the innovative process proved to be effective in maintaining almost the same antioxidant level in the puree as the traditional process, except for a greater loss of ascorbic acid and cyanidin 3-*O*-glucoside.

The lower content in native antioxidants, such as phenolics and carotenoids, observed in the purees obtained with the innovative process could be due to a lower extraction rate of antioxidants from the peels to the purees at room temperature. This difference was particularly evident in purees obtained on a pilot scale, probably because the innovative pulper/screener set up on the industrial line was more efficient than the pulper/screener used in the pilot plant. The lower content in native antioxidants and higher loss in ascorbic acid, observed in the purees obtained with the innovative process, on both pilot and industrial scales, also could be compatible with greater air incorporation since pulping/finishing was carried out at a lower temperature and deaeration occurred at a later step (**Figure 1**). Furthermore, the potential involvement of ascorbic acid oxidase, PPO, and POD, which could cause greater antioxidant degradation during the innovative process due to the delayed thermal inactivation, cannot be ruled out.

The antioxidant activity of the purees depends on the initial antioxidant content of the fruit, the level of ascorbic acid

Table 4. Kinetic Parameters for Degradation of Antioxidants and Antioxidant Activity in Purees Stored at 37 °C[a]

		process applied			
		traditional		innovative	
quality index	peach/nectarine	k (months^{-1})	$t_{1/2}$ (months)	k (months^{-1})	$t_{1/2}$ (months)
cyanidin 3-*O*-glucoside	SRG n.	−1.88 ± 0.03	0.37 ± 0.01	n.d.	n.d.
	M p.	−1.60 ± 0.04	0.43 ± 0.01	n.d.	n.d.
procyanidins	SRG n.	−0.33 ± 0.07	2.1 ± 0.6	−0.39 ± 0.04	1.8 ± 0.2
	M p.	−0.38 ± 0.04	1.8 ± 0.2	−0.46 ± 0.04	1.5 ± 0.2
catechin	SRG n.	−0.13 ± 0.02	5 ± 1	−0.12 ± 0.01	6 ± 1
	M p.	−0.12 ± 0.02	6 ± 1	−0.12 ± 0.02	6 ± 1
quercetin 3-*O*- glycosides	SRG n.	−0.078 ± 0.008	9 ± 1	−0.10 ± 0.01	7 ± 1
	M p.	−0.11 ± 0.01	6 ± 1	−0.10 ± 0.02	7 ± 2
ascorbic acid	SRG n.	−0.11 ± 0.01	6 ± 1	−0.088 ± 0.004	8 ± 1
	M p.	−0.10 ± 0.01	7 ± 1	−0.083 ± 0.01	10 ± 2
neochlorogenic acid	SRG n.	−0.040 ± 0.004	17 ± 2	−0.031 ± 0.004	22 ± 3
	M p.	−0.024 ± 0.004	28 ± 6	−0.033 ± 0.004	21 ± 3
chlorogenic acid	SRG n.	−0.027 ± 0.003	26 ± 3	−0.024 ± 0.002	29 ± 3
	M p.	−0.012 ± 0.002	58 ± 12	−0.017 ± 0.002	40 ± 5
antioxidant activity	SRG n.	−0.082 ± 0.01	8 ± 1	−0.072 ± 0.01	10 ± 2
	M p.	−0.11 ± 0.01	6 ± 1	−0.11 ± 0.01	6 ± 1

[a] Mean values ± SD. Data were fitted to pseudo-first-order kinetics: $\ln(C) = \ln(C_0) + kt$. Determination coefficients were >0.96. SRG n.: Stark Red Gold nectarine and M p.: mixture of different peach varieties. n.d.: Cyanidin 3-*O*-glucoside was not detectable after 1.5 months.

Table 5. Kinetic Parameters for Color Degradation in Nectars as a Function of Length of Their Storage Phase in Glass Bottles (in the Dark at Room Temperature (t_n)) and of Length of Storage Phase of Their Corresponding Purees in the Tank (in the Dark at Room Temperature (t_p))[a]

		process applied					
		traditional			innovative		
color index	kinetic parameter	mean	95% confidence	limits	mean	95% confidence	limits
a^*	*a*	3.29	3.09	3.50	−1.28	−1.65	−0.90
	b	−2.53	−3.74	−1.32	−1.95	−2.59	−1.31
	c	0.40	0.09	0.71	0.32	0.15	0.49
	d	−1.22	−1.59	−0.85	−0.50	−0.73	−0.27
	e	0.08	0.5	0.11	0.04	0.02	0.06
L^*	*a*	36.74	36.43	37.04	39.48	39.22	39.73
	b	2.15	1.86	2.45	2.04	1.78	2.30
	c	−0.52	−0.60	−0.45	−0.59	−0.65	−0.52
	d	0.15	0.04	0.26	0.08	−0.02	0.18
	e	−0.02	−0.03	−0.01	−0.02	−0.03	−0.01
ΔE_{RH}	*a*	6.63	6.35	6.91	4.58	4.10	5.06
	b	−2.40	−2.69	−2.12	−2.28	−2.72	−1.84
	c	0.55	0.48	0.62	0.61	0.50	0.72
	d	−0.11	−0.21	0	−0.24	−0.41	−0.07
	e	0.02	0.01	0.03	0.03	0.01	0.04

