QUALITY ASSESSMENT OF NORTHEAST PEACH AND APRICOT VARIETIES AND THEIR VALUE-ADDED PRODUCTS

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From 2009 to 2011, ten peach and five apricot varieties cultivated and commercially available in the Northeast were assessed for quality indices and phytochemical content. The objective was to generate qualitative and quantitative information on the phenolic, antioxidant, and carotenoid content of these varieties and how they were affected by seasonal variations, maturity at harvest, storage and processing. Selected varieties were made into value-added, shelf-stable products and evaluated after processing and storage for 6 months at 18-20 ˚C. Apricot products had higher phytochemical content compared to peaches. Varieties with greatest phenolic and antioxidant content were 'PF 22-007' peach and 'Hargrand' apricot while 'Babygold 5' peach and 'Hargrand' apricot had highest carotenoid content. Phenolic and antioxidant content generally decreased with on-tree ripening while these components remained relatively stable after harvest in cold storage. Carotenoid content increased three to six-fold in apricots with both on- and off-tree ripening. Individual phenolic and carotenoid compounds identified and quantified by HPLC were influenced by fruit type, variety and pre- and postharvest conditions. Evaluation of canned products showed a reduction of phytochemical content with peeling and storage. Losses of hydrophilic constituents were partly due to migration into syrup while lipophilic constituents were less susceptible to leaching. Pre-drying treatments significantly influenced dried fruit color and phytochemical content, with a sulfiting treatment the most effective. Two alternative treatments, blanching and rhubarb juice+blanching,

proved promising in the production of dried fruit with acceptable color while retaining a good level of phenolic content and antioxidant capacity; a rhubarb juice-only treatment was suitable only for carotenoid retention. Fruit and sucrose content of jam and nectar influenced quality and phytochemical content. Increasing fruit content resulted in higher nutraceutical value post-processing and in storage; this effect was better assessed using HPLC. Overall results position peaches and apricots as important sources of phenolics, antioxidants and carotenoids, with apricots being good to excellent sources of vitamin A. Production, varietal selection and postharvest handling are important to maximize the nutraceutical quality of fresh fruits, while processing conditions and formulation can be optimized to retain healthful bioactive compounds thus providing better options for consumers.

BIOGRAPHICAL SKETCH

Oluranti obtained a B.Sc. degree in Biochemistry from the Kwame Nkrumah University of Science and Technology, Ghana. Her final year research was in the area of Immunology, with the dissertation titled 'The Prevalence of Asthma and other Allergic Diseases among KNUST Students Residing in Hostels'. Upon graduation, she worked with the Noguchi Memorial Institute for Medical Research as a research assistant on the Global View of Food Allergy (GLOFAL) project, a study of environmental and dietary influences on the development of food allergies. Here, she developed an interest in the use of processing technologies to reduce allergenicity of foods and the production of value-added products using indigenous foods. Thereafter, she secured an internship with the Agriculture and Consumer Protection Department of the Food and Agriculture Organization of the United Nations (FAO). She commenced her doctoral program in 2008, with a concentration in fruit and vegetable processing, process optimization and product development, and minors in Horticulture and Microbiology. During her time at Cornell University, she engaged in diverse extra-curricular activities including the Student Association of the Geneva Experiment Station, Ghanaians @ Cornell, The Food Science College Bowl Team and a number of Product Development Teams. She looks forward to a career in food product research and development.

Dedicated to God and family.

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CHAPTER 1: LITERATURE REVIEW

Background

The origins of peaches and apricots date back to 10th century BC China and central Asia. Both fruits are considered part of Chinese culture, with the peach featuring in the legend of the Monkey King (Sun Wukong) in which he attained immortality by eating from the Garden of Immortal Peaches. Apricots, first discovered growing wild on Chinese mountain slopes, are now primarily associated with Armenia and the Mediterranean; the latter remains among the chief producers of the fruit. The peach remains relevant in Chinese lore, with tree, fruit and color representing longevity and immortality. Both peaches and apricots were imported into Europe – by ancient traders and Roman conquerors – and from there to the rest of the world: to North America by early Spanish explorers (Mehlenbacher and others 1990; Siddiq 2006a; Siddiq 2006b; Bassi and Monet, 2008).

The peach (*Prunus persica L.*) and apricot (*Prunus armeniaca L.*) are two of the most consumed stone fruits worldwide. Global production for peach in 2010 was 20,278,439 tonnes[1] and 3,442,450 tonnes for apricots, with China the top producer of the former and Turkey the latter. The USA accounted for 1,044,440 tonnes of peaches and 59,400 tonnes of apricots, representing approximately 5.15% and 1.73% of world production. These figures show a decline from those of 2009: 1,197,665 and 61,980 tonnes for the two commodities (FAOSTAT 2012). Despite avid production in

[1] FAOSTAT figures available are for peaches and nectarines. Production values for these two fruits are

California (peaches and apricots), South Carolina (peach), Georgia (peach), Washington (apricot) and Utah (apricot), overall production and consumption of these fruits show year-to-year declines – fractionally and irregularly for peaches but steadily for apricots – with 2011 apricot production estimated to be the lowest in five years (USDA ERS 2011; USDA NASS 2011). A suggested reason for this trend is the perceived decline in eating quality – mainly taste and juiciness – of both fruits over the years (Kader and Mitchell 1989b; Manolopoulou and Mallidis 1999). This can in turn be linked to varietal, climatic, distribution and marketing system changes, as well as the current demands of urbanization and commercialization (Scorza 2005).

Erstwhile agricultural systems limited crop production and distribution to relatively small geographical areas. Customers patronized local orchards almost exclusively, and farmers were assured of sale of produce within a relatively short period postharvest. Fruit could be allowed to remain on trees until fully ripe, attaining optimum development of color, aroma and taste. The current state of produce marketing and distribution, separating producers and consumers by considerable distances, has necessitated alterations in horticultural practices, particularly harvest and postharvest management. Peaches and apricots, both climacteric fruits, present a challenge in postharvest storage. Fruit must therefore be picked early enough to ensure sufficient shelf life during storage and transport until they reach the final consumer. While advantageous to commercial viability of produce, this practice is detrimental to fruit development and attainment of optimum quality, offering validity to the consumer

complaints (Kader and Mitchell 1989b; Manolopoulou and Mallidis 1999; Kader and Barrett 2005).

Historically, peaches and apricots produced in the Northeast have not enjoyed the same scale of interest relative to other producing states (e.g. California) and other local fruits (e.g. apples). This can be attributed to a significant number of environmental and socio-economic challenges involved in stone fruit cultivation in this region. These make both fruits less attractive options for local farmers (Merwin 1994; Hoying and others 2005; NYS Climate Office).

Recent developments may indicate a change. These include the USDA/NYSDAM Specialty Crops Block Grant Program – born out of the Specialty Crops Competitiveness Act of 2004 – which aims to enhance the competitiveness of specialty crops, a classification under which these fruits fall (NYSDAM 2010; USDA AMS 2012). Other supportive trends include the Buy Local Campaign (NYSDAM 2012), Community Supported Agriculture (USDA NAL 2012), and food trends promoting consumption of fresh and minimal processed foods. The greatest proponent for public attention is the ever-increasing evidence of the various health benefits of fruits and vegetables (Kader and Barrett 2005; Sanchez-Moreno and others 2006; Sloan 2010; USDA HHS 2011). Peaches and apricots have been found to contain significant amounts of phenolic and carotenoid compounds and therefore have great marketing potential as sources of recommended healthful components – antioxidants and vitamin A (Gil and others 2002; Ruiz and others 2005a; Ruiz and others 2005b; Vizzotto and others 2006; Dragovic-Uzelac and others 2007).

Geography and climate of New York State

New York State (NYS) has a land area of 128,397 square kilometres with the major portion of the state lying between latitudes 42° and 45° N and longitudes 73° 30' and 79° 45' W. Notable highland regions are the Adirondacks in the northeast and the Appalachian (Southern) Plateau in the south. The state contains and is bordered by a number of lakes, including the Great Lakes on the Canada-United States border, Lakes Champlain and George in the east; St. Lawrence River, Lake Ontario, and Lake Erie in the north and west. The Finger Lakes – named for their resemblance to fingers extended from a hand – are found in the western part of upstate New York and include Canandaigua, Keuka, Seneca, Cayuga and Skaneateles (NYS Climate Office). This study was conducted with fruit grown in this region.

The moderating effect of these bodies of water on temperature, aptly called the 'lake effect', plays an integral role in agriculture in this region. In the fall season, lake waters cool more slowly than the land. This reduces the cooling of the atmosphere at night on land, delaying the occurrence of freezing temperatures and lengthening the growing season for freeze-sensitive crops. The highlands also aid in mitigating the full effect of southbound cold fronts from the north. On the other hand, the waters warm slowly in spring, reducing atmospheric warming in neighbouring land areas. This phenomenon retards plant growth and allows freeze-sensitive crops to reach critical early stages of development when the risk of freeze injury is minimized. This also implies the lengthening of the cold season and possible fluctuations in early spring, posing a threat to early blooming fruits, such as the fruits in question (NYS Climate Office; Westwood 1993; Layne and others 1996).

Summers tend to be humid in this region, creating favorable conditions for pests and diseases whose agricultural damage is exacerbated by harsh winter conditions that weaken tree structure and integrity (Westwood 1993). Average orchard lifespan for peach in NYS is about 15 years, mainly due to winter damage leading to Cytospora canker (Hoying and others 2007). The difficulties in finding suitable varieties that can survive in or adapt to this climate and cost of disease-resistant varieties coupled with the uncertainty of good yield and monetary gain make investment in and cultivation of these fruits unpopular (Lamb and Stiles 1983; Mehlenbacher and others 1990; Merwin 1994).

Due to the aforementioned issues, breeding programmes have been aimed mainly at climatic adaptation – instilling a longer chilling period and a slower response to warmth and subsequent bud break (Anderson and Seeley 1993; Layne 1996; Layne and others 1996). One of the successes is the 'Redhaven' peach, cultivated widely in NYS due to its cold hardiness (Scorza and Sherman 1996; Monet and Bassi 2008). The work of Richard Layne at the Harrow Research Centre in Ontario, Canada, yielded a number of hardy apricot varieties, including 'Harlayne', 'Harogem' and 'Hargrand', which have fared well in NYS given the similarity in climate (Lamb and Stiles 1983; Layne and others 1996). Other varieties grown in NYS, with varying degrees of productivity and hardiness, are the peaches 'Babygold 5', 'Glohaven' and 'Harrow Beauty', and apricots 'Vivagold', 'Harlayne' and 'Harcot' (Lamb and Terry 1973; Lamb and Stiles 1983; Brown and others 1986).

Physiology

The peach and apricot stem from the order *Rosales,* family *Rosaceae* and the genus *Prunus L.* Under this classification, peaches belong to the subgenus *Amygdalus* while apricots fall under subgenus *Prunophora*, section *Armeniaca* (Layne and others 1996; Bassi and Monet 2008; ITIS 2012a; ITIS 2012b). The trees are deciduous and fruits classified as drupes due to the hard, lignified stone (pit) derived from the ovary wall of the flower (Westwood 1993). Peach flowers are pink and apricot flowers white, while both fruits are in various shades ranging from white to yellow and orange. Young fruits start out green (ground color), developing into variety-dependant shades with maturity and, with some varieties, attaining a red blush on the portion of the surface exposed to the sun. Although visually similar, peaches may be distinguished from apricots by the presence of pubescence (fuzz) on their skin (Mehlenbacher and others 1990; Okie 1998; Scorza 2005).

Fruit may be classified according to ripening date (for peaches, relative to ripening date of the variety 'Elberta'), color (peel, flesh), firmness (high, medium, low firmness; melting flesh, non-melting flesh), adhesion of pit to flesh (clingstone, freestone), shape (oblong, elliptical, flat) and eating quality (poor, fair, good, excellent). Fruits may also be classified as low, medium or high acid cultivars (Okie 1998; Manolopoulou and Mallidis 1999). Citric and malic acid are the predominant acids in both fruits but relative quantities vary according to variety and stage of ripening (Kader and Mitchell 1989b; Wang and others 1993; Aubert and Chanforan 2007). Sucrose, glucose and fructose are the main sugars, with sucrose dominant, and

increase in concentration with ripening as starch breaks down (Vizzotto and others 1996; Drogoudi and others 2008).

Cultivation

Site selection and management

Peach and apricot trees do well in light to medium-textured, well-drained gravelly or sandy loam soils with moderate fertility, but fare badly in poorly-drained or waterlogged soils. Under wet conditions, trees are more susceptible to diseases such as *Phytophthora* root rot. Tile drainage or planting on raised beds may be used to improve tree survival, growth, and fruiting at marginal sites. Excessively dry or droughty conditions may increase the frequency and cost of irrigation. When required, fertilizer can be added to soils of low to moderate fertility; older trees usually require only nitrogen fertilizer. Highly fertile soils may result in excessive tree growth (causing shading in the lower and interior portions of trees) and undue vigour which can contribute to susceptibility to disease, poor fruit quality and reduced productivity of the tree in subsequent years (Lamb and Stiles 1983; LaRue 1989; Lockwood and Striegler).

Rootstocks

Rootstocks are selected for their positive influence on yield and fruit quality. For cultivation in the Northeast, rootstocks are graded on their cold hardiness, disease and pest resistance. Additional advantages include an ability to withstand unfavorable soil conditions (pH extremes, poor drainage, waterlogging). Apricot scions generally fare well on peach rootstocks, and the most common for both fruit trees are ‘Lovell’,

'Bailey', 'Nemaguard' and 'Blenheim' (apricot). A protective coating of white latex paint can be applied on trunks to prevent injury caused by temperature fluctuations (Yoshikawa and others 1989; Merwin 1994; Andersen and others 2005; Lockwood and Striegler).

Training

The plants require appropriate structuring and orientation to allow for the access and penetration of sunlight into the canopy. This improves color development and air circulation, reducing the risk of diseases like brown rot (*Monilinia* sp.) and perennial canker (*Leucostoma* sp.). The best time to train trees is at a young age, when plants limbs are more pliable and amenable to restructuring. The most predominant shape for peach and apricot trees in the Northeast is the open-center/vase system, with a scaffold arrangement of 4 scaffold branches with 4 bifurcations. This system involves heavy pruning and a limit to tree height, which has repercussions on survival, hardiness and yield of tree/orchard but gives good fruit size. The perpendicular-v is a variation that allows for greater density, color and crop value (Walser and others 1994; Hoying and others 2005; Hoying and others 2007).

Pruning and thinning

Pruning is done in spring and may also be conducted in summer, although the latter option may result in reduced biomass, lost carbohydrate stores and decreased winter hardiness in peaches (Hoying and others 2005; Hoying and others 2007). Thinning is usually performed by hand or with a pole, with fruits about 2-4 inches apart either at time of pit hardening or just after June drop, which in itself provides a natural form of

thinning. Thinning is considered the most expensive practice in production, due to the non-mechanized labour involved. Chemical thinning has been proposed as a less expensive alternative, but variability in results and the high risk of over-thinning – and, by extension, reduction of yield/crop value – makes it an unattractive option (Yoshikawa and Johnson 1989; Ingels and others 2001; Osborne and Robinson 2008).

Pests and diseases

Pests of peaches and apricots, targeting different parts of the tree and fruit, include the codling moth (*Cydia pomonella),* peachtree borer (*Synanthedon exitiosa*), peach twig borer (*Anarsia lineatella*) and European red mite (*Panonychus ulmi*). Plum curculio (*Conotrachelus nenuphar)* is of great economic importance in the Northeast as it thrives in this climate, being native to regions east of the Rocky Mountains. Knowledge of pest life history and characteristics (visual appearance, life cycle, time of year, number of generations, overwintering period, interaction with host), record keeping (insect sightings, trap catches), conversance with necessary information (region-specific insect events, thresholds) and keeping abreast of relevant literature (e.g., Scaffolds Fruit IPM Newsletter) are necessary in determining when and how to control for pests (Lamb and Stiles 1983; Barnett and Rice 1989; Westwood 1993). The opossum (*Didelphis virginiana),* raccoon (*Procyon lotor*) and various species of birds are larger pests that may directly or otherwise negatively impact yield (Merwin 1994).

Similar to other stone fruits, peaches and apricots are susceptible to several diseases. Fungal diseases such as brown rot (*Monilinia fructicola and M. fructigena* for peach, *M. laxa* for apricot) affect blossoms and fruit and are exacerbated by rainfall.

Waterlogged conditions and high humidity can also result in Phytophtora root and crown rot (*Phytophtora spp.)* and powdery mildew (*Sphaerotheca pannosa, Podosphaera oxycanthae* or *P. Leucotricha)* respectively. Bacterial (*Pseudomonas syringae*) and fungal (*Cytospora spp.)* cankers threaten root and tree integrity and can lead to plant death. Plum pox (Sharka virus) is considered the most serious diseases of these stone fruits, as infestation requires the destruction of all possibly infected trees in an area, resulting in significant economic losses (Lamb and Stiles 1983; Teviotdale and others 1989; Mehlenbacher and others 1990; Westwood 1993; Scorza 2005).

Pest and disease control may utilize conventional, organic or integrated pest management (IPM) methods, depending on cultural, financial and environmental considerations (Cornell University Cooperative Extension, 2011).

Harvest

In the Northeast, peaches and apricots are two of the earliest tree fruit species to bloom in the spring (March or April). The harvest period runs from July to August for apricots and August to September for peaches, varying slightly from year to year. Optimum harvest time is based primarily on visual maturity indices such as size, shape and color, along with previous experience. Physical (firmness) and chemical (soluble solids content, titratable acidity and ethylene production) indices may also be used (Kader and Mitchell 1989a; Mehlenbacher and others 1990; Okie 1998). In practice, actual assessment of maturity tends to be arbitrary as it is left to the discretion of onsite labour. For both fruits, objective and accurate gauges of maturity are needed.

Time of harvest, postharvest treatment and storage depend on the intended purpose or target market of the fruits. Fruits intended for wide-range distribution are harvested earlier and stored at near-freezing temperatures for transport and distribution, while fruits meant for local markets can be harvested later. With the latter group, taste, juiciness, flavor and the aroma of fruit are more pronounced but shelf life is significantly reduced. Contrarily, harvesting fruit earlier sacrifices aesthetic and eating quality for longer shelf life. Nevertheless, the climacteric nature of both fruits typically necessitates harvesting prior to attaining optimum quality, regardless of intended use (Kader and Mitchell 1989b; Manolopoulou and Mallidis 1999).

Fruits are harvested by hand to prevent bruising, a practice also made possible by the small commercial quantities produced in this region. Harvesting should be selective as rate of ripening is influenced by position on tree, although labour costs may influence this practice significantly. The fruits are cooled shortly after picking to extend shelf life. Thereafter, they are graded, sorted and stored at low temperatures (0-1 ºC) under high humidity (90-95%) to discourage further ripening by inhibiting respiration and ethylene production. Postharvest treatment is especially pertinent for apricots given their susceptibility to moisture loss and shrivelling. Controlled and modified atmosphere storage are two options to prolong shelf life of these fruits (Kader and Mitchell 1989b; Manolopoulou and Mallidis 1999; Siddiq 2006a; Siddiq 2006b).

Typical shelf life is 2-4 weeks for peaches and 1-3 weeks for apricots. During harvesting, transport and storage, peach and apricot fruit may suffer physiological disorders such chilling injury, pit burn (apricots), wounding (bruising), increased

respiration and ethylene production all of which can reduce shelf life and lower commercial value of produce (Kader and Mitchell 1989a; Westwood 1993; Manolopoulou and Mallidis 1999; Siddiq 2006a).

Processing

Peaches and apricots are consumed fresh, dried and canned, and are also used in the manufacture of puree, jam, jelly and beverages (Manolopoulou and Mallidis 1999; Siddiq 2006a, Siddiq 2006b). Processing serves as a good means to add value to these products, as their climacteric nature limits the amount of time within which they may be stored and sold fresh. In the USA, peaches are predominantly consumed fresh (52%), canned (38%), frozen (8%) and dried (2%). Apricots, on the other hand, are largely utilized as dried products (64%) with other popular forms being canned (16%), fresh (15%) and frozen (5%) (USDA ERS 2011). The large size, vibrant color and blush coupled with an appealing sugar-to-acid balance may explain why peaches are preferentially consumed fresh.

Different requirements exist for fruit channelled into the various products. For fresh markets, emphasis is placed on large size, good color (uniform for apricots and with a bright blush for peaches), freestone, firm flesh, aroma, uniform ripening and good overall appearance (absence of cracks and blemishes) (Mehlenbacher and others 1990; Okie 1998). Firmness and color are important attributes in canned or dried goods and fruit for such products are harvested early, while still firm in a bid to ensure shape retention after processing. Other desired characteristics are uniform shape, regular size and good sugar-to-acid ratio. Slices of fruit, peeled or otherwise, are canned in light

(20 ºBrix), medium (30 ºBrix) or heavy (40 ºBrix) syrup. Clingstone peaches are preferred for canning given their ability to retain texture and flavor (Layne and others 1996; Siddiq 2006a; Siddiq 2006b).

For dried fruit, color is a critical factor as it influences the perception, appeal and commercial potential of the product. To achieve this, there has been a reliance on sulfur dioxide in the manufacturing process due to its antibrowning (enzymatic and non enzymatic) and preservative and textural properties it lends to dried fruit. However, with a rising incidence of sulfite sensitivity, as well as trends towards organic, all natural and additive free products, there is an increasing need for alternative means of production (Potter and Hotchkiss 1998; Manolopoulou and Mallidis 1999). So far, studies conducted using ascorbic acid and blanching variations have been moderately successful at best, often not faring favorably in shelf life studies or at elevated temperatures. There is still an opening for an effective sulfite-free drying treatment (Manolopoulou and Mallidis 1999; Somogyi 2005).

Fruit intended for jam, jelly and beverage production may be harvested later because softening, bruising and blemishes do not detract substantially from the raw product. Preferably, fruit should have good sugar-to acid balance, with food flavor and aroma (Horvath-Kerkai 2006). Peach and apricot puree may be used as starting materials for secondary products or considered products in themselves for use as fillings, baby food or as an oil substitute (Siddiq 2006a; Siddiq 2006b).

Juice is produced on a small scale in some part because of the difficulty of juice extraction and clarification due to high pulp and suspended solids content. Efforts to improve yield and clarity involve the use of enzymatic liquefaction and decanter centrifuges. Fruit beverages are therefore often found in the form of nectars (diluted juice beverages), pulpy juices or ingredients in less turbid beverages produced in combination with other fruits (Beveridge and Harrison 1995; Beveridge and Rao 1997; FDA 2003; McLellan and Padilla-Zakour 2005; Siddiq 2006b; Santin 2008). Jam remains a popular product as the production process is simple and requires little financial and mechanical input. With changing consumer preferences, there is growing demand for lower sugar or calorie versions of these. The challenge here is the maintenance of taste, consistency and color with reduction of added sugar or replacement with sugar substitutes (Somogyi 2005; Siddiq 2006a; Siddiq 2006b).

Although processing waste may be used as animal feed and kernels channelled into oil production, there is ongoing research into making this industry more environmentally sustainable by utilizing by-products as sources of dietary fibre and biofuel (Iordanidou and others 1999; Monspart-Senyi 2006).

Health and nutrition

Peaches and apricots are rich reserves of healthful compounds, mainly polyphenolics, carotenoids and antioxidants, as well as vitamin C, iron, fibre and potassium. Levels of these nutrients vary according to variety, region of cultivation, fruit maturity, climatic and environmental factors (Gil and others 2002; Dragovic-Uzelac and others 2007). Additionally, bitter apricot kernels contain the chemical laetrile, an amygdalin

derivative reputed to have anti-cancer properties but also associated with stomach upsets and cyanide production (Femenia and others 1995; Gomez and others 1998).

Polyphenolics

Phenolics are aromatic compounds with one or more hydroxyl substituents. These secondary metabolites are widely distributed in plant tissue and involved in a range of functions, acting as part of the plant's defence system and playing vital roles in color (pigmentation and browning) and taste (astringency) of fruit. They can be categorized into three major groups: phenolic acids, flavonoids and tannins. Phenolic acids include hydroxycinnamic, hydroxybenzoic and hydroxyphenylacatic acids, the first of which is relevant to the fruits of interest. Flavanoids are the largest and most important phenolic subgroup in peaches and apricots, and are classified as flavan-3-ols, flavonol glycosides or anthocyanins, the last of which lends pink, red to violet color to fruits and vegetables. The presence of tannins has not been reported in either fruit (Tomas-Barberan and others 2001; Kim and Lee 2002; Shahidi and Naczk 2004).

Major phenolic compounds in both fruits are catechin, epicatechin, chlorogenic acid, neochlorogenic acid and derivatives of cyanidin and quercetin (Tomas-Barberan and others 2001; Andreotti and others 2005; Dragovic-Uzelac and others 2005; Ramina and others 2008). These compounds have been found in much greater concentrations in the peel of both fruits than in the flesh; anthocyanins, located mainly in the skin, have been detected in small quantities specifically in flesh tissue near the stone in peaches (Tomas-Barberan and others 2001; Gil and others 2002; Ruiz and other 2005a). Dragovic-Uzelac and others (2007) reported that phenolic compounds in

apricots are predominant in the initial and early ripening stages of development, but decrease with maturity. Studies have yet to prove strong and consistent correlations between color and phenolic content.

Carotenoids

Carotenoids are tetraterpenoid (C_{40}) compounds composed of isoprenoid (C_8) units. They are regarded as the most widespread pigments in nature and responsible for colors in shades ranging from yellow to orange and red. Animals, unable to synthesize carotenoids, obtain them from food consumed. These provide nutrition and color, e.g., bird feather color and egg yolk (Rodriguez-Amaya 1999; Fraser and Bramley 2004; Melendez-Martinez and others 2006; Britton and Khachik 2009).

Carotenoids detected in peaches and apricots include carotenes α, β and γ-carotene and xanthophylls (mono- or dihydroxylated carotenoids) zeaxanthin, lutein, β-cryptoxanthin and violaxanthin, with β-carotene the predominant carotenoid. Proportions differ significantly between varieties, and varietal flesh color can be an indication of carotenoid content. In peaches, yellow-fleshed fruit was found to possess greater carotenoid content as compared to white-fleshed ones (Gil and others 2002; Vizzotto and others 2006) while in apricots, correlations have been found between color, *a*, of flesh (r=0.93) and hue angle of peel (r=0.84) and carotenoid content (Ruiz and others 2005b). Lycopene has been detected in some peach and apricot varieties (Katayama and others 1971; Khachik and others 1989; Ruiz and others 2005b). β-carotene is present throughout fruit development while the presence and concentrations of other carotenoids, particularly xanthophylls, has been found to alter

from carotenogenesis through fruit development and maturity (Katayama and others 1971; Breithaupt and Bamedi 2001). Carotenoid content has been reported to increase with increasing ripeness, with concentration in peel being 2-3 times higher than in flesh (Gil and others 2002; Ruiz and others 2005b; Dragovic-Uzelac and others 2007).

Antioxidants

Similar to other fruits receiving attention for their nutraceutical potential, the putative health benefits of peaches and apricots are accredited mainly to their antioxidant content. Antioxidants are compounds active against free radical species (oxidative by-products from metabolic processes) that damage DNA, proteins and lipids. Although research is largely on-going and, in some cases, inconclusive or even contradictory, antioxidants are believed to work against the incidence of cardiovascular diseases, cancers and aging (Block and others 1992; Ames and others 1993).

Antioxidant properties of peaches and apricots are attributed to both phenolic and carotenoid compounds. The chemical structures of both groups (presence of conjugated double bonds) allows for the acceptance/donation of electrons from/to free radicals (singlet oxygen, superoxide, hydrogen peroxide, hydroxyl peroxide), retarding or terminating free radical mechanisms. In both fruits, antioxidant capacity is derived from hydrophilic (phenolic) and lipophilic (carotenoid) components, with the former being the primary contributor (Prior and others 2003; Wu and others 2004; Drogoudi and others 2008). Gil and others (2002) found that white-fleshed peaches possessed higher antioxidant capacity as compared to yellow-fleshed ones, while Drogoudi and others (2008) found such correlations to be weak in apricots.

Although more information is required on the antioxidant activity of specific polyphenolic compounds, lycopene has been identified as the main carotenoid antioxidant, serving as an efficient singlet oxygen quencher due to its open ring structure, with β-carotene displaying antioxidant capabilities to a lesser degree (Paiva and Russell 1999; Stahl and Sies 2003; Sass-Kiss and others 2005). Chlorogenic and neochlorogenic acid have been found to be chemopreventive towards breast cancer (Noratto and others 2009), β-carotene has been suggested to have a preventive effect against lung and colorectal cancer (Fraser and Bramley 2004) and lycopene linked to a reduced risk of cancer and heart disease (Rao and Agarwal 2000).

Vitamin A

Peaches and apricots are also sources of vitamin A precursors: carotenoids β-carotene, α-carotene and β-cryptoxanthin. Vitamin A deficiency can lead to xerophthalmia, blindness and premature death; it remains a leading cause of child mortality in developing countries (Rodriguez-Amaya 1999; Fraser and Bramley 2004) and is often not consumed in adequate quantities by most Americans (Moshfegh and others 2005). Provitamin A compounds are cleaved to produce retinal which is converted to retinol, the storage form of vitamin A, in the small intestine by intestinal mucosa. Retinol may thereafter be converted into vitamin A for vision and stored in the liver, or retinoic acid, which aids in skin health and bone growth. Zeaxanthin and lutein, although lacking provitamin A properties, accumulate in the macular of the eye and protect against age-related macular degeneration (Landrum 2001; Fraser and Bramley 2004).

A recommended dietary value of 300-600 µg retinol equivalents (RE) for children, 900-1300 µg RE for women, and 900-1200 µg RE for men, equivalent to the consumption of 100-200 g per day of a fruit or vegetable containing high carotenoid content, has been suggested and upper limits set to prevent hypervitaminosis. Peaches and apricots have been described as 'good' sources of vitamin A, possessing 10-19% of daily value (Ruiz and others 2005b; NIH 2006; USDA ARS 2011; USDA FNIC 2011). However, given the multifactorial nature of absorption and conversion of carotenoids from different food sources, Scott and Rodriguez-Amaya (2006) suggested that such assertions be treated with caution.

Bioavailability and bioactivity

On-going research in this area aims at identifying and quantifying phenolic and carotenoid compounds in different varieties and evaluating their antioxidant and vitamin A bioavailability and activity *in vitro* as well as *in vivo* (Fraser and Bramley 2004; Shahidi and Naczk 2004; Van Buggenhout and others 2010). Further information is also sought on how climatic, cultivation, harvesting, storage and processing conditions affect the concentration and availability of these nutrients.

Food safety

Common microbiological considerations with fresh stone fruits include contamination by bacteria *Escherichia coli* O157:H7, *Salmonella* and *Staphylococcus*. These are primarily due to soil and human contact and, as they are restrained to the fruit surfaces, maintenance of intact skin during and after harvest, and cleaning before consumption, is adequate treatment. Moulds *Rhizopus*, *Aspergillus* and *Penicillum*

present quality and commercial concerns in fresh and processed products. In processed products, handling under sanitary conditions and heat treatment coupled with high acid content and low water activity are sufficient to render most peach and apricot products safe and shelf stable. The low pH of these fruits (~ 3.5) protects against *Clostridium botulinum* growth but may allow for growth of aciduric yeasts and moulds (Worobo and Splittstoessser 2005; Kalia and Gupta 2006).

A cause for concern with stone fruits and their products is allergenicity. Food allergies linked to stone fruits have been widely observed and documented in the European and Mediterranean population with reactions ranging from mild (local) to severe (systemic) (Brenna and others 2000; Brenna and others 2005; Oussama and others 2007). The unique feature of this phenomenon is the observed allergenic cross-reactivity among fruits of the family Rosaceae, and between these and the pollen of birch (*Betula* sp.) trees; such linkage between digestive and respiratory allergens is uncommon (Pastorello and others 1994). It also significantly increases the risk of allergic episodes since an individual, once sensitized to the allergen from one source, may be susceptible to allergic reactions by consumption or inhalation of related fruit or pollen. The exact mechanism of cross-reactivity is still unknown, but some headway has been made in identifying and characterising relevant proteins: Pru p 1, a PR-10 14 kDa protein, and Pru p 3, a PR-14 9 kDa non specific lipid transfer protein (nsLTP) highly resistant to extremes of temperature and pH (Pastorello and others 1999; Hoffmann-Sommergruber 2002; Immunocap 2009).

Significant research has been conducted on these two allergens in the Mediterranean where they present a problem, and Japan, for scientific interest and as a proactive measure. Although most American varieties originate from Europe and some have proven to have high concentrations of these allergens no significant medical issues have been reported till date (Oussama and others 2007). This may be due to a genetic dilution of varieties or a less susceptible consumer population.

Aim of project

Given the challenges involved in the cultivation of peaches and apricots in Northeast, most research on available varieties has revolved around improving climatic adaptation, disease and pest resistance. The nutritional implications of these modifications have not received adequate attention, although some work has been conducted on physical, chemical and sensory characteristics (Lamb and Terry 1973; Lamb and Stiles 1983; Brown and others 1986). Available literature is from major producing states such as California and it is therefore necessary to determine how the unique conditions in the Northeast impact varietal traits and nutrients.

With current trends for increased consumption of fruits and vegetables and increased awareness about health complications and diseases linked to poor diet choices, consumers are looking for good quality products with proven health benefits. The primary aim of this research project was therefore to provide information on the quality and nutraceutical value of peach and apricot varieties commercially available in the Northeast and to increase knowledge about the health benefits of local varieties by assessing their phenolic, carotenoid and antioxidant content in fresh and processed

form. Qualitative and quantitative data obtained were intended to contribute to the appeal and marketability of these local varieties.

The following hypotheses were tested in the course of this project:

- Peach and apricot varieties vary in phytochemical content and composition.
- Fruit maturity at harvest and postharvest storage influences nutritional content.
- Peach and apricot varieties and their beneficial compounds respond differently to processing treatments.

These were addressed over a course of three harvest seasons: 2009, 2010 and 2011. In total, ten peach and five apricot varieties and four categories of processed products were evaluated. In 2009 and 2010, varieties were assessed on the basis of their physical (color, weight, size, firmness, edible portion), chemical (soluble solids, pH, titratable acidity, moisture content) and phytochemical (phenolic, carotenoid and antioxidant) properties. Athough summarized in their respective chapters, detailed information on varietal physical and chemical parameters, as well as pictures, are presented in the appendix (Illustrations A.1 to A.4 and Tables A.1 to A.8).

Of these, three peach and three apricot varieties were selected and evaluated in 2010 for their phytochemical or economic importance and used to study the effects of maturity at harvest and postharvest storage on quality indices and phytochemical content. In the same year, the fruit were utilised in the manufacture of typically processed fruit products – canned fruit, dried fruit, puree, nectar and jam – to study the influence of formulations and processing conditions on nutritional content. The final

harvest season (2011) focused on improving the manufacturing processes and products based on experiences from the previous year. One variety of each fruit type was used for this process and fresh fruit evaluated as in previous years.

The results of the study are presented in this manuscript. The second chapter focuses on the results of varietal, seasonal and maturity at harvest studies for peaches in 2009 and 2010. The third chapter deals similarly with apricots. In the fourth chapter and fifth chapters, observations and results for canned and dried fruit from the 2010 and 2011 seasons are reported. The 2011 jam and nectar study is covered in the sixth chapter. Chapters are presented as individual papers for submission to relevant journals.

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CHAPTER 2: PHENOLIC, ANTIOXIDANT AND CAROTENOID CONTENT OF SELECTED NORTHEAST PEACH VARIETIES AND THE EFFECT OF MATURITY AT HARVEST AND STORAGE ON THESE COMPOUNDS.

Introduction

There is growing evidence to support claims of the healthful benefits of fruit consumption (Kader and Barrett 2005; Sanchez-Moreno and others 2006; Sloan 2010; USDA HHS 2011). The peach, *Prunus persica*, has been found to contain significant quantities of phenolic and carotenoid compounds and is therefore considered a notable source of antioxidants and vitamin A, both recommended for their positive impacts on health (Tomas-Barberan and others 2001; Gil and others 2002; Vizzotto and others 2006). Antioxidants, which include both phenolic and carotenoid compounds, are understood to reduce the risk of cardiovascular diseases and some cancers while carotenoids, particularly those with provitamin A potential, play a role in vision (Ames and others 1993; Fraser and Bramley 2004).

The main phenolic compounds identified in peaches include flavan-3-ols (catechin, epicatechin), cinnamic acids (neochlorogenic acid, chlorogenic acid), flavonol glycosides (quercetin-3-glycosides, rutin) and anthocyanins (cyanidin derivatives) (Tomas-Barberan and others 2001; Gil and others 2002; Shahidi and Naczk 2004; Andreotti and others 2006). Major carotenoids include carotenes (alpha-, beta- and gamma-carotene) and xanthophylls (lutein, zeaxanthin, violaxanthin and beta-cryptoxanthin) (Katayama and others 1971; Breithaupt and Bamedi 2001; Vizzotto and others 2006). The presence and quantities of these are subject to varietal, climatic,

horticultural and plant developmental influences as well as the portion of fruit analyzed (Chang and others 2000; Gil and others 2002; Ramina and others 2008).

