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Processing-induced changes in total phenolics and procyanidins in clingstone peaches

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Abstract: Clingstone peaches contain a wide array of complex secondary plant metabolites and polyphenolics, and increasing evidence indicates that many of these components are important in human health. Oligomeric flavan-3-ol metabolites (procyanidins) are particularly interesting owing to their potent antioxidant activity and protective cardiovascular effects. To date, little information is available on how postharvest and processing conditions impact levels of phenolics and procyanidins in fruit. This research addresses the impact of lye peeling, freezing, storage temperature (4 and 30 °C) and three different time–temperature sterilisation combinations on levels of total phenolics (TPs) in Ross clingstone peaches. Additionally, we describe the profile of procyanidin oligomers (monomers through heptamers) in clingstone and freestone peaches and demonstrate a dramatic decrease in procyanidins in thermally processed peaches. TP levels ranged between 316 and 397 mg kg^{-1} in peeled peaches and between 376 and 609 mg kg^{-1} in unpeeled peaches. Cold storage at 4 °C for 14 days or freezing and storing at −12 °C for 3 months produced no loss in TPs. Peaches stored at 30 °C for 24 h resulted in a 1.7-fold increase in TPs. Studies of TPs in peaches processed at temperatures of 213 °F for 40 min, 220 °F for 10 min and 230 °F for 2.4 min indicate that processing above 213 °F decreases levels of both TPs (up to 21%) and procyanidins (up to 100%). Processing at 213 °F for 40 min produced no significant loss in TPs. Furthermore, studies reveal that a 30–43% loss in phenolic levels occurs during the first 3 months in storage after canning. It is clear that both storage and thermal processing conditions profoundly impact the levels of polyphenolics in peaches. More interestingly, these studies indicate that peaches are a rich source of procyanidins, having profiles similar to those found in cocoa, apples, wine and tea.

Keywords: peaches; procyanidins; phenolics; thermal processing; freezing; HPLC

INTRODUCTION

Clingstone peaches contain a wide array of complex secondary plant metabolites and polyphenolics.[1] Phenolic plant metabolites are natural components of clingstone peaches that function in plant defence against insect and animal herbivory and oxidative damage.[2–4] A growing body of evidence indicates that certain plant phenolics also play an important role in human health and disease prevention.[5–8] Procyanidins are of particular interest owing to their potent antioxidant activity, ability to scavenge free radicals and nitrogen species[9–12] and protective cardiovascular effects.[13–15] Structurally, procyanidins are composed of the polyhydroxyl flavan-3-ol units (+)-catechin or (−)-epicatechin and exist in fruits and vegetables as monomers (Fig 1) and in more complex polymeric forms, such as when two monomers condense to form dimers as illustrated in Fig 2. Oligomeric procyanidins (polymers of the monomeric forms) demonstrate antioxidant activity that increases linearly with the number of reactive catechol and/or pyrogallol groups existing in the molecule.[16,17] To date, little quantitative information is available on the procyanidin content of various fruits, and even less is know about how postharvest and processing conditions impact levels of procyanidins in foods. With the increased recognition of the role phenolics may play in human health, it has become increasingly more important to investigate the impact of postharvest and processing conditions on levels of total phenolics and procyanidins in foods.

The composition of phenolic constituents in fruits is impacted by both internal and external factors. These include genetic variation at the species and subspecies (cultivar) level,[1,18–21] maturity at harvest,[1,18,21,22] preharvest agronomic conditions[23] and postharvest processing conditions.[24,25] In addition, phenolic compounds are not uniformly distributed within the tissue of fruits.[26] For example, at the subcellular level, phenolics are deposited in the cell wall and stored in vacuoles, whereas, at the tissue level, phenolics are concentrated in the epidermal and subepidermal layers

