Antioxidant Changes and Sensory Properties of Carrot Puree Processed with and without Periderm Tissue

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Carrot purees were thermally processed with and without the periderm tissue after a long and short blanch time, with and without vacuum deaeration treatments. Samples were stored at an elevated temperature (40 °C for 4 weeks) to determine physicochemical changes affecting antioxidant activity (AOX), as measured by the coupled oxidation of β-carotene and linoleic acid assay, and overall quality characteristics. Differences in AOX between treatments before thermal processing and during storage were associated with increased levels of phenolic acids and the subsequent development of numerous compounds thought to be oxidation products of phenolic acids. Samples processed with periderm tissue contained higher levels of phenolic acids, total carotenoids, and sugars than samples processed without periderm tissue. Strained carrot color was adversely affected by a long blanch time compared to a short blanch in treatments with and without periderm tissue, indicating improved color with reduced preprocessing heating. Sensory analyses by a quantitative descriptive analysis panel indicated increased musty/moldy and terpene flavors in samples processed with periderm tissue that were seemingly related to elevated levels of phenolic acids and volatile terpenoids. Terpenoid levels were reduced with deaeration steps prior to thermal processing. Processing carrots without removal of periderm tissue has proven to be a viable option when short blanch times and deaeration steps are employed.

Keywords: *Carrot puree; antioxidant activity; phenolic acids; terpenoids*

INTRODUCTION

By eliminating peeling steps prior to maceration, the processing efficiency and overall yield of strained fruits and vegetables may be increased. However, utilizing periderm tissue may result in incorporation of chemical components that present potential quality and flavor problems. Numerous phenolic compounds are located in the periderm of fruits and vegetables, many of which are removed by peeling steps prior to processing (Mercier et al., 1994). Acting as free-radical terminators, phenolic acids have been shown to be potent antioxidants in numerous systems (Donovan et al., 1998; Lee et al., 1995; Aruoma et al., 1993; Gil et al., 1999). Simple phenols have a pK_a of approximately 10 (Larson, 1995), an indication that at physiological pH these compounds are not ionized, relating to excellent antioxidant activity (AOX) potential. The relative AOX can generally be deduced from the number of hydroxy groups present (Rice-Evans et al., 1996). However, little information is available concerning the oxidation of phenolic compounds in vivo and the resultant AOX changes due to processing and storage.

Relating oxidation reactions of phenolic acids to carrot flavor attributes and AOX has not been reported in the literature. Phenolic oxidation is highly dependent on oxygen levels and the pH of the system, and oxidation rates have been related to the concentration of the phenolate ions present (Cilliers and Singleton, 1989, 1991). Bucheli and Robinson (1994) demonstrated the dependence of phenolic oxidation on oxygen and pH in sugarcane juice. Detailed tracing of phenolic oxidation has been investigated in numerous model systems. Generally, cinnamic acid derivatives, common to most fruits and vegetables, will oxidize and polymerize into compounds with decreased polarity (Oszmianski and Lee, 1990) as demonstrated by a loss of low molecular weight phenolics during processing and storage of strained carrots (Talcott and Howard, 1999). Characterization of these oxidation compounds in caffeic acid model systems has indicated reactions involving polymerization (dimers and trimers), partial and complete loss of side chain functionality, or benzene ring opening (Cilliers and Singleton, 1991; Cheynier and Moutounet, 1992).

The purpose of this investigation was to determine the feasibility of processing carrot puree with periderm tissue as influenced by preprocessing conditions and storage at an elevated temperature. By determining the physicochemical and sensory changes that occur after thermal processing and prolonged storage, the influence of periderm tissue and processing parameters on antioxidant compounds was evaluated.

MATERIALS AND METHODS

Materials and Processing. Carrots (*Daucus carota* L.) cv. Royal Cross were obtained from Gerber Products Co. (Ft. Smith, AR) and stored at 4 °C until processed. Roots were randomly divided into two homogeneous groups of which half were individually washed with a hand-held scrub brush to completely remove visible soil and external debris, without removal of periderm tissue (peel on), while the remaining roots were manually peeled (peel off), to remove approximately 2

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mm of periderm tissue. Carrots were then sliced into 1-cm pieces (Robot Coupe, Gateshead, Tyne and Wear, U.K.) and steam blanched for either 2 (short blanch) or 20 (long blanch) min in a stainless steel pan. Samples were then blended into a puree with 50% added water (carrot blanch weight) and passed through a 0.84 mm finishing screen. The four purees were individually mixed into homogeneous pools, and half of each treatment was vacuum deaerated for 40 min (635 mmHg) while the remaining half received no deaeration treatment. All treatments (eight total) were filled into 211 × 300 metal cans for thermal processing. The deaerated treatments included flushing the can headspace with nitrogen prior to closure. Carrots were retorted at 250 °C for 75 min in a vertical still retort. Samples were stored at 40 °C and analyzed at 0, 1, 2, and 4 weeks of storage for physicochemical attributes and at 0, 2, and 4 weeks for sensory evaluation. A nonretorted sample from each treatment was analyzed to compare physicochemical changes that occurred during processing.