In the United States, peach production is based mainly in California (approximately 80%), with Georgia and South Carolina rounding up the top three; the industry has however experienced a decline in recent years (USDA ERS 2011; USDA NASS 2011). The Northeast USA is also a producer, albeit of limited quantities. Cultivation in this region is fraught with challenges due to adverse climatic conditions in coupled with the species' inherent restrictions to climatic adaptation (Merwin 1994; Layne 1996; Hoying and others 2005; NYS Climate Office). Breeding programs have therefore been aimed at improving acclimatization, pest and disease resistance and research on resultant produce focused on aesthetic and sensory characteristics, with little data available on the impact of these modifications on inherent bioactive compounds (Brown and others 1986; Anderson and Seeley 1993; Layne 1996).

In an era with heightened concern and interest about the healthful benefits of various foods, the marketability of fruit and fruit products is increasingly less dependent on their taste and appearance, with greater emphasis placed on their nutritive and nutraceutical potential. The aim of this study was therefore primarily to evaluate phenolic, antioxidant and carotenoid content of a selection of peach varieties currently cultivated in the Northeast. Conducted over a two-year period, it also examined the effect of seasonal variations, fruit maturity and postharvest storage on bioactive compounds. The information obtained will contribute to a more complete picture of peach production in the United States beyond the noted powerhouses of the West and Southeast.

Materials and Methods

Harvest

The study was conducted over two years. Ten yellow-fleshed peach varieties were sourced from local producers in 2009 and 2010. Of these, three varieties were selectively harvested at two developmental stages in 2010 – 'commercial ripe' and 'tree ripe' – with the latter occurring 6 days after the former. Fruit harvested at commercial ripe were stored for four weeks then analysed as a third treatment – storage.

Commercial ripe represented fruit harvested early with adequate firmness to withstand handling, transport and storage conditions until it reaches the final consumer; tree ripe represented fruit intended for local market and almost immediate consumption (ready-to-eat). Harvests were mainly conducted in line with recommendations of and practices by local farms and fruit harvesting personnel. Fruit was considered commercially ripe when it had attained full color and size development while tree ripe fruit had decreased firmness and could easily be abscised from the tree. All fruit was harvested by hand directly by or under the supervision of the same researcher (to reduce bias) and stored at 0 - 1 °C and relative humidity of 90 - 95% until analysis.

Quality indices

Analyses were performed in triplicate, allotting 5 fruit per replicate. Color parameters were measured with a HunterLab UltraScan XE (Hunter Associates Laboratory Inc., Reston, VA) and firmness with a TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY) using a compression test conducted with a 50 mm cylindrical

probe. Weight and cross-sectional diameter were also recorded. Soluble solids (Leica Auto ABBE refractometer; Leica Inc., Buffalo, NY), pH (Accumet Basic AB15 pH meter; Fisher Scientific, Waltham, MA) and titratable acidity in malic acid equivalents (manual titration and Mettler Toledo 20 compact titrator; Mettler-Toledo Inc., Columbus OH) were measured from juice extracted using a food processor. Moisture content values were obtained from the weight differences before and after lyophilisation to constant weight. Homogenized lyophilized fruit was packaged in moisture proof bags and stored at 0 ˚C protected from light until antioxidant, phenolic and carotenoid analyses.

Phenolic analysis

Extraction

Extraction of phenolic compounds followed the method described by Kim and Lee (2002). Ten mL 80% methanol was added to 1 g of freeze-dried sample, headspace flushed with nitrogen and samples sonicated (Branson 200; Fisher Scientific, Waltham, MA) in ice for 20 min, shaking midway. Samples were then centrifuged at 10,000 rpm for 20 min at 4 °C (Sorvall RC-5B Centrifuge; ThermoScientific, Waltham, MA). Supernatant was decanted into a 25 mL volumetric flask and the extraction procedure was repeated. Supernatants were combined and topped up to 25 mL with 80% methanol then transferred into an amber glass vial. Vials were flushed with nitrogen, capped and kept at -30 °C until analysis.

Total phenolic content

Procedures by Singleton and Rossi (1965) and Kim and Lee (2002) were used to determine total phenolic content. A 200 µL aliquot of phenolic extract was added to 2.6 mL distilled deionized water (DDW) in a test tube; 200 µL of Folin-Ciocalteu phenol was added and the mixture left to stand at room temperature for 6 min. Two mL of 7% sodium carbonate solution was added and the mixture vortexed then left to stand for 90 min. Absorbance of final product was measured at 750 nm (Barnstead Turner spectrophotometer SP-830; Thermo Scientific) and expressed in mg gallic acid equivalents (GAE).

HPLC phenolic analysis

Qualitative and quantitative phenolic compounds analyses followed methods of Kim and Padilla-Zakour (2004) and Chantanawarangoon (2005). An Agilent/Hewlett Packard series 1100 (Agilent Tech., Palo Alto, CA) was used with a C18 reversed-phase Symmetry Analytical column (250-mm x 4.6-mm, 5-µm; Water Corp. Milford, MA) and a Symmetry Sentry guard column (Water Corp. Milford, MA) of the same packing material. The thermostat was set at 25 °C and flow rate at 1 mL/min; the diode-array was set to monitor the wavelengths 280 (flavan-3-ols), 320 (cinnamic acids), 370 (flavonol glycosides) and 520 nm (anthocyanins). A linear solvent gradient was composed of a binary mobile phase system with solvent A, 0.1% phosphoric acid in HPLC grade water, and solvent B, 0.1% phosphoric acid in HPLC grade acetonitrile. Solvents were applied for 55 minutes as follows: 92% A/ 8% B at 0 min, 89% A/ 11% B at 4 min, 65% A/ 35% B at 25 min, 40% A/ 60% B at 30 min, 40% A/ 60% B at 40 min, 65% A/ 35% B at 45 min, 89% A/ 11% B at 50 min, 92% A/ 8% B

at 55 min; post-run was for 5 min. One mL of sample was filtered with a 0.45 µm nylon filter (Fisherbrand; Fisher Scientific, Waltham, MA), injected and analysed.

Chlorogenic acid, catechin, epicatechin, rutin, cyanidin-3-glucoside and quercetin-3-glucoside were identified using authentic standards (Sigma Aldrich, St. Louis, MO), while epigallocatechin, neochlorogenic acid, kaempferol-3-rutinoside were identified using retention time and spectra reported in related literature. Results were reported as mg or mg equivalents (eqv) of available standards, with neochlorogenic reported as chlorogenic acid eqv, kaempferol-3-rutinoside as kaempferol eqv, cyanidin-3-glucoside as cyanidin eqv, epigallocatechin and unknown 1 as catechin eqv, and quercetin-3-glucoside, unknown 2 and 3 as quercetin eqv.

Total antioxidant capacity assay

The oxygen radical absorbance capacity (ORAC) assay, as described by Huang and others (2002) and Held (2005) was employed. Aliquots of 25 µL of phenolic extract, blank (75 mM phosphate buffer), and standardized dilutions (0 - 100 µM) of 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox; Sigma Aldrich) were pipetted in triplicate into a Costar 96-well black opaque plate (Corning Costar Corporation, Cambridge, MA) in a preset format. 150 uL of 0.004 µM sodium fluorescein solution was dispensed into each well and the plate inserted into a BioTek Synergy HT plate reader (BioTek Instruments, Winooski, VT). After a 30-min incubation at 37 °C, 25 µL of 2,2'-Azobis (2-amidinopropane) dihydrochloride (AAPH; Wako Chemicals, Richmond VA) was dispensed into each well. The plate was shaken for 10 sec and fluorescence measured at 1 min intervals over 1 hr at 485

nm excitation wavelength and 528 nm emission wavelength. Results were reported as µmol Trolox equivalents (TE).

Carotenoid analysis

A combination of methods by de Sá and Rodriguez-Amaya (2004), Craft (2005), and Kwasniewski and others (2010) was used for the extraction, HPLC identification and quantification of carotenoids. Ground-up freeze dried sample, 1 g, was reconstituted with DDW then extracted with 20 mL of 50:50 methanol/tetrahydrofuran and 10% (w/w) magnesium carbonate. Extracts were centrifuged at 6000 rpm for 10 min at 4 °C, supernatant recovered and precipitate re-extracted. Supernatants were combined and transferred to a separatory funnel with 50 mL petroleum ether stabilized with 0.2% butylhydroxytoluene (BHT) and 25 mL 20% sodium chloride solution. Upon phase separation, the petroleum ether fraction was collected and evaporated almost to dryness with a rotary vacuum (Buchi rotavapor R-114; Flawil, Switzerland) finishing under nitrogen gas. Aliquots were dissolved in 2 mL ethanol stabilized with 30 ppm BHT and samples filtered with a 0.2 µm PTFE filter (Millipore Millex; Billerica, MA) prior to injection.

An Agilent series 1100 with a Zorbax XDB-C18 column (150 mm x 4.6 mm, 5 µm; Agilent Tech., Palo Alto, CA) fitted with a guard column of the same packing material was used. The thermostat was set at 23 °C and flow rate at 1 mL/min; the diode-array was set to monitor the wavelengths 450, 455, 470 and 475 nm. A gradient was set up with a binary mobile phase system of solvent A, 0.1% phosphoric acid in HPLC grade water, and solvent B, 0.1% phosphoric acid in HPLC grade acetone. Solvents were

applied for 35 min as follows: 30% A/ 70% B from 0 to 20 min, 0% A/ 100% B from 20 to 30 min and 70% A/ 30% B from 30 to 35 min with a 5 min post-run. β-carotene, β-cryptoxanthin, zeaxanthin and lutein were identified and quantified using authentic reference samples (Sigma Aldrich) and astaxanthin used as an internal standard. Results were reported as µg or µg equivalents (eqv) of available standards. Total carotenoid content was derived by the summation of individual compound concentrations expressed in β-carotene equivalents.

Statistical analysis

Data was analysed with JMP 9.0 Statistical Software (SAS Institute Inc, Cary, NC). Tests included multivariate analysis, analysis of variance (ANOVA) at $p < 0.01$ and $p < 0.05$ and comparison of means with the Tukey Significant Difference test at 95% confidence interval. Data for bioactive compounds was reported per 100 g edible portion (flesh+skin) of fresh fruit.

Results and discussion

Varietal characterization

There was significant variation in the harvest dates of varieties over the two years, presumably due to different weather conditions each year (Table 2.1). Varieties obtained were a mix of clingstone, semi-clingstone and freestone, as well as melting and non-melting flesh, with varietal characteristics observed largely corresponding with available literature (Okie 1998; Wheatley and Thuente 2001, Frecon and Ward 2008). In both study years, 'Redhaven' peach was the earliest to ripen, in agreement with Okie (1998), and 'Babygold 5' the latest.

Table 2.1. Source, flesh adherence and harvest dates of evaluated Northeast peach varieties.

Variety	Source (Orchard)	Flesh adherence to pit	Harvest dates	
			2009	2010
Babygold 5	1	Clingstone	Sept 8	Aug 29
Bounty	2	Freestone	Sept 7	Aug 29
Harrow Beauty	2	Freestone	Aug 24	Aug 29
John Boy	2	Semi-clingstone	Aug 24	Aug 17
John Boy II	2	Freestone	Aug 24	Aug 17, Aug 23
PF 22-007	2	Freestone	Sept 7	Aug 23
PF 23	2	Freestone	Aug 24	Aug 23, Aug 29
PF Lucky 13	2	Freestone	Aug 24	Aug 11
Redhaven	3	Semi-clingstone	Aug 14	Aug 4, Aug 10
Vivid	2	Freestone	Aug 20	Aug 10

Contributing orchards: Orchard 1 (Geneva, NY), Orchard 2 (Phelps, NY); Orchard 3 (Geneva, NY).

Quality indices

Mean firmness, weight, cross-sectional diameter and edible portion percentage for the evaluated varieties, with ranges in parentheses, were 41.7 N (24.6 – 51.4), 184.7 g (96 - 296), 70.1 mm (56.5 – 83.3) and 95.1% (93.2 – 96.6). Fruit weight correlated strongly with size ($r > 0.97$) with 'PF 22-007' the largest variety in terms of both size and weight, while 'Harrow Beauty' was the smallest. 'Harrow Beauty' also ranked highest in firmness. When left to ripen and soften on the tree, the flesh of this variety attains an undesirable, mealy texture. It is therefore preferably harvested while still firm and ripened off-tree under cool conditions.

Visually, in 2009 the fruit were larger than those obtained in 2010 (2009 size data not available). A possible explanation for these variations was the difference in climatic factors over the two years. Average temperature, rainfall and relative humidity (hours with RH $\geq$ 90) over the two growing seasons of March through September were 14.0

°C, 7.4 cm, 262.4 h for 2009 and 16.2 °C, 4.6 cm, 266.1 h for 2010 (NEWA 2011). Rainfall was copious throughout the 2009 growing season and negligible post-June in 2010. Overall rainfall amount and pattern, particularly the water deficit late in the season (stage III of fruit growth – cell expansion) may explain the smaller fruit in 2010 due to smaller cell size (Crisosto and others 1994; Behboudian and Mills 1997; Johnson 2008). Additionally, pruning and thinning practices in the two years, given these were not strictly controlled research orchards, could have exerted some influence since early removal of competing flowers/fruits during stage I (cell-division) can increase cell numbers (Scorza and others 1991; Marini and Reighard 2008).

Color was reported as Hunter components *L* (lightness), *a* (red/green), *b* (yellow/blue), *H* (hue angle)[2], and *C* (chroma)[3]; *a* and *b* were consistently in the positive range indicating the colors red and yellow (McLellan and others 1995). A comparison of varietal skin color from 2009 to 2010 showed decreases in all five color parameters (Table 2.2); differences in flesh color between the two years were less uniform. Possible links between these observations and available climate data were not found. Given the suggested relationship between light exposure and particularly red color development (Bassi and Monet 2008), skin color data may be more informative when considered together with measured annual or monthly light availability or exposure. Observed correlations between color parameters and other measured variables are identified and discussed in later sections.

[2] Hue angle = $\tan^{-1}$ (b/a)

[3] Chroma = $\sqrt{(a^2 + b^2)}$

Table 2.2. Mean values and ranges of quality indices of Northeast peach varieties evaluated in 2009 and 2010 (n = 15).

Parameters	2009		2010	
	Mean	Range	Mean	Range
Skin *L*	50.9[a]	40.3 – 59.5	47.0[b]	41.9 – 58.2
Skin *a*	27.9[a]	18.5 – 33.2	23.2[b]	17.3 – 31.3
Skin *b*	31.5[a]	22.4 – 40.3	24.4[b]	17.4 – 38.0
Skin *H*	47.0[a]	36. 8 – 57.7	43.2[b]	34.8 – 61.0
Skin *C*	42.3[a]	29.0 – 48.9	33.9[b]	24.6 – 42.3
Flesh *L*	68.3[a]	59.7 – 74.8	62.3[b]	56.1 – 68.0
Flesh *a*	8.8[b]	4.8 – 13.6	11.2[a]	8.6 – 13.7
Flesh *b*	43.8[b]	38.4 – 48.2	45.7[a]	40.2 – 51.0
Flesh *H*	78.6[a]	78.6 – 82.9	76.0[b]	71.4 – 80.0
Flesh *C*	44.7[b]	38.7 – 49.2	47.1[a]	41.7 – 52.1
Soluble solids (%)	10.0[a]	8.3 – 12.9	11.0[b]	8.51 – 13.0
Titratable acidity	0.58[b]	0.44 – 0.74	0.70[a]	0.51 – 1.01
Sugar-to-acid ratio	17.5[a]	13.1 – 23.5	16.0[a]	11.5 – 21.0
pH	3.62[a]	3.39 – 3.93	3.62[a]	3.39 – 4.01
Moisture content (%)	88.6[b]	86.2 – 90.8	87.7[a]	85.3 – 90.3

Means not connected by the same letter indicate a significant difference in that parameter between the two years (alpha = 0.05).

Peach soluble solids content (SSC) was within the ranges of 8 – 12% and 8 – 14% given by Kader and Mitchell (1989a) and Okie (1998). ‘PF23’ and ‘PF 22-007’ ranked highly in both years with ‘Redhaven’ consistently showing low values. Mean SSC increased in 2010 while mean moisture content, inversely correlated to SSC, decreased. Both observations can be attributed to rainfall patterns in these years, particularly the low amount of rain four to six weeks before the 2010 harvest resulting in a greater concentration of soluble solids in 2010 (Li and others 1989, Crisosto and others 1994, Crisosto and Costa 2008). Fruit pH remained steady across both years and was within the range of 3.5 – 3.8 provided by Tomas-Barberan and others (2001) for yellow-fleshed peaches. Titratable acidity (TA) was comparable to values given by Gil and others (2002), 0.45 – 0.87 and Kader and Mitchell (1989a), 0.4 – 0.9.

Sugar-to-acid ratio (SSC/TA) was computed from measured SSC and TA and did not differ significantly between years, despite significant increases in some individual varieties (‘Babygold 5’ and ‘Redhaven’). SSC/TA is an indication of the perceived sweetness and palatability of fruit. However, other attributes such as firmness and water concentration (Lopez and others 2011) and fruit maturity at harvest (Vallverdu and others 2012) affect the quality of fruit.

These observations regarding the multifactorial nature of perceived fruit quality were confirmed by a sensory (hedonic) test conducted in 2010 with freshly cut tree ripe peach slices (Figure 2.1). Correlations were not found between SSC/TA and acceptability, with ‘Bounty’ being most accepted and ‘PF Lucky 13’, the most popular of the Flaming Fury® peaches (Friday 2011), least accepted. ‘PF 23’, despite its low SSC/TA, was second highest, with panel members responding positively to its ‘juiciness’. Harvest date and postharvest storage also influenced perception, as varieties with later harvest dates – obtained closer to the sensory test and stored for shorter periods – were typically ranked higher than varieties which were harvested earlier in the season. A better representation of consumer acceptability could be acquired by conducting tests within equivalent periods after harvest for the various varieties.

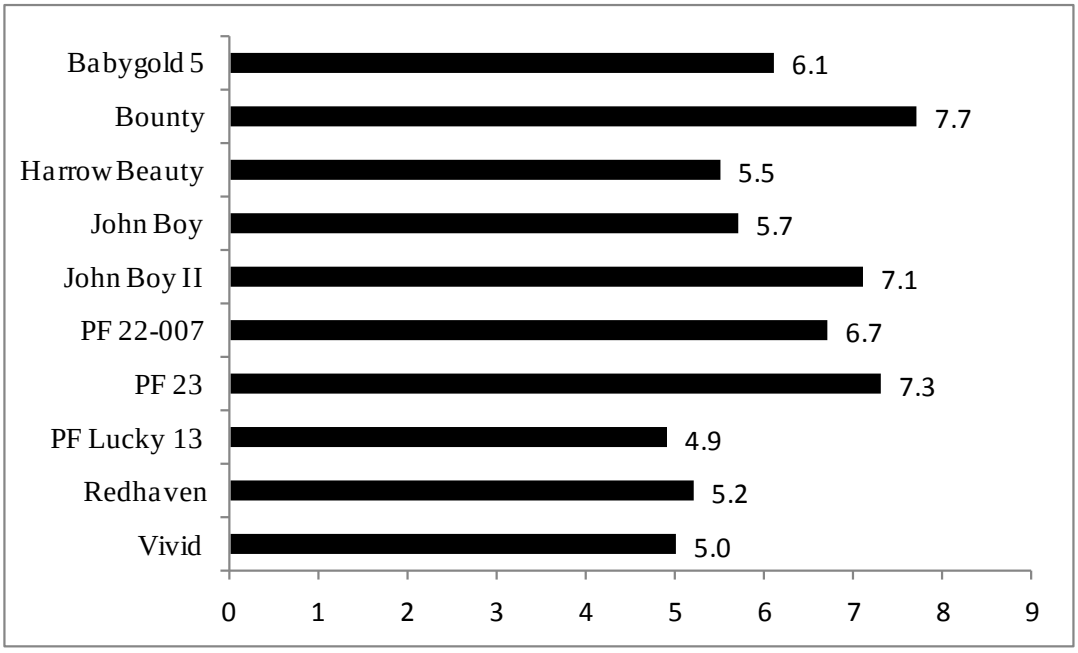

Figure 2.1. Results of sensory evaluation showing acceptability of selected Northeast peach varieties in 2010 with ranking based on a 9-point hedonic scale (n = 20).

Phenolic content

Mean total phenolic content (TP) of peaches was similar in the two years, being 53 mg in 2009 and 54 mg in 2010. These values were similar to those reported by Marinova and others (2005), 50.9 mg, and fell within the range given by Chang and others (2000), 41.5 – 76.5 mg, but were lower than those reported by Wu and others (2004) and the USDA database for the phenolic content of selected foods (2010), 163 and 133 mg respectively. The latter two sources did not specify the color of fruit and may have included values for white-fleshed peaches, which have been found to have higher phenolic content as compared to yellow-fleshed ones (Gil and others 2002; Bassi and Monet 2008). 2009 TP ranges were from 40 (‘PF Lucky 13’) to 89 (‘PF 23’) and 2010’s from 36 (‘PF Lucky 13’) to 103 mg (‘PF 22-007’) (Figure 2.2).

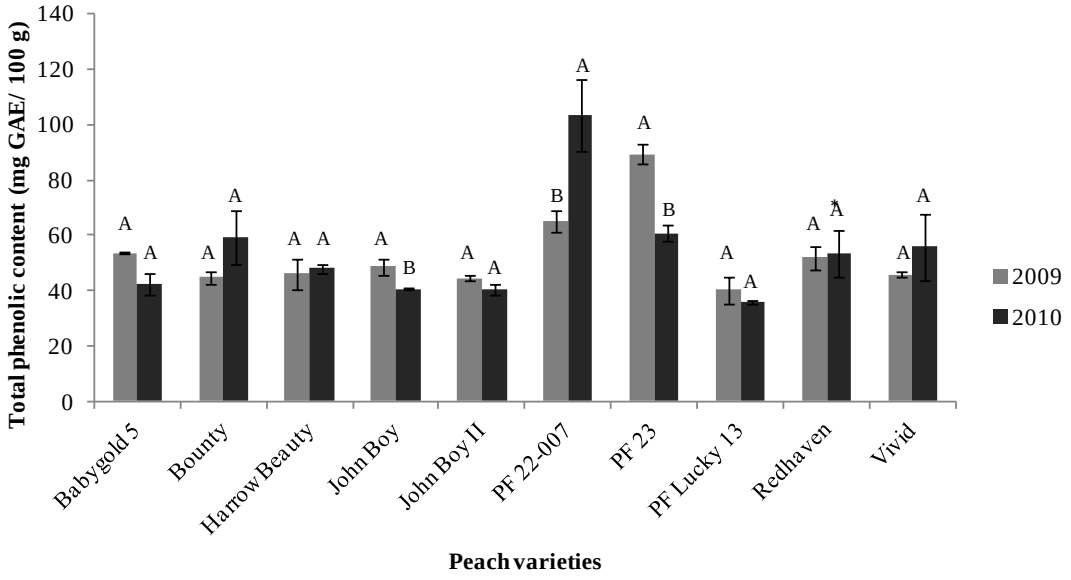

Figure 2.2. Total phenolic content of Northeast peach varieties evaluated in 2009 and 2010 (GAE:Gallic acid equivalents). Bars not connected by the same letter indicate a significant difference between the two years (alpha = 0.05).

Varieties exhibited similar phenolic compound composition (Figure 2.3), although epigallocatechin was absent in some varieties in 2009 (Table 2.3). Flavan-3-ols were most qualitatively diverse and together with hydroxycinnamates were found in greatest concentrations. Overall, ranges for these compounds among varieties (per 100 g whole fruit) were as follows: Flavan-3-ols: catechin (0.3 – 12 mg), epicatechin (1.8 – 5.8 mg), epigallocatechin (0.2 – 8.0 mg) and unknown 1 (0.3 – 2.9 mg); hydroxycinnamic acids: chlorogenic acid (1 – 10 mg) and neochlorogenic acid (1.2 – 8.0 mg); flavonol glycosides: kaempferol-3-rutinoside (3.1 – 6.4 mg), quercetin-3-glucoside (0.4 – 0.8 mg), rutin (0.46 – 0.83 mg), unknown 2 (0.5 – 0.9 mg) and unknown 3 (0.4 – 0.9 mg); anthocyanins: cyanidin-3-glucoside (0.7 – 6.2 mg).

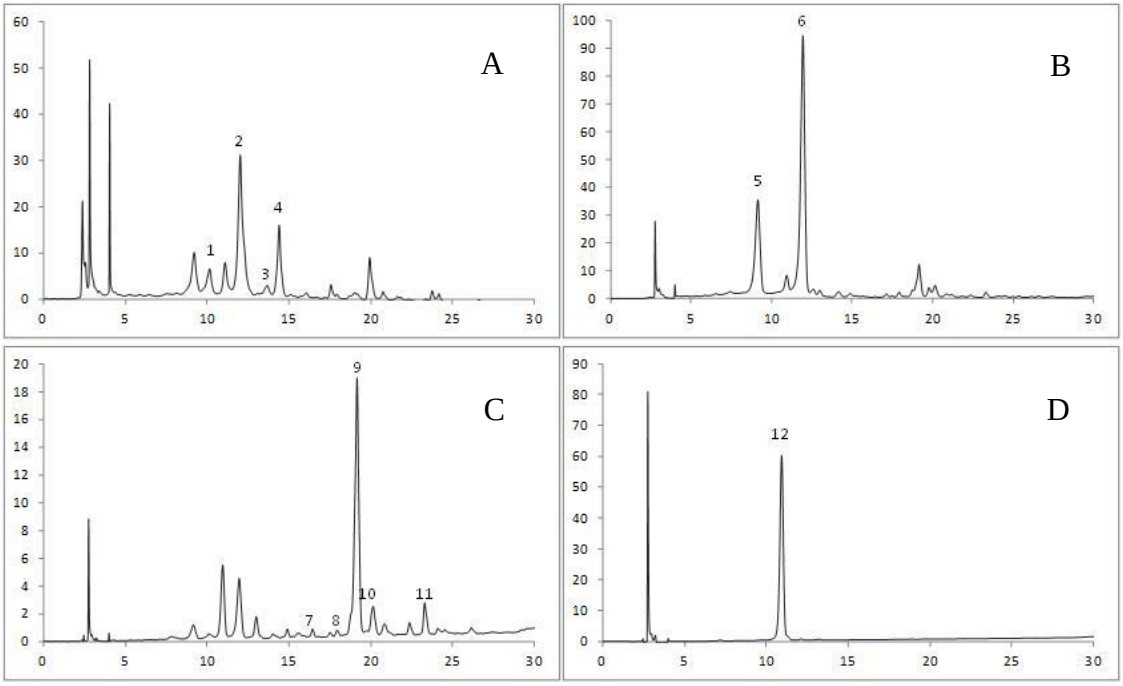

Figure 2.3. HPLC chromatograms of a peach showing phenolic compounds at 280 nm (A), 320 nm (B), 370 nm (C) and 520 nm (D). Compounds identified are epigallocatechin (1), catechin (2), unknown 1 (3), epicatechin (4), neochlorogenic acid (5), chlorogenic acid (6), rutin (7), quercetin-3-glucoside (8), kaempferol-3-rutinoside (9), unknown 2 (10), unknown 3 (11) and cyanidin-3-glucoside (12).

A rather weak correlation of $r > 0.64$ was found between spectrophotometrically-determined TP and HPLC-determined TP. Contrary to spectrophotometric-TP, mean 2010 HPLC-TP (31.0) was significantly higher than that of 2009 (28.8). Recognizing this as a more accurate measure of phenolic content, this disparity was attributed to the difference in rainfall in the two years.

Table 2.3. Phenolic compounds (mg/100 g) in Northeast peach varieties evaluated in 2009 and 2010 (n = 3).

Phenolic compounds	Babygold 5		Bounty		Harrow Beauty	
	2009	2010	2009	2010	2009	2010
Catechin	0.4 ± 0.2[a]	6.4 ± 0.2[b]	2.3 ± 0.1[b]	4.9 ± 0.9[a]	0.5 ± 0.0[b]	3.4 ± 0.2[a]
Chlorogenic acid	5.8 ± 0.9[a]	6.1 ± 0.8[a]	6.5 ± 0.8[b]	8.1 ± 0.2[a]	2.7 ± 0.4[b]	3.7 ± 0.3[a]
Cyanidin-3-glucoside	3.4 ± 0.5[a]	1.3 ± 0.0[b]	1.5 ± 0.3[b]	3.9 ± 0.1[a]	1.6 ± 0.5[b]	9.7 ± 2.4[a]
Epicatechin	5.0 ± 0.7[b]	5.9 ± 1.1[a]	4.3 ± 0.5[a]	4.4 ± 0.1[a]	3.7 ± 0.3[b]	4.5 ± 0.0[a]
Epigallocatechin	1.5 ± 0.3[b]	4.6 ± 0.1[a]	3.8 ± 0.3[a]	3.4 ± 0.2[a]	0.2 ± 0.0[b]	1.4 ± 0.3[a]
Kaempferol-3-rutinoside	4.6 ± 0.3[a]	6.4 ± 0.8[b]	3.8 ± 0.4[b]	5.8 ± 0.8[a]	3.9 ± 0.2[b]	5.2 ± 0.3[a]
Neochlorogenic acid	3.7 ± 1.3 [a]	2.9 ± 0.4[a]	4.3 ± 0.5[a]	3.6 ± 0.5[a]	4.6 ± 0.2[a]	1.8 ± 0.2[b]
Quercetin-3-glucoside	0.58 ± 0.03[b]	0.77 ± 0.02[a]	0.50 ± 0.02[b]	0.81 ± 0.07[a]	0.55 ± 0.01[b]	0.75 ± 0.03[a]
Rutin	0.63 ± 0.04[b]	0.83 ± 0.04[a]	0.56 ± 0.06[b]	0.82 ± 0.04[a]	0.60 ± 0.01[b]	0.78 ± 0.01[a]
Unknown 1	2.40 ± 0.01[b]	2.87 ± 0.17[a]	2.02 ± 0.06[a]	2.43 ± 0.52[a]	0.92 ± 0.22[b]	2.10 ± 0.52[a]
Unknown 2	0.67 ± 0.03[b]	0.92 ± 0.06[b]	0.53 ± 0.03[b]	0.78 ± 0.04[a]	0.60 ± 0.02[b]	0.74 ± 0.05[a]
Unknown 3	0.63 ± 0.04[b]	0.88 ± 0.04[a]	0.49 ± 0.03[b]	0.74 ± 0.05[a]	0.57 ± 0.02b	0.68 ± 0.05a
Total	**29.3 ± 4.4[b]**	**39.9 ± 3.7[a]**	**30.6 ± 3.1[b]**	**39.7 ± 3.5[a]**	**20.4 ± 1.9[b]**	**34.8 ± 4.4[a]**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the two years (alpha = 0.05).

Table 2.3. (Continued).

Phenolic compounds	John Boy		John Boy II		PF 22-007	
	2009	2010	2009	2010	2009	2010
Catechin	0.9 ± 0.1[b]	2.1 ± 0.1[a]	0.6 ± 0.1[b]	2.3 ± 0.4[a]	3.2 ± 1.3[b]	12.4 ± 0.7[a]
Chlorogenic acid	2.0 ± 0.3[a]	2.1 ± 0.2[a]	2.2 ± 1.2[a]	2.2 ± 0.5[a]	2.4 ± 0.2[b]	6.3 ± 0.3[a]
Cyanidin-3-glucoside	3.2 ± 0.8[b]	5.3 ± 0.3[a]	1.9 ± 0.5[a]	2.6 ± 0.1[a]	4.9 ± 0.4[a]	4.3 ± 0.0[a]
Epicatechin	2.8 ± 0.2[b]	4.1 ± 0.2[a]	3.3 ± 1.2[b]	5.2 ± 0.6[a]	2.6 ± 0.3[b]	3.5 ± 0.4[a]
Epigallocatechin	ND	1.7 ± 0.5	ND	1.4 ± 0.5	1.0 ± 0.0[b]	8.0 ± 0.7[a]
Kaempferol-3-rutinoside	4.0 ± 0.5[a]	4.8 ± 0.3[a]	4.5 ± 0.2[a]	4.9 ± 0.3[a]	4.1 ± 0.2[b]	5.2 ± 0.1[a]
Neochlorogenic acid	2.3 ± 0.4[a]	1.5 ± 0.0[b]	2.5 ± 1.3[a]	1.6 ± 0.4[a]	4.5 ± 0.8[a]	4.9 ± 0.3[a]
Quercetin-3-glucoside	0.55 ± 0.04[b]	0.66 ± 0.03[a]	0.65 ± 0.02[a]	0.63 ± 0.07[a]	0.61 ± 0.06[b]	0.76 ± 0.06[a]
Rutin	0.58 ± 0.06[b]	0.68 ± 0.00[a]	0.68 ± 0.05[a]	0.60 ± 0.04[a]	0.65 ± 0.10[b]	0.76 ± 0.06[a]
Unknown 1	1.12 ± 0.14[a]	1.06 ± 0.07[a]	0.59 ± 0.13[b]	1.51 ± 0.05[a]	0.91 ± 0.10[b]	2.95 ± 0.18[a]
Unknown 2	0.58 ± 0.03[b]	0.70 ± 0.06[a]	0.58 ± 0.03[b]	0.70 ± 0.06[a]	0.65 ± 0.03[b]	0.78 ± 0.02[a]
Unknown 3	0.58 ± 0.03[b]	0.69 ± 0.03[a]	0.58 ± 0.03[b]	0.69 ± 0.03[a]	0.61 ± 0.01[b]	0.74 ± 0.02[a]
Total	**18.61 ± 2.6[b]**	**25.4 ± 1.8[a]**	**18.1 ± 4.8[a]**	**24.3 ± 3.1[a]**	**26.1 ± 3.5[b]**	**50.6 ± 2.8[a]**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the two years (alpha = 0.05).

Table 2.3. (Continued).

Phenolic compounds	PF 23		PF Lucky 13		Redhaven	
	2009	2010	2009	2010	2009	2010
Catechin	6.8 ± 0.8[a]	3.7 ± 0.4[b]	0.4 ± 0.1[b]	2.1 ± 1.0[a]	1.7 ± 0.5[b]	3.6 ± 0.3[a]
Chlorogenic acid	8.5 ± 1.9[a]	4.5 ± 0.5[b]	3.5 ± 0.4[a]	2.2 ± 0.1[b]	3.2 ± 0.2[b]	3.6 ± 0.0[a]
Cyanidin-3-glucoside	2.1 ± 0.9[b]	6.2 ± 0.9[a]	2.0 ± 0.7[b]	5.0 ± 0.8[a]	1.3 ± 0.3[b]	2.1 ± 0.4[a]
Epicatechin	1.8 ± 0.1[b]	5.8 ± 0.4[a]	2.0 ± 0.2[a]	2.6 ± 0.6[a]	4.3 ± 0.4[a]	3.8 ± 0.2[a]
Epigallocatechin	3.7 ± 0.7[a]	1.6 ± 0.3[b]	ND	0.5 ± 0.0	1.6 ± 0.2[b]	2.2 ± 0.2[a]
Kaempferol-3-rutinoside	3.9 ± 0.2[b]	6.0 ± 0.3[a]	3.1 ± 0.0[b]	4.7 ± 0.4[a]	3.3 ± 0.5[a]	4.2 ± 0.5[a]
Neochlorogenic acid	8.0 ± 0.7[a]	1.9 ± 0.0[b]	2.7 ± 0.8[a]	1.2 ± 0.0[b]	3.7 ± 0.8[a]	1.8 ± 0.0[b]
Quercetin-3-glucoside	0.58 ± 0.03[b]	0.78 ± 0.06[a]	0.47 ± 0.01[b]	0.67 ± 0.02[a]	0.48 ± 0.07[b]	0.65 ± 0.06[a]
Rutin	0.57 ± 0.00[b]	0.74 ± 0.03[a]	0.46 ± 0.01[b]	0.62 ± 0.03[a]	0.51 ± 0.10[a]	0.64 ± 0.05[a]
Unknown 1	1.89 ± 0.12[a]	2.03 ± 0.02[a]	0.41 ± 0.05[b]	0.89 ± 0.19[a]	0.84 ± 0.30[a]	1.12 ± 0.10[a]
Unknown 2	0.60 ± 0.00[b]	0.84 ± 0.02[a]	0.51 ± 0.00[b]	0.70 ± 0.05[a]	0.50 ± 0.02[b]	0.67 ± 0.06[a]
Unknown 3	0.58 ± 0.01[a]	0.81 ± 0.04[a]	0.48 ± 0.0[b]	0.68 ± 0.05[a]	0.45 ± 0.02[b]	0.61 ± 0.08[a]
Total	**39.0 ± 5.5[a]**	**34.9 ± 3.0[a]**	**16.0 ± 2.3[a]**	**21.9 ± 3.2[a]**	**21.9 ± 3.4[a]**	**25.0 ± 2.0[a]**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the two years (alpha = 0.05).