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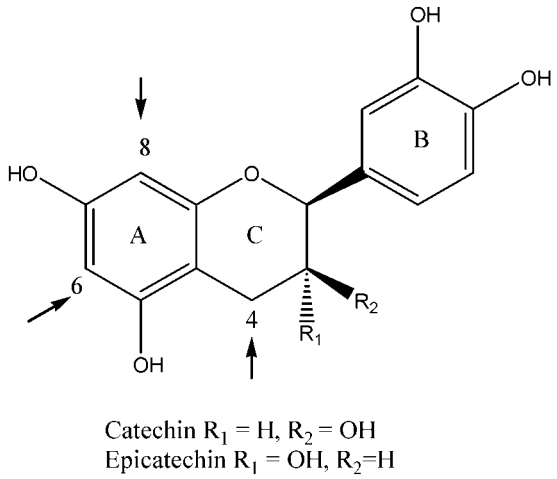

Catechin R_1 = H, R_2 = OH
Epicatechin R_1 = OH, R_2=H

Figure 1. Representative structure of catechin and epicatechin.

of the fruit.[26,27] As in the case of apples and grapes, the accumulation of low-molecular-weight phenolic compounds is greater in the outer tissues of peaches than in the inner tissues.[28,29] Phenolic distribution is important with respect to the overall phenolic composition and antioxidant capacity of industrially processed foods. To date, few studies address the variations in phenolic composition of processed peaches,[1,30,31] even though variations in phenolic composition can have profound impacts on the antioxidant capacity of processed peaches.

The harvest date for clingstone peaches is influenced both by the overall maturity of the fruit on the tree and by the availability of other fruit to the processor. Peaches are either hand or machine harvested and placed into wooden bins prior to processing. Clingstone peaches are typically processed within a few hours of harvesting in order to prevent softening and decay. Many companies have established a target time interval from harvest to process of 6–8 h. Nevertheless, a number of factors may cause processors to either shorten or lengthen this time interval. Mechanical harvesting generally results in more damage to the fruit than hand harvesting, therefore accelerating the deterioration process. While hand-harvested peaches may be stored under refrigeration conditions for hours or days, mechanically harvested fruit must be processed quickly. However, even though certain peaches are given priority in the process schedule, they may remain in a receiving yard at temperatures of up to 40 °C for hours before they are processed.

Clingstone peaches are most commonly preserved using thermal processing methods such as canning. Clingstones differ from freestone peaches in that they are considerably firmer in texture and, owing to a lack of the enzyme polygalacturonase, the stone clings to the flesh. Prior to canning, clingstone peaches are halved, pitted and peeled using lye (sodium hydroxide) to remove the thin skin. The use of heat in preservation of clingstone peaches assists in softening the texture to a degree that the fruit is acceptable to the consumer. The thermal process applied is greater than that required for microbiological destruction; in fact, the target is more related to texture modification.

This research addresses the influence of common postharvest processing practices on the levels of total phenolics in Ross clingstone peaches. Specific conditions assessed in these studies include the evaluation of lye-assisted peeling, freezing, cold storage (−12 and 4 °C), short-term warm storage (30 °C), 6 months of canned storage and the effects of three different time–temperature sterilisation processes on total phenolic activity. Additionally, we describe the profile of procyanidin oligomers in frozen clingstone and freestone peaches and assess the impact of thermal processing on procyanidins in Ross clingstone peaches. Studies addressing the impact of postharvest and processing conditions on total phenolics in processed foods are becoming more critical owing to the role plant-based phenolics may play in human health and disease