[a] Data were fitted to polynomial equations, as represented in **Figure 4**: color index $= a + b^*t_p + c^*t_p^2 + d^*t_n + e^*t_n^2$.

addition (which is relevant, as shown in **Table 3**), and antioxidant loss during processing. The antioxidant activity of fresh fruits and that of purees that were selected for the storage study are reported in **Table 3**. These values were lower in the purees obtained by applying the innovative process with respect to the traditional process. This result is consistent with the higher ascorbic acid degradation caused by the innovative process with respect to the traditional one as the difference in phenolics and carotenoids is marginal.

Effect of Storage on Quality of Purees Obtained from Traditional and Innovative Industrial Plants. During storage at 37 °C, the colorimetric parameters changed by following similar trends in all purees. A positive variation of color occurred in the first 1.5 months of storage at 37 °C: the redness index a^* decreased, whereas the yellowness index b^* and the lightness index L^* increased (**Figure 2**). During this period, the anthocyanin content decreased to zero, and the changes in a^* and L^* values were related to anthocyanin degradation with correlation coefficients of 0.96 and 0.84, respectively (**Figure 3**). At the end of this initial period, the a^* values of the purees obtained by the innovative process were −0.39 (Stark Red Gold nectarine) and 0.13 (peach mixture), whereas the corresponding a^* values of the purees obtained by the traditional process were 1.74 and 1.58. Therefore, according to this color parameter, the purees obtained by the innovative process were still better than the corresponding purees obtained by the traditional process.

After 1.5 months of storage at 37 °C, and until 12 months, a negative variation of color occurred: a^* increased markedly, whereas b^* and L^* decreased. It is likely that nonenzymatic browning accounted for color degradation and for the underlying difference in color between the puree produced with traditional and innovative technology. Accordingly, similar variation trends of a^*, b^*, and L^* were observed in peach puree during treatment at temperatures in excess of 80 °C (*24, 25*). The color of the purees obtained by the innovative process was better than that of the purees obtained by the traditional process up until 12 months of storage. At room temperature, the same phenomenon occurred at a slower rate.

The color of the purees produced from the Stark Red Gold nectarine and from the mixture of peaches also was evaluated against the puree of the Redhaven peach variety, which was considered optimal. This comparison was made by calculating $\Delta E_{RH,}$ which takes into account the differences in a^*, b^*, and L^*. As shown in **Figure 2**, the ΔE_{RH} values of the purees obtained by applying the innovative process were lower than those of purees obtained by the traditional process. Antioxidant degradation occurred during storage at 37 °C with a similar pattern in all purees. Ascorbic acid and phenolics decreased following pseudo-first-order kinetics, whereas β-carotene was stable (**Table 4**).

Cyanidin 3-*O*-glucoside was the least stable compound; its pseudo-first-order rate constant was in the range of 1.6−1.9 months^{-1}. After 3 months of storage, this compound was not detectable in any of the purees. Accordingly, it previously was reported that black carrot anthocyanins, added to peach nectar as a colorant, degrade following pseudo-first-order kinetics, with a rate constant of 1.5 months^{-1} at 37 °C (*26*).