Table 2.3. (Continued).

Phenolic compounds	Vivid	
	2009	2010
Catechin	2.1 ± 0.8[b]	7.6 ± 1.6[a]
Chlorogenic acid	10.0 ± 2.1[a]	10.0 ± 1.3[a]
Cyanidin-3-glucoside	1.7 ± 1.1[b]	4.6 ± 0.6[a]
Epicatechin	3.0 ± 0.1[b]	5.6 ± 0.7[a]
Epigallocatechin	3.0 ± 0.5[b]	5.4 ± 1.0[a]
Kaempferol-3-rutinoside	3.4 ± 0.2[b]	4.8 ± 0.6[a]
Neochlorogenic acid	4.8 ± 2.2[a]	4.7 ± 0.2[a]
Quercetin-3-glucoside	0.53 ± 0.02[a]	0.63 ± 0.05[a]
Rutin	0.53 ± 0.04[a]	0.61 ± 0.05[a]
Unknown 1	0.56 ± 0.04[b]	2.00 ± 0.30[a]
Unknown 2	0.56 ± 0.04[b]	0.71 ± 0.08[a]
Unknown 3	0.51 ± 0.03[b]	0.64 ± 0.06[a]
Total	**30.7 ± 7.2[b]**	**47.3 ± 6.5[a]**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the two years (alpha = 0.05).

While Balakumar and others (1993) and Estiarte and others (1994) observed some increases in phenolic content of cowpea and pepper leaves with water stress, Tavarini and others (2011) found this phenomenon to vary with peach variety and class of phenolic compound assessed while Buendia and others (2008) found concentrations to increase in the peel but not the flesh of fruit. In this study, increases were observed in some varieties but not others, 'PF 22-007' showed the greatest response, doubling in HPLC-TP from 2009 to 2010. Changes in individual phenolic compound concentration were also variety-dependent with no common trend observed.

Correlations were found between HPLC-TP and catechin ($r > 0.89$) and epigallocatechin ($r > 0.86$), with varieties having highest spectrophotometric-TP and HPLC-TP ('PF 23' in 2009 and 'PF 22-007' in 2010) having consistently higher quantities of these compounds. Levels of these two compounds may therefore be considered indicative of fruit phenolic content. The susceptibility of epigallocatechin to varietal and seasonal influences underlines the need for further clarification regarding the nutraceutical properties of individual phenolic compounds in order to better understand the implications of their absence in fruit varieties or products.

No significant correlations were found between total or individual phenolic content and any quality (physical or chemical) index, although it was noted that 'Harrow Beauty', which presented visually with a uniform deep red color, was relatively high in anthocyanin content. The lack of further information and/or diversity was thought to be due to the phenotypic similarities in varieties used, in contrast to a study by Vizzotto and others (2007) where phenolic and particularly anthocyanin content was

found to have some correlation with flesh color, being highest in red-fleshed peaches, followed by white- and yellow-fleshed ones.

Antioxidant capacity

In 2009, noting the contribution of both phenolic and carotenoid compounds to total antioxidant capacity (AOX), hydrophilic and lipophilic antioxidant capacities were measured separately (Prior and others 2003). The highest contribution was however found to be from the hydrophilic fraction, correlating highly with AOX ($r > 0.91$), with lipophilic compounds contributing on average only 3% of AOX (data not shown). This observation informed the decision to employ a variation of the ORAC assay by Huang and others (2002) which more directly determined AOX (Figure 2.4); it had previously not been used due to its propensity to favor hydrophilic antioxidants.

A good correlation was found between AOX and both spectrophotometric-TP ($r > 0.73$) and HPLC-TP ($r > 0.76$), agreeing with work by Gil and others (2002) and Prior and others (2003). Accordingly, varieties with greatest phenolic content in the two years – 'PF 23' in 2009 and 'PF 22-007' in 2010 – had greatest AOX, 2218 and 3020 µmol respectively. 'PF Lucky 13' had the least AOX in both years (865 µmol in 2009 and 1160 µmol in 2010).

It is difficult to compare these AOX values reliably with those from other studies, mainly due the various means by which AOX is measured, given credence to the need for a standardized mode of measurement. However, in 2010 the AOX (1973 µmol TE)

was very close to the peach ORAC values supplied by the USDA antioxidant database for selected foods (2010), 1922.0 µmol, and by Wolfe and others (2008), 1848 µmol.

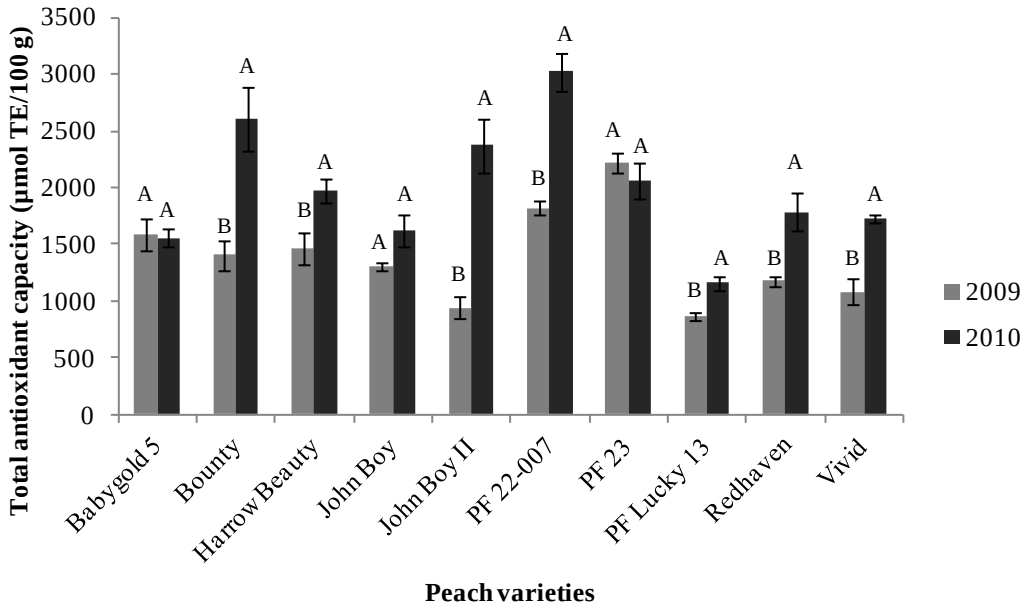

Figure 2.4. Total antioxidant capacity (ORAC) of Northeast peach varieties evaluated in 2009 and 2010 (TE: Trolox equivalents). Bars not connected by the same letter indicate a significant difference between the two years (alpha = 0.05).

Wang and others (2006) and Buendia and others (2008) found that changes in climatic factors including irrigation and sunlight exposure could influence the concentration and stability of antioxidant constituents and metabolites; Buendia and others also reported a decrease in antioxidant content with regulated deficit irrigation, although their assessment was based primarily on vitamin C content. In our study, the 2010 mean AOX of all varieties, 1973.2, was 40% higher than that of 2009, 1386.6 ($p < 0.01$); the majority of varieties showed increases. Given the relationship between antioxidant and phenolic content, and the antioxidant assay used (ORAC), this

increase was attributed to the differences in rainfall, between the two years, with water stress leading to increases in both phenolic and antioxidant content. ORAC results were also in better agreement with HPLC-TP, implying that this was a better indicator of antioxidant content than spectrophotometric-TP and more accurately showed seasonal variation.

Carotenoid content

Total carotenoid content (TC) was obtained by expressing concentrations of identified compounds as µg β-carotene equivalents (BCE). An earlier procedure to spectrophotometrically measure total carotenoid content using a modification of the method by Davis and others (2007) showed large, inconsistent variations and was therefore discontinued.

Carotenoid content varied considerably between varieties, particularly in 2009 (Figure 2.5). 'Babygold 5' had highest TC in both years (596 and 839 µg in 2009 and 2010 respectively) while 'Redhaven' was lowest in 2009 (124.4) and PF 22-007 in 2010 (425.0). Mean total carotenoid values exceeded the range reported by Gil and others (2002) for selected Carlifornia-grown yellow-fleshed peaches (71 – 210 µg/100 g) but were lower than those from Vizzotto and others (2006), 2000 – 3000 µg BC/100 g. 2010 carotenoid concentration fell within the range of 800 to 3700 µg given by Vizzotto and others (2007) for yellow-fleshed peach genotypes. These significant differences in reported values may be in part due to the various methods of analysis and quantification employed.

Mean for 2009 was 354 µg while that for 2010 was 60% higher at 558 µg BCE. This was in contrast to observations by Buendia and others (2008) who reported decreases with deficit irrigation but also mentioned influences by other factors including crop load and sunlight exposure. In our study, variety played an important role in the degree of fruit carotenoid response to water stress.

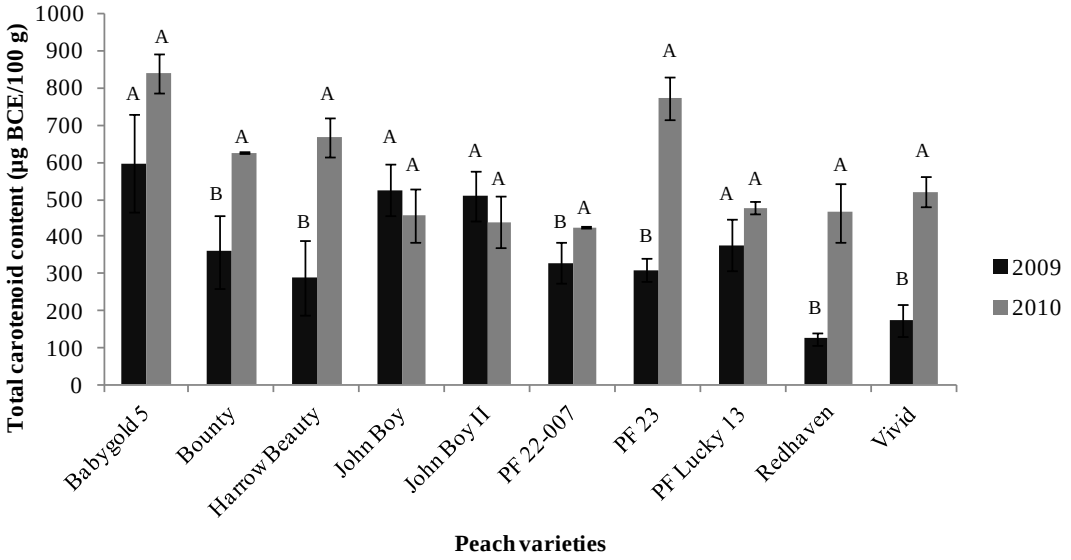

Figure 2.5. Total carotenoid content of Northeast peach varieties evaluated in 2009 and 2010 (BCE: β-carotene equivalents). Bars not connected by the same letter indicate a significant difference between the two years (alpha = 0.05).

Previous studies have reported links between fruit quality, carotenoid content and color variables, with color variable *a* being identified as indicative of fruit maturity (Kader and others 1982; Tourjee and others 1998). In our study, the flesh color variable *a* did show a correlation with TC ($r > 0.63$); although this was not particularly high, it was the strongest correlation between TC and any other physical variable. Ruiz and others (2005) have reported a similar correlation between apricot flesh *a* and total

carotenoid content (0.93). This parameter has potential as a means of assessing peach fruit carotenoid content.

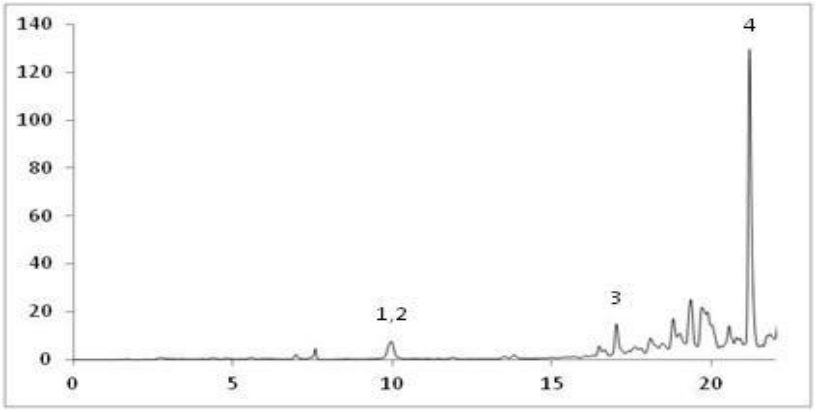

Figure 2.6. HPLC chromatograms of peach varieties showing carotenoid compounds at 450 nm. Compounds identified are zeaxanthin (1), lutein (2), β-cryptoxanthin (3) and β-carotene (4).

Four carotenoid compounds were definitively identified (Figure 2.6) and their ranges are as follows: β-carotene (62.1 – 588.1 µg), β-cryptoxanthin (3.6 – 57.6 µg), lutein (5.8 – 7.9 µg) and zeanxanthin (50.5 – 401.9). While β-carotene, β-cryptoxanthin and zeaxanthin were found in all varieties, lutein were absent in some (Table 2.4). Although α-carotene has been found in some peach varieties (Gil and others 2002) it was not found in ours. A number of unidentified compounds, including one tentatively identified as violaxanthin, were also noted. β-carotene was the main indicator of total carotenoid content, showing strong correlations in both years ($r > 0.9$). As previously mentioned, some carotenoids, notable β-carotene, possess antioxidant properties; in this study, no correlations were observed between β-carotene or TC and AOX.

The main appeal of high carotenoids content in peach varieties remains their vitamin A potential. This was evaluated taking into consideration the recommended dietary allowance (RDA) of 900 μg retinol activity equivalent (RAE) given by the Institute of Medicine for males 14 years and older, and accepted methods of calculation of dietary provitamin A (1 RAE = 12 μg β –carotene and 24 μg β –cryptoxanthin) (USDA FNC 2011; NIH 2012). Peach varieties assessed provided 1 to 7% RDA for vitamin A in a 154 g serving (USDA NAL 2012), making them noteworthy sources of this nutrient.

Table 2.3. Carotenoid compounds (µg/100 g) in Northeast peach varieties evaluated in 2009 and 2010 (n = 3).

Carotenoid compounds	Babygold 5		Bounty		Harrow Beauty		John Boy	
	2009	2010	2009	2010	2009	2010	2009	2010
Beta-carotene	520 ± 19^{a}	550 ± 83^{a}	189 ± 67^{b}	380 ± 45^{a}	207 ± 20^{b}	510 ± 65^{a}	321 ± 38^{a}	295 ± 65^{a}
Beta-cryptoxanthin	46 ± 5.1^{a}	58 ± 8.4^{a}	21 ± 2.3^{b}	47 ± 5.8^{a}	4.5 ± 0.6^{b}	26 ± 2.8^{a}	20 ± 4.6^{a}	18 ± 2.3^{a}
Lutein	ND	ND	8.5 ± 1.3^{a}	7.9 ± 0.4^{a}	ND	ND	ND	ND
Zeaxanthin	205 ± 14^{b}	290 ± 7.2^{a}	170 ± 28^{a}	150 ± 18^{a}	210 ± 21^{a}	211 ± 2.4^{a}	370 ± 38^{a}	290 ± 2.9^{b}
Total	**770 ± 38^{a}**	**890 ± 100^{a}**	**390 ± 99^{b}**	**590 ± 69^{a}**	**420 ± 41.6^{b}**	**750 ± 70.2^{a}**	**710 ± 80^{a}**	**603 ± 70.2^{a}**

Carotenoid compounds	John Boy II		PF 22-007		PF 23		PF Lucky13	
	2009	2010	2009	2010	2009	2010	2009	2010
Beta-carotene	380 ± 48^{a}	360 ± 54^{a}	210 ± 18^{b}	320 ± 21^{a}	199 ± 27^{b}	590 ± 60^{a}	260 ± 24^{a}	290 ± 33^{a}
Beta-cryptoxanthin	13 ± 3.4^{a}	11 ± 0.7^{a}	14 ± 2.6^{b}	18 ± 1.4^{a}	9.3 ± 0.5^{b}	34 ± 2.9^{a}	11 ± 1.6^{b}	21 ± 1.9^{a}
Lutein	ND	4.6 ± 0.2	ND	ND	6 ± 0.5^{a}	5.6 ± 0.1^{a}	ND	5.2 ± 0.2
Zeaxanthin	270 ± 21^{a}	160 ± 14^{b}	220 ± 21^{a}	210 ± 47^{a}	230 ± 13^{a}	208 ± 17^{b}	240 ± 24^{b}	310 ± 12^{a}
Total	**660 ± 72^{a}**	**540 ± 70^{a}**	**440 ± 42^{b}**	**550 ± 69^{a}**	**440 ± 40^{b}**	**840 ± 80^{a}**	**510 ± 50^{b}**	**630 ± 47^{a}**

Carotenoid compounds	Redhaven		Vivid	
	2009	2010	2009	2010
Beta-carotene	62 ± 1.1^{b}	290 ± 27^{a}	170 ± 15^{b}	320 ± 17^{a}
Beta-cryptoxanthin	6.5 ± 1.1^{b}	178 ± 2.3^{a}	10 ± 1.6^{b}	28 ± 2.7^{a}
Lutein	5.8 ± 0.3^{b}	6.4 ± 0.2^{a}	ND	ND
Zeaxanthin	108 ± 11^{b}	402 ± 66^{a}	101 ± 9.8^{b}	302 ± 30^{a}
Total	**180 ± 14^{b}**	**880 ± 96^{a}**	**280 ± 26^{b}**	**650 ± 50^{a}**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the two years (alpha = 0.05).

Maturity at harvest and storage effect

The influence of maturity at harvest and stated postharvest storage conditions was determined for three varieties, 'John Boy II', 'PF 23' and 'Redhaven' in 2010. These were selected based on information obtained in 2009 on these varieties, namely high phenolic content ('PF 23'), high carotenoid content ('John Boy II') and economic importance to the Northeast ('Redhaven').

A comparison of commercial ripe (CR) to tree ripe (TR) harvests indicated changes occurring when the fruit was allowed to ripen on the tree while contrasting CR with storage (ST) showed changes when a fruit was harvested early and stored under cold conditions for prolonged periods, in this case, four weeks. Comparing ST to TR allowed a study of the effects of early harvest and subsequent long-term cold storage (as is largely done in commercial fruit production) versus late harvest (after which fruit is consumed within a short period) on fruit properties and constituents.

It should be noted that the definition for CR in particular differs between producing regions depending on the required shelf life of fruit, which in turn may be influenced by the length of time to consumption or distance over which the produce must be transported to its final market. As such, while orchards used for our study required full color development for CR harvest, the practice in other producing areas with greater output or a wider area of distribution may require that fruit be harvested while still green or with minimal colour. Changes in quality indiced and phytochemical content as reported in our study should be considered with this in mind.

Quality indices

Firmness decreases with ripening due to loss of tugor, starch degradation and breakdown of fruit cell walls owing to the action of cell enzymes and plant hormones, mainly pectinmethylesterase and ethylene respectively. It is therefore considered a reliable index of fruit maturity or ripeness (Kader and others 1982; Kader and Mitchell 1989b; Crisosto 1994; Ramina and others 2008). Fruit experienced an average of 70% decrease in firmness from CM to TR and 72% from CR to ST (Table 2.5). There were no significant differences in mean weight, size or edible portion from CR to TR. Given that fruit at this point was at stage IV of development (ripening), significant increase in size was not expected between the two harvests (Ramina and others 2008).

Fruit was assessed for possible changes in color of skin and flesh with ripening on- or off-tree. No significant differences were observed in skin of fruit (*a*, *b*, *L*, *H* or *C*) from CR to TR, changes in CR to ST were variety dependant. Flesh color was more informative. Mean *b*, *L*, *C* and *H* decreased from CR to TR and from CR to ST (Table 10). Differences were most pronounced in changes in *b* from CR to ST, implying a decreased yellowness in the flesh.

Fruits undergo physiological changes with ripening that result in, among other things, changes in concentrations of sugars, with increase in sucrose content and overall SSC (Kader and Mitchell 1989a; Ramina and others 2008). Other major sugars, primarily glucose and fructose, show stable (Brooks and others 1993) or decreased (Vizzotto and others 1996) concentration with ripening. Moing and others (2000) found that changes in organic acid during ripening, leading to decreases in TA and increase in

pH, were regulated mainly by the enzyme phosphoenolpyruvate carboxylase. Overall flavor development and consumer acceptability increases with ripening, and this is assessed instrumentally using SSC/TA, ideally increasing as the fruit ripens (Salunkhe and others 1968; Kader and others 1982; Kader and Mitchell 1989b).

Table 2.4. Mean values of quality indices of selected Northeast peach varieties ('John Boy II', 'PF 23' and 'Redhaven') at commercial ripe, tree ripe and in storage (n = 15).

	Commercial ripe	Tree ripe	Storage
Firmness (N)	121.1[a]	35.8[b]	34.2[b]
Weight (g)	168.5[a]	160.1[a]	168.5[a]
Diameter (mm)	69.5[a]	67.5[a]	69.5[a]
Edible portion (%)	94.6[a]	94.9[a]	94.6[a]
Skin *L*	47.6[a]	45.5[a]	47.1[a]
Skin *a*	22.8[a]	22.1[a]	17.9[b]
Skin *b*	23.7[a]	22.5[a]	21.0[a]
Skin *H*	42.6[a]	43.1[a]	46.5[a]
Skin *C*	33.0[a]	31.6[ab]	27.7[b]
Flesh *L*	66.4[a]	60.9[b]	62.9[b]
Flesh *a*	9.8[b]	11.7[a]	11.1[a]
Flesh *b*	51.0[a]	45.2[b]	41.6[c]
Flesh *H*	79.0[a]	75.2[b]	74.9[b]
Flesh *C*	52.0[a]	46.8[b]	43.0[c]
Soluble solids (%)	10.0[b]	10.6[b]	12.4[a]
Titratable acidity	0.80[a]	0.75[a]	0.69[a]
Sugar-to-acid ratio	12.8[b]	14.4[b]	18.5[a]
pH	3.51[b]	3.60[b]	3.86[a]
Moisture content (%)	87.8[a]	88.1[a]	85.4[b]

Means not connected by the same letter indicate a significant difference in that parameter between the stages (alpha = 0.05).

Fruits undergo physiological changes with ripening that result in, among other things, changes in concentrations of sugars, with increase in sucrose content and overall SSC (Kader and Mitchell 1989a; Ramina and others 2008). Other major sugars, primarily glucose and fructose, show stable (Brooks and others 1993) or decreased (Vizzotto and others 1996) concentration with ripening. Moing and others (2000) found that

changes in organic acid during ripening, leading to decreases in TA and increase in pH, were regulated mainly by the enzyme phosphoenolpyruvate carboxylase. Overall flavor development and consumer acceptability increases with ripening, and this is assessed instrumentally using SSC/TA, ideally increasing as the fruit ripens (Salunkhe and others 1968; Kader and others 1982; Kader and Mitchell 1989b).

A comparison of all three varieties showed no significant changes in mean SSC, pH, TA, SSC/TA or moisture content from CR to TR. Trends were similar to those reported by Salunkhe and others (1968) and Kader and others (1982), i.e., increasing SSC and SSC/TA and decreasing TA. From CR to ST, however, mean SSC increased by 22%, pH by 10%, and SSC/TA by 44% ($p < 0.01$ in all cases). Moisture content decreased by 2% ($p < 0.01$) while TA did not change significantly.

For all parameters assessed, ST samples had higher SSC, pH and SSC/TA and lower TA compared to TR. Although these results would imply good quality fruit, possibly with better taste than TR samples, the ST samples had poor texture with fibrous flesh and little juice, particularly 'Redhaven'. These characteristics matched the descriptions for chilling injury and internal breakdown as described by Mitchell and Kader (1989b) and Lurie and Crisosto (2005).

Phenolic content

There was no significant change in mean TP from CR to TR or from CR to ST for 'Redhaven'. In 'John Boy II' and 'PF 23', however, TP declined from CR to TR ($p < 0.05$) but did not change significantly from CR to ST (Figure 2.7). This agrees with

findings by Kader and others (1982) and Tomas-Barberan and others (2001), who reported no clear differences in phenolic content with ripening, as well as those by Scordino and others (2011) who reported decreases in phenolic content of yellow-fleshed peaches with ripening. Tomas-Barberan and others (2001) also observed differences in the responses of different varieties, as is the case here, although the overarching trend is a decline in TP with on-tree ripening. The lack of change from CR to ST echoes a study by Senter and others (1989). Overall, fruit allowed to ripen on-tree (TR) had lowest TP, with the order being CR ≥ ST ≥ TR.

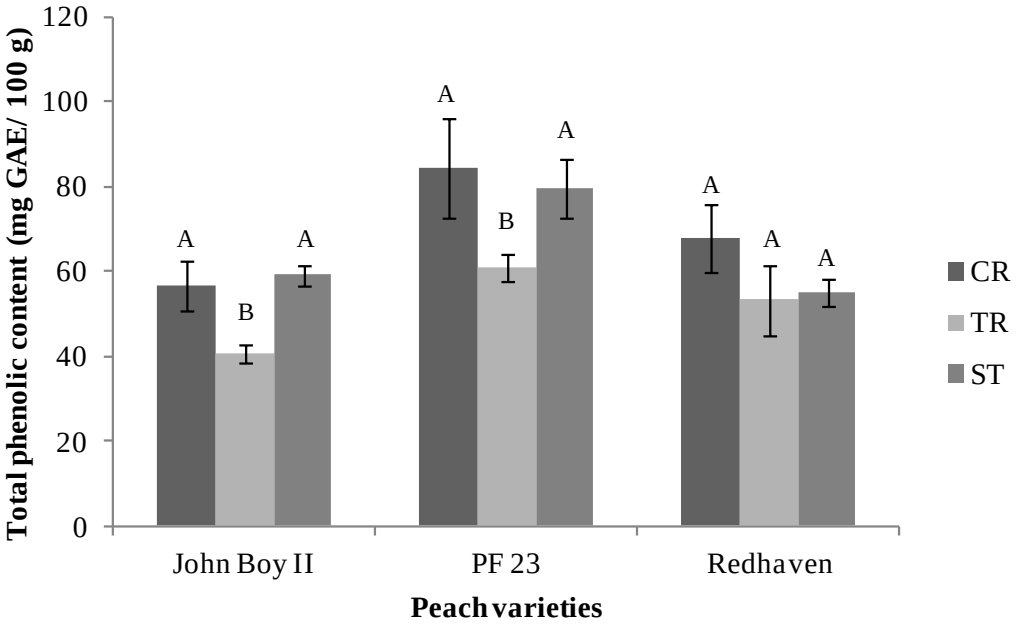

Figure 2.7. Total phenolic content of 'John Boy II', 'PF 23' and 'Redhaven' peaches at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (GAE: Gallic acid equivalents). Bars not connected by the same letter indicate a significant difference between the stages (alpha = 0.05).

Suggested reasons for observed decreases in phenolic content with ripening include a change in their role in the plant, with phenolic decreases leading to a reduction in astringency for more acceptable taste and flavor (Dalla Valle and others 2007).

Andreotti and others (2008) also reported a decrease in phenolic compounds with on-tree ripening and recommended further research into the effect of environmental and agronomic conditions on the phenolic compounds accumulation to aid in optimisation of phenolic levels in ripe fruits.

Changes in individual phenolic compounds were largely variety dependent (Table 2.6). Catechin, which as noted earlier correlated strongly with phenolic content, decreased with both on and off-tree ripening. Epigallocatechin declined from CR to TR but CR to ST also proved variety dependent – declining in 'Redhaven', stable in 'PF 23' and disappearing entirely in 'John Boy II'. Flavonol glycosides rutin, quercetin-3-glucoside and unknowns 1 and 2 (quercetin derivatives) increased significantly with from CR to ST but remained stable with on-tree ripening. HPLC-TP decreased from CR to TR in 'PF 23' and 'Redhaven', supporting the theory of phenolic decline with on-tree ripening.

Table 2.5. Phenolic compounds (mg / 100 g) in ‘John Boy II’, ‘PF 23’ and ‘Redhaven’ peaches at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (n = 3).

Phenolic compounds	John Boy II			PF 23		
	CR	TR	ST	CR	TR	ST
Catechin	3.5 ± 0.5^{a}	2.3 ± 0.4^{a}	2.3 ± 0.0^{a}	7.3 ± 0.7^{a}	3.7 ± 0.4^{b}	4.5 ± 0.5^{b}
Chlorogenic acid	2.5 ± 0.4^{a}	1.9 ± 0.3^{a}	2.4 ± 0.0^{a}	7.6 ± 0.8^{a}	4.5 ± 0.5^{b}	5.7 ± 0.7^{ab}
Cyanidin-3-glucoside	7.2 ± 1.5^{a}	2.6 ± 0.1^{b}	7.0 ± 1.9^{a}	7.0 ± 0.7^{a}	6.2 ± 0.9^{a}	6.3 ± 0.8^{a}
Epicatechin	3.9 ± 0.2^{b}	5.2 ± 0.6^{a}	4.7 ± 0.1^{ab}	6.2 ± 1.7^{ab}	5.8 ±0.4^{b}	9.1 ± 0.4^{a}
Epigallocatechin	2.2 ± 1.0^{a}	1.4 ± 0.5^{a}	ND	2.8 ± 0.2^{a}	1.8 ± 0.1^{b}	2.8 ± 0.2^{a}
Kaempferol-3-rutinoside	4.6 ± 0.2^{a}	4.9 ± 0.3^{a}	5.4 ± 0.6^{a}	5.8 ± 0.2^{a}	6.0 ± 0.3^{a}	6.4 ± 0.4^{a}
Neochlorogenic acid	2.6 ± 0.4^{a}	1.8 ± 0.3^{a}	2.4 ± 0.4^{a}	3.0 ± 0.4^{a}	1.9 ± 0.0^{a}	2.7 ± 0.3^{a}
Quercetin-3-glucoside	0.64 ± 0.04^{b}	0.60 ± 0.04^{b}	0.78 ± 0.05^{a}	0.77 ± 0.07^{a}	0.75 ± 0.05^{a}	0.86 ± 0.01^{a}
Rutin	0.66 ± 0.02^{ab}	0.60 ± 0.04^{b}	0.80 ± 0.09^{a}	0.79 ± 0.07^{a}	0.74 ± 0.03^{a}	0.84 ± 0.04^{a}
Unknown 1	1.8 ± 0.2^{ab}	1.5 ± 0.1^{b}	2.2 ± 0.2^{a}	2.9 ± 0.4^{b}	2.0 ± 0.0^{c}	4.8 ± 0.2^{a}
Unknown 2	0.70 ± 0.04^{b}	0.68 ± 0.02^{b}	0.86 ± 0.06^{a}	0.86 ± 0.06^{a}	0.84 ± 0.02^{a}	0.94 ± 0.06^{a}
Unknown 3	0.66 ± 0.04^{b}	0.67 ± 0.02^{b}	0.82 ± 0.05^{a}	0.78 ± 0.06^{a}	0.81 ± 0.04^{a}	0.88 ± 0.04^{a}
Total	**31.0 ± 4.5^{a}**	**24.2 ± 2.7^{a}**	**29.7 ± 3.5^{a}**	**45.8 ± 5.4^{a}**	**35.0 ± 2.7^{b}**	**45.8 ± 3.7^{a}**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the stages (alpha = 0.05).

Table 2.6. (Continued).

Phenolic compounds	Redhaven		
	CR	TR	ST
Catechin	7.7 ± 0.6[a]	3.6 ± 0.3[b]	3.4 ± 0.6[b]
Chlorogenic acid	3.1 ± 0.1[b]	3.6 ± 0.0[a]	2.6 ± 0.1[c]
Cyanidin-3-glucoside	2.9 ± 0.7[a]	2.2 ± 0.4[a]	3.6 ± 0.4[a]
Epicatechin	4.5 ± 0.5[a]	3.8 ± 0.2[a]	5.2 ± 1.1[a]
Epigallocatechin	3.6 ± 0.0[a]	2.2 ± 0.2[b]	2.8 ± 0.1[b]
Kaempferol-3-rutinoside	4.3 ± 0.4[a]	4.2 ± 0.5[a]	5.5 ± 0.9[a]
Neochlorogenic acid	2.3 ± 0.2[a]	1.8 ± 0.0[b]	1.7 ± 0.0[b]
Quercetin-3-glucoside	0.67 ± 0.05[ab]	0.53 ± 0.03[b]	0.76 ± 0.08[a]
Rutin	0.67 ± 0.06[a]	0.64 ± 0.05[a]	0.80 ± 0.09a
Unknown 1	2.8 ± 1.1[a]	1.1 ± 0.1[a]	2.6 ± 0.2[a]
Unknown 2	0.67 ± 0.01[b]	0.67 ± 0.06[b]	0.90 ± 0.02[a]
Unknown 3	0.62 ± 0.01[a]	0.61 ± 0.08[a]	0.75 ± 0.07[a]
Total	**33.8 ± 3.7[a]**	**25.0 ± 1.9[b]**	**30.6 ± 3.7[a]**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the stages (alpha = 0.05).

Antioxidant capacity

A number of compounds in fruits have been found to possess antioxidant activity, including polyphenols, carotenoids and vitamins E and C (Dalla Valle and others 2007). There are various views on the contributions of these compounds, and how these are best represented by the different tests available for measuring total antioxidant capacity. These concerns were most realized in the assessment of changes in AOX with maturity at harvest and storage.

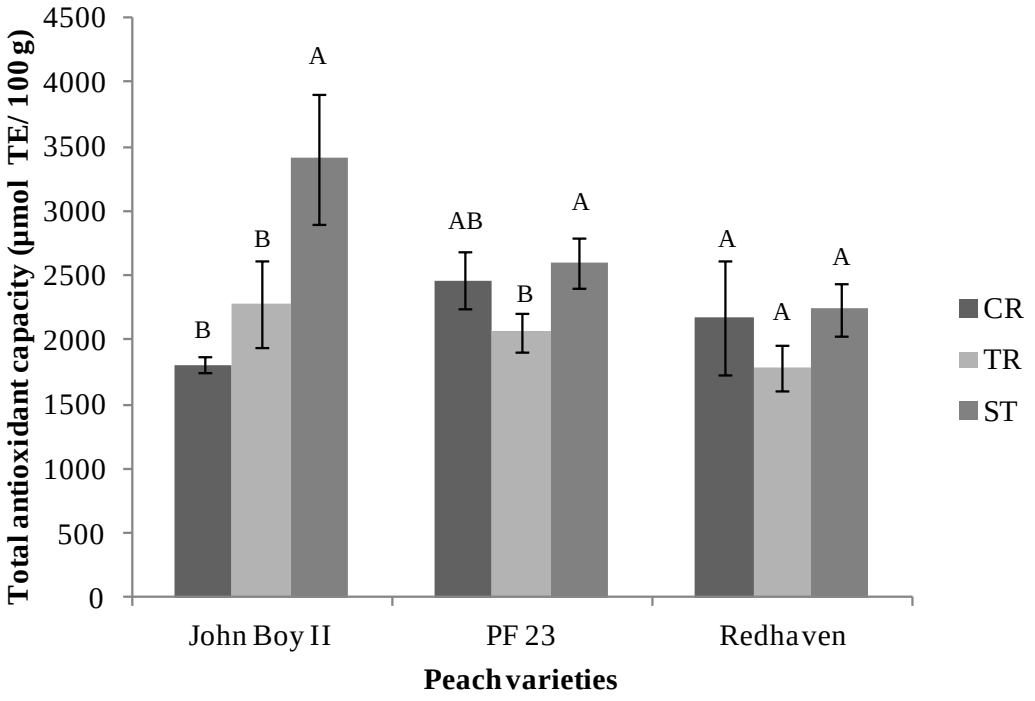

Figure 2.8. Total antioxidant capacity of 'John Boy II', 'PF 23' and 'Redhaven' peaches at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (TE: Trolox equivalents). Bars not connected by the same letter indicate a significant difference between the stages (alpha = 0.05).

Given the significant correlation between AOX and phenolics, similar results as seen with phenolics were expected (i.e. decline or relative stability of phenolics with ripening) but not realized. The three varieties studies were all unique with regards to changes in AOX with ripening (Figure 2.8). In 'John Boy II', AOX was stable with on-tree ripening but increased in storage ($p < 0.01$); 'PF 23' remained relatively stable from CR to TR and from CR to ST but ST was significantly higher than TR ($p < 0.05$); 'Redhaven' AOX was stable/equivalent for all three points.

Since the ORAC method employed favors the activity of hydrophilic constituents (Prior and others 2003), the influence of other hydrophilic antioxidant compounds such as vitamin C could influence AOX values. Both Salunkhe and others (1968) and Kader and others (1982) reported increases in ascorbic acid content in peaches with both on- and off-tree ripening. The measurement of changes in ascorbic acid concentration at different stages of maturity for the various varieties might therefore have shed more light on the observed trends. Contrary to this line of thought, Kalt and others (1999) and Gil and others (2002) reported that in berries and peaches respectively, phenolic content and not vitamin C was mainly responsible for antioxidant activity as observed by the ORAC test. However, the Kalt study also showed that storage time and temperature did influence changes in antioxidant capacity in these fruits. In our study, the differences in varietal reponse meant we could not establish a common trend for changes in antioxidant capacity with peach ripening or storage.