Physicochemical Analysis. Phenolic acids were extracted by blending 50 g of carrot puree with 100 mL of methanol acidified with HCl (1000:1) for 1 min. The homogenate was filtered through Miracloth (Calbiochem, San Diego, CA) and washed four times with 25 mL of methanol. The extract was concentrated using a rotary evaporator at 45 °C, and the final volume was adjusted to 25 mL with water. A 3-mL portion was then centrifuged at 2500*g* for 5 min at 18 °C, filtered, and analyzed by HPLC for individual phenolic acids. Separation was conducted on a 100 × 4.6 mm Alltech Spherisorb ODS C_{18} column (Alltech Associates, Inc., Deerfield, IL) connected in series to a 150 × 3.9 mm Waters Nova-Pak C_{18} column (Waters Corporation, Milford, MA), and peaks were monitored using a Waters 996 photodiode array detector at 280 nm. A gradient mobile phase was run consisting of 98% water and 2% acetic acid in phase A and 68% water, 30% acetonitrile, and 2% acetic acid in phase B (Ramamurthy et al., 1992). The gradient of phase B ran 0−30% in 20 min, 30−50% in 10 min, 50−70% in 20 min, and 70−100% in 5 min at 0.8 mL/min. Phase B ran for an additional 15 min to elute remaining nonpolar compounds, and the column was equilibrated with 100% phase A prior to the next sample injection. Spectral characteristics of phenolic acids, including 5-hydroxymethyl-2-furaldehyde (HMF), were compared to that of external standards (Sigma Chemical Co., St. Louis, MO) for identification and quantification.

Color, pH, sugars, total carotenoids, and total soluble phenolics (Folin−Ciocalteu assay) were analyzed according to Howard et al. (1996). Total solids were measured by drying carrots in a forced air oven (2 h at 135 °C), and all chemical data, except volatiles, were expressed on a dry weight (DW) basis. Antioxidant activity was determined on 50 μL of an aqueous carrot extract (5 g/30 mL) filtered through a 0.45 μm filter using the coupled oxidation of β-carotene and linoleic acid as described by Lee et al. (1995) with 8.8 mM hydrogen peroxide used as the oxidant source. The method estimates the relative ability of the antioxidant compounds in the plant extract to scavenge the radical of linoleic acid peroxide (LOO*) that oxidizes β-carotene in the emulsion phase.

Dynamic headspace constituents were collected using a 100-μm PDMS solid-phase microextraction fiber (SPME, Supelco Inc., Bellefonte, PA) at weeks 0 and 4. Carrot puree was filtered through Miracoth, and a 1-mL aliquot of liquid was mixed with 200 mg of NaCl in a 2-mL sampling vial and absorbed onto the SPME for 45 min at 25 °C using a Varian 8200 autosampler (Varian Associates Inc., Walnut Creek, CA). Compounds were thermally desorbed at 250 °C for 3 min into a 1078 injection port of a Varian 3400 GC equipped with a Saturn 2000 ion trap mass spectrometer. Detection was from 50 to 450 *m*/*z* in the electron ionization mode, and fragmentation patterns were compared to known standards when available. Spectral libraries (NIST 1998, Gaithersburg, MD) tentatively identified remaining compounds. Separation conditions included a helium flow rate of 60 mL/min, while transfer line, ion trap, and manifold temperatures were 250, 200, and 60 °C, respectively. An internal standard (166 ppb) of cuminaldehyde was dissolved in ethanol, diluted with water, and added to each vial for quantification. Various concentrations of cuminaldehyde spiked into filtered carrot puree confirmed extraction, adsorption, and a linear detector response from the sample. Separation was conducted using a 30 m × 0.25 mm i.d., 0.25 μm Varian DB-5 capillary column (Varian Associates, Walnut Creek, CA). Initial column temperature was held at 60 °C during a 6-min splitless injection and ramped to 250 °C at 6 °C/min holding for 5 min.

Sensory Analysis. Six professionally trained panelists (Sensory Spectrum, Chatham, NJ), employed by the Institute of Food Science and Engineering at the University of Arkansas, performed quantitative descriptive analysis on deaerated samples at times 0, 2, and 4 weeks of storage. All samples were evaluated under red light in a sensory testing laboratory consisting of individual testing booths and positive air pressure. Attributes tested included the following: sweet, sour, bitter, cooked, uncooked, rooty/dirty/earthy, musty/moldy, terpene, burnt/caramel, metallic, astringent, and numbing. Intensities of each attribute were quantified to one significant digit on a 0−15 Spectrum intensity scale. Each treatment at each time was evaluated in duplicate by each of the panelists.

Statistical Analysis. Chemical data represent the mean of 3 subsamples (individual cans) taken from each treatment, at each sampling time. The experiment was analyzed as a factorial (2 × 2 × 2) with the factors peeling (peel on or peel off), blanching (long or short), and deaeration (deaerated or nondeaerated) tested over time. Sensory data represent the mean of two subsamples evaluated by each of the panelists. Multiple linear regression, analysis of variance, and Pearson correlations were conducted using JMP software (SAS Institute, 1996) and mean separation using LSD test ($P < 0.05$).