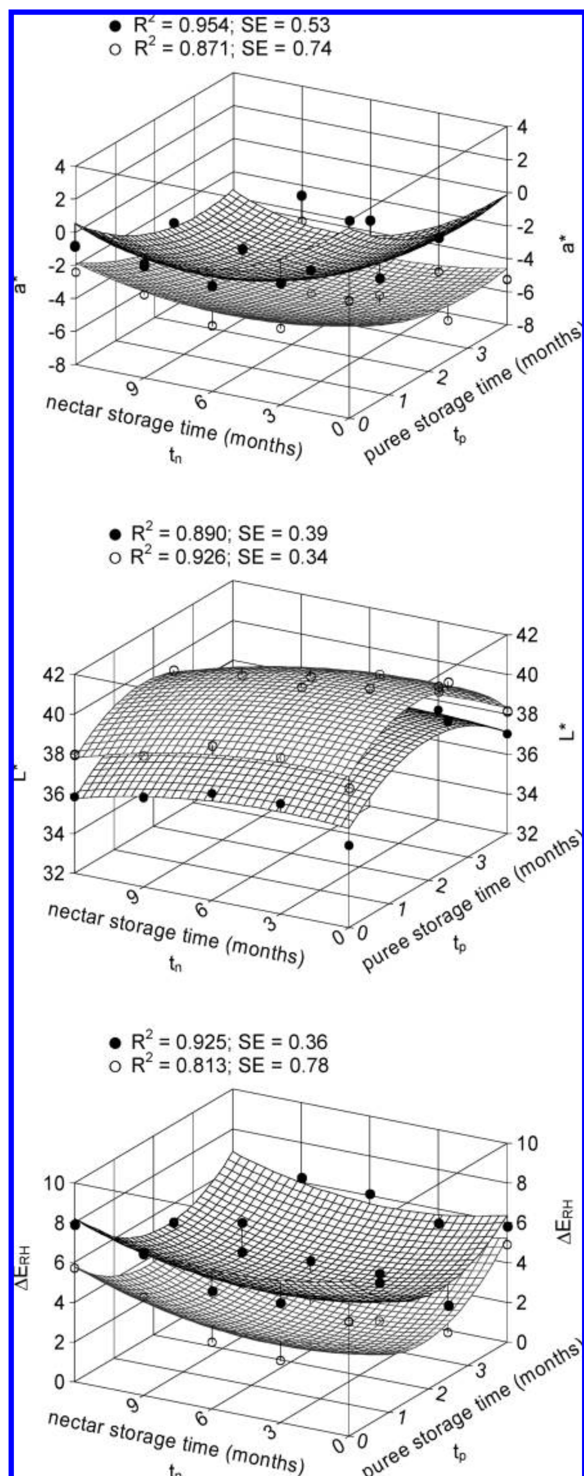

Figure 4. Colorimetric parameters a^*, L^*, and ΔE_{RH} of nectars as a function of the length of their storage phase in glass bottles, in the dark at room temperature (t_n), and of the length of the storage phase of their corresponding purees in the tank, in the dark at room temperature (t_p). Nectars were produced from purees obtained by applying the traditional process (●) or the innovative process (○). Data were fitted to polynomial equations: color index $= a + b^* t_p + c^* t_p^2 + d^* t_n + e^* t_n^2$. Coefficients of determination and standard errors are indicated at the top of each box. The b^* values of nectars were not different (not shown).

The pseudo-first-order rate constants of procyanidin and catechin degradation were in the range of 0.33−0.46 and 0.12−0.13 months^{-1}, respectively. Quercetin glycosides and ascorbic acid had similar degradation rates: the pseudo-first-order rate constants were in the range of 0.78−0.11 months^{-1}. Hydroxycinnamic acids were the most stable compounds: their pseudo-first-order constants were in the range of 0.024−0.040 months^{-1} (neochlorogenic acid) and 0.017− 0.027 months^{-1} (chlorogenic acid).

In accordance with antioxidant degradation, it was found that the antioxidant activity of the purees, as evaluated by DPPH radical scavenging activity, decreased during storage by following pseudo-first-order kinetics with rate constants in the range of 0.072−0.11 months^{-1}. These results showed that the rate constants for antioxidant degradation were similar between the purees, whatever the process applied.

Effect of Innovative and Traditional Processes Applied in Industrial Plants on Quality of Nectars. Among different technologies for peach and nectarine processing, nectar production is prevalent. Therefore, the purees produced industrially by traditional and innovative technology were processed into nectars, and the effect of the innovative process on nectar color was investigated. During nectar production, ascorbic acid is added to reach a final concentration of ∼300 mg/kg. The β-carotene and phenolic contents of the nectars were not affected by nectar manufacturing in any of the batches (data not shown).

The color of nectars obtained from purees obtained by innovative and traditional processes was studied as a function of storage length (in glass bottles, at room temperature in the dark) and of the storage of their corresponding purees (in a tank at room temperature, in the dark). The relationships among these variables were described by polynomial equations (**Figure 4** and **Table 5**). The 3-D plots of the fitted equations confirmed that the innovative process improved the color of the nectars with respect to the traditional process. The greatest advantages were found at the beginning of storage and slowly decreased with increasing storage times of the puree or that of the nectar.

In conclusion, in comparison to the traditional process, the new process, scaled up to an industrial level, improved the color of peach and nectarine products, whatever the variety studied; maintained almost the same levels of carotenoids, hydroxycinnamates, flavan-3-ols, and flavonols; and reduced the level of cyanidin 3-*O*-glucoside. The presence of cyanidin 3-*O*-glucoside was correlated to an unstable and undesirable red hue of the products (even if its concentration was very low in all products), and the decreased level obtained by the innovative process is considered to be positive. The greater loss in ascorbic acid, which occurred during the innovative process, might be counteracted by either a higher addition during the pitting/pulping stage or nectar manufacturing or by a more effective deaeration step.

This innovative process could be applied to peach and nectarine varieties that are not suitable for puree production using the traditional technology. With respect to the traditional process, it opens up two possibilities: (a) utilization of the fresh market fruit surplus and (b) processing of selected fruit varieties that are rich in antioxidants but have a high browning potential, such as the Stark Red Gold nectarine, thus enhancing the nutritional quality of purees. Furthermore, as the positive impact on the innovative technology is optimal at the beginning of storage, this technology is particularly suitable for fruit-based products with a short shelf life, such as refrigerated fruit nectars and spoonable fruit purees.

ACKNOWLEDGMENT

We thank Rita Mezzini and Ludovico Martignoni for their collaboration in the experimental work.

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Received for review March 18, 2008. Revised manuscript received May 27, 2008. Accepted June 4, 2008.

JF8008469