Carotenoid content

Previous studies have reported increases in carotenoid content with ripening (Kader and others 1982; Salunkhe and others 1989). In 'John Boy II' and 'PF 23', this phenomenon was observed with on-tree ripening ($p < 0.05$) but not significantly from CR to ST (Figure 2.9). Changes in TC with ripening or storage for 'Redhaven' were not significant.

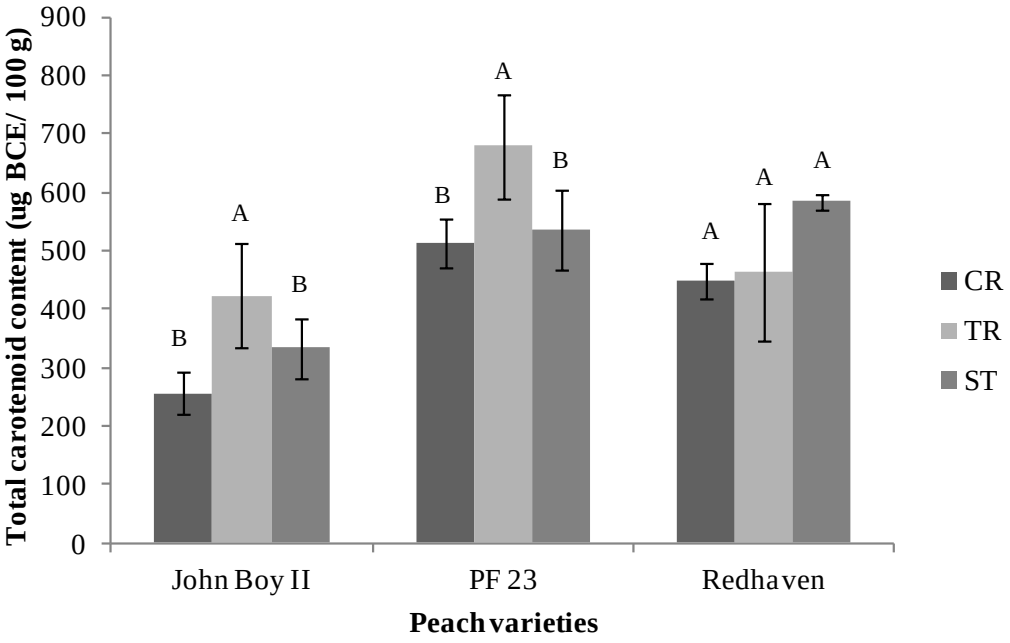

Figure 2.9. Total carotenoid content of 'John Boy II', 'PF 23' and 'Redhaven' peaches at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (BCE: β-carotene equivalents). Bars not connected by the same letter indicate a significant difference between the stages (alpha = 0.05).

Carotenoid development and syntheses of new carotenoids with ripening are due to the transformation of chloroplast into chromoplast, resulting in an accumulation of carotenoid pigments. These changes also cause changes in color, sometimes

augmented by increase in anthocyanins (Ramina and others 2008; Ferrer and others 2005). Based on this, a correlation between carotenoid content and one or more color variables was anticipated; this was not the case in our study. Such clear indices may have been realized with a more phenotypically diverse group.

Identified carotenoid compounds were present at all stages except lutein, which was absent in CR 'John Boy II' (Table 2.7). The overall low quantities of this compound, as well as the inability to isolate its precursor α-carotene, may be linked to a number of factors. One possible cause may be its destruction or inadequate extraction by the chosen methodology; another is low levels of these particular compounds in sampled varieties due to varietal, geographic or climatic factors. Alternatively, the cause may lie in the metabolic processes involved in carotenogenesis. Britton and Khachik (2009) stated that carotenoid composition of fruit during maturation is determined by the presence and activity of ripening-specific genes, with absence or low activity of ε-cyclase and ε-hydroxylase resulting in low levels of α-carotene and lutein.

Katayama and others (1971) reported an increase in β-carotene and β-cryptoxanthin concentration with ripening. This was observed together with the increase in TC in 'PF 23', while only β-carotene increased with ripening in 'John Boy II'. Both observations would imply an increase in vitamin A content with on-tree ripening in these varieties.

Table 2.6. Carotenoid compounds (µg / 100 g) in 'John Boy II', 'PF 23' and 'Redhaven' peaches at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (n = 3).

Variety	Maturity	Beta-carotene	Beta-cryptoxanthin	Lutein	Zeaxanthin	Total
John Boy II	CR	220 ± 11[b]	9.5 ± 2.6[a]	ND	170 ± 27[a]	400 ± 41[b]
	TR	360 ± 54[a]	11 ± 0.7[a]	4.6 ± 0.2[b]	160 ± 14[a]	540 ± 69[a]
	ST	230 ± 35[b]	10 ± 0.7[a]	10 ± 1.4[a]	130 ± 20[a]	380 ± 57[b]
PF 23	CR	420 ± 54[b]	22 ± 1.7[b]	5.1 ± 0.5[b]	210 ± 41[a]	660 ± 97[b]
	TR	590 ± 60[a]	34 ± 2.9[a]	5.6 ± 0.1[b]	208 ± 17[a]	840 ± 80[a]
	ST	406 ± 110[b]	24 ± 0.4[b]	7.1 ± 1.1[a]	233± 0.2[a]	670 ± 110[a]
Redhaven	CR	250 ± 26[a]	16 ± 1.2[a]	4.9 ± 0.7[a]	380 ± 64[a]	650 ± 92[a]
	TR	290 ± 27[a]	18 ± 2.3[a]	6.4 ± 0.2[a]	402 ± 66[a]	720 ± 96[a]
	ST	290 ± 63[a]	17 ± 1.4[a]	5.5 ± 0.2[a]	530 ± 15[a]	840 ± 80[a]

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the stages (alpha = 0.05).

Conclusion

The study achieved its primary aim of sampling and providing information about a substantial number of local peach varieties. It also identified important varieties in terms of phenolic and antioxidant (‘PF 22-007’, ‘PF 23’) and carotenoid content (‘Babygold 5’). Catechin and β-carotene proved most important indicators for phenolic and antioxidant, and carotenoid content respectively. Differences in rainfall in the two study years, with 2010 fruit subjected to greater water stress, resulted in higher phenolic, antioxidant and carotenoid values for 2010 samples. Maturity at harvest and storage studies showed little change in varietal phenolic, antioxidant and carotenoid content overall, but variations in varietal response were observed. Trends, although not significant with all varieties considered, pointed to declining phenolic and increasing carotenoid content with on-tree ripening, while cold storage appeared to keep levels of bioactive constituents fairly stable. Changes in antioxidant content were very variety-dependant. Inadequate or ineffective storage conditions, coupled with long storage time, resulted in chilling injury in fruit. The effects of pre- and post-harvest practices and conditions on bioactive compounds illustrated the susceptibility of these to a range horticultural practices and climatic factors and highlighted the need for better understanding and, where possible, control of these in order to ensure optimum levels of the nutraceuticals of interest while maintaining or improving aesthetic value.

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CHAPTER 3: EFFECT OF VARIETY, MATURITY AT HARVEST AND STORAGE ON THE PHENOLIC, ANTIOXIDANT AND CAROTENOID CONTENT OF SELECTED NORTHEAST APRICOT VARIETIES.

Introduction

Consumption of fruits has been encouraged because of their myriad health benefits (Kader and Barrett 2005; Sloan 2010; USDA HHS 2011). The apricot, *Prunus armeniaca*, contains significant quantities of phenolic and carotenoid compounds and is therefore considered an important source of antioxidants and vitamin A, both of which have positive impacts on human health (Stahl and Sies 2003; Ruiz and others 2005a; Ruiz and others 2005b; Dragovic-Uzelac and others 2007). Antioxidants, comprising both phenolic and carotenoid compounds, reduce the risk of cardiovascular diseases and some cancers, while carotenoids play a role in vision (Ames and others 1993; Paiva and Russell 1999; Fraser and Bramley 2004).

The main phenolic compounds identified in apricots include flavan-3-ols (catechin, epicatechin), hydroxycinnamic acids (neochlorogenic acid, chlorogenic acid), flavonol glycosides (rutin, quercetin-3-glucoside and other quercetin derivatives) and anthocyanins (cyanidin-3-glucoside) (Radi and others 1997; Ruiz and others 2005a; Dragovic-Uzelac and others 2007). Carotenoids include carotenes (alpha-, beta- and gamma-carotene) and xanthophylls (lutein, zeaxanthin, violaxanthin and beta-cryptoxanthin) (Katayama and others 1971; Breithaupt and Bamedi 2001; Ruiz and others 2005b). Phenolic and carotenoid composition and concentration are subject to varietal, climatic and horticultural influences as well as the part of fruit (peel or flesh)

analyzed (Katayama and others 1971; Wu and others 2004b; Ruiz and others 2005a; Wang and others 2006; Dragovic-Uzelac and others 2007; Drogoudi and others 2008). In the United States, apricot production is based mainly in California (approximately 80%), Washington and Utah. The industry has experienced a decline in consumption in recent years (Ledbetter 2010; USDA ERS 2011; USDA NASS 2011). The Northeast USA is also a producer but with much smaller quantities than the aforementioned states. Apricot cultivation in this region is challenging due to adverse climatic conditions which, together with this fruit tree's inherent restrictions to climatic adaptation, limit production (Lamb and Stiles 1983; Merwin 1994; Layne 1996; NYS Climate Office). Breeding programs have therefore focused on improving cold hardiness, late blooming, pest and disease resistance. Research on resultant produce has focused on physical and other sensory characteristics (Anderson and Seeley 1993; Westwood 1993; Layne 1996; Layne and others 1996) with little data available on the impact of these changes on nutrients and bioactive compounds.

Today, the marketability of fruit and fruit products is increasingly less dependent on their aesthetic attributes and more strongly linked to their health benefits. The aim of this study was therefore to evaluate phenolic, antioxidant and carotenoid content of a selection of apricot varieties currently cultivated in the Northeast. The study also examined the effect of seasonal variations, fruit maturity and postharvest storage on these bioactive compounds. The information obtained contributes to literature on this fruit, particularly how it responds to this region's climatic conditions, and allows for better understanding of the its nutraceutical and economic potential.

Materials and methods

Harvest

The study was conducted over two years, with the harvesting protocol smilar to that described in chapter 2 for peaches. Five orange-fleshed apricot varieties were sourced from local producers in 2009 and 2010. Of these, four varieties were selectively harvested at two developmental stages in 2010 – 'commercial ripe' and 'tree ripe'. Fruit of one variety ('Hargrand') harvested at commercial ripe were stored for four weeks then analysed as a third treatment – storage.

Quality indices

These were evaluated as described in chapter 2.

Phenolic analysis

Extraction, total phenolic content and HPLC analysis were performed as described in chapter 2.

Total antioxidant capacity assay

This was performed as described in chapter 2.

Carotenoid analysis

This was performed as described in chapter 2.

Statistical analysis

Data was analysed as described in chapter 2.

Results and discussion

Varietal characterization

There was variation in the harvest dates of varieties during the two years, in response to different climatic conditions in each study year (Table 3.1). All varieties were ready for harvest between late July and the first week of August. Varieties sourced were a mixture of cold-hardy varieties originating from the Harrow Research Station ('Hargrand', Harlayne' and 'Harogem') and the Vineland Station ('Vivagold') in Ontario, Canada; 'Tomcot' was developed at the Washington State University (Layne 1996; Conev 2003; NNII 2006).

Table 3.1. Source and harvest dates of selected Northeast apricot varieties.

Variety	Source (Orchard)	Harvest dates	
		2009	2010
Hargrand	1	August 4	July 23, July 29
Harlayne	1	August 3	July 23, August 3
Harogem	1	July 28	July 24, August 4
Tomcot	2	July 27	July 16
Vivagold	2	July 27	July 16, July 23

Contributing orchards: Orchard 1 (Geneva, NY), Orchard 2 (Geneva, NY)

Quality indices

Mean values for firmness, weight and size provided information for characterization of the evaluated varieties as they performed specific to this region; some parameters, mainly size and weight, were not in accord with the same varieties grown in different areas (Mehlenbacher and others 1990; Drogoudi and others 2008). Mean firmness, weight, cross-sectional diameter and edible portion percentage for the five evaluated varieties, with ranges in parentheses, were 11.7 N (6.7 – 17.7), 44.0 g (24.4 – 49.6), 42.6 mm (35.1 – 47.8) and 93.2% (91.5 – 94.4).

Fruit weight correlated well with size ($r > 0.86$) with the three Harrow varieties being largest (> 48 g, > 43 mm). These varieties were also visually attractive, with 'Harogem' possessing a striking red shade, evident even in its flowers. The uniform orange color and large size of 'Harlayne' has proven appealing to customers and made it a top seller for a major New York fruit producer.

Color was reported as Hunter components *L* (lightness), *a* (red/green), *b* (yellow/blue), *H* (hue angle), and *C* (chroma); *a* and *b* were consistently in the positive range indicating the colors red and yellow (McLellan and others 1995). Given the phenotypic similarity between varieties assessed, skin and flesh color between varieties was not significantly different. Skin color was typically orange, ranging from more yellow ('Tomcot' and 'Vivagold') to more red ('Harogem') shades, reflected in high *b* readings for the former group and high *a* readings for the latter. Differences in color over the two study years were less pronounced in the skin as compared to the flesh (Table 3.2).

Results of chemical analyses were comparable to those from other studies for apricot soluble solids content (SSC), titratable acidity (TA), sugar-to-acid ratio (SSC/TA), moisture content and pH (Aubert and Chanforan 2007; Drogoudi and others 2008; Mratinic and others 2011). Harlayne and Harogem ranked high in SSC (> 10%) and SSC/TA in both years. 2010 varieties had higher SSC, SSC/TA and pH and lower TA and moisture content compared to 2009 ($p < 0.01$ in all cases). SSC, SSC/TA and moisture content results were in line with differences in climatic conditions between the two years. Average rainfall over the growing season was 2.9 inches in 2009 and

1.8 inches in 2010 (NEWA 2011). Rainfall was copious throughout the 2009 growing season but negligible post-June in 2010, resulting in a greater concentration of solids in fruit that year (Perez-Pastor and others 2007). As with other stone fruits, rainfall amount and patterns, particularly the water deficit late in the season (stage III of fruit growth – cell expansion) was also implicated in the visually smaller 2010 fruit (Crisosto and others 1995; Behboudian and Mills 1997; Johnson 2008).

Table 3.2. Mean values and ranges of quality indices of Northeast apricot varieties evaluated in 2009 and 2010 (n = 15).

Parameters	2009		2010	
	Mean	Range	Mean	Range
Skin *L*	56.8[a]	(50.3 – 61.8)	54.5[a]	(50.5 – 60.3)
Skin *a*	27.2[a]	(18.5 – 33.8)	26.2[a]	(17.8 – 31.5)
Skin *b*	45.0[a]	(36.7 – 50.8)	38.3[b]	(33.4 – 45.0)
Skin *H*	58.6[a]	(47.8 – 65.5)	55.3[a]	(47.8 – 64.5)
Skin *C*	53.3[a]	(44.2 – 58.8)	46.9[b]	(39.5 – 51.5)
Flesh *L*	59.3[a]	(53.6 – 63.0)	51.4[b]	(40.8 – 58.2)
Flesh *a*	22.4[a]	(17.3 – 24.6)	21.5[a]	(17.6 – 26.8)
Flesh *b*	43.5[a]	(36.1 – 47.1)	37.8[b]	(30.0 – 43.7)
Flesh *H*	62.9[a]	(61.5 – 64.7)	60.4[b]	(55.7 – 64.7)
Flesh *C*	49.0[a]	(45.3 – 51.8)	43.5[b]	(36.3 – 51.3)
Soluble solids (%)	11.8[b]	(9.9 – 13.7)	13.8[a]	(10.8 – 15.1)
Titratable acidity	1.82[a]	(1.54 – 2.63)	1.22[b]	(0.82 – 2.05)
Sugar-to-acid ratio	6.61[b]	(4.89 – 8.71)	12.01[a]	(7.12 – 17.32)
pH	3.29[b]	(3.04 – 3.49)	3.66[a]	(3.46 – 3.78)
Moisture content (%)	86.7[a]	(84.7 – 88.2)	84.7[b]	(80.5 – 88.1)

Means not connected by the same letter indicate a significant difference for that parameter between the two years (alpha = 0.05).

Phenolic content

Mean total phenolic content (TP) of apricots was 121.7 mg in 2009 and 151.0 mg in 2010. These values were greater than those by the USDA Database for selected foods (2010), 79 mg, but overall ranges were within those from studies by Drogoudi and

others (2008), 30.3 – 559.6, and Sochor and others (2010) 41 – 170, using similar methods of analyses. 2010 mean TP compared favorably against those of more popular fruits (e.g. peach, 133 mg and grapes, 170 mg) (USDA ARS 2010). 'Hargrand' consistently stood out in both years, having more than twice the TP of the next closest variety (Figure 3.1); 'Vivagold' had lowest TP. Mean TP did not differ significantly between the two years, with the varieties responding differently ($p < 0.01$) to conditions in the study years (Scalzo and others 2005).

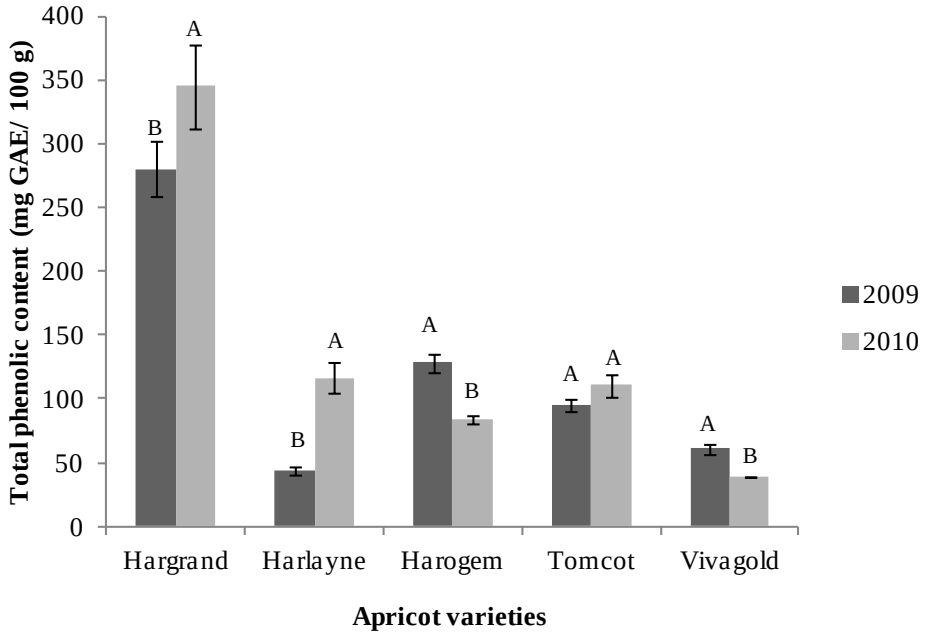

Figure 3.1. Total phenolic content of Northeast apricot varieties evaluated in 2009 and 2010 (GAE:Gallic acid equivalents). Bars not connected by the same letter indicate a significant difference between the two years (alpha = 0.05).

Flavan-3-ols were predominant quantitatively, and showed the most diversity qualitatively (Figure 3.2). Mean values for phenolic compounds in 2009 and 2010 respectively, reported as mg/ 100 g, were as follows: Flavan-3-ols: catechin (8.0 and 7.6), epicatechin (3.1 and 3.7), epigallocatechin (3.7 and 6.4), unknown 1 (1.5 and

4.2)‡ and unknown 2 (3.6 and 5.2)‡; hydroxycinnamic acids: chlorogenic acid (7.4 and 5.8) and neochlorogenic acid (10.0 and 8.9); flavonol glycosides: rutin (9.1 and 6.1)‡, quercetin-3-glucoside (1.0 and 1.0), quercetin derivative (1.0 and 1.4)‡; anthocyanins: cyanidin-3-glucoside (0.5 and 0.5)[4].

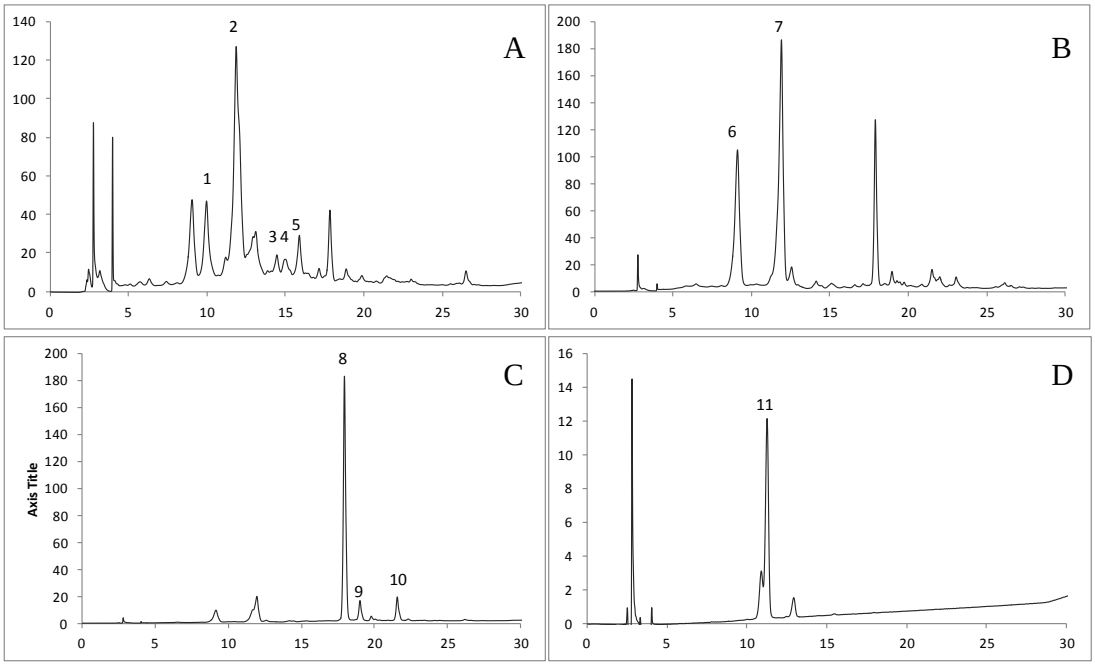

Figure 3.2. HPLC chromatograms of an apricot showing phenolic compounds at 280 nm (A), 320 nm (B), 370 nm (C) and 520 nm (D). Compounds identified are epigallocatechin (1), catechin (2), unknown 1 (3), epicatechin (4), unknown 2 (5), neochlorogenic acid (6), chlorogenic acid (7), rutin (8), quercetin-3-glucoside (9), quercetin derivative (10) and cyanidin-3-glucoside (11).

Similar to spectrophotometrically-determined TP, mean total phenolic content as determined by this method (HPLC-TP) did not vary significantly between the two years despite differences in rainfall and water availability, factors which found to influence phenolic content in some crops (Balakumar and others 1993; Estiarte and

[4] Symbol (‡) indicates that mean values for the two years were significantly different.

others 1994). Differences in varietal responses to water stress were observed, as reported in peaches by Tavarini and others (2011).

A strong correlation ($r > 0.92$) was found between HPLC-determined TP and spectrophotometrically-determined TP, implying that for this fruit both methods were equivalent gauges of relative varietal phenolic content. Good correlations were also found between HPLC-TP and catechin ($r > 0.95$), chlorogenic acid ($r > 0.88$) and epigallocatechin ($r > 0.81$). Levels of these compounds, particularly catechin, may therefore be indicative of apricot varietal phenolic content. The varieties exhibited similar phenolic profiles, although a lack of anthocyanins was noted in 'Hargrand' and 'Vivagold' and, in 2010, 'Tomcot' (Table 3.3). This underlines the need for further clarification regarding the nutraceutical properties of individual phenolic compounds in order to better understand the implications of their absence in fruit varieties or products.

No significant correlations were found between total phenolic content, or individual phenolic compounds, and any physical or chemical component although 'Harogem', a variety which presented visually with a deep red color, did stand out in its consistently high anthocyanin content (approximately twice the concentration of the next highest variety). The lack of further information on correlations in this regard was thought to be due to the similarities in flesh and skin colour of varieties evaluated. However, Ruiz and others (2005), who evaluated apricots of varying flesh colors (white, yellow, light orange and orange) reported no correlations between phenolic content and flesh color.

Table 3.3. Phenolic compounds (mg / 100 g) in Northeast apricot varieties evaluated in 2009 and 2010 (n = 3).

Phenolic compounds	Hargrand		Harlayne		Harogem	
	2009	2010	2009	2010	2009	2010
Catechin	18.5 ± 0.4[b]	26.4 ± 1.2[a]	3.4 ± 0.3[a]	0.2 ± 0.0[b]	8.7 ± 0.6[a]	2.7 ± 0.2[b]
Chlorogenic acid	15.0 ± 0.3[b]	18.4 ± 0.1[a]	8.7 ± 0.3[a]	2.3 ± 0.2[b]	3.8 ± 0.2[a]	2.3 ± 0.1[b]
Cyanidin-3-glucoside	ND	ND	0.8 ± 0.0[a]	0.9 ± 0.0[a]	1.2 ± 0.0[b]	2.4 ± 0.3[a]
Epicatechin	3.6 ± 0.2[b]	4.1 ± 0.3[a]	1.4 ± 0.1[b]	5.8 ± 0.4[a]	5.8 ± 0.2[a]	4.3 ± 0.2[b]
Epigallocatechin	9.6 ± 1.0[b]	22.7 ± 1.1[a]	1.4 ± 0.2[b]	3.4 ± 0.5[a]	3.6 ± 0.3[b]	4.7 ± 0.3[a]
Neochlorogenic acid	7.0 ± 0.7[b]	12.9 ± 0.8[a]	5.6 ± 0.2[a]	6.6 ± 0.7[a]	10.2 ± 0.1[a]	5.8 ± 0.1[b]
Quercetin-3-glucoside	1.1 ± 0.0[b]	1.3 ± 0.0[a]	0.9 ± 0.0[a]	0.9 ± 0.1[a]	1.0 ± 0.0[a]	1.2 ± 0.1[a]
Quercetin derivative	1.3 ± 0.0[a]	1.3 ± 0.0[a]	1.0 ± 0.0[a]	0.9 ± 0.0[a]	1.3 ± 0.0[a]	1.0 ± 0.1[b]
Rutin	7.8 ± 0.2[b]	10.8 ± 1.8[a]	6.7 ± 0.4[a]	4.4 ± 0.4[b]	7.1 ± 0.5[a]	6.3 ± 0.4[a]
Unknown 1	2.0 ± 0.3[b]	7.1 ± 0.6[a]	0.1 ± 0.0[b]	6.0 ± 0.9[a]	3.7 ± 0.1[a]	3.2 ± 0.1[b]
Unknown 2	7.3 ± 0.7[b]	6.6 ± 0.6[a]	1.7 ± 0.1[b]	5.5 ± 0.6[a]	3.3 ± 0.3[a]	3.9 ± 0.3[a]
Total	**73.1 ± 3.8[b]**	**111.6 ± 6.5[a]**	**31.7 ± 1.7[a]**	**37.0 ± 3.8[a]**	**49.6 ± 2.4[a]**	**37.8 ± 3.2[b]**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the two years (alpha = 0.05).

Table 3.3. **(**Continued).

Phenolic compounds	Tomcot		Vivagold	
	2009	2010	2009	2010
Catechin	4.6 ± 0.1[b]	6.5 ± 0.6[a]	3.1 ± 0.0[a]	2.1 ± 0.0[b]
Chlorogenic acid	6.3 ± 0.2[a]	5.2 ± 0.8[a]	3.4 ± 0.3[a]	3.1 ± 0.0[a]
Cyanidin-3-glucoside	0.8 ± 0.1	ND	ND	ND
Epicatechin	1.4 ± 0.1[b]	2.2 ± 0.1[a]	1.9 ± 0.0[a]	2.0 ± 0.1[a]
Epigallocatechin	1.8 ± 0.1[b]	5.2 ± 0.6[a]	1.3 ± 0.0	ND
Neochlorogenic acid	18.6 ± 0.7[a]	12.8 ± 0.9[b]	8.3 ± 0.8[a]	4.6 ± 0.1[b]
Quercetin-3-glucoside	1.0 ± 0.0[a]	0.8 ± 0.0[b]	0.9 ± 0.0[a]	0.9 ± 0.0[a]
Quercetin derivative	1.5 ± 0.1[a]	0.9 ± 0.0[b]	1.4 ± 0.1[a]	1.1 ± 0.0[b]
Rutin	14.5 ± 1.0[a]	4.7 ± 0.1[b]	9.7 ± 0.9[a]	4.9 ± 0.1[b]
Unknown 1	0.6 ± 0.1[b]	2.8 ± 0.4[a]	1.0 ± 0.2[a]	1.1 ± 0.1[a]
Unknown 2	2.9 ± 0.2[b]	7.1 ± 0.5[a]	2.2 ± 0.1[b]	2.7 ± 0.1[a]
Total	**54.0 ± 2.7[a]**	**48.1 ± 4.0[a]**	**33.1 ± 2.4[a]**	**22.5 ± 0.5[b]**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the two years (alpha = 0.05).

Antioxidant capacity

In 2009, recognizing the contribution of both phenolic and carotenoid compounds to apricot antioxidant capacity (Wu and others 2004; Scalzo and others 2005), hydrophilic and lipophilic antioxidant capacities were measured separately in the method described by Prior and others (2003). The highest contribution was found to be from the hydrophilic fraction, correlating highly with total antioxidant capacity ($r > 0.91$), with lipophilic compounds contributing only 2% of AOX (data not shown). These results were similar to those reported by Wu and others (2004), who found the ORAC lipophilic fraction to be 2.4% of total apricot antioxidant capacity. This observation informed the decision to employ a variation of the ORAC assay by Huang and others (2002) to determine AOX (Figure 3.3); it had previously not been used due to its propensity to favor hydrophilic antioxidants.

A good correlation was found between AOX and both spectrophotometric TP ($r > 0.96$) and HPLC TP ($r > 0.92$), agreeing with work by Prior and others (2003) and Drogoudi and others (2008). Accordingly, the variety with greatest phenolic content in both years, 'Hargrand', had the greatest AOX (6282 and 7165 µmol, in 2009 and 2010, respectively) while Harlayne and Vivagold were lowest in those two years (2182 and 2097 µmol, respectively). There was no set trend in varietal response to the difference in climatic factors in the two years and other factors, including variety and maturity at harvest, were suggested to be more influential. As with phenolic content, AOX correlated most with catechin ($r > 0.91$), chlorogenic acid ($r > 0.83$) and epigallocatechin ($r > 0.80$); catechin and chlorogenic acid had previously been found to relate significantly with apricot AOX (Roussos and others 2011).

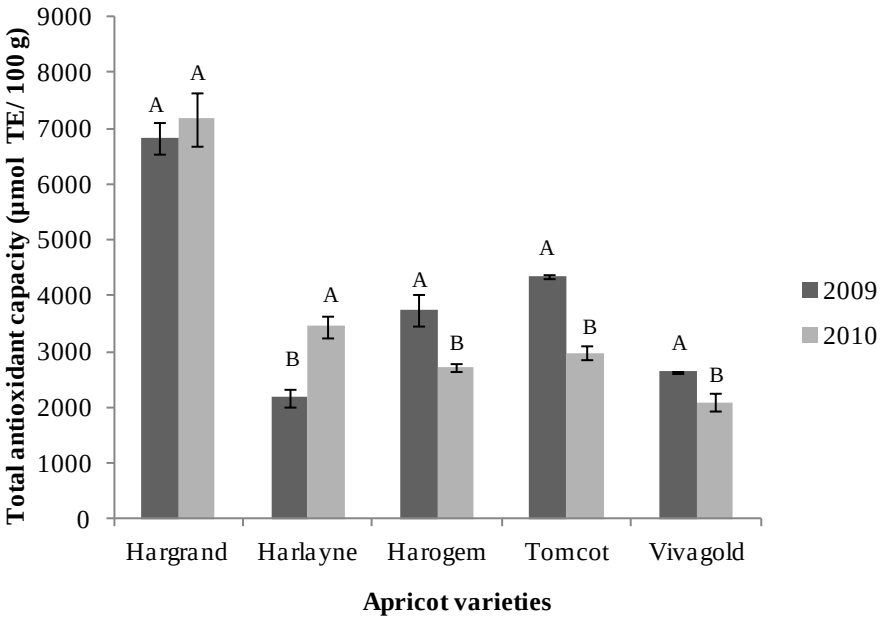

Figure 3.3. Total antioxidant capacity (ORAC) of Northeast apricot varieties evaluated in 2009 and 2010 (TE: Trolox equivalents). Bars not connected by the same letter indicate a significant difference between the two years (alpha = 0.05).

It is difficult to compare these AOX values with those from other studies, mainly due to the various methods by which antioxidant capacity is measured, giving credence to the need for a standardized mode of measurement (Cao and Prior 1998; Ou and others 2001; Wu and others 2004b). However, mean ORAC AOX (3945 in 2009 and 3796 in 2010, and not significantly different from 2009 to 2010) surpassed values given by the USDA database for selected foods, 1110 µmol/100 g, and Kevers and others (2007) of 1027 µmol/100 g. The values from our study also exceeded those reported for two highly consumed fruits, apples and grapes (approximately 3000 and 2000 µmol, respectively) positioning apricots and 'Hargrand' in particular as very important dietary sources of the antioxidants.

Carotenoid content

An initial assessment of carotenoid content was conducted in 2009 (data not shown). Varietal ranking that year was, in decreasing order, 'Hargrand', 'Harogem', 'Vivagold', 'Tomcot' and 'Harlayne'. The methodology was optimized and varieties reevaluated in 2010 (Figure 3.4).

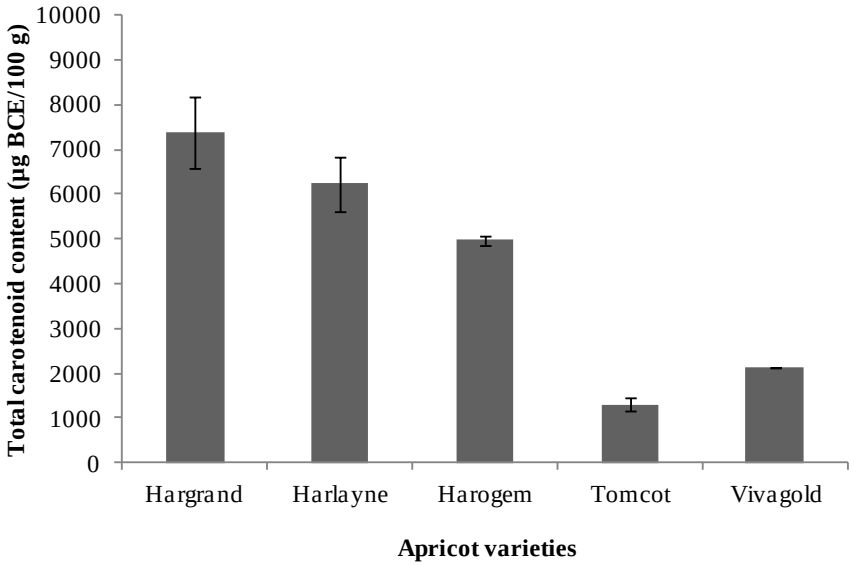

Figure 3.4. Total carotenoid content of Northeast apricot varieties evaluated in 2009 (BCE: β-carotene equivalents).

'Hargrand' was again found to have greatest TC (7371 µg). As had been the case with TP and AOX, 'Harlayne' rallied from the last position it had assumed in 2009 to second place, leaving 'Tomcot' with lowest TC (1312 µg). TC range exceeded that by Kurz and others (2008), 150 – 3989 µg. Mean TC (4000 µg) has higher than the value of 2554 µg given by the USDA (Holden and others 1999), relatively close to that by Salunkhe and others (1968), approximately 5000 µg, and lower than those reported by Ruiz and others (2005) for light-orange (7385 µg) and orange (12750 µg) flesh apricot varieties. The wide variations in reported values are mirrored by the difference in

methods by which these compounds were extracted and quantified in the various studies. However, using values both from our study and the USDA database (Holden and others 1999), apricot TC remained higher than those of other more frequently consumed fruits. Relationships observed by Ruiz and others (2005) between color parameter *a* of flesh (r = 0.93) as well as hue angle of peel (r = 0.84) and total carotenoid content were not observed in our study, nor were any strong correlations with any other skin or flesh color parameter. A correlation of r = 0.75 was however found between TC and AOX, suprisingly high despite the low contribution found from lipophilic constituents to total phenolic content.