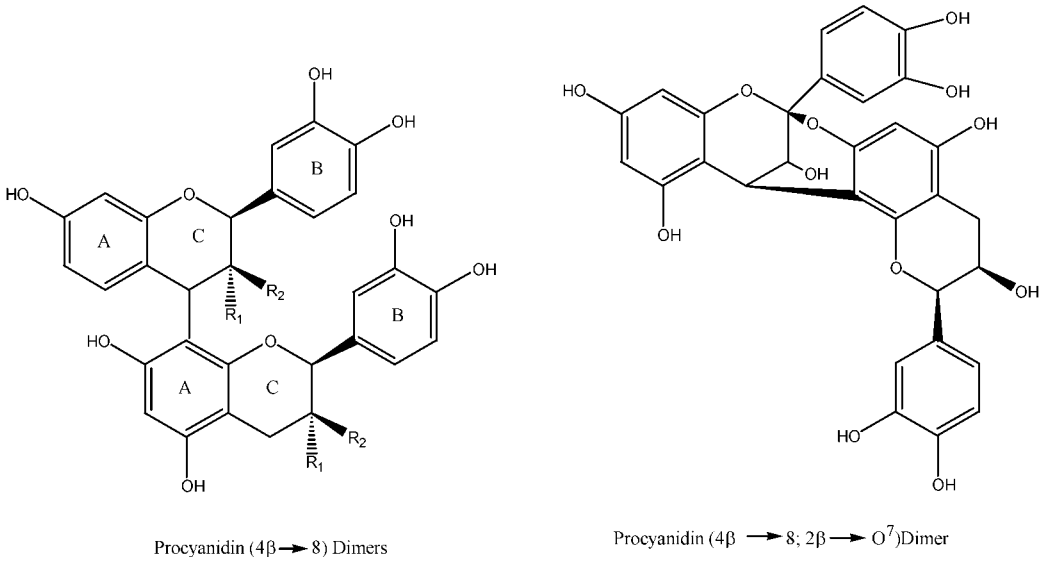

Figure 2. Representative structures of singly linked procyanidin B-type dimers and doubly linked procyanidin A-type dimers.

prevention. Determining the relationships between postharvest and processing conditions and levels of phenolics in fruits is essential for understanding how to optimise and maintain levels of beneficial phenolics in commercially processed commodities.

MATERIALS AND METHODS

Chemicals

Folin and Ciocalteau's phenol reagent and gallic acid were purchased from Sigma (St Louis, MO, USA). HPLC-grade acetone, methylene chloride, acetonitrile and acetic acid were obtained from Fisher Scientific (Houston, TX, USA). Reagent-grade, bacteria-free water was generated by a Barnstead (Dubuque, Iowa, USA) E-pure four-module deionisation system.

Peaches

Clingstone peaches of the Ross cultivar were hand picked from the University of California orchard (Winters, CA, USA). Fruits were harvested randomly from both the outer and internal canopy of selected trees in order to obtain a homogeneous sample. Following harvest, peaches were divided into four maturity classes, MI, MII, MIII and MIV, on the basis of external skin colour and firmness.[32] Maturity class MIII peaches were stored at three different temperatures for different periods of time. One group of peaches was frozen at −12 °C for 0, 1, 2 and 3 months to simulate frozen storage for analytical purposes. Another group was stored under refrigeration (4 °C) conditions for 0, 7 and 14 days to mimic storage at a processor site prior to processing. A third group was stored at 30 °C for 0, 12, 24 and 48 h to simulate fruit waiting in bins in a receiving yard prior to processing.

Extraction of total phenolics

Phenolics were extracted from peach samples by homogenising peach material in an acetone/water/acetic acid (70:29.5:0.05 v/v) extraction mixture. Specifically, pulverised samples (6 g each) were spiked with 30 mg of theobromine and pulse sonicated at 20 min intervals for 1 h. Extracts were centrifuged at 3000 rpm for 15 min at 20 °C and resulting supernatants were filtered and concentrated using a rotary evaporator under partial vacuum at 40 °C. Concentrated samples were brought up to a total volume of 30 ml and analysed for total phenolics. Procyanidin polymers were further extracted from samples using an additional solid phase extraction step on Supercosil Envi-18 20 ml SPE columns (Supelco, Inc, Bellefonte, PA, USA). The columns were preconditioned with 3 column volumes (5 ml) of nanopure water, followed by 3 column volumes of methanol and 6 column volumes of nanopure water. Extracts were loaded onto the preconditioned SPE columns and washed with 10 column volumes (5 ml) of nanopure water. The columns were then dried under vacuum for 1–2 min. Procyanidins were eluted from the SPE columns with 10 ml of an elution solvent containing acetone/water/acetic acid (70:29.5:0.5 v/v).