RESULTS AND DISCUSSION

Chemical Analysis. *Phenolic Acids and Antioxidant Activity.* Significant differences ($P < 0.05$) in chemical characteristics were determined between samples processed with the periderm tissue intact and blanch time, but no changes were observed from deaeration treatments for nonvolatile chemical attributes. For this reason, deaerated treatments were combined with nondeaerated treatments for statistical analysis of nonvolatile chemical attributes. The overall chemical reducing capacity of the carrot puree was estimated using the Folin−Ciocalteu assay for total soluble phenolics, which was 45.6 mg/kg higher for samples with periderm than without periderm. Samples with periderm had an average of 8.19% more AOX than samples without periderm. Overall, the short blanch generally resulted in decreased detection of chemical components, due to reduced tissue softening during blanching, that was also apparent after thermal processing and during sample extraction. However, no significant effect on AOX was observed due to blanch time during the 4-week storage period. Total soluble phenolics and the sum of individually quantified phenolic compounds both correlated well to AOX (Tables 1 and 2). For all treatments, total soluble phenolics increased immediately after thermal processing by 70% and then linearly declined during storage as a result of oxidative reactions (Talcott and Howard, 1999).

An increase in AOX (Figure 1) due to thermal processing occurred in all samples by an average of 34.3% and continued to increase through the first week of storage. A linear decline in AOX was then observed throughout the remainder of the study. A similar trend was observed for total soluble phenolics and the occurrence of numerous oxidation products from phenolic acids. Total carotenoids were only slightly higher in samples with the periderm intact, while the longer blanch time resulted in only 8 mg/kg (7.2%) more than

Table 1. Relationships between Physicochemical Measurements and AOX of Strained Carrot Puree before Retorting and during 4 Weeks Storage at 40 °C ($P < 0.05$)

physicochemical attribute	AOX Pearson correlation
total soluble phenolics[a]	0.78
glucose	0.74
lightness	−0.84
chroma	−0.86
pH	−0.83
HMF	0.57
compound **1**	0.78
compound **2**	0.56
compound **4**	0.70
compound **6**	0.67
compound **7**	0.75
compound **8**	0.73
total HPLC phenolics[b]	0.71

[a] Folin−Ciocaluteu assay. [b] Sum of individually quantified phenolic compounds.

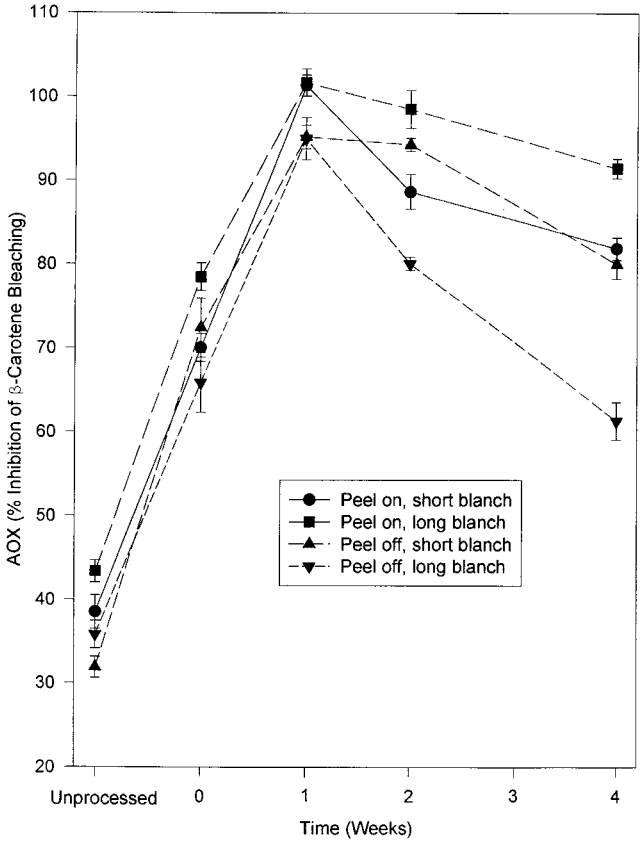

Figure 1. Changes in antioxidant activities (AOX) of carrot puree processed with and without removal of periderm tissue and after a long or short blanch time. Samples were stored at 40 °C for 4 weeks. Bars represent standard error of the mean ($n = 3$).

the short blanch. No significant relationship to AOX was found with total carotenoids, which was likely the result of using an aqueous extract for the AOX assay.