Four carotenoid compounds were definitively identified and quantified (Figure 3.5) and the concentrations of one unknown but prominent and ubiquitous compound also recorded. While β-carotene, β-cryptoxanthin, lutein and 'unknown' were found in all varieties, zeaxanthin was not detected in 'Tomcot' and 'Vivagold' (Table 3.4). β-carotene was the predominant carotenoid compound, forming > 90% of quantified carotenoid content in all varieties and having a high correlation (r > 0.98) with TC.

A major appeal of apricots remains their provitamin A properties. This was evaluated taking into consideration the recommended dietary allowance (RDA) of 900 µg retinol activity equivalent (RAE) given by the Institute of Medicine for males 14 years and older, and accepted methods of calculation of dietary provitamin A (1 RAE = 12 µg β – carotene and 24 µg β –cryptoxanthin) (USDA FNC 2011; NIH 2012). On average, a 155 g serving (USDA NAL 2012) of the apricot varieties assessed provided on average 40% RDA, making them excellent sources of vitamin A.

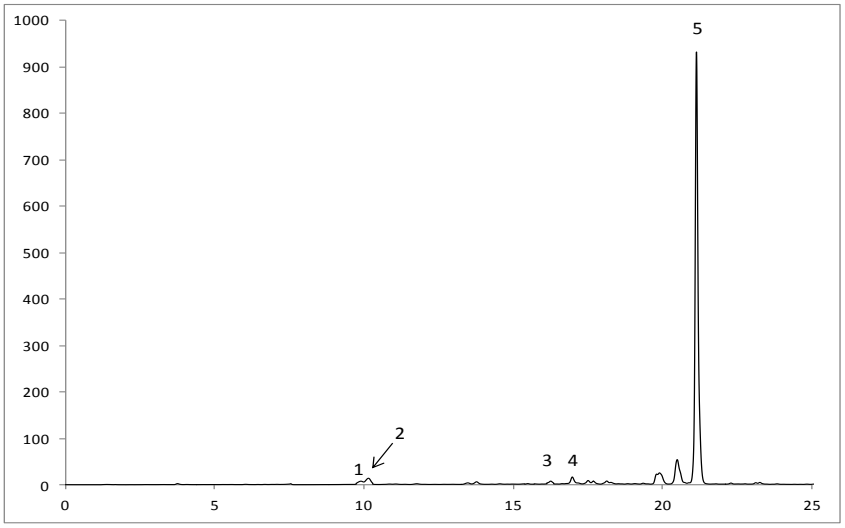

Figure 3.5. HPLC chromatogram of apricot showing carotenoid compounds at 450 nm. Identified compounds are zeaxanthin (1), lutein (2), unknown (3), β-cryptoxanthin (4) and β-carotene (5).

Table 3.4. Carotenoid compounds (µg / 100 g) in selected Northeast apricot varieties evaluated in 2010 (n = 3).

Carotenoid compounds	Hargrand	Harlayne	Harogem	Tomcot	Vivagold
Beta-carotene	7200 ± 660	5600 ± 110	4400 ± 350	1150 ± 74	1970 ± 50
Beta-cryptoxanthin	32 ± 3.9	41 ± 4.1	31 ± 4.0	8 ± 0.5	14 ± 0.0
Lutein	11 ± 1.1	12 ± 0.1	10 ± 0.3	8 ± 0.6	7 ± 1.1
Zeaxanthin	240 ± 16	104 ± 7.4	95 ± 10.2	ND	ND
Unknown	26 ± 2.7	29 ± 5.0	41 ± 8.4	68 ± 9.5	67 ± 0.8
Total	**7500 ± 690**	**5800 ± 130**	**4500 ± 370**	**1200 ± 85**	**2100 ± 50**

Maturity at harvest and storage effect

In 2010, the influence of maturity at harvest was determined for four varieties – 'Hargrand', 'Harlayne', 'Harogem' and 'Vivagold'. The effect of postharvest storage was also evaluated for 'Hargrand', primarily because it was the only variety that endured the previously stated postharvest conditions. The selection of these varieties was based on seasonal availability as well as information obtained in 2009, namely high phenolic and antioxidant content ('Hargrand'), high carotenoid content ('Harogem') and economic importance ('Harlayne').

A comparison of commercial ripe (CR) to tree ripe (TR) harvests indicated changes occurring when the fruit was allowed to ripen on the tree while contrasting CR with storage (ST) showed changes when a fruit was harvested early and stored under cold conditions for prolonged periods, in this case, four weeks. Comparing ST to TR allowed a study of the effects of early harvest and subsequent long-term cold storage (as is largely done in commercial fruit production) versus late harvest (after which fruit is consumed within a short period) on fruit properties and constituents.

It should be noted that the description of CR in particular differs between regions of production or even orchards depending on the required shelf life of fruit, which in turn may be influenced by the length of time to consumption or distance over which the produce must be transported to its final market. As such, while orchards used for our study required full color development for CR harvest, the practice in other producing areas with a greater output or a wider area of distribution may require that fruit be harvested while still green.

Quality indices

Firmness decreases with ripening due to breakdown of fruit cell walls, pectin degradation and loss of tugor owing to the action of cell enzymes (including pectin methylesterase and β-galactosidase) and plant hormones (including ethylene). Firmness is therefore considered a reliable index of fruit maturity or ripeness (Brecht and others 1982; Cardarelli and others 2002; Kovacs and Nemeth-Szerdahely 2002; Payasi and Sanwal 2010).

Fruit experienced an average of 60% decrease in firmness from CR to TR (Table 3.5); with a 73% decrease in 'Hargrand' from CR to ST. Mean TR firmness 11.7 N (2.6 lb) was within the range of 2-3 lb given by Crisosto and Kader (1999) for 'ready-to-eat' fruit. There were no significant differences in mean weight, size or edible portion between CR and TR. Given that by CR, fruit was in the ripening stage and growth had ceased, significant differences in these parameters was not expected between the two harvests (Salunkhe and others 1968; Femenia and others 1998).

Fruit was also assessed for possible changes in color of skin and flesh with ripening on- or off-tree; strong observations or relationships here could have contributed to the search for nondestructive methods of assessment of apricot maturity. However, no significant differences were observed in skin or flesh of fruit (*a*, *b*, *L*, *H* or *C*) from CR to TR. This stood to reason since one of the criteria for pickers in harvesting CR fruit (in our study orchards) was full color development, and thus significant increases in *a* or *b*, as occur in the transition from ground color, were not present in this case (Femenia and others 1998).

Table 3.5. Mean and range values of quality indices of selected Northeast apricot varieties ('Harlayne', 'Hargrand' and 'Harogem') at commercial and tree ripe stages (n = 15).

Maturity	Commercial ripe		Tree ripe	
	Mean	Range	Mean	Range
Firmness (N)	28.3[a]	17.5 – 44.3	11.7[b]	5.5 – 19.9
Weight (g)	44.3[a]	32.6 – 55.6	48.9[a]	45.0 – 51.6
Diameter (mm)	44.3[a]	38.2 – 48.1	44.4[a]	41.4 – 48.1
Edible portion (%)	92.4[a]	87.8 – 94.7	93.6[a]	91.4 – 94.5
Skin *L*	54.7[a]	46.9 – 62.3	54.0[a]	50.5 – 59.2
Skin *a*	26.3[a]	18.9 – 30.6	26.6[a]	17.8 – 31.5
Skin *b*	36.5[a]	27.1 – 44.8	37.5[a]	33.4 – 42.4
Skin *H*	53.0[a]	40.9 – 61.6	54.3[a]	47.8 – 64.5
Skin *C*	45.9[a]	40.5 – 53.1	46.5[a]	39.5 – 51.5
Flesh *L*	54.5[a]	44.8 – 60.3	51.9[a]	40.8 – 58.2
Flesh *a*	23.4[a]	21.3 – 26.7	21.8[a]	17.6 – 26.8
Flesh *b*	40.3[a]	34.1 – 45.0	38.1[a]	30.0 – 43.7
Flesh *H*	59.8[a]	57.8 – 62.1	60.2[a]	55.7 – 64.7
Flesh *C*	46.6[a]	40.2 – 52.4	44.0[a]	36.3 – 51.3
Soluble solids (%)	12.7[b]	11.5 – 14.6	14.4[a]	13.9 – 15.1
Titratable acidity	1.91[a]	0.83 – 3.57	1.14[b]	0.82 – 1.77
Sugar-to-acid ratio	8.47[b]	3.53 – 14.03	13.27[a]	8.07 – 17.32
pH	3.53[b]	3.42 – 3.60	3.70[a]	3.62 – 3.78
Moisture content (%)	86.5[a]	84.6 – 89.9	84.0[b]	80.5 – 86.4

Means not connected by the same letter indicate a significant difference in parameter between the stages (alpha = 0.05).

Being climacteric fruits, apricots can ripen either on or off the tree (Kader 1999; Payasi and Sanwal 2008). Physiological changes as the fruit ripens result in, among other things, changes in sugar (sucrose accumulation) and acid concentrations (Bureau 2006). Overall taste/flavor development and thus consumer acceptance (sensory perception) increases with ripening. This may be gauged instrumentally using SSC/TA, although actual acceptability tests remain the best means of assessment (Salunkhe and others 1968; Crisosto and others 1995; Manolopoulou and Mallidis 1999; Siddiq 2006).

Varieties responded similarly from CR to TR, with increases in SSC ($p < 0.01$), SSC/TA ($p < 0.01$) and pH ($p < 0.01$) and decreases in TA ($p < 0.05$) and MC ($p < 0.01$). Observed trends were similar to those reported by Salunkhe and others (1968), Crisosto (1994), Gomez and Ledbetter (1997) and Bureau and others (2006). While TR SSC (14%) was in excess of that recommended by Crisosto and Kader (1999) for consumer acceptance, TA (1.14) was slightly above what they suggested (0.7 – 1.0); both observations can be considered characteristic of the selection of varieties evaluated. Trends in 'Hargrand' from CR to ST were similar to those reported above, although TA did not change significantly.

Phenolic content

Dragovic-Uzelac and others (2007) found declines in phenolic content with maturity while the findings of Hegedus and others (2011) were to the contrary. Both groups of results were subject to individual varietal characteristics as well as specific developmental stages at which sample fruit were harvested and/or evaluated. In this study, mean TP at CR and TR (180.7 and 163.2 mg, respectively) did not differ significantly; however, the influence of 'Hargrand' in skewing mean data was apparent. In the three other varieties, TR TP was significantly lower than CR TP ($p < 0.01$ in 'Harlayne' and 'Vivagold', $p < 0.05$ in 'Harogem') (Figure 3.6). Suggested reasons for observed decreases in phenolic content with ripening include a change in their role in the plant, and a neccesity to ensure the reduction of astringency for better taste and palatability (Dalla Valle and others 2007). Andreotti and others (2008), who observed similar trends in peaches, recommended further research into the effect of

environmental and agronomic conditions on the phenolic compounds accumulation to aid in optimisation of phenolic levels in ripe fruit.

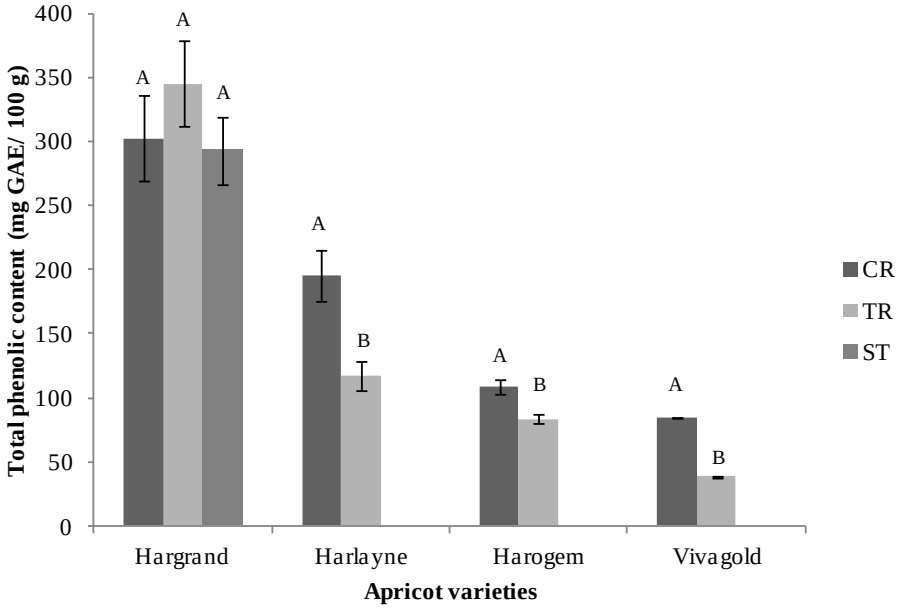

Figure 3.6. Total phenolic content of 'Hargrand', 'Harlayne', 'Harogem' and 'Vivagold' apricots at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (GAE: Gallic acid equivalents). Bars not connected by the same letter indicate a significant difference between the stages (alpha = 0.05).

Comparing the three stages in 'Hargrand', no significant differences were seen across the board, implying that – for this variety – phenolic content remained fairly stable regardless of the maturity at harvest (once fruit had reached CR) or post-harvest storage, subject to parameters described in our study since storage temperature and time have been found to affect phenolic content in other fruits (Kalt and others 1999).

Changes in individual phenolic compound composition and concentration with ripening were variety-dependent (Table 3.6). Flavan-3-ols increased in 'Hargrand' and

decreased in ‘Harlayne’ and ‘Vivagold’, with no significant trend in Harogem. Hydroxycinnamic acids decreased in ‘Harlayne’, ‘Harogem’ and Vivagold’ but showed the opposite trend in ‘Hargrand’. Flavonol glycosides decreased in ‘Harogem’ and ‘Vivagold’ but remained stable in ‘Hargrand’ and ‘Harlayne’. Anthocyanins disappeared in ‘Hargrand’ and ‘Vivagold’ (the latter variety also losing epigallocatechin) while they increased in ‘Harlayne’ and ‘Harogem’. TR ‘Hargrand’ had higher concentrations of individual compounds compared to CR and ST samples.

TP-HPLC remained highly correlated with spectrophotometrically-determined TP ($r > 0.96$) and with flavan-3-ols catechin and epigallocatechin and hydroxycinnamic acids chlorogenic and neochlorogenic acid ($r > 0.90$ in all cases). This assay therefore confirmed the decline in phenolic content with ripening in the majority of the compounds assessed. Catechin and chlorogenic acid, which as noted earlier were correlated well with TP decreased with ripening in all four varieties, giving more credence to the theory that levels of these compounds were indicative of fruit or varietal phenolic content.

Table 3.6. Phenolic compounds (mg / 100 g) in ‘Hargrand’, ‘Harlayne’, ‘Harogem’ and ‘Vivagold’ apricots at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (n = 3).

Phenolic compounds	Hargrand			Harlayne	
	CR	TR	ST	CR	TR
Catechin	21.6 ± 0.3[b]	26.4 ± 1.2[a]	14.4 ± 0.9[c]	8.7 ± 0.2[a]	0.2 ± 0.0[b]
Chlorogenic acid	14.8 ± 0.6[b]	18.4 ± 0.1[a]	17.0 ± 2.6[a]	3.4 ± 0.1[a]	2.3 ± 0.2[b]
Cyanidin-3-glucoside	0.8 ± 0.0	ND	ND	0.8 ± 0.0[b]	0.9 ± 0.0[a]
Epicatechin	2.8 ± 0.2[b]	4.1 ± 0.3[a]	2.7 ± 0.2[b]	10.8 ± 0.1[a]	5.8 ± 0.4[b]
Epigallocatechin	18.4 ± 0.8[b]	22.7 ± 1.1[a]	12.5 ± 0.3[c]	6.6 ± 0.2[a]	3.4 ± 0.5[b]
Neochlorogenic acid	10.7 ± 0.6[b]	12.9 ± 0.8[a]	9.7 ± 0.7[b]	10.6 ± 0.2[a]	6.6 ± 0.7[b]
Quercetin-3-glucoside	1.1 ±0.1[a]	1.3 ± 0.0[a]	1.2 ± 0.1[a]	0.9 ± 0.1[a]	0.9 ± 0.1[a]
Quercetin derivative	1.2 ± 0.0[a]	1.3 ± 0.0[a]	1.2 ± 0.1[a]	0.9 ± 0.1[a]	0.9 ± 0.0[a]
Rutin	9.9 ± 1.1[a]	10.8 ± 1.8[a]	12.0 ± 1.2[a]	4.9 ± 0.1[a]	4.4 ± 0.4[a]
Unknown 1	8.7 ± 0.7[a]	7.1 ± 0.6[a]	4.0 ± 0.2[b]	13.3 ± 0.3[a]	6.0 ± 0.9[b]
Unknown 2	6.6 ± 0.5[a]	6.6 ± 0.6[a]	5.8 ± 0.6[a]	9.7 ± 0.6[a]	5.5 ± 0.6[b]
Total	**96.6 ± 4.9[b]**	**110.3 ± 6.6[a]**	**80.5 ± 6.9[c]**	**70.6 ± 2.0[a]**	**37.0 ± 3.8[b]**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the stages (alpha = 0.05).

Table 3.6. (Continued).

Phenolic compounds	Harogem		Vivagold	
	CR	TR	CR	TR
Catechin	10.3 ± 0.8[a]	2.7 ± 0.2[b]	6.6 ± 1.0[a]	2.1 ± 0.0[b]
Chlorogenic acid	4.0 ± 0.4[a]	2.3 ± 0.1[b]	9.2 ± 0.3[a]	3.1 ± 0.0[b]
Cyanidin-3-glucoside	1.5 ± 0.1[b]	2.4 ± 0.3[a]	0.9 ± 0.0	ND
Epicatechin	2.6 ± 0.2[b]	4.3 ± 0.2[a]	2.8 ± 0.1[a]	2.0 ± 0.1[b]
Epigallocatechin	6.5 ± 0.6[a]	4.7 ± 0.3[b]	1.4 ± 0.0	ND
Neochlorogenic acid	8.1 ± 0.8[a]	5.8 ± 0.1[b]	11.8 ± 0.5[a]	4.6 ± 0.1[b]
Quercetin-3-glucoside	0.9 ± 0.1[a]	1.2 ± 0.1[a]	1.4 ± 0.1[a]	0.9 ± 0.0[b]
Quercetin derivative	1.5 ± 0.0[a]	1.0 ± 0.1[b]	2.2 ± 0.1[a]	1.1 ± 0.0[b]
Rutin	10.6 ± 0.4[a]	6.3 ± 0.4[b]	18.5 ± 0.9[a]	4.9 ± 0.1[b]
Unknown 1	2.6 ± 0.2[b]	3.2 ± 0.1[a]	1.9 ± 0.5[a]	1.1 ± 0.1[b]
Unknown 2	2.4 ± 0.1[b]	3.9 ± 0.3[a]	2.6 ± 0.3[a]	2.7 ± 0.1[a]
Total	**51.0 ± 3.7[a]**	**37.8 ± 3.2[b]**	**59.3 ± 3.8[a]**	**22.5 ± 0.5[b]**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the stages (alpha = 0.05).

Antioxidant capacity

Given the significant correlation between AOX and phenolics, similar results as seen with phenolics were expected (i.e. decline or relative stability of phenolics with ripening). This was largely realized (Figure 3.7), with mean AOX at CR and TR (4667 and 4019 µmol respectively) not differing significantly. Similar to their responses per TP, 'Hargrand' AOX remained constant while 'Harlayne' and 'Vivagold' AOX decreased with ripening ($p < 0.01$). The decreases contrasted reports by Hegedus and others (2011), one of the few published studies on the effect of ripening on apricot AOX. 'Harogem', which had shown relatively less phenolic decline with ripening, did no change significantly in AOX with ripening.

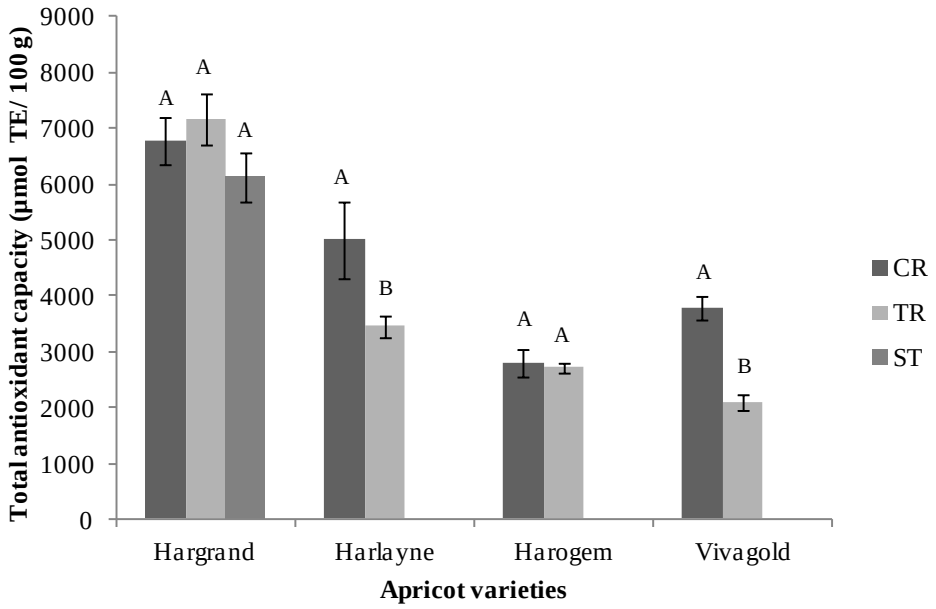

Figure 3.7. Total antioxidant capacity of 'Hargrand', 'Harlayne', 'Harogem' and 'Vivagold'apricots at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (TE: Trolox equivalents). Bars not connected by the same letter indicate a significant difference between the stages (alpha = 0.05).

The lack of similar studies with apricots leaves little data with which to contrast our observations. Our results indicate that changes in varietal antioxidant capacity with ripening are strongly linked with changes in phenolic content. This agrees with findings by Gil and others (2002) and Kalt and others (1999), who found phenolic compounds to be mainly responsible for antioxidant activity as measured by the ORAC test in peaches and berries, respectively.

Carotenoid content

In all four apricot varieties, an increase in carotenoid content was observed from CR to TR. Similar results had been reported by Salunkhe and others (1968), Katayama and others (1971) and Dragovic-Uzelac and others (2007) The phenomenon has been attributed to an upregulation of carotenoid gene expression (phytoene synthase) with ripening (Fraser and Bramley 2004). This enzyme catalyzes the first committed step of carotenoid synthesis, the conversion of geranylgeranyl pyrophosphate to phytoene; phytoene serves as a precursor of lycopene from which several other carotenoid compounds are synthesized.

Of the three categories of bioactive compounds evaluated in this study, carotenoids were the only group to show significant change under cold storage, with 'Hargrand' TC increasing five-fold from CR to ST. Increase in TC with on-tree ripening ranged from three-fold in 'Vivagold' to six-fold in 'Hargrand' (Figure 3.8).

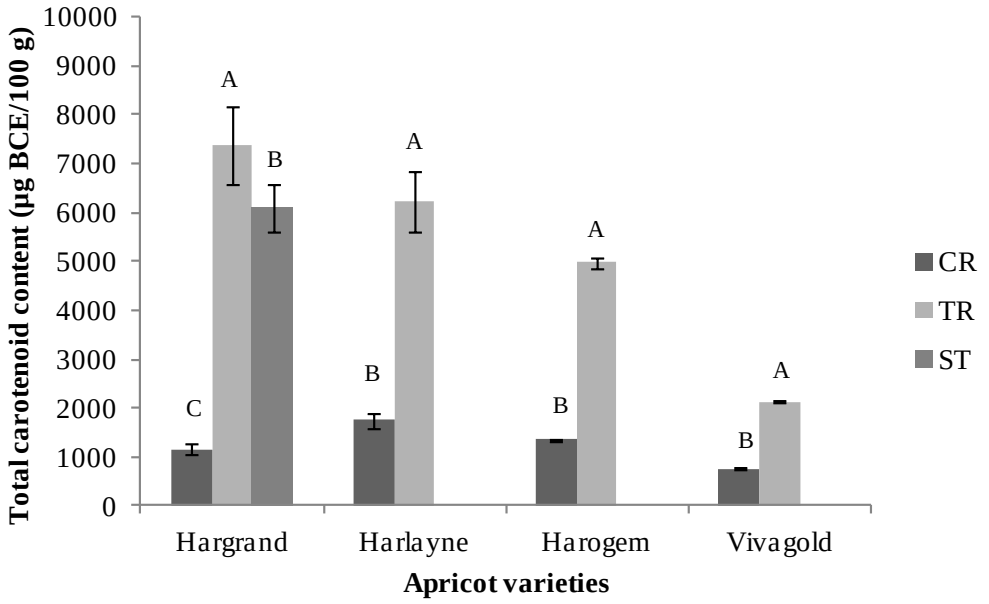

Figure 3.8. Total carotenoid content of 'Hargrand', 'Harlayne', 'Harogem' and 'Vivagold' apricots at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (BCE: β-carotene equivalents). Bars not connected by the same letter indicate a significant difference between the stages (alpha = 0.05).

Consistent increases with ripening were observed in β-carotene and β-cryptoxanthin, as seen by Katayama and others (1971). β-carotene remained the predominant carotenoid and main determinant of fruit carotenoid content; the marked increase in TC were due to the increases in the concentration of this compound (Table 3.7). Zeaxanthin content with ripening was variety-dependant.

The degree of carotenoid increase with apricot ripening was a particularly important finding of this study. It has significant implications on how production practices or personal preferences (e.g. eating fruit while still firm or unripe) affect the amount of vitamin A available (at least *in vitro*) to consumers.

Table 3.7. Carotenoid compounds (µg / 100 g) in 'Hargrand', 'Harlayne', 'Harogem' and 'Vivagold apricots at commercial ripe (CR), tree ripe (TR) and storage (ST) stages (n = 3).

Carotenoid compounds	Hargrand			Harlayne	
	CR	TR	ST	CR	TR
Beta-carotene	1040 ± 78^{c}	7200 ± 763^{a}	5900 ± 570^{b}	1700 ± 150^{b}	5600 ± 120^{a}
Beta-cryptoxanthin	12 ± 2.9^{b}	32 ± 3.9^{a}	25 ± 3.5^{ab}	12 ± 2.8^{b}	41.1 ± 8.1^{a}
Lutein	8.4 ± 0.8^{a}	11 ± 1.1^{a}	112 ± 1.4^{a}	7.3 ± 0.5^{b}	12.0 ± 0.1^{a}
Zeaxanthin	108 ± 2.8^{a}	240 ± 10.5^{b}	ND	ND	104.0 ± 8.4
Unknown	9.6 ± 1.8^{b}	26 ± 2.7^{a}	36 ± 10^{a}	19 ± 0.8^{b}	29 ± 5.0^{a}
Total	**1400 ± 86^{c}**	**7500 ± 780^{b}**	**6003 ± 580^{a}**	**1700 ± 160^{b}**	**5800 ± 140^{a}**

Carotenoid compounds	Harogem		Vivagold	
	CR	TR	CR	TR
Beta-carotene	1200 ± 35^{b}	4400 ± 150^{a}	690 ± 64^{b}	2000 ± 51^{a}
Beta-cryptoxanthin	9.3 ± 0.3^{b}	31 ± 3.4^{a}	8.7 ± 0.9^{b}	14 ± 0.0^{a}
Lutein	13 ± 1.6^{a}	10 ± 0.3^{b}	5.6 ± 0.1^{b}	7.4 ± 1.0^{a}
Zeaxanthin	68 ± 5.2^{b}	95 ± 7.0^{a}	ND	ND
Unknown	6.6 ± 0.1^{b}	41 ± 8.4^{a}	63 ± 5.2^{a}	67 ± 0.8^{a}
Total	**1300 ± 42^{b}**	**4600.0 ± 170^{a}**	**760 ± 71^{b}**	**2060 ± 52^{a}**

ND: Not detected. Means not connected by the same letter indicate a significant difference in compound concentration between the stages (alpha = 0.05).

Conclusion

This study provided detailed profiles of locally-grown Northeast apricot varieties. It also identified 'Hargrand' apricot as having impressive phenolic, antioxidant and carotenoid content. Flavan-3-ols (catechin and epigallocatechin) and hydroxycinnamic acids (chlorogenic and neochlorogenic acid) proved reliable indicators of varietal phenolic and antioxidant content, while β-carotene was most indicative of carotenoid content. Apricots compared favorably against more popular fruits (apples and grapes) in phenolic content and antioxidant capacity and it surpassed them in carotenoid content.

Seasonal variations over two years influenced some quality (mainly chemical) indices but had less categorical influences on bioactive compound concentration. Varieties differed in the responses of their phenolic and antioxidant components to ripening, although a trend of decreasing phenolic content was observed in the majority of varieties. In all varieties, however, a large increase in carotenoids content was observed as fruit ripened on-tree. In the one variety assessed for changes with cold storage, phenolic and antioxidant content remained stable while carotenoid content increased sharply. The effects of varietal and harvest variations on bioactive compounds illustrated the susceptibility of these compounds to horticultural practices, and highlighted the need for better understanding and, where possible, control of these in order to ensure optimum levels of the nutraceuticals in fruit.

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CHAPTER 4: THE EFFECT OF PROCESSING AND STORAGE ON THE PHENOLIC, ANTIOXIDANT AND CAROTENOID CONTENT OF CANNED PEACHES AND APRICOTS.

Introduction

The peach (*Prunus persica*) and apricot (*Prunus armeniaca*) contain phenolic and carotenoid compounds and are considered important sources of antioxidants and vitamin A, both recommended for their health benefits (Tomas-Barberan and others 2001; Gil and others 2002; Ruiz and others 2005a; Ruiz and others 2005b). Dietary antioxidants are understood to reduce the risk of cardiovascular diseases and some cancers while carotenoids play a role in vision and prevent age-related macular degeneration (Ames and others 1993; Paiva and Russell 1999; Fraser and Bramley 2004; Kader and Barrett 2005).

Being climacteric fruits, peaches and apricots present a challenge in postharvest storage (Kader and Mitchell 1989; Kader 1999; Payasi and Sanwal 2008). Processing serves as a means to add value, extend fruit shelf life and ensure availability when fruit is out of season. In the United States, fruits are consumed more in processed than fresh form; 38% of peaches and 16% US of apricots produced in the USA are consumed as canned products (Rickman and others 2007b; USDA ERS 2011). An area of concern with these products is the successful combination of aesthetic appeal and nutritive value (Rickman and others 2007a).

Peaches and apricots are often peeled before canning to ensure a uniform, attractive appearance and good mouthfeel (Manolopoulou and Mallidis 1999; Ramaswamy

2005; Siddiq 2006a; Siddiq 2006b). Given the higher quantities of phenolic and carotenoid compounds in the peel of both fruits as compared to the flesh, this practice may result in significant losses in these phytochemicals in peeled canned products (Ramaswamy 2005; Tomas-Barberan and others 2001; Gil and others 2002; Ruiz and other 2005a).

The thermal treatment involved in canning may also degrade heat labile constituents, polymerizing polyphenols and oxidizing antioxidant compounds; results from different studies have varied with processing time and temperature (Hamama and Nawar 1991; Howard and others 1996; Asami and others 2003). Contrarily, other studies have indicated an increase in antioxidant capacity due to the antioxidant properties of Maillard reaction products formed during heating (Lingnert and Lundgreen 1980; Elizalde and others 1991; Anese and others 1999). The effect of heating on carotenoids has been found to be beneficial in some studies and detrimental in others (Edwards and Lee 1986; Lessin and others 2007).

The aim of our study was therefore to assess the effect of peeling, thermal treatment as well as storage on the composition and concentration of phenolic, antioxidant and carotenoid compounds in canned peaches and apricots. The syrup in which fruit was canned, a component often unexamined in other studies, was also analysed post-processing and over a 6-month shelf life study better assess the significance of losses due to leaching as opposed to degradation during processing or storage. Results were intended to provide insight into the effect of typical canning procedures on healthful compounds in this product.

Materials and methods

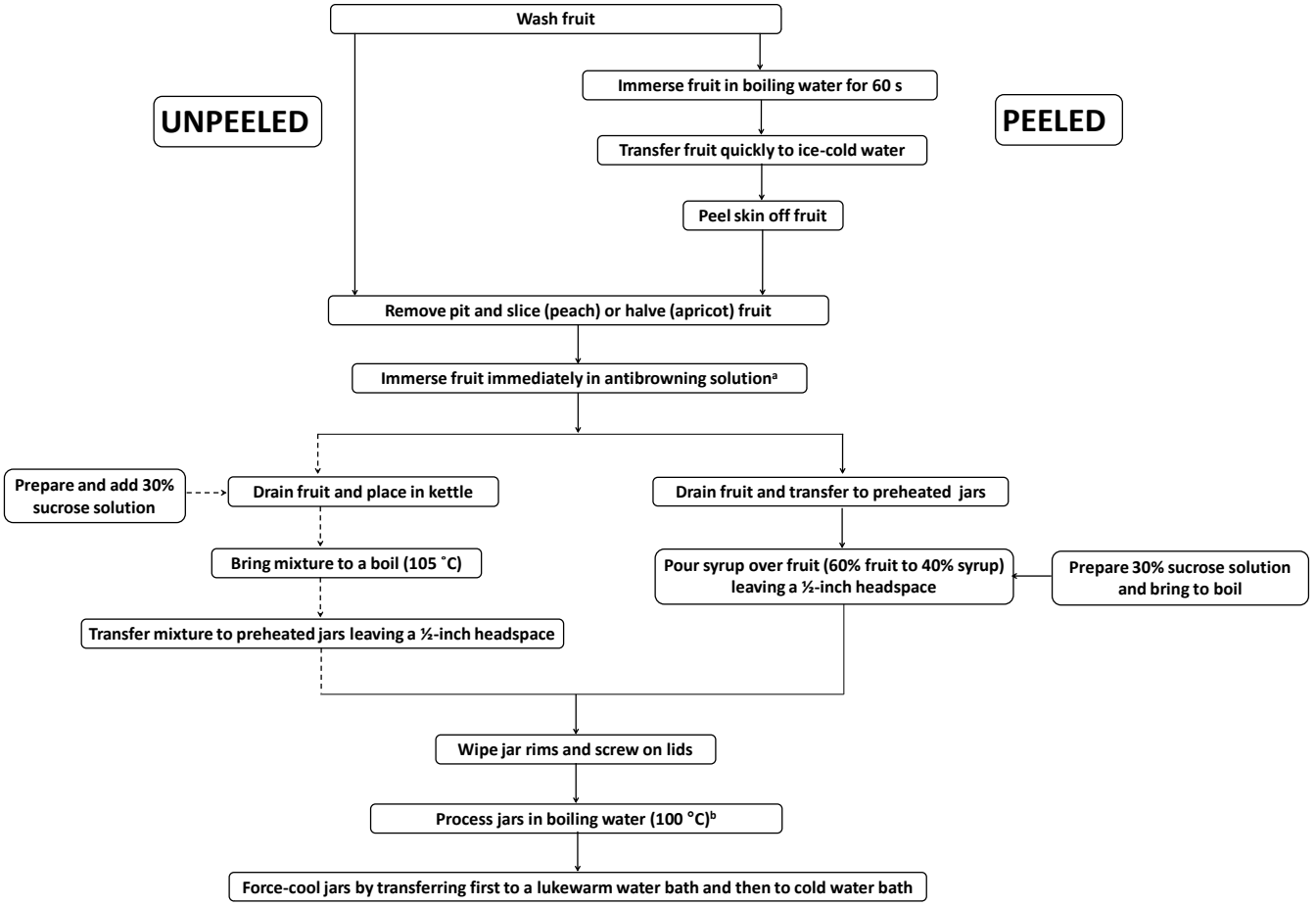
The study was in two phases, with the first focusing on the effect of peeling prior to canning on three peach and three apricot varieties. In the second phase involved one peach and one apricot variety; a 6-month shelf life study conducted to monitor the stability of phytochemicals in storage.

Harvest

Three yellow-fleshed peach and orange-fleshed apricot varieties were harvested at commercial ripeness (firm, full color development) from local Northeast orchards in 2010 and 2011. Fruits were harvested at this point to ensure adequate ripeness yet sufficient firmness to withstand processing conditions (Ramaswamy 2005; Siddiq 2006a). Varieties were chosen based on a previous study on Northeast peaches and apricots (Campbell and others 2011) for high phenolic content and antioxidant capacity ('PF 23' peach and 'Hargrand' apricot'), high carotenoid content ('John Boy II' peach and 'Harogem' apricot) and economic importance to the Northeast ('Redhaven' peach and 'Harlayne' apricot). 'Redhaven' peach and 'Harlayne' apricot were reassessed in the second phase of the study. Fresh fruit samples were lyophilized, homogenized and stored at 0 ˚C until analyses.

Canning

Canning was conducted following typical canning protocols (Reynolds and others 1993). The process is illustrated in Figure 4.1, with differences in the two phases indicated using broken lines (---) for the first phase and continuous lines for the second. Pictures of the final products are shown in Illustration A.5.