Measurement of total phenolics

Total phenolics were analysed by the Folin–Ciocalteau assay. This reaction is based on the reduction of phosphomolybdic acid by phenols in aqueous alkali. The method determines the total free phenolic groups and is therefore a method to determine total soluble phenolics in a sample. Total phenolics were based upon gallic acid equivalents.

HPLC analysis of procyanidins

Procyanidin analysis was performed using a Waters 2690 Alliance HPLC system (Waters, Milford, MA, USA) according to established methods.[33] Procyanidin oligomers were detected using a Waters 474 scanning fluorescence detector recording at excitation wavelength 276 nm and emission wavelength 316 nm and a Waters 996 PDA detector. Procyanidin oligomers were separated into oligomer classes, based upon their degree of polymerisation up to the decamer, using a Phenomenex (Torrance, CA, USA) 5 μm Lichrosphere silica column (250 mm × 4.6 mm). The binary mobile phase consisted of solvent A composed of methylene chloride/methanol/water/acetic acid (82:14:2:2 v/v) and solvent B composed of methanol/water/acetic acid (96:2:2 v/v). Separations were performed by linear gradients of B in A at a flow rate of 1 ml min^{-1} as follows: 0–30 min, 0–17.6% B in A; 30–45 min, 17.6–30.7% B in A; 45–50 min, 30.7–87.8% B in A. In all cases the columns were re-equilibrated between injections with the equivalent of 25 ml (10 column volumes) of the initial mobile phase. All samples were run in triplicate.

Determination of recovery

Theobromine was used as an internal standard. Extraction recoveries were determined using standard spike and recovery techniques. Briefly, a known amount of theobromine was added to samples prior to extraction. Recoveries of theobromine were determined using a standard curve based upon HPLC peak areas of a set of known theobromine standards generated using the same conditions as for procyanidin (PC) sample analysis (see below). Linear calibration curves ($r^2 > 0.995$) were obtained in the range of 0.1–5 mg ml^{-1}.

Relative quantitation and spectral identification of individual PCs

PC oligomers were identified by comparing PDA spectra, fluorescence spectra and t_R with those corresponding to PC oligomer standards isolated from cocoa.[34] Isomeric forms of PC oligomers were grouped according to their degree of polymerisation. Peak areas for each isomer group were summed and compared with the summed area of isomers corresponding to PC oligomers within the standard. The

combined peak area of each oligomer set was normalised to the peak area for the theobromine standard.

Peach processing and commercial sterilisation conditions

Peaches were sorted by maturity and processed by experienced personnel in the Food Processing Laboratory of the University of California, Davis. Prior to canning, peaches were sliced, pitted and peeled with 2% lye, rinsed and packed into number $2\frac{1}{2}$ cans. Cans were made with enamel-coated bodies and tin-plated lids. Filled cans were weighed and the peach content was adjusted to 19 oz of fruit per can. Cans were filled with 11.5 oz of 30 °Brix syrup prior to pulling a vacuum on the pack and seaming the lids to the cans. Processing conditions were designed to ensure commercial sterility, and similar temperature (°F) values were chosen for the three processes. Fruit was processed in a Food Manufacturing Corp Steritort (Madera, CA, USA). Conditions tested were 213 °F for 40 min, 220 °F for 10 min and 230 °F for 2.4 min. All three processes were started with a 3 min come-up time to evacuate air from the Steritort chamber and to bring the cans up to temperature. All cans were cooled with ambient-temperature water for 10 min after processing.