The predominate phenolic acids in carrots have been previously identified (Sarker and Phan, 1979; Babic et al., 1993; Parr et al., 1997). For the carrots utilized in this study, the primary phenolics consisted of chlorogenic acid, caffeic acid, *p*-OH-benzoic acid, ferulic acid, and other unidentified cinnamic acid isomers (Figure 2; Table 2). Tryptophan was present in nonretorted purees but was significantly reduced after thermal processing. As a result of thermal processing and

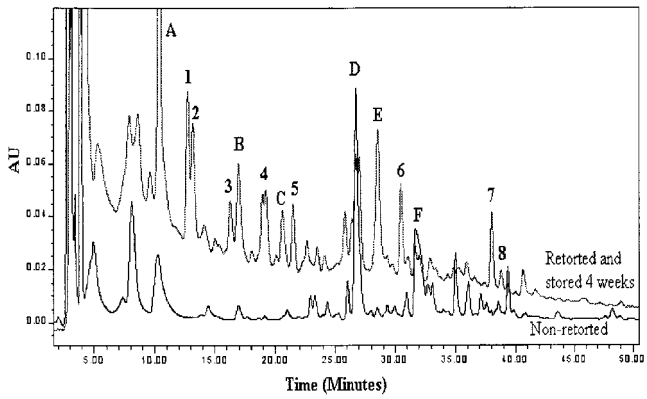

Figure 2. Typical phenolic acid profile of carrot puree with the periderm intact before thermal processing and after 4-weeks storage at 40 °C. Peak identification: A = HMF; B = chlorogenic acid isomer; C = *p*-OH-benzoic acid; D = chlorogenic acid; E = caffeic acid; F = tryptophan; compounds **1**−**5** = hydroxybenzoic acids; compounds **6**−**8** = caffeic acid oxidation products.

storage at elevated temperatures, HMF was also detected in the HPLC phenolic acid assay as found by Pompei et al. (1986). Fructose is the major reactant in the formation of HMF, reacting 31.2 times faster than glucose (Lee and Nagy, 1988). On average, HMF levels were higher in carrot samples processed and stored with the periderm intact (+42 mg/kg) and after a long blanch (+20 mg/kg). A small relationship to AOX was observed and was likely an indication of storage temperature duration and subsequent degradation reactions of HMF. Ferulic acid was present at higher levels in samples with periderm intact, but was unaffected by blanch time.

Chlorogenic acid, the predominate phenolic acid in carrots, demonstrated a linear decline throughout storage with subsequent evolution of caffeic acid observed as a degradation product. Levels of individually quantified phenolic acids were higher in samples with periderm tissue intact and samples processed after a long blanch. Chlorogenic acid was 77 mg/kg higher in periderm intact samples, and the long blanch time resulted in 35 mg/kg more chlorogenic acid than the short blanch. However, the evolution of caffeic acid did not follow a linear increase corresponding to the loss of chlorogenic acid. The occurrence of a chlorogenic acid isomer, more polar than chlorogenic acid and tentatively identified as neochlorogenic acid (Fernández de Simón et al., 1992), that increased during storage from 10 to 40 mg/kg (chlorogenic acid equivalents) may account for part of this observation. However, caffeic acid significantly increased after thermal processing and remained relatively constant through the first 2 weeks of storage, indicating possible oxidation reactions upon its formation from chlorogenic acid. By the end of 4 weeks of storage, 12.8 mg/kg more caffeic acid evolved during storage in samples with periderm tissue intact. No appreciable correlation to AOX was observed for either chlorogenic or caffeic acid alone. The polar phenolic *p*-OH-benzoic acid (4-hydroxybenzoic acid) was not detected in nonretorted samples or samples with the periderm removed. This would indicate a physiological relationship for its presence in periderm tissue. After thermal processing, 11.7 mg/kg was detected in periderm intact samples, and levels increased in a linear manner during storage, doubling by the end of the study. No correlation to AOX was observed, presumably

Table 2. Predominant Phenolic Acids (mg/kg DW) Detected in Carrot Puree As Influenced by Processing Treatments[a]

	peel on		peel off		short blanch		long blanch	
	nonretorted	av[b]	nonretorted	av	nonretorted	av	nonretorted	av
total soluble phenolics[c]	517 b[d]	705 a	471 b	659 a	429 b	677 a	561 b	687 a
HMF	nd[e] b	162 a	nd b	170 a	nd b	158 a	nd b	174 a
neochlorogenic acid	14.3 b	48.5 a	3.43 b	6.51 a	3.38 b	17.5 a	14.3 b	37.4 a
p-OH-benzoic acid	nd b	15.7 a	nd a	nd a	nd b	8.04 a	nd b	7.71 a
chlorogenic acid	104 a	92.9 a	28.3 a	15.2 b	47.3 a	37.2 a	84.8 a	70.9 b
caffeic acid	3.95 b	19.2 a	1.33 b	6.52 a	1.61 b	11.9 a	3.67 b	13.9 a
ferulic	2.04 b	5.25 a	2.05 a	2.12 a	1.49 b	3.61 a	2.60 b	3.76 a
compound **1**	nd b	39.7 a	nd b	40.1 a	nd b	37.1 a	nd b	42.7 a
compound **2**	nd b	23.4 a	nd b	26.5 a	nd b	22.3 a	nd b	27.5 a
compound **3**	nd b	12.7 a	nd b	9.33 a	nd b	11.1 a	nd b	11.1 a
compound **4**	nd b	38.3 a	nd b	40.5 a	nd b	35.6 a	nd b	43.3 a
compound **5**	nd b	12.2 a	nd b	9.03 a	nd b	10.8 a	nd b	10.4 a
compound **6**	nd b	36.8 a	nd b	35.1 a	nd b	34.8 a	nd b	37.2 a
compound **7**	nd b	20.1 a	nd b	17.1 a	nd b	21.6 a	nd b	15.6 a
compound **8**	nd b	4.43 a	nd b	3.11 a	nd b	4.15 a	nd b	3.40 a