[a]Antibrowning solution comprised 1.2% citric acid, 0.06% calcium chloride and 0.2% ascorbic acid (Hall 1989).
[b]Jars (8 oz, 237 mL) were capped and processed for 17 min to achieve shelf stability, based on heat penetration studies (lethality of 0.1 min, T_{ref} = 93 ˚C, z = 9 ˚C) (Padilla-Zakour 2009).

Figure 4. 1. Flow chart for the production of unpeeled and peeled canned peaches and apricots.

Phenolic analysis

One gram freeze-dried and 5 g canned fruit or syrup were extracted following the method described in chapter 2 with 80% methanol used for freeze-dried samples and 100% methanol for canned fruit and syrup. Total phenolic content and HPLC phenolic analysis were also performed as in chapter 2.

Total antioxidant capacity assay

This was performed as described in chapter 2.

Carotenoid analysis

This was performed as described in chapter 2; 5 g canned fruit or syrup was extracted and analysed.

Shelf life study

Samples were stored at 18 - 20 ˚C for six months (mo) under dark conditions. Phenolic, antioxidant and carotenoid analyses were conducted at 3 mo and again at 6 mo. Results were compared to those obtained post-processing.

Statistical analysis

Data was analysed as described in chapter 2, with the respective weights for bioactive data stated as required.

Results and discussion

The first phase studied varietal phytochemical response to canning with unpeeled or peeled fruit. The effect of these treatments on structural integrity and product appearance was noted. Loss of structural integrity was anticipated because the canning process results in the solubilization of cell wall polysaccharides and eventual softening and breakdown of fruit tissue (Chitarra and others 1989; Apostolopoulos and Brennan 1993). Visually, unpeeled samples had better integrity compared to peeled samples with 'John Boy II' peach and 'Harlayne' apricots retaining best structure. Apricots held together better than peaches, in part due to the less destructive nature of fruit sectioning. While peeled and unpeeled apricot samples were visually similar, a diffusion of pink to red color into syrup was observed in unpeeled peach samples while peeled samples had a more uniform appearance.

As in the fresh samples, canned apricots had on average higher phenolic (four-fold), antioxidant (two-fold) and carotenoid (ten-fold) values compared to canned peaches. While canned 'PF 23' peach retained highest total phenolic content (TP) for both peeled and unpeeled samples, peach varieties did not differ significantly in total antioxidant capacity (AOX) and total carotenoid content (TC) (Figure 4.2). In apricots canned 'Hargrand' remained highest in TP and AOX but did not differ from other varieties in TC (Figure 4.3).

Previous studies have reported higher concentration of phenolic and carotenoid compounds in the peel of fresh peaches and apricots compared to the flesh (Tomas-Barberan and others 2001; Gil and others 2002; Ruiz and others 2005a; Ruiz and

others 2005b). The removal of peel was therefore anticipated to reduce the concentrations of these compounds, although few studies have examined the effect of this practice in canned fruit. Available literature by Asami and others (2003) reported higher phenolic content (1.5-fold) in unpeeled peaches compared to peeled canned peaches while Talcott and others (2000) saw higher antioxidant and individual phenolic content in peach puree produced from unpeeled peaches compared to the alternative. Tomatoes undergoing prolonged heating with their peels intact had greater carotenoid compared to their peeled counterparts (Graziani and others 2003).

In our study, although a general decrease in TP was observed with peeling, it was only significant ($p < 0.05$) in 'PF 23' (19.2%). No significant differences were observed in AOX between the two treatments in all varieties. In TC, lower values ($p < 0.01$) were observed with peeling in 'PF 23' (24.7%) and 'Redhaven' (27.3%) but not in 'John Boy II'. In apricots, peel removal resulted in decreases in phenolic content ($p < 0.01$) and antioxidant capacity ($p < 0.01$) only in 'Hargrand' (22.1% and 33.9%, respectively). However, all apricot varieties showed a decrease in TC ($p < 0.01$) with peeling – 16.1% in Hargrand, 27.0% in Harlayne and 30.1% in Harogem. The differences in varietal response to peeling and canning indicate variations in distribution of bioactive compounds (between peel and flesh) in the various varieties. The results could also imply differences in the stability of these compounds, in the various varieties, under the processing conditions. The uniform decline in TC with peeling in apricots corroborated the findings of greater, or at least substantial, concentration of carotenoids in the skin of fruit. Within reason, that conclusion can also be drawn with peaches, given that the majority of varieties responded similarly.

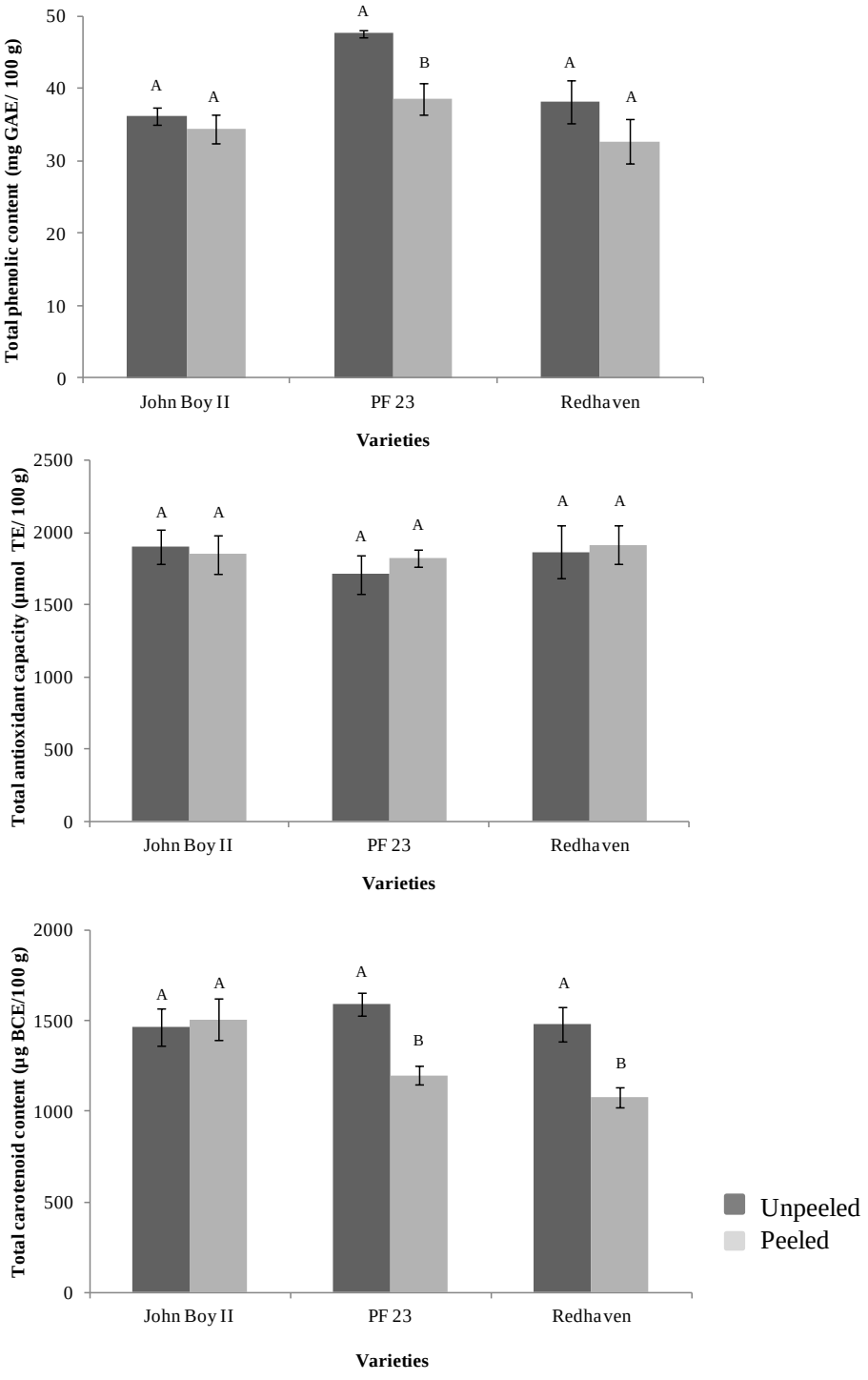


Figure 4. 2. Total phenolic content, total antioxidant capacity and total carotenoid content of unpeeled and peeled canned 'John Boy II', 'PF 23' and 'Redhaven' peaches (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents). Bars not connected by the same letter indicate a significant difference between treatments (alpha = 0.05).

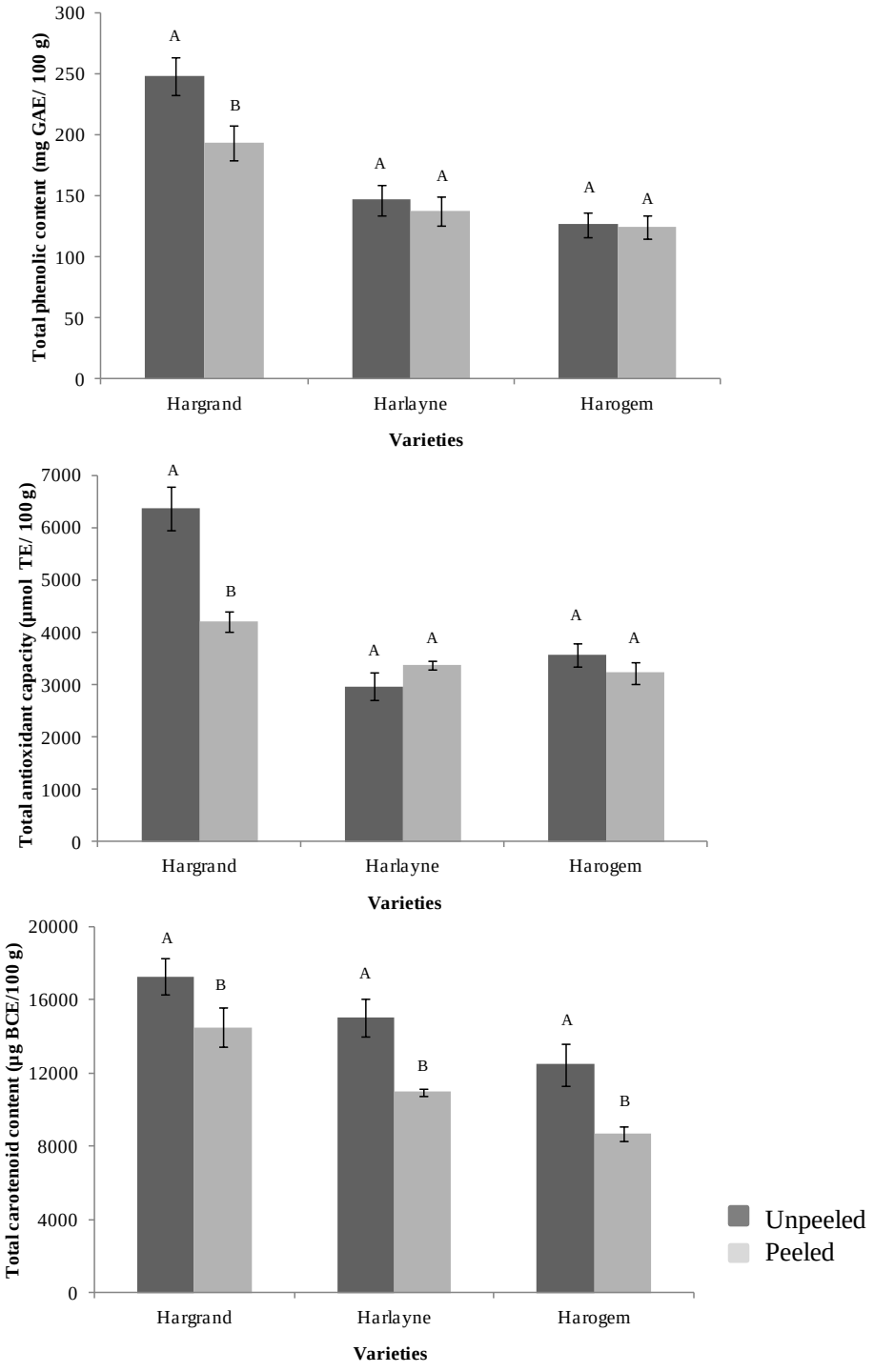


Figure 4. 3. Total phenolic content, total antioxidant capacity and total carotenoid content of unpeeled and peeled canned ‘Hargrand’, ‘Harlayne’ and ‘Harogem’ apricots (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents). Bars not connected by the same letter indicate a significant difference between treatments (alpha = 0.05).

Canned fruit syrup or brine is often drained to reduce sugar or sodium intake; this practice may result in losses of hydrophilic compounds and nutrients (such as phenolics and vitamin C) which can migrate from fruit into the surrounding liquid. In their review of nutritional comparison of fresh and processed fruits and vegetables, Rickman and others (2007a) noted that most studies did not analyse this fraction. Chaovanalikit and Wrolstad (2004) who did conduct this analysis found that approximately 50% of phenolic compounds were lost into syrup in canned cherries.

In our study, we assessed the contribution of syrup to the total phytochemical content of the canned unit. In peaches, syrup contained 34 – 38% TP, 48 – 52% AOX and 0.5 – 1% TC and in apricots, 34 – 38% TP, 30 – 48% AOX and 0.5 – 1 % TC of canned product after processing. No significant differences were seen with treatment or variety except in apricot AOX, with syrup of peeled 'Hargrand' (48%) and 'Harogem' (41%) contained higher AOX ($p < 0.01$) than that of unpeeled samples (40% and 30%, respectively), suggesting that in these varieties there was greater leaching of antioxidant compounds in peeled compared to unpeeled samples, which are relatively more physically intact. These results confirmed substantial losses of hydrophilic compounds – phenolic compounds and ORAC antioxidants, which are comprised primarily of phenolic compounds (Kalt and others 1999; Gil and others 2002; See Chapters 1 and 2) – if canned fruit syrup was discarded or not consumed.

Studies on nutrient retention with canning vary greatly in their approach. Available studies were conducted with different canning procedures and losses computed alternatively on wet or dry weight bases. In our study, comparing equivalent quantities

of canned to fresh fruit on wet weight basis, the trend in both fruits was decreases in phenolic content and antioxidant capacity with canning. These observations were in agreement with work by Asami and others (2003) and Chaovanalikit and Wrolstad (2004) who reported a reduction of phenolic content with processing of canned peaches and cherries respectively, with losses attributed both to processing conditions and leaching of these hydrophilic components into syrup. These studies mentioned the influence of factors such as processing temperature and syrup composition on losses, as well as the varying responses of specific phenolic compounds to treatments. Contrarily, Durst and Weaver (2012) observed similar phenolic content and higher antioxidant content in canned as opposed to fresh peaches.

We noted higher values in carotenoid content of canned compared to fresh fruits. This was in line with studies reporting greater extractability of carotenoids after heat processing due to a breakdown of the cellular matrix (Stahl and Sies 1992; Seybold and others 2004). Additionally carotenoids, due to their lipophilic nature, are less susceptible to leaching into syrup and therefore less affected by the canning process, although they can undergo some degradation with oxidation, light or heat (Paiva and Russell 1999; Abushita and others 2000; Britton and Khachik 2009). A previous study by Durst and Weaver (2012) had resulted in higher but not significantly different carotenoid content while Lessin and others (2007) saw decreases in canned peaches. Edwards and Lee (1986) also reported nonsignificant differences and suggested that changes could be better assessed by accurately accounting for the losses of water and water-soluble fruit components, a view supported by Britton and Khachik (2009).

HPLC analysis allowed for an examination of the effect of the two canning treatments on specific phenolic compounds (Tables 4.1 and 4.2) and accounted for inadequacies of the more generalized Folin-Ciocalteu assay, which is susceptible to interference by sugar (Waterhouse 2002). Although the effect of peeling on the different classes of phenolic compounds varied, peeling typically resulted in a significant decrease in specific phenolic compounds and overall HPLC-determined TP. As in the Folin-Ciocalteu assay, 'John Boy II' peach and 'Hargrand' apricot were most affected by peeling.

Peach flavan-3-ol responses were variety dependent; losses of catechin and epigallocatechin, found to correlate best with peach total phenolic content (See Chapter 1) influenced final unpeeled versus peeled HPLC-TP. For hydroxycinnamic acids, chlorogenic acid decreased across the board while neochlorogenic acid was not significantly impacted by peeling. Flavonol glycosides and anthocyanins were most uniformly affected by peeling, agreeing with reports of greater concentration of these two groups in the peel of these fruits (Chang and others 2000; Tomas-Barberan and others 2001). Quercetin-3-glucoside and rutin disappeared in all peeled samples and the unidentified flavonol glycoside (unknown 2) in 'John Boy II' and 'Redhaven' but not in 'PF 23'; kaempferol-3-rutinoside was not significantly affected. The sole anthocyanin, cyanidin-3-glucoside, decreased in all peeled samples. Anthocyanins are very unstable compounds and known to be influenced by a range of factors including pH, temperature, sugar content and food composition (Shahidi and Naczk 2004) which in part explains their degradation.

Table 4.1. Phenolic compounds (mg / 100 g) in unpeeled and peeled canned 'John Boy II', 'PF 23' and 'Redhaven' peaches (n = 4).

Phenolic compounds	John Boy II		PF 23		Redhaven	
	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled
Catechin	1.05 ± 0.12[a]	0.89 ± 0.01[a]	1.52 ± 0.09[a]	0.75 ± 0.04[b]	1.63 ± 0.13[a]	0.51 ± 0.07[b]
Chlorogenic acid	2.70 ± 0.24[a]	2.37 ± 0.09[b]	6.47 ± 0.38[a]	3.98 ± 0.13[b]	3.73 ± 0.09[a]	2.83 ± 0.13[b]
Cyanidin-3-glucoside	2.88 ± 0.10[a]	1.88 ± 0.11[b]	4.19 ± 0.26[a]	1.60 ± 0.02[b]	2.22 ± 0.13[a]	1.51 ± 0.07[b]
Epicatechin	3.81 ± 0.17[a]	4.44 ± 0.31[b]	4.47 ± 0.20[a]	3.99 ± 0.22[a]	4.41 ± 0.65[a]	2.65 ± 0.12[b]
Epigallocatechin	1.11 ± 0.11[a]	0.95 ± 0.03[a]	1.33 ± 0.07[a]	0.65 ± 0.09[b]	1.18 ± 0.15[a]	0.85 ± 0.31[a]
Kaempferol-3-rutinoside	7.12 ± 0.02[a]	7.17 ± 0.02[b]	7.38 ± 0.01[a]	7.40 ± 0.04[a]	7.16 ± 0.13[a]	6.94 ± 0.01[b]
Neochlorogenic acid	2.15 ± 0.22[a]	2.07 ± 0.02[a]	3.75 ± 0.05[a]	2.34 ± 0.11[a]	2.37 ± 0.22[a]	2.48 ± 0.14[a]
Quercetin-3-glucoside	1.12 ± 0.01	ND	1.15 ± 0.02	ND	1.11 ± 0.01	ND
Rutin	1.07 ± 0.00	ND	1.07 ± 0.01	ND	1.07 ± 0.00	ND
Unknown 1	0.94 ± 0.06[a]	0.61 ± 0.11[b]	1.64 ± 0.01[a]	1.31 ± 0.03[b]	1.53 ± 0.10[a]	0.87 ± 0.08[b]
Unknown 2	1.12 ± 0.01	ND	1.17 ± 0.01[a]	1.12 ± 0.01[b]	1.17 ± 0.01	ND
Total	**25.07 ± 1.06[a]**	**20.38 ± 0.07[b]**	**34.14 ± 1.11[a]**	**23.14 ± 0.69[b]**	**27.58 ± 1.62[a]**	**18.19 ± 0.93[b]**

ND: Not detected. Unknown 1: flavan-3-ol; Unknown 2: flavonol glycoside. Means not connected by the same letter indicate a significant difference between treatments for that compound (alpha = 0.05).

Table 4.2. Phenolic compounds (mg / 100 g) in unpeeled and peeled canned ‘Hargrand’, ‘Harlayne’ and ‘Harogem’ apricots (n = 4).

Phenolic compounds	Hargrand		Harlayne		Harogem	
	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled
Catechin	10.29 ± 1.23[a]	4.22 ± 0.30[b]	2.08 ± 0.49[a]	1.02 ± 0.09[b]	2.39 ± 0.16[a]	1.67 ± 0.13[b]
Chlorogenic acid	13.11 ± 0.81[a]	6.93 ± 0.74[b]	2.43 ± 0.22[a]	2.29 ± 0.25[a]	3.69 ± 0.16[a]	3.00 ± 0.10[b]
Cyanidin-3-glucoside	ND	ND	ND	ND	1.35 ± 0.03	ND
Epicatechin	2.17 ± 0.21[a]	2.32 ± 0.32[a]	4.79 ± 0.76[a]	5.17 ± 0.53[a]	2.41 ± 0.16[a]	2.28 ± 0.18[a]
Epigallocatechin	11.30 ± 0.55[a]	6.43 ± 0.38[b]	1.73 ± 0.10[a]	1.33 ± 0.08[b]	3.08 ± 0.20[a]	2.33 ± 0.22[b]
Neochlorogenic acid	8.85 ± 0.41[a]	4.18 ± 0.32[b]	6.59 ± 1.51[a]	5.34 ± 0.57[a]	7.97 ± 0.38[a]	5.59 ± 0.13[b]
Quercetin-3-glucoside	1.27 ± 0.05	ND	1.15 ± 0.02	ND	1.31 ± 0.02	ND
Quercetin derivative	1.31 ± 0.07	ND	1.18 ± 0.03	ND	1.42 ± 0.03[a]	1.12 ± 0.00[b]
Rutin	7.99 ± 1.44[a]	1.33 ± 0.09[b]	3.74 ± 0.09[a]	1.39 ± 0.03[b]	6.15 ± 0.28[a]	1.59 ± 0.06[b]
Unknown 1	3.16 ± 0.20[a]	3.30 ± 0.22[a]	6.61 ± 1.98[a]	7.96 ± 0.66[a]	2.51 ± 0.15[a]	1.77 ± 0.17[b]
Unknown 2	3.45 ± 0.44[a]	3.48 ± 0.16[a]	3.94 ± 0.46[a]	3.09 ± 0.21[a]	1.46 ± 0.08[a]	1.26 ± 0.01[b]
Total	**62.90 ± 5.41[a]**	**32.19 ± 2.53[b]**	**34.24 ± 5.66[a]**	**27.59 ± 2.42[a]**	**33.74 ± 1.65[a]**	**20.61 ± 1.00[b]**

ND: Not detected. Unknown 1 and 2: flavan-3-ols. Means not connected by the same letter indicate a significant difference between treatments for that compound (alpha = 0.05).

Ruiz and others (2005a) reported larger quantities of all four classes of phenolic compounds in the skin as compared to the flesh of apricots and therefore peeling was theorized to significantly impact the concentrations of these compounds. In our canned products, the effect on flavan-3-ols was largely variety-dependent as with peaches, although catechin and epigallocatechin – indicators of total phenolic content (See Chapter 2) – were observed to decline in all varieties with peeling. Hydroxycinnamic acids were reduced significantly in peeled 'Hargrand' and 'Harogem' but not 'Harlayne'. As with peaches, flavonol glycosides were most affected, with quercetin-3-glucoside and the quercetin derivative disappearing with peeling in all but one instance ('Harogem') and rutin content being reduced by more than half in all cases. Anthocyanin cyanidin-3-glucoside was completely lost in 'Hargrand' and 'Harlayne' but not in Harogem, a variety particularly unique for its deep red blush and marked by high anthocyanin content in fresh form (See Chapter 2).

Generally, the losses of these compounds could be attributed to a number of factors, including degradation of unstable anthocyanins or greater susceptibility to leaching of polar glycosylated flavonol compounds into syrup (Kim and Lee 2002). Additionally, some phenolic compounds act as antioxidants and may therefore be oxidized during processing and storage (thermal action, exposure to oxygen and light) of canned produce (Hamama and Nawar 1991; Smith and others 2005). The absence of specific compounds in peeled samples gives credence to their reported situation in fruit peel, while the reduction in quantities of specific compounds implies that they may be more greatly concentrated in the peel.

Carotenoid compounds have been found to be more concentrated in the peel of both fruits, being 2-3 times higher in peel of apricots, with β-carotene being the predominant carotenoid (Gil and others 2001; Ruiz and others 2005b). This was illustrated by the reduction with peeling in two of the three peach varieties evaluated and all three apricot varieties (Tables 4.3 and 4.4). Although a significant decrease in β-carotene was observed in these varieties (possibly more noticeable or measurable due to its high quantities) changes to other compounds were more variety dependent. Our findings generally agreed with those of Graziani and others (2003) discussed previously.

These observations informed the design of the second phase of the study, which examined in more detail the effect of treatments on total and individual phenolic and carotenoid content and antioxidant capacity by processing as well as storage. Given the observed losses in canned fruit, in part from leaching into the liquid component of the canned product, the syrup fraction was analysed post-processing and during storage. 'Redhaven' peach was selected for revaluation because of its economic importance to the Northeast due to its cold hardiness (Lamb and Terry 1973; Scorza and Sherman 1996) and its reputation as a reliable commercial variety (Monet and Bassi 2008). 'Harlayne' apricot was also chosen for its cold hardiness (Layne 1996) as well as its consumer appeal which has made it a top selling variety in the Northeast.

Table 4.3. Carotenoid compounds (µg / 100 g) in unpeeled and peeled canned 'John Boy II', 'PF 23' and 'Redhaven' peaches (n = 4).

Carotenoid compounds	John Boy II		PF 23		Redhaven	
	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled
Beta-carotene	870 ± 89[a]	860 ± 98[a]	1010 ± 39[a]	730 ± 42[b]	930 ± 76[a]	707 ± 42[b]
Beta-cryptoxanthin	170 ± 7[a]	190 ± 6[a]	170 ± 20[a]	130 ± 2[b]	160 ± 10[a]	110 ± 2[b]
Lutein	ND	ND	ND	ND	ND	ND
Zeaxanthin	85 ± 10[b]	130 ± 9[a]	70 ± 4[b]	97 ± 9[a]	110 ± 11[a]	96 ± 10[a]
Total	**1130 ± 106[a]**	**1180 ± 110[a]**	**1250 ± 63[a]**	**970 ± 53[b]**	**1200 ± 97[a]**	**909 ± 53[b]**

ND: Not detected. Means not connected by the same letter indicate a significant difference between treatments for that compound (alpha = 0.05).

Table 4.4. Carotenoid compounds (µg / 100 g) in unpeeled and peeled canned 'Hargrand', 'Harlayne' and 'Harogem' apricots (n = 4).

Carotenoid compounds	Hargrand		Harlayne		Harogem	
	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled
Beta-carotene	17000 ± 980[a]	14100 ± 1070[b]	14600 ± 1030[a]	10600 ± 170[b]	12000 ± 1080[a]	8400 ± 380[b]
Beta-cryptoxanthin	73 ± 9[b]	101 ± 11[a]	110 ± 7[a]	97 ± 6[b]	107 ± 8[a]	84 ± 8[b]
Lutein	9 ± 1[a]	9 ± 0.4[a]	15 ± 0.4[a]	13 ± 0.3[b]	16 ± 2[a]	13 ± 1[b]
Zeaxanthin	270 ± 1[a]	170 ± 1[b]	160 ± 1[a]	160 ± 2[a]	150 ± 20[a]	140 ± 6[a]
Total	**17300 ± 990[a]**	**14400 ± 1080[b]**	**14900 ± 1030[a]**	**10800 ± 180[b]**	**12300 ± 1110[a]**	**8600 ± 390[b]**

ND: Not detected. Means not connected by the same letter indicate a significant difference between treatments for that compound (alpha = 0.05).

Figures 4.4 and 4.5 show changes in bioactive compound concentration in canned peaches and apricots post-processing and after 3 and 6 mo storage at 18 - 20 ˚C. In peaches, unpeeled fruit and syrup had significantly higher TP post-processing. This treatment effect was nullified at 3 mo in both fruit and syrup and remained thus until 6 mo. The decrease in TP with storage contrasted with its increase in canned cherries (5 mo, 22 ˚C) as reported by Chaovanalikit and Wrolstad (2004), who attributed this to increased extraction efficiency or depolymerisation of high molecular weight polyphenolics. Asami and others (2003) noted differences in TP, alternately increasing or decreasing, with different storage time and temperature while Rickman and others (2007a) cautioned that the material type of container used could affect observed results. In apricots, decrease in fruit TP was only significant at 6 mo of storage. These losses appeared to be due in some part to migration during storage (Hong and others 2004) as syrup TP steadily increased.

No significant differences were observed between peeled and unpeeled peach AOX post-processing, although unpeeled syrup had higher AOX, indicating progressively increasing leaching of antioxidant constituents into syrup. Peeled fruit and syrup AOX equilibrated over time, while in unpeeled samples, syrup increased while fruit decreased in AOX. This observation, namely the marked decrease in unpeeled but not peeled fruit AOX, was noted as an anomaly or experimental error. A precise cause was not identified although a possible scenario is the easier osmotic equilibration between peeled fruit and syrup given the reduced structural integrity of peeled samples, as seen in the first phase with ‘Hargrand’ and ‘Harogem’ syrup in unpeeled samples. In apricots, fruit AOX decreased while syrup AOX increased, with the two components, for both treatments, attaining equilibrium by 6 mo of storage.

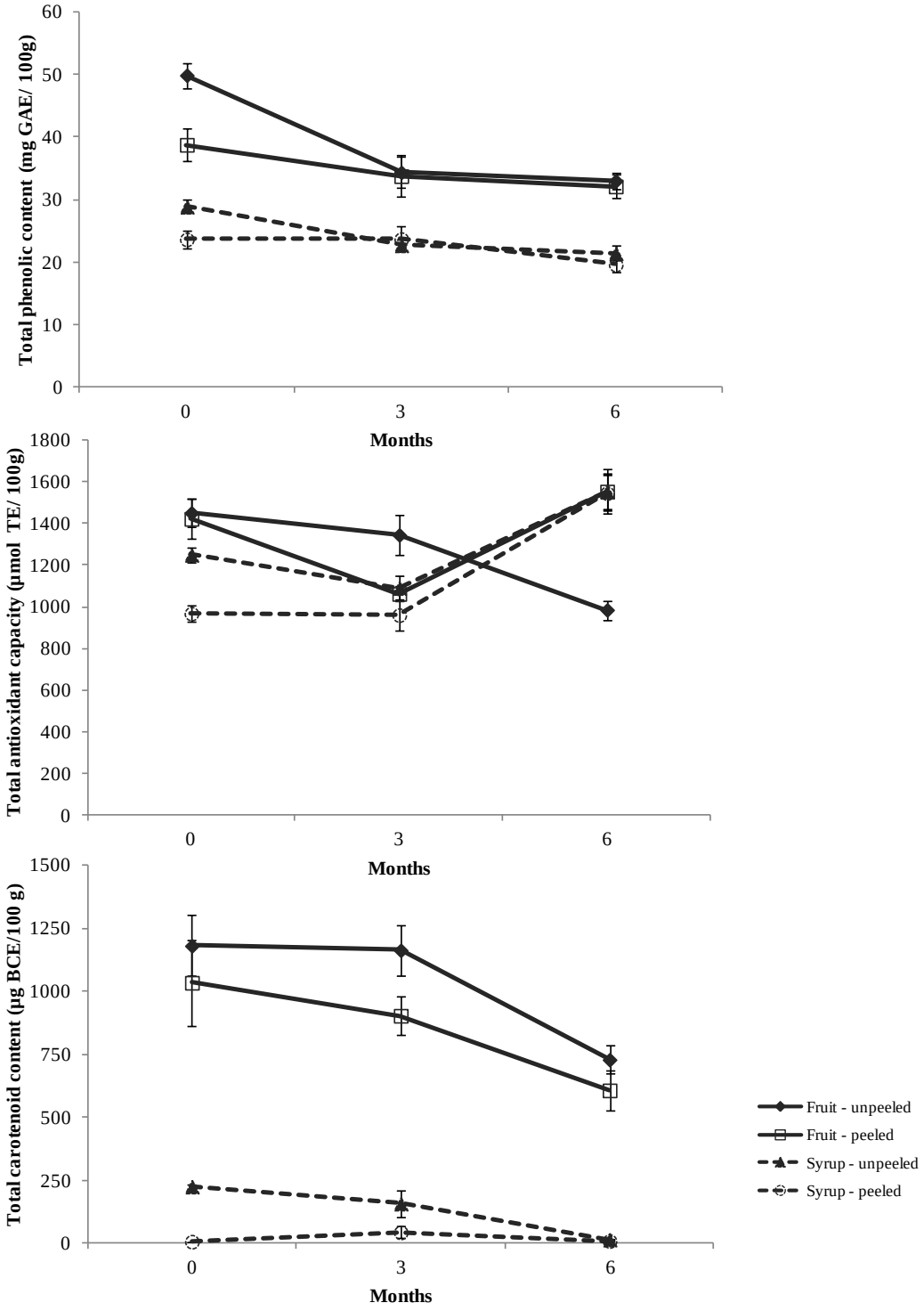


Figure 4. 4. Total phenolic content, total antioxidant capacity and total carotenoid content of unpeeled and peeled canned 'Redhaven' peach fruit and syrup after processing and after storage at 3 and 6 months at 18 – 20 ˚C. (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents).

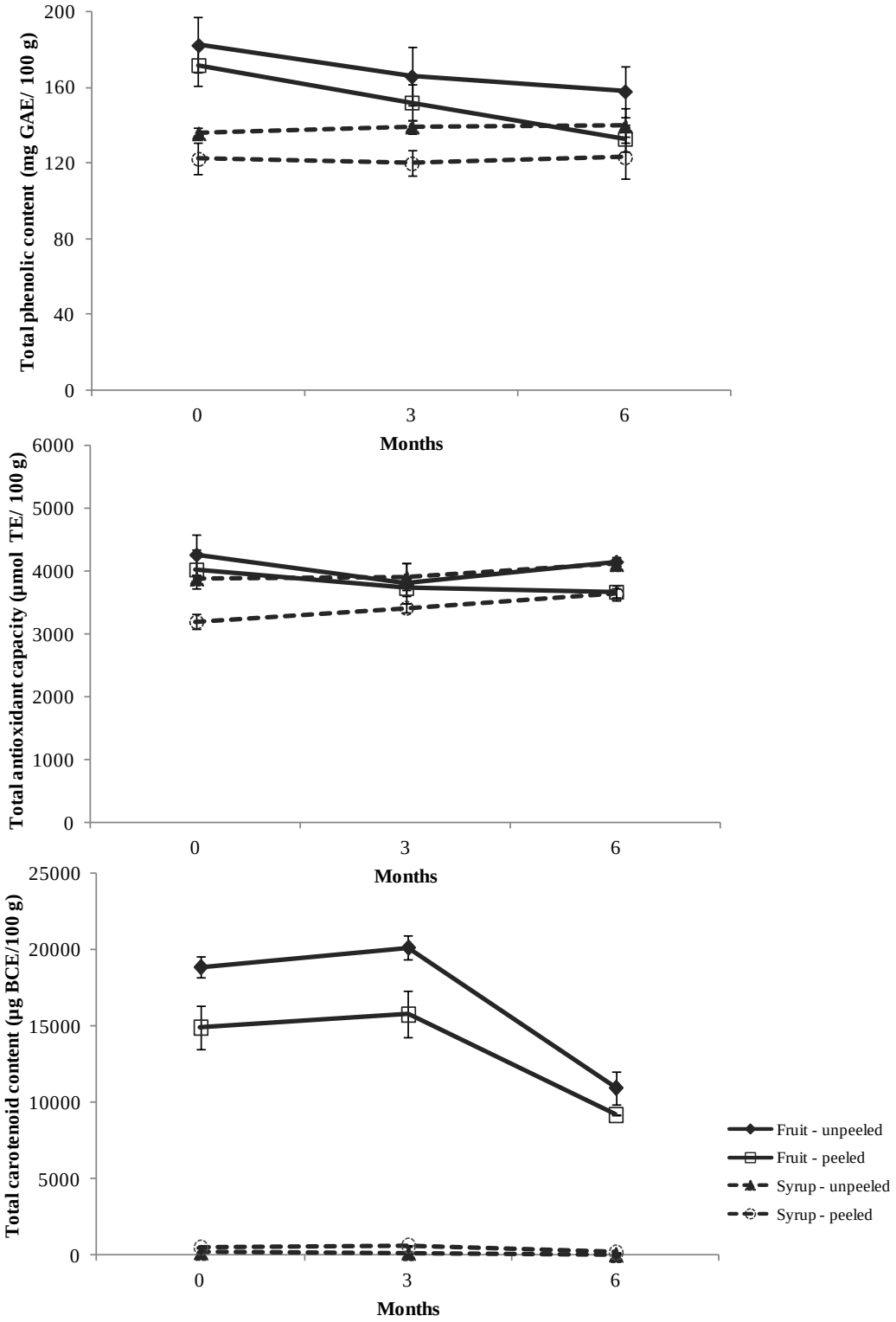


Figure 4. 5. Total phenolic content, total antioxidant capacity and total carotenoid content of unpeeled and peeled canned 'Harlayne' apricot fruit and syrup after processing and after storage at 3 and 6 months at 18 – 20 ˚C (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents).