RESULTS AND DISCUSSION

The impact of maturation on total phenolics in peaches was assessed in Ross clingstone peaches harvested from the same field and sorted into one of four maturity classes, MI, MII, MIII or MIV, based upon visual inspection of the fruit and comparison with colour standards.[32] Although phenolic levels were measured in all maturity classifications, the primary interest was in MIII peaches, as this grade is most commonly used in the canning process. Total phenolics were measured in both peeled and unpeeled fruit. Phenolic levels ranged between 316 and 397 mg kg^{-1} in peeled fruit and between 376 and 609 mg kg^{-1} in unpeeled fruit (Table 1). On average, unpeeled fruit contained 1.5-fold higher levels of phenolics than peeled fruit. Levels of phenolics were statistically highest ($P > 0.05$) in unpeeled fruit of maturity classes

Table 1. Effect of fruit maturity level on concentrations of total phenolics (mg kg^{-1} fresh weight) in Ross clingstone peaches

	Total phenolics (mg kg^{-1})[a,b]	
Maturity class	*Peeled*	*Unpeeled*
MI	316 ± 19.2a	609 ± 39.4a
MII	397 ± 18.3b	569 ± 39.3b
MIII	326 ± 8.5a	376 ± 25.8c
MIV	382 ± 17.3b	455 ± 31.6d

[a] Results presented as mean ± SD for triplicates. Maximum relative SD is 6.9%.
[b] Means followed by a different letter within a column are significantly different ($P < 0.05$).

Table 2. Effect of peel removal method on concentrations of total phenolics (mg kg^{-1} fresh weight) in Ross clingstone peaches

Peeling method	*Total phenolics (mg kg^{-1})*[a,b]
Lye-assisted	274 ± 10.7a
Manual	347 ± 24.0b
Unpeeled	537 ± 10.0c

[a] Results presented as mean ± SD for triplicates. Maximum relative SD is 6.9%.
[b] Means followed by a different letter are significantly different ($P < 0.05$).

MI and MII. This result is not surprising, as the peel is a primary location for phenolic species, and younger fruit has a higher surface-to-flesh ratio than older fruit. Levels of total phenolics in unprocessed MIII peaches were 326 ± 8.5 mg kg^{-1} for peeled fruit and 376 ± 25.8 mg kg^{-1} for unpeeled fruit. Because most peaches undergo lye-assisted peeling prior to processing, we assessed the impact of lye-assisted peeling (2% lye solution) on levels of total phenolics in MIII fruit. These results indicated that manual peeling results in a 1.3-fold higher retention of total phenolics than lye-assisted peeling (Table 2). It is known that the use of lye results in damage to cells and increases the degradation of phenolic compounds in fruit.

The impact of several postharvest storage conditions on levels of total phenolics (TPs) in MIII peaches was also investigated. To evaluate the impact of freezing and frozen storage on total phenolic levels, a group of randomly selected MIII peaches were peeled, pitted, sliced, frozen and stored at −12 °C for a period of 3 months. Total phenolic levels were measured in these

Table 3. Effects of storage at −12, 4 and 30 °C on concentrations of total phenolics (mg kg^{-1} fresh weight) in Ross clingstone peaches

	Total phenolics (mg kg^{-1})[a,b]	
Time	*Peeled*	*Unpeeled*
Stored at −12°C		
0 months	423 ± 9.0a	501 ± 16.0a
1 month	643 ± 6.7b	717 ± 25.3b
2 months	457 ± 7.9c	591 ± 13.2c
3 months	500 ± 19.8d	526 ± 13.5a
Stored at 4°C		
0 days	398 ± 8.5a	468 ± 4.2a
7 days	385 ± 1.6ab	439 ± 7.0b
14 days	378 ± 6.4b	443 ± 9.0b
Stored at 30°C		
0 h	427 ± 11.0a	515 ± 23.2a
12 h	601 ± 9.4b	698 ± 5.1b
24 h	721 ± 2.8c	785 ± 6.2c
48 h	643 ± 13.4d	736 ± 14.2d

[a] Results presented as mean ± SD for triplicates. Maximum relative SDs are 3.9, 2.1 and 4.5% respectively.
[b] Means followed by a different letter within a column are significantly different ($P < 0.05$).