[a] Values represent each treatment nonretorted and the average concentration after 4 weeks storage at 40 °C [b] Average concentration over 4-week storage time. [c] Folin−Ciocaluteu assay. [d] Values between columns with similar letters are not significantly different (LSD test, $P < 0.05$). [e] None detected.

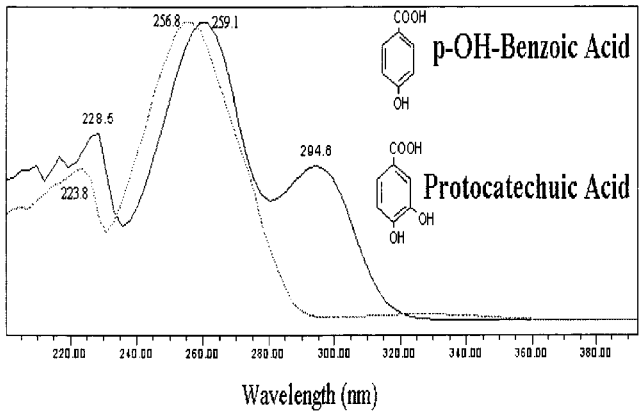

Figure 3. UV spectrum and peak maxima of *p*-OH-benzoic (dashed line) and protocatechuic acid (solid line).

since *p*-OH-benzoic acid has no hydrogen-donating ability to stop free-radical generation (Rice-Evans, 1996). A relationship between the evolution of hydroxy benzoic acid analogues and a subsequent decline in hydroxycinnamic acids in shredded carrots was observed by Babic et al. (1993). However, this reaction mechanism is likely enzymatically driven and would not occur in thermally processed products.

Phenolic Oxidation Products. Numerous additional compounds were identified in the phenolic acid extracts that resulted from processing and prolonged storage at elevated temperatures. These peaks were not positively identified but appeared to be degradation products due to oxidative reactions ("oxidation peaks"), and many correlated well with AOX. None of these compounds were present in nonretorted carrot purees. Most of the compounds demonstrated a positive correlation to AOX, and, hence, the total reducing capacity of the carrot purees (Table 1). Spectral characteristics of these oxidation compounds were either similar to those of hydroxyl-substituted benzoic acid derivatives (compounds **1**−**5**, Figure 3) quantified as *p*-OH-benzoic acid or to cinnamic acid degradation peaks (compounds **6**−**8**) quantified as chlorogenic acid.

Spectral properties (or absorbance bands) for *p*-OH-benzoic acid demonstrated absorbance maximums at 223.8 and 256.8 nm, while protocatechuic acid (3,4-dihydroxybenzoic acid) absorbed at 228.5, 259.1, and 294.6 nm as identified by spectral analysis and reported by Bartolemé et al. (1993). The presence of spectral bands from 220 to 230 nm were generally indicative of a benzene ring, common to all compounds identified in this study, while bands from 240 to 300 nm were generally indicative of hydroxy ring substitutions. Spectral bands >300 nm were good indications of side-chain hydrocarbons.

The polar oxidation peaks labeled **1**, **3**, **4,** and **5** had a maximum absorbance at 294.6 nm, indicating a possible *o*- or *m*-hydroxy substitution on a benzene ring based on the spectral characteristics of hydroxy-substituted benzoic acid standards. A meta substitution would likely increase the AOX of the carrot puree as this structural arrangement has hydrogen-donating ability (Rice-Evans, 1996). Compounds **1** and **4** showed good correlation to AOX during storage, increasing through the first week (43 and 47 mg/kg, respectively) and then decreasing with time. Compound **3** was at its maximum concentration immediately after processing (19 mg/kg) but then declined with storage. Though showing only a minor correlation to AOX ($r = 0.39$), it likely contributed to the initial reducing capacity of the purees. Spectral characteristics of compound **2**, which increased from 0 to 35 mg/kg after processing and during storage, exhibited a maximum absorbance at 252.1 nm, which is not indicative of a hydroxy substitution and may indicate the presence of a quinone. The presence of ester-linked hydroxybenzoic acids in carrot cell wall isolates has been well documented (Parr et al., 1997; Ng et al., 1998). The evolution of highly polar phenolic acids in this study may be the result of oxidation and hydrolysis of cell wall phenolics, which was accentuated by thermal processing and storage at elevated temperatures.