The lipophilic nature of carotenoids and thus their decreased susceptibility to leaching was well-illustrated in the comparison of fruit to syrup TC post-canning and with storage in both fruits (Rickman and others 2007b). Peeling made little difference in carotenoid content of peach fruit post-processing, suggesting either a smaller difference in the peel versus flesh carotenoid concentration of this variety, or some transference during the initial pre-peeling heat treatment. Both treatments reduced in TC with storage as reported by Elkin and others (1979), with decreases largely due to lipid oxidation; unpeeled fruit eventually had greater TC at 3 and 6 mo. Unpeeled syrup TC remained higher then peeled TC after processing and throughout the storage study.

As with peaches, apricot fruit retained most of its carotenoid content, with unpeeled fruit having greater TC after processing and during storage. Contrary to peach syrup, however, syrup from peeled fruit had greater TC at all time points. The trend for carotenoid content in canned peach and apricot fruit, therefore, appears to be a greater concentration with intact peel. However, different factors dictate the level of migration, with syrup concentration correlating with initial fruit content in peaches, while in apricots, the fracturing of the cell matrix by peeling appeared to enhance leaching.

As in the first phase of the study, it was important to gauge the impact of discarding syrup. Since canned fruit is typically consumed months to a year after production, the contributions of fruit and syrup to TP, AOX and TC of the canned product was calculated at 6 mo, taking into consideration the 60:40 fruit to syrup ratio per can and transfer of soluble solids. In peaches, syrup contained 30% TP, 51% AOX and 1% TC in unpeeled and 29% TP, 40% AOX and 1% TC in peeled

samples. For apricots, syrup had 37% TP, 40% AOX and 0.2% TC in unpeeled and 38% TP, 40% AOX and 1% TC in peeled samples. These values, particularly those for hydrophilic constituents, suggest the need to develop consume syrup with fruit or find alternative uses for syrup to obtain the full nutraceutical content in canned fruits. It would be good to inform consumers of the value of syrup and also to direct processors to use syrup with minimal amount of sugar for palatability to allow it to be consumed as well without being overly concerned about calories.

Tables 4.5 to 4.8 provides detail on the effect of peeling after canning and by the end of the shelf life study (6 mo) on specific phenolic and carotenoid compounds in both fruit and syrup. Data corroborated TP values post-processing and indicated that for both fruits, unpeeled fruit and syrup retained greater phenolic compound content post-processing and after 6 mo. It also showed an equilibration of phenolic concentration between fruit and syrup by the end of the storage period.

Peach hydroxycinnamic acids and anthocyanins were found in relatively equivalent amounts in fruit and syrup and typically decreased with storage. As in the study by Chaovanalikit and Wrolstad (2004), flavonol glycosides, some of which disappeared with peeling, remained relatively stable with storage. Flavan-3-ol response to storage differed considerably. In apricots, anthocyanins were absent post-processing while hydroxycinnamates and flavonol glycosides, significantly reduced or eliminated by peeling, were evenly distributed in fruit and syrup where available. While hydroxycinnamates decreased with storage, flavonol glycosides differed in their responses: rutin decreasing and quercetin glycosides remaining stable. Flavan-3-ols responded differently to leaching and storage, with all but catechin decreasing over time.

Table 4.5. Phenolic compounds (mg / 100 g) in unpeeled and peeled canned 'Redhaven' peach fruit and syrup after processing and after storage for 6 months at 18 – 20 ˚C (n = 4).

Phenolic compounds	After processing				After 6 months			
	Fruit		Syrup		Fruit		Syrup	
	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled
Catechin	0.6 ± 0.0[a]	0.4 ± 0.0[b]	ND	ND	ND	ND	0.5 ± 0.0[a]	0.6 ± 0.0[a]
Chlorogenic acid	5.6 ± 0.1[a]	3.9 ± 0.2[b]	5.4 ± 0.1[a]	3.8 ± 0.1[b]	4.5 ± 0.1[a]	3.8 ± 0.3[b]	4.4 ± 0.3[a]	3.5 ± 0.3[b]
Cyanidin-3-glucoside	1.7 ± 0.1[a]	1.2 ± 0.0[b]	1.7 ± 0.2[a]	1.2 ± 0.0[b]	1.2 ± 0.0	ND	ND	ND
Epicatechin	3.2 ± 0.2[a]	2.5 ± 0.3[b]	2.6 ± 0.1[a]	2.0 ± 0.1[b]	1.9 ± 0.1[a]	1.7 ± 0.1[b]	2.4 ± 0.2[a]	2.1 ± 0.1[a]
Epigallocatechin	9.8 ± 0.6[a]	7.0 ± 0.1[b]	1.5 ± 0.1	1.1 ± 0.1	1.1 ± 0.1[a]	0.9 ± 0.1[b]	1.0 ± 0.2[a]	0.8 ± 0.1[a]
Kaempferol-3-rutinoside	7.1 ± 0.0[a]	6.9 ± 0.1[b]	6.9 ± 0.1[a]	6.9 ± 0.0[a]	6.9 ± 0.1[a]	6.7 ± 0.1[b]	6.9 ± 0.3[a]	6.7 ± 0.0[a]
Neochlorogenic acid	3.7 ± 0.2[a]	3.2 ± 0.4[b]	3.6 ± 0.0[a]	3.3 ± 0.2[b]	3.1 ± 0.1[a]	2.7 ± 0.0[b]	3.1 ± 0.1[a]	2.6 ± 0.0[b]
Quercetin-3-glucoside	ND	ND	1.1 ± 0.0	ND	1.2 ± 0.0	ND	1.2 ± 0.1	ND
Rutin	1.1 ± 0.0	ND	1.1 ± 0.0	ND	1.1 ± 0.0	ND	1.2 ± 0.1	ND
Unknown 1	1.1 ± 0.1[a]	0.9 ± 0.1[b]	0.5 ± 0.0[b]	0.8 ± 0.0[a]	1.2 ± 0.1[a]	0.4 ± 0.0[b]	1.0 ± 0.0[a]	0.4 ± 0.0[b]
Unknown 2	ND	ND	1.2 ± 0.0	ND	1.2 ± 0.0	ND	1.2 ± 0.1	ND
Total	**33.9 ± 1.4[a]**	**25.9 ± 1.2[b]**	**25.6 ± 0.7[a]**	**19.0 ± 0.5[b]**	**23.3 ± 0.7[a]**	**16.3 ± 0.6[b]**	**23.0 ± 1.4[a]**	**16.6 ± 0.5[b]**

ND: Not detected. Unknown 1: flavan-3-ol; Unknown 2: flavonol glycoside. Means not connected by the same letter indicate a significant difference between treatments for that compound (alpha = 0.05).

Table 4.6. Phenolic compounds (mg / 100 g) in unpeeled and peeled canned ‘Harlayne’ apricot fruit and syrup after processing and after storage for 6 months at 18 – 20 ˚C (n = 4).

Phenolic compounds	After processing				After 6 months			
	Fruit		Syrup		Fruit		Syrup	
	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled
Catechin	0.8 ± 0.1[a]	0.6 ± 0.0[b]	1.1 ± 0.1[a]	0.6 ± 0.1[b]	0.8 ± 0.1[a]	0.2 ± 0.0[b]	0.5 ± 0.0[a]	0.2 ± 0.0[b]
Chlorogenic acid	3.8 ± 0.2[a]	2.6 ± 0.1[b]	4.0 ± 0.2[a]	2.5 ± 0.1[b]	3.7 ± 0.1[a]	2.6 ± 0.1[b]	3.2 ± 0.3[a]	2.3 ± 0.1[b]
Cyanidin-3-glucoside	ND	ND	ND	ND	ND	ND	ND	ND
Epicatechin	11.1 ± 0.8[a]	8.7 ± 0.4[b]	11.0 ± 0.6[a]	8.0 ± 0.5[b]	8.3 ± 0.9[a]	5.7 ± 0.4[b]	7.8 ± 0.3[a]	6.0 ± 0.6[b]
Epigallocatechin	2.4 ± 0.2[a]	2.3 ± 0.2[a]	3.9 ± 0.6[a]	2.5 ± 0.3[b]	2.6 ± 0.0[a]	1.9 ± 0.2[b]	3.2 ± 0.2[a]	2.5 ± 0.3[b]
Neochlorogenic acid	12.4 ± 0.7[a]	8.6 ± 0.3[b]	14.6 ± 0.9[a]	9.3 ± 0.3[b]	10.7 ± 7.5[a]	7.5 ± 0.3[b]	11.6 ± 0.4[a]	7.9 ± 0.1[b]
Quercetin-3-glucoside	1.2 ± 0.0	ND	1.2 ± 0.0	ND	1.2 ± 0.0	ND	1.1 ± 0.0	ND
Quercetin derivative	1.2 ± 0.0	ND	1.2 ± 0.0	ND	1.2 ± 0.0	ND	1.1 ± 0.0	ND
Rutin	7.1 ± 0.3[a]	2.0 ± 0.0[b]	7.3 ± 0.2[a]	2.0 ± 0.0[b]	5.6 ± 0.1[a]	1.9 ± 0.0[b]	5.3 ± 0.2[a]	1.9 ± 0.0[b]
Unknown 1	13.3 ± 1.1[a]	10.6 ± 1.1[b]	12.0 ± 1.3[a]	9.4 ± 0.1[b]	9.7 ± 0.7[a]	8.0 ± 0.7[a]	11.6 ± 0.6[a]	8.5 ± 0.7[b]
Unknown 2	7.8 ± 0.5[a]	6.7 ± 0.2[b]	5.9 ± 0.5[a]	5.1 ± 0.4[a]	5.4 ± 0.5[a]	4.0 ± 0.0[b]	4.7 ± 0.2[a]	3.4 ± 0.5[b]
Total	**61.1 ± 3.9[a]**	**42.0 ± 2.3[b]**	**62.2 ± 4.4[a]**	**39.3 ± 1.7[b]**	**49.2 ± 3.4[a]**	**31.9 ± 1.9[b]**	**50.2 ± 2.2[a]**	**32.5 ± 2.1[b]**

ND: Not detected. Unknown 1 and 2: flavan-3-ols. Means not connected by the same letter indicate a significant difference between treatments for that compound (alpha = 0.05).

Table 4.7. Carotenoid compounds (µg / 100 g) in unpeeled and peeled canned 'Redhaven' peach fruit and syrup after processing and after storage for 6 months at 18 – 20 ˚C (n = 4).

Carotenoid compounds	After processing				After 6 months			
	Fruit		Syrup		Fruit		Syrup	
	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled
β-carotene	1030 ± 73[a]	900 ± 96[a]	220 ± 7[a]	5 ± 0.4[b]	630 ± 52[a]	503 ± 74[a]	14 ± 2[a]	8 ± 0.4[a]
β-cryptoxanthin	36 ± 4[a]	37 ± 6[a]	ND	ND	24 ± 3[a]	27 ± 2[a]	ND	ND
Lutein	10 ± 0.1	ND	ND	ND	ND	ND	ND	ND
Zeaxanthin	390 ± 44[a]	400 ± 69[a]	ND	ND	ND	ND	ND	ND
Total	**1470 ± 120[a]**	**1330 ± 170[a]**	**220 ± 7[a]**	**5 ± 0.4[b]**	**650 ± 55[a]**	**530 ± 77[b]**	**14 ± 2[a]**	**8 ± 0.4[b]**

ND: Not detected. Means not connected by the same letter indicate a significant difference between treatments for that compound (alpha = 0.05).

Table 4.8. Carotenoid compounds (µg / 100 g) in unpeeled and peeled canned 'Harlayne' apricot fruit and syrup after processing and after storage for 6 months at 18 – 20 ˚C (n = 4).

Carotenoid compounds	After processing				After 6 months			
	Fruit		Syrup		Fruit		Syrup	
	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled	Unpeeled	Peeled
β-carotene	18300 ± 640[a]	14400 ± 1400[b]	190 ± 5[b]	509 ± 31[a]	10600 ± 1080[a]	8900 ± 15[b]	37 ± 2[b]	190 ± 18[a]
β-cryptoxanthin	140 ± 10[a]	130 ± 12[a]	ND	ND	86 ± 7[a]	79 ± 3[a]	ND	ND
Lutein	19 ± 0.6[a]	15 ± 2[b]	ND	ND	12 ± 0.8[a]	10 ± 1[a]	ND	ND
Zeaxanthin	150 ± 10[a]	150 ± 13[a]	ND	ND	ND	ND	ND	ND
Total	**18600 ± 660[a]**	**14700 ± 1400[b]**	**190 ± 5[b]**	**509 ± 31[a]**	**10700 ± 1090[a]**	**9000.0 ± 20.0**	**37 ± 2[b]**	**190 ± 18[a]**

ND: Not detected. Means not connected by the same letter indicate a significant difference between treatments for that compound (alpha = 0.05).

β-carotene was the only carotenoid found in syrup in both canned peaches and apricots. Given carotenoid insolubility in water, this presence of this compound in syrup was thought to be largely due to dispersed plant material in syrup, with β-carotene most easily and identified and quantified given its high concentration in the two fruits. β-carotene and β-cryptoxanthin decreased over the storage period while lutein (in peaches) and zeaxanthin (in both fruits) were lost. Even with these losses, canned peaches and apricots remained noteworthy sources of vitamin A. At 6 mo, considering a 140 g serving of canned fruit (FDA 2012), canned peaches supplied 9% (unpeeled) and 7% (peeled) RDA for vitamin A while both canned apricot treatments provided > 100% (USDA FNC 2011; NIH 2012).

Using HPLC data, apricot phenolic and carotenoid compounds were more stable under storage than those of peaches. Losses in phenolic content by 6 mo were significantly greater in peeled (38%) compared to unpeeled (30%) peaches and also in peeled (24%) compared to unpeeled (20%) apricots. Lipid oxidation was more severe for both fruits, with losses in storage 60% and 56% in peeled and unpeeled peaches and 38% and 42% in peeled and unpeeled apricots. The effect of peeling on phytochemical content by the time the product was consumed (in this case, 6 mo) was also evaluated. Unpeeled peaches had 30% greater phenolic and 18% greater carotenoid content compared to peeled samples; unpeeled apricots had 35% and 16% greater phenolic and carotenoid content compared to peeled samples. These results are support, at least *in vitro*, the phytochemical benefits of canning fruit with skin. How these changes translate *in vivo* or in terms of bioavailability would require further study.

Conclusion

This study provided information on the effect of canning procedures on the phenolic, antioxidant and carotenoid content of different peach and apricot varieties. Water-soluble fruit phytochemicals, phenolics and antioxidants, were negatively impacted by heat treatment and leaching into the surrounding syrup, the extent of losses differed between varieties. Carotenoids showed higher values after processing and suffered negligible leaching. Peeling prior to canning reduced both phenolic and carotenoids content, with flavonol glycosides, anthocyanins and β-carotene most affected. Phenolic and carotenoid compounds showed different responses to storage time and conditions. HPLC analyses revealed decreases in phenolics and carotenoids compounds with storage, with hydrophilic compounds equilibrating in fruit and syrup over time while carotenoid compound migration into syrup was minimal. While peeling was more detrimental to phytochemical content in apricots than in peaches, apricot compounds were more stable under storage than those of peaches. The loss of phenolic and antioxidant compounds to syrup suggests the need for consumption of the whole product or secondary use of syrup to derive maximum benefit from canned produce. Results also illustrated the distribution and relative concentrations of some compounds in fruit (flesh and peel). Although research still remains on the specific nutraceutical properties of specific compounds, this study does contribute to an understanding of the implications of the commercial practice of skin removal prior to canning.

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CHAPTER 5: AN EVALUATION OF THE EFFECT OF FOUR PRE-DRYING TREATMENTS ON THE COLOUR AND PHYTOCHEMICAL CONTENT OF DRIED PEACHES AND APRICOTS.

Introduction

The peach (*Prunus persica*) and apricot (*Prunus armeniaca*) are sources of phenolic and carotenoid compounds which have been found to be beneficial to human health (Tomas-Barberan and others 2001; Gil and others 2002; Kader and Barrett 2005; Ruiz and others 2005a; Ruiz and others 2005b). Carotenoid compounds play a role in vision and protect against macular degeneration (Fraser and Bramley 2004). Some phenolic and carotenoid compounds serve as antioxidants, which are understood to reduce the risk of cardiovascular diseases and some cancers (Ames and others 1993; Paiva and Russell 1999).

Peaches and apricots, both climacteric fruits, present a challenge in postharvest storage (Kader and Mitchell 1989; Kader 1999; Payasi and Sanwal 2008). Processing serves to add value to fruit, extend shelf life and ensure availability when fruit is out of season. The majority of apricots produced in the United States, 64%, and 2% of peaches are consumed in dried form as final products or as ingredients in other products, including baked goods or confectionery (USDA ERS 2011; Barta 2006).

An area of concern with dehydrated fruits is the use of sulfites to maintain the bright yellow-to-orange color vital to the favorable perception and appeal of dried peaches and apricots (Potter 1998; Siddiq 2006a; Siddiq 2006b). Sulfur dioxide, in a gaseous or liquid medium, is commercially employed as an antimicrobial agent and to prevent both the enzymatic and nonenzymatic browning of dried fruit

(Joslyn and Braverman 1954; Embs and Markakis 1965; McWeeny and others 1974). Drying without sulfites results in a leathery texture and a brown to black coloration. However, given regulations in different countries restricting sulfite levels in dried produce, the incidence of sulfite sensitivity particularly in asthmatic individuals and the increasing trends towards all-natural, additive-free products, there is the need for sulfite-free processing treatments that can achieve the desired texture and color in dried fruit (Freedman 1980; Sapers 1993; Pilizota and Subaric 1998). Studies evaluating the potential of alternative antibrowning agents including ascorbate, honey, and sulfur-containing amino acids have reported moderate successes at best, often not faring well in storage studies or at elevated temperatures (Son and others 2001; Somogyi 2005).

Our study therefore sought to develop a viable alternative to sulfited dried peaches and apricots with a focus on maintaining color as well as healthful compounds. We assessed the effect of a number of pre-drying treatments, two of which are unique to this study, on the composition and concentration of phenolic, antioxidant and carotenoid compounds in Northeast peach and apricot varieties. We also evaluated the responses of different peach and apricot varieties to pre-drying treatments and conducted a shelf life study to monitor the stability of color as well as the stated compounds over time.

Given that in the United States, fruits are predominantly consumed more in processed than fresh form (Rickman and others 2007), the results of this study were intended to provide useful qualitative and quantitative information on the effect of typical drying procedures and a range of pre-drying treatments on both the healthful and aesthetic quality of dried peaches and apricots.

Materials and methods

Harvest

The harvesting protocol and selected varieties were identical to chapter 4.

Drying

Processing was conducted following typical drying protocols (Brekke and Nury 1964; Reynolds and others 1993). The study was conducted in two phases, with the first (Figure 5.1) evaluating the effect of two treatments on three peach and three apricot varieties. In the second phase (Figure 5.2), modifications in blanching time and packaging of dried fruit were made based on observations from the first phase. One peach and one apricot variety were subjected to four pre-drying treatments. Residual sulfur dioxide in sulfited samples was determined using AOAC 963.20; post-drying, this was found to be 250 ppm in peaches and 240 ppm in apricots. Picture of the final products are shown in Illustration A.6.

Phenolic analysis

Extraction of phenolic compounds followed the method described in chapter 2 with 80% methanol used for both freeze-dried and dried samples; 2 g of dried samples were extracted. Total phenolic content and HPLC phenolic analysis were also performed as in chapter 2.

Total antioxidant capacity assay

This was performed as described in chapter 2.

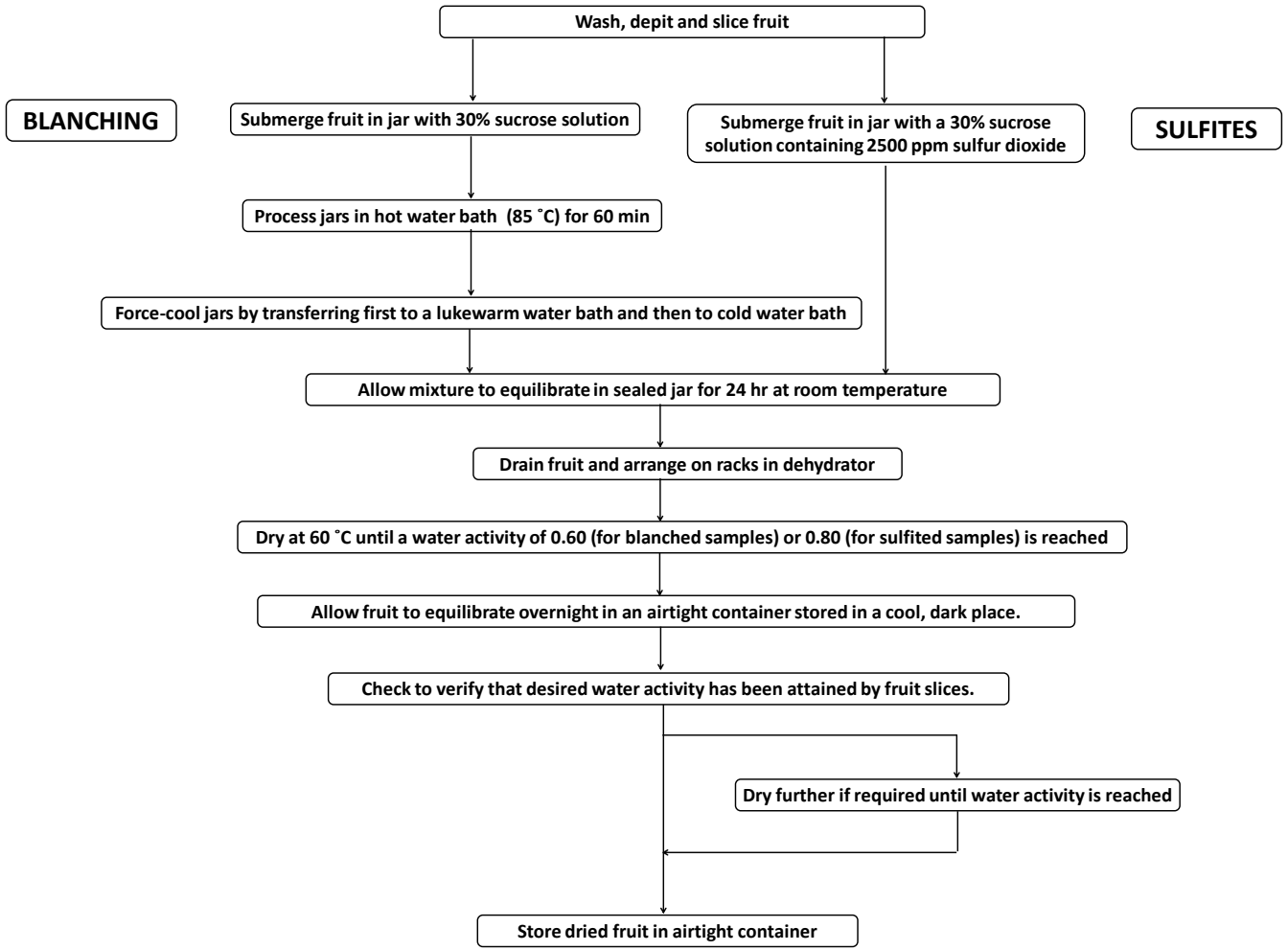

Figure 5. 1. Flow chart for the production of dried peaches and apricots (phase 1).

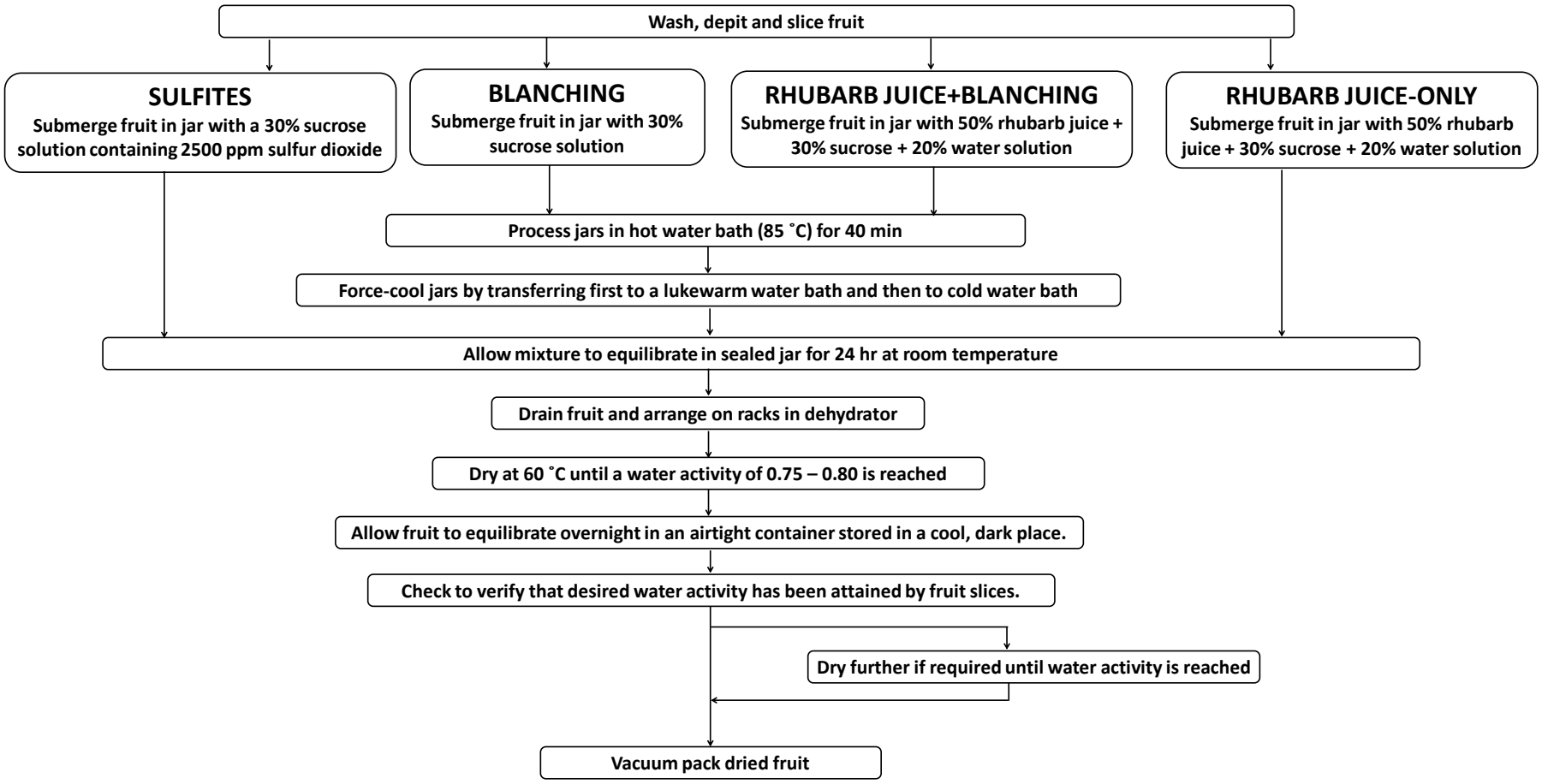

Figure 5. 2. Flow chart for the optimized production of dried peaches and apricots (phase 2).

Carotenoid analysis

This was performed as described in chapter 2; 2 g dried sample was reconstituted, extracted and analysed.

Shelf life study

Samples were stored at 18 - 20 ˚C for 6 months (mo) under dark conditions. Phenolic, antioxidant and carotenoid analyses were conducted at 3 mo and 6 mo and the results compared to those obtained post-processing. Lightness (*L), a* and *b* color values were measured post-processing and on a monthly basis over the course of the shelf life study with a HunterLab UltraScan XE (Hunter Associates Laboratory Inc., Reston, VA); hue (*H*) and chroma (*C*) were calculated as $\tan^{-1}$ (b/a) and $\sqrt{(a^2 + b^2)}$ respectively. A subset of samples was also stored at 4 ˚C and their color compared to those at 18 ˚C after the 6 mo.

Statistical analysis

Data was analysed as described in chapter 2, with the respective weights for bioactive data stated as required.

Results and discussion

The first phase studied fruit and varietal response to different pre-drying treatments. After initial trials with a series of treatments including ascorbic acid, the stated blanching treatment was selected to compare against the commercial practice of sulfite use in terms of their effect on phytochemical content as well as organoleptic properties. The procedure we selected employed a longer time-lower temperature blanching, based on studies by Lee and Smith (1979) and Lee and others (1979). This approach activated pectin methyl esterase, increasing fruit

firmness by facilitating cross-linking of free carboxyl groups and decreasing solubility of pectic substances. Concomitantly, polyphenol oxidase was denatured, limiting enzymatic browning (Queiroz and others 2008). The addition of sucrose in both treatments was pertinent to attain better flavor, given the low sugar-to-acid ratio of these fruits (7.8 – 13.8 for peaches and 8.9 – 11.7 for apricots). The infused sucrose also served as a humectant, maintaining acceptable texture despite the low water activity of the dehydrated product.

The low acid nature of both fruits as well as the thermal treatment applied in blanched samples served to destroy pathogenic microorganisms. For shelf stability and to prevent the growth of spoilage microorganisms, low water activity is the main preservative factor in dried products. A final water activity (a_w) of less than 0.85 is necessary to prevent the activity of pathogenic bacteria and 0.6 will suppress osmophilic moulds. However, given the antimicrobial properties of sulfur dioxide, drying of sulfited products could be halted at a higher a_w (0.8) yet remain microbiologically stable (Roberts and McWeeny 1972; Ramaswamy 2005; Worobo and Splittstoessser 2005; Patkai 2006).

As in fresh form (See chapters 1 and 2), dried apricots had higher total phenolic content (TP), total antioxidant capacity (AOX) and total carotenoid content (TC) than dried peaches. Fruits responded differently to the two treatments. While blanched apricots had four-fold TP, three-fold AOX and fourteen-fold TC compared to similarly blanched peaches, sulfited apricots had two-fold TP and AOX and eight-fold TC compared to sulfited peaches.

Blanching and sulfites protect against the oxidation of phenolic compounds (Joslyn and Braverman 1954; Pilizota and Subaric 1998; Queiroz and others 2008). Given that the antioxidant capacity of peaches and apricots stems mainly from their phenolic content (Prior and others 2003; Wu and others 2004; Drogoudi and others 2008), these treatments were expected to have a similar protective effect on antioxidant components. Baloch and others (1987) reported the ability of both blanching and sulfites to protect carotenoid compounds in dehydrated carrots, with the use of sulfites deemed more effective; Sabry (1961) recommended a combination of the two treatments for best results in dried apricot pulp.

Experimental results generally matched up with these previous studies. In peaches, sulfited samples consistently had greater TP, AOX and TC (two-fold in all cases) compared to blanched samples (Figure 5.3). Differences in varietal responses to the drying process were noted, with dried 'Redhaven' surpassing other varieties although it was of considerably lower TP and AOX in fresh form. The response to treatment in apricots was not as uniform (Figure 5.4). While similar results as in peaches were seen in 'Hargrand' and 'Harogem' TP and TC and 'Hargrand' AOX, 'Harogem' AOX did not differ significantly between treatments. Blanched 'Harlayne' samples had higher TP, AOX and TC than sulfited samples.

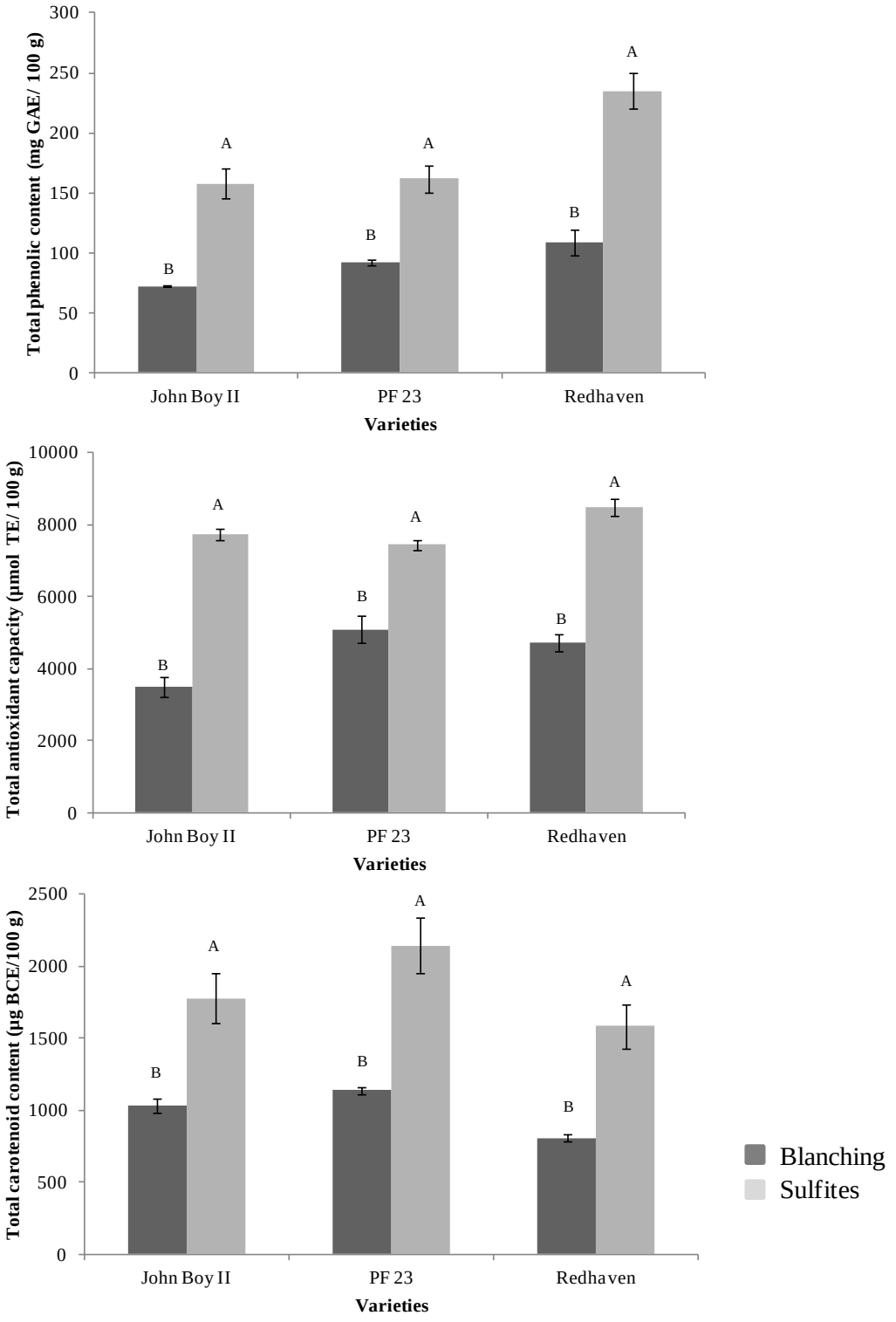

Figure 5. 3. Total phenolic content, total antioxidant capacity and total carotenoid content of blanched and sulfited dried 'John Boy II', 'PF 23' and 'Redhaven' peaches (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents). Bars not connected by the same letter indicate a significant difference between treatments (alpha = 0.05).