samples at time 0, 1, 2 and 3 months (Table 3). These data indicate that storage of peeled peaches at −12 °C results in a statistically significant increase ($P < 0.05$) in TP activity, as compared with fresh peach, over a 3 month period. Unpeeled peaches demonstrated a statistically significant increase ($P < 0.05$) in TPs at 1 and 2 months. However, we believe that the levels of TPs in the samples taken at the 1 month time period are artificially high owing to an error in non-biased sampling. Specifically, these samples had a significantly greater proportion of flesh surrounding the seed incorporated into them. This area of the peach contains high levels of TPs in comparison with the flesh closer to the surface and therefore resulted in artificially high measures of TPs. Sampling errors were corrected in months 2 and 3. It appears that the increase in TPs occurred as a result of the freezing process, but that TP levels were most likely constant during the storage periods. The freezing process may result in disruption of the cellular matrix and more facilitated extraction of the phenolics.

To investigate the impact of cold storage on TP levels, MIII peaches were stored at 4 °C for a period of 14 days. TP levels were measured in peeled and unpeeled fruit on days 0, 7 and 14. These results indicate that cold storage of peaches for 14 days resulted in no loss in TP activity in either the peeled or unpeeled fruit (Table 3) as compared with fresh peach. In fact, a small increase ($P < 0.05$) in TP levels was observed on day 14 in peeled fruit and on days 7 and 14 in unpeeled fruit. One possible explanation for the small increases in TPs observed during cold storage may be that the fruit lost moisture to the environment, and this slight dehydration resulted in a relative increase in the phenolics present. The impact of short-term above-room-temperature (30 °C) storage on TP levels was also investigated in this study. Peaches were stored in a climate-controlled temperature room at 30 °C for a period of 48 h. TPs were measured at times 0, 12, 24 and 48 h. Storage of peaches for 24 h at 30 °C resulted in a 69% increase in TPs in peeled fruit and a 36% increase in unpeeled fruit (Table 3). Levels of total phenolics began to decline after 24 h, with levels of total phenolics 50% higher than initial levels in peeled fruit and 28% higher in unpeeled fruit at 48 h. Stresses to fruit tissue, in the form of either insect attack or cellular damage due to peeling, are known to result in activation of enzymes such as phenylalanine ammonia lyase (PAL), which catalyses the synthesis of phenolic compounds. In addition, enzymes are most active at temperatures above room temperature (30–50 °C); therefore PAL-catalysed phenolic synthesis would cause levels in peeled fruit to be higher than in unpeeled fruit. Polyphenol oxidase, which catalyses oxidation and polymerisation of phenolics, may also be quite active during the 48 h storage period at 30 °C used in this study. Polymerised phenolics may not be identified in the assay used in this study, which may explain the apparent decrease in concentration after 24 h.

Clingstone peaches are typically thermally processed using conditions that ensure commercial sterility, defined as the absence of micro-organisms of public health significance, under normal conditions of transportation and storage. Typical canning conditions involve heat sterilisation at 220 °F for 10 min. To date, little is known of how thermal processing impacts phenolics. However, it has been shown that thermal processing may result in polymerisation of phenolics.[35] It is not clear whether polymerised phenolics have the same biological activity as lower-molecular-weight phenols, and at what specific size their effectiveness as antioxidants declines. Indeed, very little is known about the phenolic profiles of both raw and processed clingstone peaches. To assess these issues, we tested the impact of three different time–temperature heat sterilisation conditions on levels of TPs in MIII peaches. Conditions tested were 213 °F for 40 min, 220 °F for 10 min and 230 °F for 2.4 min. Thermal processing of peaches at 220 °F for 10 min resulted in a 21% loss in total phenolics, a temperature of 230 °F for 2.4 min resulted in an 11% loss in total phenolics, whereas a temperature of 213 °F for 40 min produced no significant loss in total phenolics as compared with raw material (Table 4). While it may be possible to prevent loss of phenolics by using lower temperatures during the canning process, our results indicate that dramatic changes in the phenolic levels also occur in the cans stored at room temperature during the first 3 months (Table 4). For example, storing canned peaches at room temperature during the first 3 month period results in a 30–43% loss in total phenolics in all samples ($P < 0.05$). Total phenolic levels increased slightly between the 3 and 6 month period in fruit processed above 213 °F, whereas fruit processed at 213 °F for 40 min demonstrated a significant reduction in TPs between the 3 and 6 month period ($P < 0.05$). It may be that the phenolics present after initial canning serve as antioxidants during the storage period and are themselves consumed during the initial 3 months. The cans used in this study had enamel-coated bodies with tin-plated lids. Tin can serve as an antioxidant; therefore, if tin-plated bodies were used, there may have been less phenolic oxidation. Further