Chlorogenic Acid Oxidation. Several compounds were detected in nonretorted carrot puree with the periderm intact with the spectral characteristics of hydroxycinnamic acids, namely chlorogenic and caffeic acid ($\lambda_m = 327.8$ and 323.1 nm, respectively). The close spectral characteristics of these two compounds made quantification difficult, but since caffeic acid was not present in nonretorted samples, the peaks were likely chlorogenic acid analogues. These compounds were not detected in peeled carrots, and all had retention times longer than chlorogenic acid ($t_R = 35.0$, 36.0, and 39.5 min), indicating less polar molecules. Since these compounds were only present in samples with the periderm

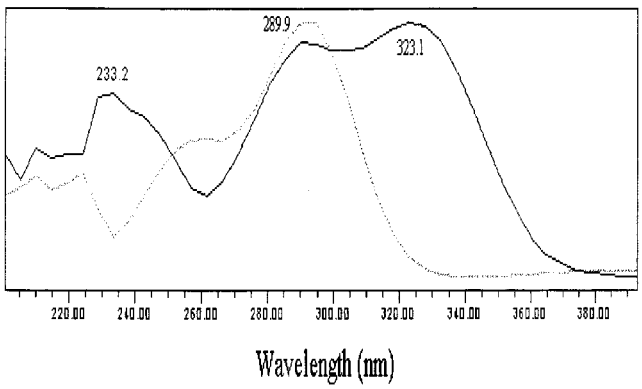

Figure 4. UV spectrum and peak maxima for oxidation compounds **6**−**8** (dashed line) compared to caffeic acid (solid line).

intact, which were higher in chlorogenic acid, their presence was likely from residual phenol oxidase activity or surface oxidation prior to thermal processing. These compounds were similar to the enzymatic oxidation products of chlorogenic acid reported by Oszmianski and Lee (1990). Upon thermal processing, these compounds were no longer detectable, and although their concentration was relatively low (<10 mg/kg), they may play an important role in the formation of colored pigments detrimental to product quality.

Caffeic Acid Oxidation. After thermal processing, three additional phenolic degradation compounds were formed that increased during storage (peaks 6−8). These compounds all had a maximum absorbance at 289.9 nm and were likely the result of caffeic acid oxidation as it was evolved from chlorogenic acid (Figure 4). Although it was difficult to determine the degree of oxidation and identity of the parent phenolic in vivo, their spectral characteristics were consistent with losses of caffeic acid side-chain (ethylene) conjugation (Cheynier and Moutounet, 1992). Characteristic loss of side-chain conjugation upon oxidation of caffeic acid will result in decreased absorbance (323.1 nm) of the alkene at C1 and therefore alter the absorbance ratio with the 289.9 nm (hydroxy shoulder) peak maxima (Cilliers and Singleton, 1991). The evolution of these compounds demonstrated good correlation to AOX, increasing after processing and decreasing during storage upon further oxidation (Table 1). Therefore, the nonlinear trend in the evolution of caffeic acid from chlorogenic acid may be reflected by changes in these compounds.

As indicated in earlier work (Talcott and Howard, 1999), the oxidation rate of phenolic acids in strained carrot puree was not affected by phenolic concentration, but rates were dependent on pH and oxygen concentration. Likewise, samples processed with the periderm had higher total and individual phenolic acids than peeled samples but with similar puree pH. On average, the evolution of oxidation compounds in the carrot puree was similar between treatments with the periderm on or off. This would indicate that the rate of oxidation was slow enough not to exceed the concentration of phenolics or oxygen present in either sample.

Quality Attributes. *Processing Yield.* Processing carrots with and without removal of periderm tissue and for short and long blanch times changed the physicochemical attributes impacting quality of strained carrots. The advantage of processing carrots with the periderm intact, following thorough cleaning of the roots, was an 8% increase in processing yield by weight.