Table 4. Effects of heat processing at 213, 220 and 230 °F and subsequent canned storage on concentrations of total phenolics (mg kg^{-1} fresh weight) in Ross clingstone peaches

Time (months)	*Total phenolics (mg kg^{-1})*[a,b,c]		
	213 °F	*220 °F*	*230 °F*
0	398 ± 6.3a	314 ± 12.3b	353 ± 14.6c
3	230 ± 3.3a	221 ± 9.7ab	204 ± 9.9b
6	220 ± 4.8a	247 ± 0.4b	233 ± 2.2c

[a] Results presented as mean ± SD for triplicates. Maximum relative SD is 4.9%.
[b] Means followed by a different letter within a row are significantly different ($P < 0.05$).
[c] Significant differences ($P < 0.05$) were found among the three means within each column.

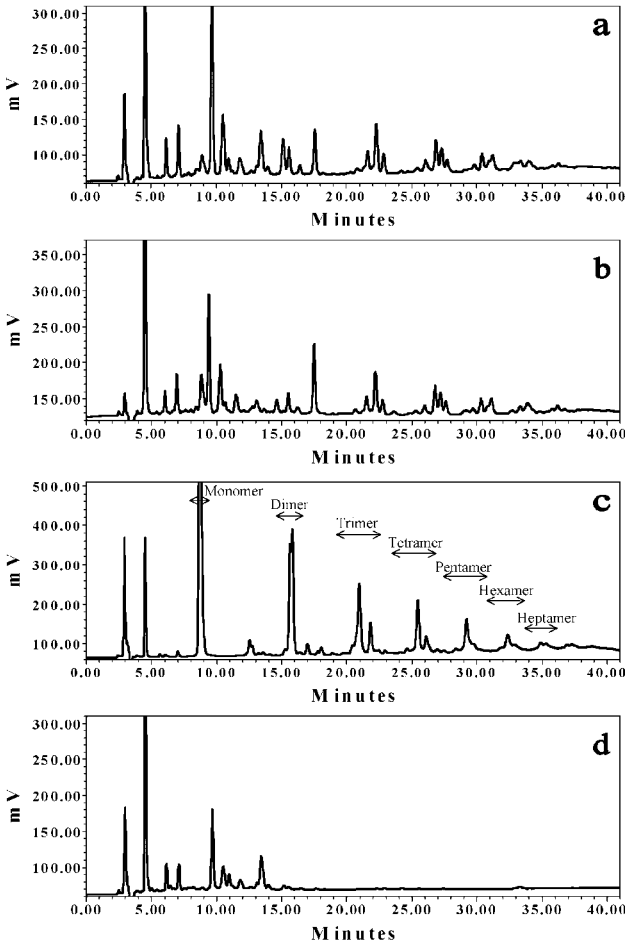

Figure 3. Normal phase high-performance liquid chromatograms of procyanidin oligomers in (a) frozen freestone peaches, (b) frozen clingstone peaches, (c) defatted cocoa extract and (d) canned clingstone peaches monitored by fluorescence detection.

studies investigating the impact of long-term storage of thermally processed peaches are currently under way in our laboratory.

The levels and degree of polymerisation of procyanidin oligomers were characterised in frozen and thermally processed clingstone peaches. HPLC profiles indicate that both clingstone and freestone peaches contain substantial amounts of procyanidin oligomers ranging from monomer through heptamer (Figs 3(a) and 3(b)). The procyanidin profile obtained in peaches is similar to profiles found in grapes, cocoa and beverages linked to health benefits, such as tea and wine. Fig 3(c) is the chromatogram of the procyanidin profile found in cocoa and demonstrates the similarities between the procyanidin profile found in peaches and that found in cocoa.[33,34] Given the tremendous body of research correlating the consumption of foods rich in procyanidins (eg tea, red wine and apples) with a reduced risk of cardiovascular disease, our current findings suggest that peaches may be an important source of dietary procyanidins. Fig 3(d) is the procyanidin profile of Ross clingstone peaches after thermal processing at 220 °F for 10 min. A comparison of the procyanidin oligomer profile in frozen peaches (Fig 3(a)) and that in peaches processed at 220 °F for 10 min (Fig 3(d)) demonstrates a profound reduction in procyanidins in canned peaches relative to frozen peaches. The profile of procyanidins in canned freestone peaches was not determined in this study. The flavonoid profile in canned freestone cultivars may differ from that in clingstone cultivars, as freestone cultivars contain higher levels of leucoanthocyanins than clingstone cultivars. Fig 4 presents the summed and normalised areas of individual procyanidin oligomers in frozen and thermally processed peaches. As can be seen in this figure, there is a 49% reduction in procyanidin monomers, an 88% reduction in procyanidin dimers and a complete loss of procyanidin oligomer trimers through heptamers in the thermally processed peaches.

CONCLUSIONS

The research described in this paper demonstrates that there are complex relationships between postharvest and processing conditions and levels of total phenolics in clingstone peaches. Studies clearly indicate that freezing and cold storage have relatively little impact on TPs and procyanidins, whereas lye-assisted peeling and canning using temperatures typically employed in commercial sterilisation have detrimental impacts on

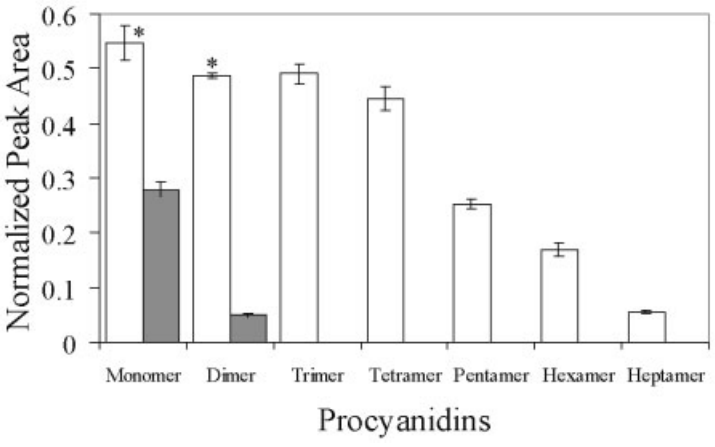

Figure 4. Comparison of individual procyanidin oligomers in frozen (white) and canned (shaded) clingstone peaches. An asterisk denotes a significant difference ($P < 0.05$) between frozen and canned procyanidin levels. Results are presented as mean ± SD for triplicates.

both TP and procyanidin levels. Interestingly, we found that levels of TPs could be increased up to 1.7-fold by simply holding peaches at 30 °C for 24 h. However, it is still unclear if increases in TPs are due to increased production of TPs or increased extractability of TPs, and more experimentation is needed to resolve this question. Additionally, the question of which individual phenolic(s) are responsible for the increase in TPs needs to be addressed, as individual phenolics have various biological activities and may impart changes in flavour and colour of the peach.

While these studies indicate that it may be possible to prevent losses of TPs and procyanidins by using lower temperatures during the canning process, dramatic reductions in TPs occur in the first 3 months of canned storage. It may be that the phenolics present after canning serve as antioxidants during the initial storage period and are themselves consumed. A possible strategy for decreasing the impact of thermal processing on levels of phenolics may be the use of tin-plated cans, since tin can serve as an antioxidant. Further studies investigating relationships between postharvest processing conditions and levels of specific phenolics, in particular the procyanidins, are currently in progress in our laboratory.

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