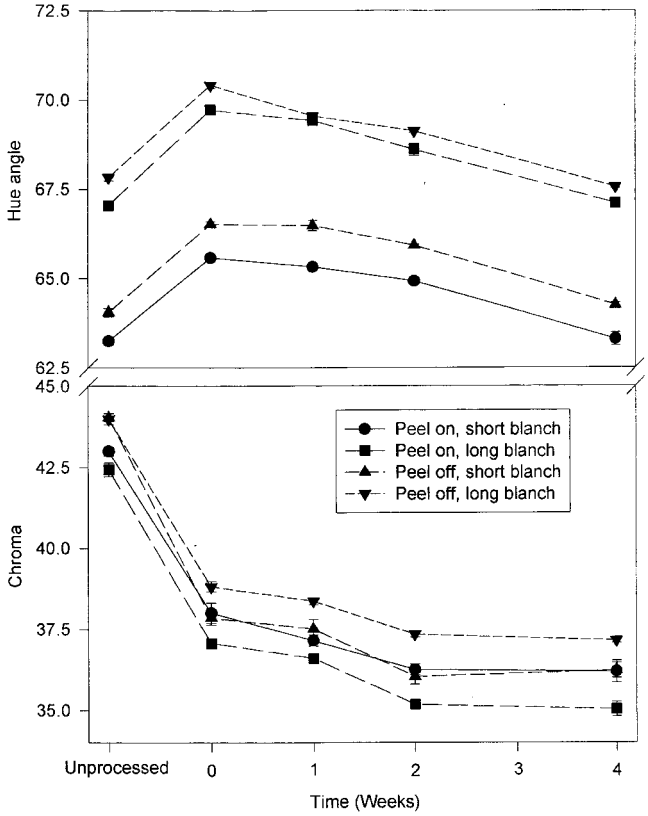

Figure 5. Changes in hue angle and chroma intensity of carrot puree processed with and without removal of periderm tissue and after a long or short blanch time. Samples were stored at 40 °C for 4 weeks. Bars represent standard error of the mean ($n = 3$).

With an increase in pectic substances present in the periderm and the formation of weak gels, the processing yield based on puree viscosity may be even higher.

Color. Differences in puree color attributes were more affected by blanch time than by peel removal prior to thermal processing. Lightness and chroma values were highly correlated ($r = 0.94$) and will generally decrease in response to product darkening due to phenolic oxidation, while hue angles initially increase toward yellow before slowly declining with storage (Talcott and Howard, 1999). Lightness values significantly decreased after thermal processing and during storage. On average, lightness was 0.48 units lower due to leaving the periderm intact but was 0.90 units higher when the short blanch was utilized. This indicated that reduced heating steps in preprocessing operations were beneficial to strained carrot color, and the oxidation of chlorogenic acid present in the periderm may have contributed to reduced lightness. Hue angles markedly increased immediately after thermal processing and declined steadily during storage (Figure 5). Samples with elevated hue angles were indicative of the puree becoming more yellow due to intermediate and final products of phenolic acid condensation/polymerization. Declining hue angles during storage were indicative of brown pigment formation, and processing with the periderm intact resulted in a decrease of 0.74° compared to peeled samples. However, more important to color was the long blanch prior to thermal processing, which resulted in a 3.68° increase compared to the short blanch. This relationship indicated that prethermal processing criteria are important for strained carrot color as reported by Howard et al. (1996). Chroma

Table 3. Tentative Identification of Predominate Terpenoids (μg/kg DW) Detected in Carrot Puree Headspace As Influenced by Processing Treatments[a]

	peel		blanch		deaerated	
volatile compound	on	off	short	long	yes	no
α-pinene	31.61a[b]	27.75b	31.12 a	28.24 b	27.54 b	31.82 a
α-citronellol	12.37 a	9.72 a	11.71 a	10.38 a	9.51 b	12.58 a
o-cymene	27.66 a	25.04 b	26.09 a	26.61 a	25.15 b	27.55 a
3-carene	37.69 a	33.70 b	36.09 a	35.30 a	33.17 b	38.22 a
β-phorone	52.24 b	55.40 a	52.64 a	54.99 a	50.31 b	57.32 a
α-terpinene	130.0 a	55.58 b	99.03 a	86.55 b	88.77 a	96.81 a
dehydro-*p*-cymene	9.70 a	6.58 a	8.69 a	7.59 a	8.73 a	7.55 a
4-terpineol	50.72 a	54.10 a	53.08 a	51.75 a	47.65 b	57.17 a
camphene	17.27 a	13.83 b	15.19 a	15.91 a	14.35 b	16.75 a
caryophyllene	376.9 a	334.0 a	311.2 b	399.7 a	296.1 b	414.8 a
α-himachalene	9.55 a	10.04 a	8.04 b	11.56 a	9.15 a	10.45 a
total volatiles[c]	755.71	625.74	652.88	728.58	610.43	771.02

[a] Values represent mean concentrations at day 0 and day 28 of carrot puree stored at 40 °C. [b] Values between columns with similar letters not significantly different (LSD test, $P < 0.05$). [c] Sum of individually quantified volatile compounds.

values (color intensity) were lower (1.04) on average for periderm intact treatments, but no differences were observed between blanch times (Figure 5). Changes in chroma were most severe after thermal processing and continued to decline during storage. As a result, an inverse relationship to AOX was observed for lightness and chroma values. Peeled samples with a long blanch resulted in better chroma intensity than samples blanched for a short duration. Color intensities may be related to carotenoid concentration, which was not significantly different between blanch treatments.

pH. As previously reported (Talcott and Howard, 1999) the pH of carrot puree will immediately decline after thermal processing and continue to decline during storage at elevated temperatures. A similar trend was observed in this study where the pH was lowered by 1.14 units (initial pH 6.08) after thermal processing and another 0.10 units during storage. On average, nonretorted carrot puree with the periderm intact was 0.36 units lower than peeled samples, while the long blanch was 0.25 units lower than the short blanch. These differences were attributed to the additional phenolic acids dissolved into solution from the periderm tissue ($r = -0.89$) and the reduced particle sizes attained from the longer blanch. The reduced pH in these treatments may serve to retard oxidative reactions that are highly pH dependent. A similar trend was observed after thermal processing and during storage, but the differences were not considered of practical importance. The evolution of hydroxybenzoic acids in all the treatment combinations, all of which were negatively correlated to pH, may partially explain the slow decline in pH over time.

Sugars. Significant differences were observed between treatments for simple sugars. Leaving the periderm intact generally resulted in 0.04−0.06% more sucrose, glucose, and fructose in the purees, while greater extraction of sugar (0.01−0.02%) was observed with the longer blanch as found for the carotenoids and phenolic acids.

Carrot Volatiles. Differences in headspace volatiles from aqueous isolates were found between the peeling, blanching, and deaeration treatments ($P < 0.05$). Predominate terpenoids tentatively identified before and after storage, averaged over time for simplicity, are listed in Table 3. Since only headspace volatiles were obtained at room temperature, compounds detected had relatively low boiling points compared to other extraction protocols (Buttery et al., 1968; Heatherbell et al., 1971). Samples processed with the periderm intact contained higher levels of α-pinene, *o*-cymene, 3-carene, α-terpinene, and camphene. The short blanch time would logically result in greater retention of volatile compounds, but levels were only significantly higher for α-pinene and α-terpinene, which are low boiling compounds compared to the remaining terpenoids. Compounds such as caryophyllene and α-himachalene, eluting at higher temperatures, were actually found in lower concentrations with a short blanch and presumably remained compartmentalized within the carrot tissue even after thermal processing. Deaeration treatments were included in this study in an effort to remove residual oxygen that may impact quality aspects in the carrot puree. This step, however, only served to lower the concentration of both high- and low-boiling terpenoids. These results imply that vacuum deaeration, in combination with nitrogen sparging techniques (Talcott and Howard, 1999), may be utilized to reduce adverse flavors imparted from terpenoids and improve the quality characteristics of carrot puree.

Sensory Analysis. For the majority of sensory attributes, no significant difference between the peeling and blanching treatments ($P > 0.35$) was observed. However, significant differences between processing treatments were found for the sensory attributes of cooked, uncooked, terpene, and musty/moldy. Increased cooked flavors were directly affected by blanch time, as the short blanch time resulted in reduced perception of cooked attributes, indicating additional benefit to reduced preprocessing heating. However, the attributes of terpene and musty/moldy were not significantly affected by the blanch time, and their increased perception was a direct result of leaving the periderm intact. Terpene and musty/moldy attributes were considered a combination of both retronasal olfactory and taste perceptions since their perception was not impacted by blanch time, and all attributes were evaluated by the panelists from a single sampling. Significant correlations between chemical components and these sensory attributes are listed in Table 4. Terpene perception (described as a harsh flavor) was best described by the sum of individually quantified volatiles ($y = -4.601 + 0.017 \times$ total volatiles; $R^2 = 0.76$) and is a logical relationship. Simon et al. (1980) reported that sweetness and overall preference were reduced by the presence of terpenoids without the presence of additional sugars. Since sugar variation between treatments was minor, any additional terpenoids present due to preprocessing

Table 4. Significant ($P < 0.05$) Physicochemical Attributes Correlating to the Sensory Attributes of Musty/Moldy and Terpene Flavors in Carrot Puree[a]

chemical attribute	musty/moldy *r* value	chemical attribute	terpene *r* value
chlorogenic acid	0.57	*p*-OH-benzoic acid	0.69
compound **2**	−0.64	chlorogenic acid	0.73
compound **3**	0.60	ferulic acid	0.78
compound **4**	0.61	α-citronellol	0.79
compound **5**	0.70	α-terpinene	0.75
α-citronellol	0.68	caryophyllene	0.67
3-carene	0.67	α-himachalene	−0.73
α-terpinene	0.65	3-carene	0.55
total soluble phenolics[b]	0.69	total HPLC phenolics	0.68
total HPLC phenolics[c]	0.53	total soluble phenolics	0.54
sum of volatiles	0.58	sum of volatiles	0.87
AOX	0.58		

[a] Samples were thermally processed with and without periderm tissue and after a long or short blanch time (2 and 20 min, respectively) [b] Folin−Ciocalteau assay. [c] Sum of individually quantified phenolic compounds.

operations likely caused a loss of carrot flavor. The concentration of phenolic acids and their degradation products in conjunction with terpenoids best described the sensory attribute of musty/moldy. However, additional studies for identifying a chemical relationship to musty and moldy flavors in carrots are needed.

CONCLUSIONS

The concentration and degree of oxidation of the phenolic acids present in carrot puree significantly impacted AOX. Phenolic acid concentration, oxidation compounds, and puree color were highly dependent on prethermal processing blanch time, indicating that overall quality may be improved with reduced heating steps. Processing carrots without the removal of periderm tissue appears to be a viable option for the food industry. Further consumer acceptability studies are needed to determine the impact of musty/moldy flavors introduced by the periderm tissue. Utilization of prethermal processing unit operations, such as deaeration treatments to reduce volatile terpenoids, can negate undesirable flavor issues associated with periderm tissue.

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