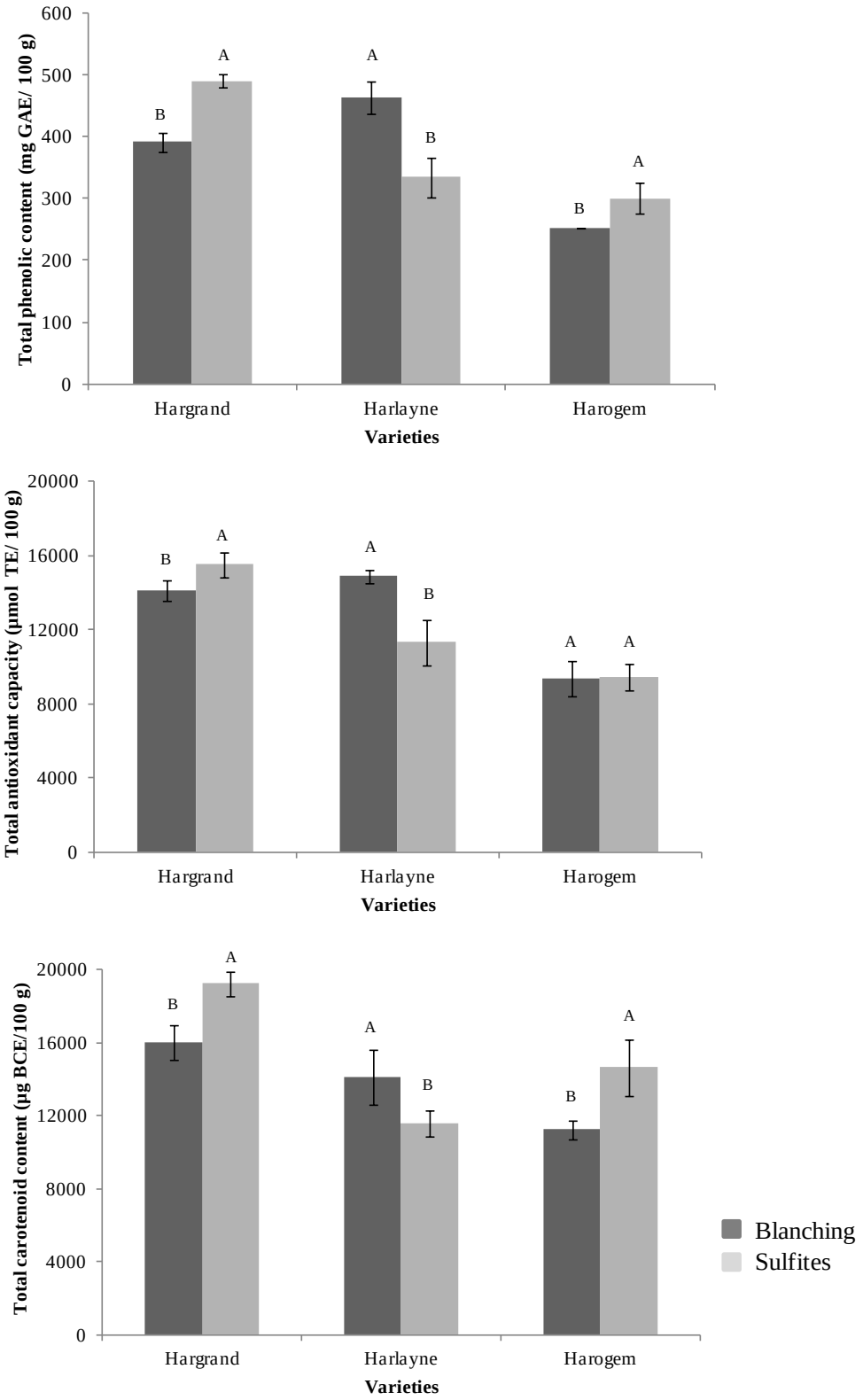

Figure 5. 4. Total phenolic content, total antioxidant capacity and total carotenoid content of blanched and sulfited dried 'Hargrand', 'Harogem' and 'Harlayne' apricots (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents). Bars not connected by the same letter indicate a significant difference between treatments (alpha = 0.05).

Given that all varieties underwent identical pre-drying treatments, these differences were theorized to be due to differences in sulfite uptake and/or retention by this variety, or alternatively a greater compatibility of this variety with the blanching procedure employed.

Color and quality were assessed visually. Sulfited samples attained the expected bright yellow color, more pronounced in peaches than in apricots. This was attributed to better sulfite uptake due to the comparatively greater exposed surface area of peach slices as opposed to apricot halves, in line with work by McBean and others (1963), who compared sulfur dioxide absorption by peeled and unpeeled peaches and apricots and found that fruit skin retarded uptake. Blanched samples, on the other hand, were unappealing in terms of both color (dark yellow to brown) and texture. It was thought that the longer drying times required to reach the 0.6 a_w could have allowed for greater nonenzymatic browning during the drying process. This treatment could therefore not be considered a suitable alternative for sulfited dried products in terms of comparable aesthetic appeal or, particularly in peaches, phytochemical content.

These results informed the design of the second phase. ‘Redhaven’ peach was selected for reevaluation because of its importance to the Northeast (Lamb and Terry 1973; Scorza and Sherman 1996) and its reputation as a reliable commercial variety (Monet and Bassi 2008). ‘Harlayne’ apricot was also chosen for its cold hardiness as well as its consumer appeal which has made it a top selling variety in the Northeast (Layne 1996).

A treatment involving the use of rhubarb juice as an antibrowning agent, due to its oxalic acid content, was developed. Oxalic acid retards enzymatic browning by competitively binding to and chelating copper ions required for polyphenol oxidase operation, inhibiting its activity (Hodgkinson 1977; Pilizota and Subaric 1998; Son and others 2000a; Son and others 2000b; Son and others 2001). In the study by Son and others (2000b), solutions containing at least 20% rhubarb juice (0.07% oxalic acid) were found to prevent browning in fresh cut apple slices after a three minute dip.

The rhubarb juice for our study, obtained by dicing and crushing rhubarb stems, was analyzed by HPLC and found to contain 1.90 g/L oxalic content, with the 50% dilution as used resulting in 0.1% oxalic acid content. Given the heat exposure required for drying, as well as the need for the dried products to sustain their color over a longer period then fresh cut products, a prolonged soak instead of a dip was deemed more appropriate. In the rhubarb juice+blanching variation of this treatment, a blanching step was incorporated as an additional hurdle.

In order to improve the color and texture obtained with the previous protocol, all four treatments were dried to a_w of 0.8, which required less heating than had been required in the previous phase to reach 0.6. Dried fruit were vacuum packed for shelf stability (Smith and others 2005). Additionally, the anaerobic conditions produced by vacuum packaging slowed down oxidation and furfural formation, reducing the rate of browning (Bolin and Steele 1987).

Color

Visually, differences in color from the various treatments were more pronounced in peaches than in apricots. As before, sulfited samples had a bright yellow-orange color. Blanching and rhubarb juice+blanching treatments proved most effective in producing bright orange colored dried fruit without the use of sulfites. The desired antibrowning effect was not achieved in rhubarb juice-only treated products, which also retained the characteristic tart rhubarb taste. The thermal component aided in sugar uptake in rhubarb juice+blanching samples, resulting in a more acceptable sugar-to-acid balance.

The efficacy of these treatments was corroborated instrumentally, with the *L* value considered most appropriate to measure differences between treatments and changes in the desired bright color as higher values on the L scale, ranging from 0 (black) to 100 (white), imply greater lightness in color. *a* and *b* were consistently in the positive range indicating the colors red and yellow (McLellan and others 1995; Son and others 2000; Son and others 2001). In peaches, post-processing *L* was in the order sulfites (62.0 ± 9.1), blanching (58.0 ± 3.4), rhubarb juice+blanching (55.0 ± 2.4) and rhubarb juice-only (53.0 ± 8.9). In apricots, the order was sulfites (52.0 ± 2.8), rhubarb juice+blanching (50.1 ± 2.1), blanching (49.0 ± 2.2) and rhubarb juice-only (41.0 ± 4.0).

Since dried products are typically consumed within a year after production, the shelf life study allowed for an assessment of the long-term impact of the various treatments on color. Visually, sulfited products maintained their color while rhubarb juice+blanching and blanched products, especially for apricots, exhibited browning over time – losing their bright color within the first month – although not

to the same degree as the rhubarb juice-only treatment (Figure 5.5).

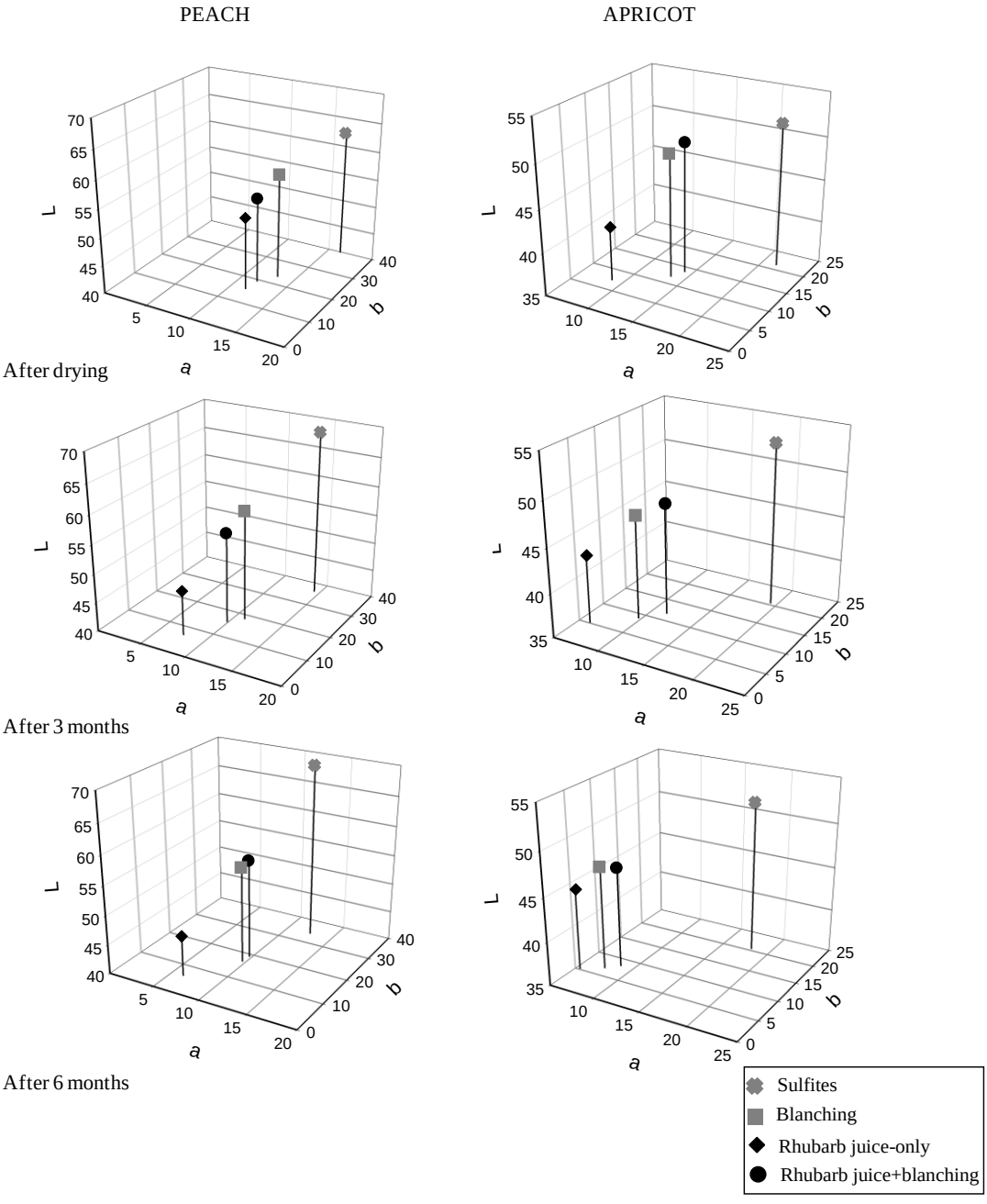

Figure 5. 5. Color (Hunter *L*, *a*, *b*) of dried peaches and apricots after drying and after storage at 3 and 6 months at 18 – 20 °C.

Ledbetter and others (2002) reported a decline in *L* and *C* values of apricot halves with storage. In our study, *L* did not change significantly within a treatment during the storage period although a decreasing trend was observed. This parameter may therefore not be best used to gauge loss of bright coloring over time. *L* values did differ significantly between treatments by the end of the shelf life study: sulfites (69.5 ± 4.0), rhubarb juice+blanching (56.8 ± 3.8), blanching (56.0 ± 6.1) and rhubarb juice-only (46.4 ± 1.3) in peaches, and sulfites (52.1 ± 2.1), blanching (46.5 ± 1.8), rhubarb juice+blanching (46.2 ± 1.2) and rhubarb juice-only (44.3 ± 1.5) in apricots. The *a* and *C* values reduced significantly over time for blanching and rhubarb juice+blanching samples in both fruits, but could not be used as a definitive means of measuring the change in dried fruit color over time because this phenomenon did not occur in all treatments.

Temperature is a critical factor in the progression of browning, increasing at higher temperatures. Rossello and others (1994), Joubert and others (2001) and Sagirli and others (2008) reported that color of sulfited dried apricot and pears remained stable at < 5 ˚C for at least 6 mo. A subset of samples was stored at 4 ˚C for the duration of the shelf life study and evaluated at 6 mo. Sulfites, blanching and rhubarb juice+blanching samples maintained acceptable color and texture while rhubarb juice-only samples retained the dark brown color established post-drying. This implied an acceptable shelf life of at least 6 mo for the two treatments, blanching and rhubarb juice+blanching, in cold storage. Although the necessity to keep these products at refrigerated temperatures may present a problem in their commercialization, they still have significant commercial potential as ‘all-natural’, aesthetically appealing alternatives to currently available darkly colored sulfite-free dried fruit.

Peaches

In peaches, phytochemical compound response to sulfites was similar to that observed in the first phase of the study, even after accounting for potential interference by residual sulfur dioxide interference in Folin-Ciocalteu and ORAC assays. Sulfited samples had significantly higher TP (153.8 mg) and AOX (4434.3 µmol) than those from rhubarb juice+blanching (101.7 mg, 3622.6 µmol), blanching (93.9 mg, 3529.5 µmol) and rhubarb juice-only (85.4 mg, 3464.5 µmol); values for the other three treatments did not differ significantly (Figure 5.4). Sulfited samples again had highest TC (2663.5 µg) while rhubarb juice+blanching and rhubarb juice-only samples had similar values (2198.8 µg and 2043.0 µg, respectively) and blanched samples had least (1590.8 µg).

In all treatments, TP increased at 3 mo then declined by 6 mo to levels similar to those seen post-drying. Similar mid-storage increases have been noted in storage studies of both fresh and thermally processed fruit, with some studies citing the possibility of increased production, while others suggested an enhanced extractability of phenolic compounds and their metabolites over time with tissue break down, not necessarily an increase in production or bioavailability (Kalt 1999; Rickman and others 2007). In blanching and rhubarb juice+blanching treated samples, AOX remained stable for the duration of the shelf life study, while AOX for both rhubarb juice-only and sulfited samples increased significantly in storage, being highest at 6 mo. Although decreases had been expected due to oxidation during storage, the observed increases could again be due to greater extractability or, particularly in rhubarb juice-only samples, the antioxidant properties of Maillard reaction products formed during storage (Lingnert and Lundgreen 1980; Bolin and Steele 1987; Elizalde and others 1991; Nicoli and others 1991).

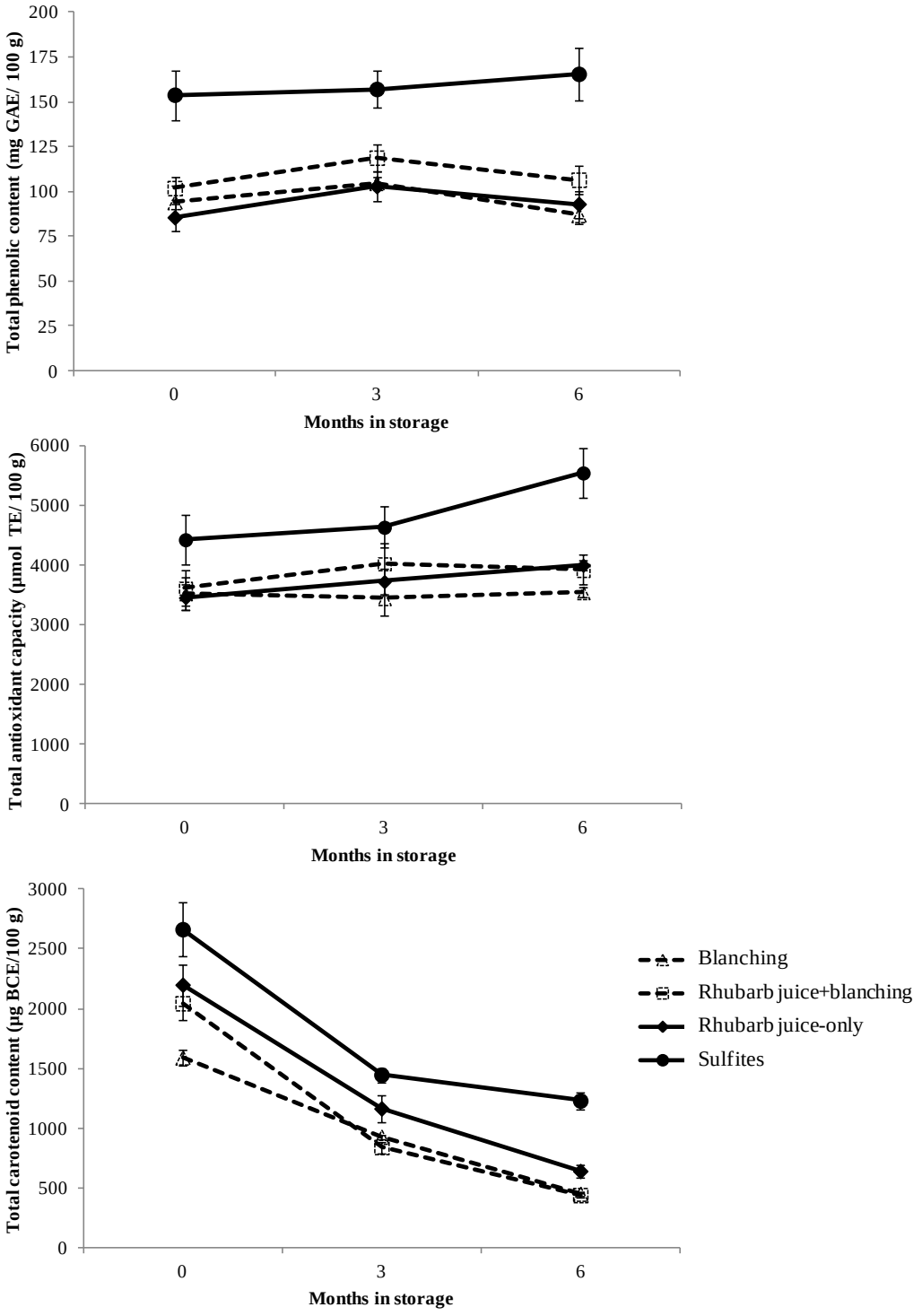

Figure 5. 6. Total phenolic content, total antioxidant capacity and total carotenoid content of dried 'Redhaven' peach post-drying after 3 and 6 months storage at 18 – 20 ˚C (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents).

In all treatments, TP increased at 3 mo, significantly in the two rhubarb juice treatments, then declined by 6 mo to levels similar to those seen post-drying. Similar mid-storage increases have been noted in storage studies of both fresh and thermally processed fruit, with some studies citing the possibility of increased production, while others suggested an enhanced extractability of phenolic compounds and their metabolites over time with tissue break down, not necessarily an increase in production or bioavailability (Kalt 1999; Rickman and others 2007). In blanching and rhubarb juice+blanching treated samples, AOX remained stable for the duration of the shelf life study, while AOX for both rhubarb juice-only and sulfited samples increased significantly over time, being highest at 6 mo. Although a decreasing trend had been expected due to oxidation during storage, the observed increases could again be due to greater extractability or, particularly in rhubarb juice-only samples, the antioxidant properties of Maillard reaction products formed during storage (Lingnert and Lundgreen 1980; Bolin and Steele 1987; Elizalde and others 1991; Nicoli and others 1991).

In all four treatments, significant decreases occurred in TC with storage for 6 mo, greatest in rhubarb juice+blanching (70%) and least in sulfited samples (50%). This agreed with work by Baloch and others (1987) and Sagirli and others (2008); the latter reported losses in dried apricots stored between 5-30 ˚C, with losses, typically via lipid oxidation, increasing with storage temperatures.

Given the susceptibility of the more generalized tests, particularly the Folin-Ciocalteu assay, to interference by sucrose and sulfur (Waterhouse 2002), HPLC analysis allowed for a more precise evaluation of treatment impact on specific phenolic and carotenoid compounds (Tables 5.1 and 5.2). The effectiveness of the

sulfiting treatment was thus confirmed, with sulfited samples having greatest concentration of the majority of phenolic compounds, particularly hydroxycinnamic acids and anthocyanins, and highest HPLC-determined total phenolic content (HPLC-TP) at post-processing. The disparity between the sulfited and other treatments was however not as great as it had been for the Folin-Ciocalteu assay-determined TP. Rhubarb juice+blanching and blanching treatments, as before, had second and third highest HPLC-TP respectively, with rhubarb juice+blanching having greater hydroxycinnamic acid content. In most cases, rhubarb juice-only samples, which lacked catechin, pertinent in measureable phenolic content, and cyanidin-3-glucoside, had lowest individual and total compound concentration.

The increase in TP at 3 mo was reflected in HPLC results for all treatments except sulfites; all treatments showed a drop by 6 mo. Of the phenolic classes evaluated, flavonol glycoside concentration was similar for the treatments and remained relatively stable over storage, the exception being kaempferol-3-rutinoside, which decreased over time. Baruah and Swain (1959) found that flavonol glycosides were more stable because glycosylation prevented, to a degree, these compounds from serving as substrates for polyphenol oxidase. Hydroxycinnamic acids followed the trend of peaking at 3 mo, significantly in blanching and rhubarb juice+blanching, declining by 6 mo. While flavan-3-ols varied in their response with storage for the different treatments, the anthocyanin cyanidin-3-glucoside remained stable in sufited samples but disappeared in storage with other treatments. This was noteworthy since Joslyn and Braverman (1954) found that sulfites had a pronounced bleaching effect on anthocyanins. Our observations may be due to the relatively low concentration of sulfites used in our study.

Table 5.1. Phenolic compounds (mg / 100 g) in fresh and dried 'Redhaven' peach post-drying after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

	Mo	Catechin	Chlorogenic acid	Cyanidin-3-glucoside	Epicatechin	Epigallocatechin	Kaempferol-3-rutinoside
Fresh		3.5 ± 0.5	2.5 ± 0.4	7.2 ± 1.5	3.9 ± 0.2	2.2 ± 1.0	4.6 ± 0.2
Blanching	0	1.3 ± 0.0^{a}	12.0 ± 0.5^{b}	3.4 ± 0.3^{a}	8.3 ± 0.6^{b}	3.3 ± 0.2^{a}	17.1 ± 0.1^{a}
	3	1.1 ± 0.1^{b}	15.7 ± 1.2^{a}	2.9 ± 0.0^{a}	10.1 ± 0.5^{a}	3.6 ± 0.4^{a}	17.3 ± 0.3^{a}
	6	0.5 ± 0.0^{c}	12.1 ± 1.4^{b}	ND	8.3 ± 0.8^{b}	2.3 ± 0.1^{b}	16.7 ± 0.2^{b}
Rhubarb juice+ blanching	0	1.6 ± 0.0^{a}	13.1 ± 1.0^{ab}	3.3 ± 0.1	9.4 ± 0.8^{a}	3.4 ± 0.4^{a}	17.3 ± 0.2^{a}
	3	1.6 ± 0.1^{a}	15.7 ± 1.2^{a}	ND	10.1 ± 0.6^{a}	3.7 ± 0.2^{a}	17.1 ± 0.1^{b}
	6	ND	11.3 ± 1.3^{b}	ND	6.6 ± 0.2^{b}	2.0 ± 0.3^{b}	16.9 ± 0.1^{b}
Rhubarb juice-only	0	ND	10.8 ± 0.9^{a}	ND	11.2 ± 0.2^{a}	2.5 ± 1.4	17.1 ± 0.1^{a}
	3	ND	12.1 ± 0.9^{a}	ND	12.6 ± 1.5^{a}	ND	16.9 ± 0.0^{a}
	6	ND	10.9 ± 1.0^{a}	ND	11.7 ± 0.7^{a}	ND	16.6 ± 0.1^{b}
Sulfites	0	4.5 ± 0.2^{a}	15.7 ± 1.6^{a}	4.0 ± 0.4^{a}	10.7 ± 1.0^{a}	6.7 ± 0.6^{a}	17.1 ± 0.1^{a}
	3	3.7 ± 0.1^{b}	16.3 ± 4.3^{a}	4.1 ± 0.2^{a}	9.7 ± 0.7^{a}	5.2 ± 0.4^{ab}	17.0 ± 0.2^{b}
	6	3.9 ± 0.0^{b}	12.7 ± 1.6^{a}	4.2 ± 0.3^{a}	9.5 ± 0.4^{a}	5.0 ± 0.2^{b}	16.8 ± 0.1^{b}

ND: Not detected. Unknown 1: flavan-3-ol; Unknown 2: flavonol glycoside. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Table 5.1. (Continued).

	Mo	Neochlorogenic acid	Quercetin-3-glucoside	Rutin	Unknown 1	Unknown 2	**Total**
Fresh		2.6 ± 0.4	0.7 ± 0.0	0.7 ± 0.0	1.8 ± 0.2	0.7 ± 0.0	**30.3 ± 4.5**
Blanching	0	8.5 ± 0.7^{a}	2.8 ± 0.0^{a}	2.8 ± 0.1^{a}	2.2 ± 0.1^{b}	2.9 ± 0.0^{a}	**64.6 ± 2.6^{b}**
	3	10.1 ± 1.1^{a}	2.9 ± 0.0^{a}	2.9 ± 0.1^{a}	2.8 ± 0.2^{a}	3.0 ± 0.0^{a}	**72.4 ± 3.9^{a}**
	6	8.8 ± 1.0^{a}	2.8 ± 0.1^{a}	2.8 ± 0.1^{a}	2.3 ± 0.1^{b}	2.9 ± 0.0^{a}	**59.5 ± 3.8^{b}**
Rhubarb juice+ blanching	0	11.0 ± 0.7^{ab}	2.8 ± 0.0^{a}	2.8 ± 0.1^{a}	2.9 ± 0.3^{a}	2.9 ± 0.0^{a}	**70.4 ± 3.6^{ab}**
	3	14.5 ± 1.2^{a}	2.8 ± 0.0^{a}	2.8 ± 0.2^{a}	2.5 ± 0.1^{ab}	2.9 ± 0.0^{a}	**73.7 ± 3.7^{a}**
	6	10.2 ± 3.1^{b}	2.8 ± 0.0^{a}	2.8 ± 0.2^{a}	2.2 ± 0.1^{b}	2.9 ± 0.1^{a}	**57.7 ± 5.4^{b}**
Rhubarb juice-only	0	9.4 ± 0.9^{a}	ND	2.7 ± 0.1^{a}	3.0 ± 0.4^{a}	2.9 ± 0.0^{a}	**59.6 ± 4.0^{a}**
	3	9.8 ± 0.9^{a}	ND	2.7 ± 0.0^{a}	2.7 ± 0.3^{a}	2.9 ± 0.1^{a}	**59.7 ± 3.7^{a}**
	6	9.5 ± 0.9^{a}	ND	2.7 ± 0.0^{a}	2.3 ± 0.1^{a}	2.9 ± 0.0^{a}	**56.6 ± 2.8^{a}**
Sulfites	0	12.7 ± 0.6^{a}	2.8 ± 0.0^{a}	2.8 ± 0.1^{a}	2.9 ± 0.6^{a}	3.0 ± 0.1^{a}	**82.9 ± 5.3^{a}**
	3	10.6 ± 2.2^{ab}	2.7 ± 0.1^{a}	2.8 ± 0.1^{a}	1.3 ± 0.0^{b}	3.0 ± 0.1^{a}	**76.4 ± 8.3^{ab}**
	6	7.7 ± 0.4^{b}	2.7 ± 0.0^{a}	2.8 ± 0.1^{a}	2.1 ± 0.2^{ab}	3.0 ± 0.0^{a}	**70.4 ± 3.3^{b}**

ND: Not detected. Unknown 1: flavan-3-ol; Unknown 2: flavonol glycoside. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Table 5.2. Carotenoid compounds (µg / 100 g) in fresh and dried 'Redhaven' peach post-drying after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

	Mo	β-carotene	β-cryptoxanthin	Lutein	Zeaxanthin	**Total**
Fresh		290 ± 17	28 ± 5.5	4 ± 0.8	380 ± 60	**706.5 ± 83**
Blanching	0	1140 ± 58^{a}	65 ± 5^{a}	31 ± 1^{a}	660 ± 10^{a}	**1890 ± 74^{a}**
	3	670 ± 38^{b}	29 ± 2^{b}	23 ± 1^{b}	500 ± 64^{b}	**1220 ± 105^{b}**
	6	350 ± 40^{c}	14 ± 1^{c}	22 ± 1^{b}	530 ± 20^{b}	**909 ± 62^{c}**
Rhubarb juice+ blanching	0	1640 ± 107^{a}	62 ± 2^{a}	25 ± 1^{a}	620 ± 83^{ab}	**2350 ± 190^{a}**
	3	620 ± 22^{b}	35 ± 0.1^{b}	24 ± 0.2^{a}	710 ± 31^{a}	**1400 ± 53^{b}**
	6	290 ± 3^{c}	11 ± 0.2^{c}	21 ± 2^{b}	430 ± 12^{b}	**750 ± 17^{c}**
Rhubarb juice-only	0	1730 ± 94^{a}	73 ± 6^{a}	25 ± 1^{a}	680 ± 75^{a}	**2500 ± 180^{a}**
	3	734 ± 94^{b}	43 ± 3^{b}	23 ± 2^{a}	730 ± 59^{a}	**1530 ± 160^{b}**
	6	490 ± 53^{c}	8 ± 1^{c}	22 ± 0.3^{a}	430 ± 34^{b}	**950 ± 88^{c}**
Sulfites	0	2150 ± 210^{a}	61 ± 3^{a}	25 ± 1^{a}	750 ± 19^{a}	**2980 ± 240^{a}**
	3	1040 ± 88^{b}	44 ± 4^{b}	24 ± 2^{a}	610 ± 5^{b}	**1710 ± 100^{b}**
	6	970 ± 33^{b}	23 ± 4^{c}	22 ± 1^{a}	540 ± 13^{c}	**1560 ± 50^{c}**

Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Although having positive effects on color and hydrophilic phytochemicals post-drying, blanching and rhubarb juice+blanching treatments fared worst in storage. At 6 mo, losses in phenolic content were in the order sulfites (negligible), rhubarb juice-only (15%), rhubarb juice+blanching (27%) and blanching (33%). It was speculated that the heating treatment, while initially beneficial, left some compounds more susceptible to oxidation and degradation in storage.

As TC was an expression of the various individual carotenoid compounds in β-carotene equivalents, the HPLC profiles echoed previously discussed results. β-carotene was the predominant carotenoid compound, comprising on average 65% of total carotenoid content in dried peaches, as opposed to 40% in fresh form. It was also the key determinant of carotenoid concentration, as treatments did not differ as greatly in the concentrations of other carotenoid compounds. Carotenoid compounds typically declined in storage; degradation was least in lutein and most in β-carotene. Losses by 6 mo were in the order sulfites (48%), blanching (51%), rhubarb juice-only (62%) and rhubarb juice+blanching (68%). Losses in carotenoid content by far exceeded those in phenolics and antioxidants.

Apricots

After drying, sulfited apricots had greatest TP (399.2 mg) which was not significantly higher than the second highest treatment, blanching (357.1 mg); rhubarb juice+blanching (332.3 mg) and rhubarb juice-only (308.0 mg) had lower values which did not differ significantly from each other or the blanching treatment. The four treatments had relatively equivalent AOX (11840.1 µmol sulfites, 11521.1 µmol rhubarb juice+blanching, 10821.4 µmol rhubarb juice-only and 10552.0 µmol blanching) and TC (18101.2 µg rhubarb juice+blanching,

16952.3 µg rhubarb juice-only, 16792.1 µg blanching and 15501.3 µg sulfites). This suggested that for apricots, or specifically this variety (as observed in the first phase), sulfite-free treatments were comparable to sulfite treatments with regards to their protective effect on the studied phytochemicals, at least post-drying.

TP during storage varied considerably with the different treatments (Figure 5.7). While no significant difference was observed throughout the storage study for blanched samples, increases were noted in rhubarb juice-only, rhubarb juice+blanching and sulfites treatments at 3 mo, decreasing to post-drying levels in rhubarb juice-only and rhubarb juice+blanching but holding steady in sulfited samples. AOX remained stable during storage in rhubarb juice-only and rhubarb juice+blanching but increased in blanched and sulfited samples, peaking at 6 mo. The suggested explanation for this phenomenon has previously been discussed. As with peaches, TC steadily decreased with storage, least in sulfited samples (Bolin and Stafford 1974) and greatest in blanched samples by 6 mo.

HPLC-determined TP mirrored results obtained spectrophotometrically, with the sulfites treatment maintaining its position with the highest phenolic content, followed by blanching, rhubarb juice+blanching and rhubarb juice-only, with successive treatment values not differing significantly from each other (Tables 5.3 and 5.4). Treatments were nonetheless noted to differ substantially in flavan-3-ol content, compound concentrations of which followed the pattern sulfites > rhubarb juice+blanching ≥ blanching > rhubarb juice-only. Although there was no clear trend for treatment effect on hydroxycinnamic acids and flavonol glycosides, rhubarb juice-only performed much better in these categories while rhubarb juice+blanching often performed worst.

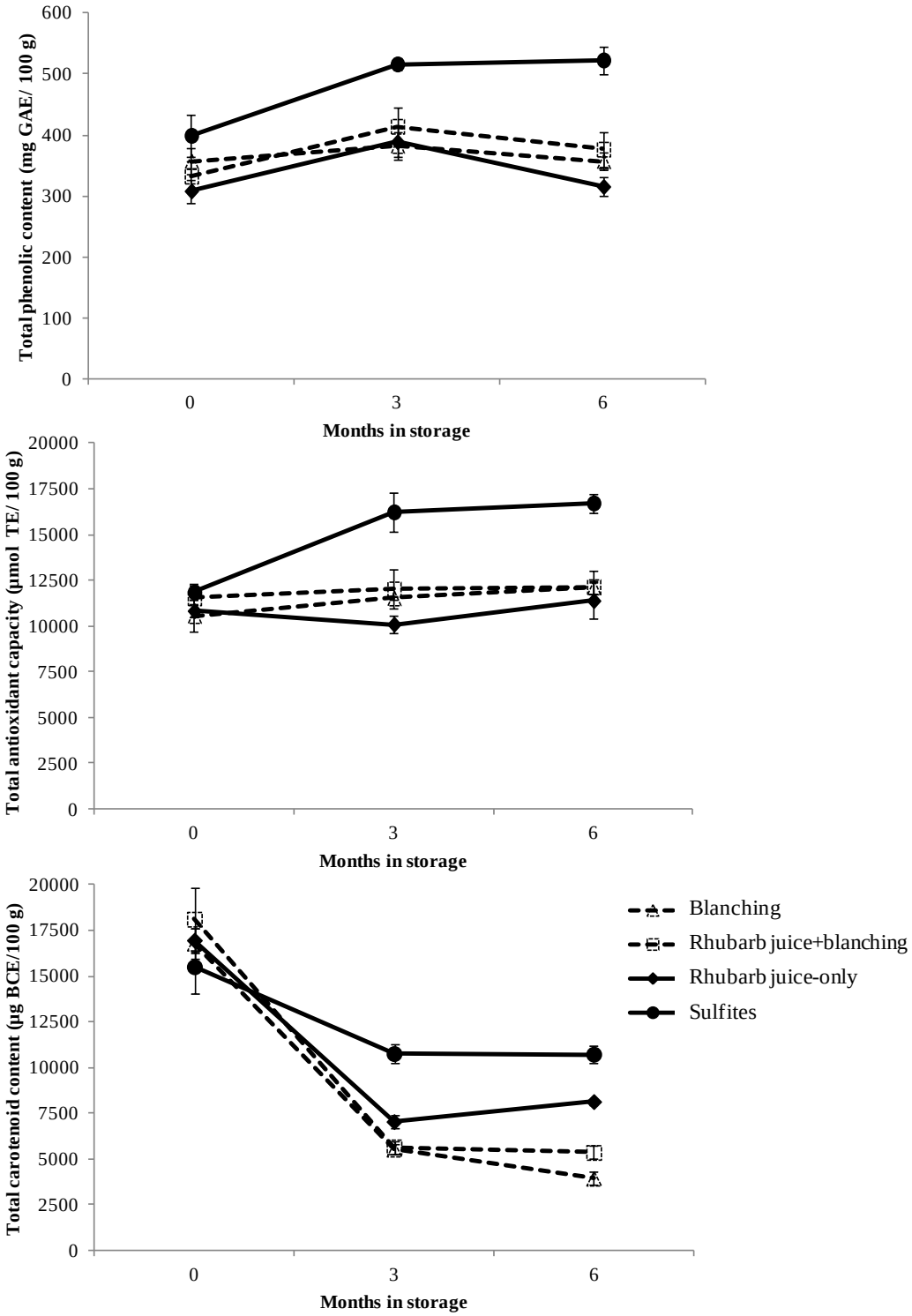

Figure 5. 7. Total phenolic content, total antioxidant capacity and total carotenoid content of dried 'Harlayne' apricot post-drying after 3 and 6 months storage at 18 – 20 ˚C (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents).

Table 5.3. Phenolic compounds (mg / 100 g) in fresh and dried 'Harlayne' apricot post-drying after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

	Mo	Catechin	Chlorogenic acid	Cyanidin-3-glucoside	Epicatechin	Epigallocatechin	Neochlorogenic acid
Fresh		9.6 ± 1.0	6.5 ± 0.7	1.1 ± 0.1	15.9 ± 1.0	6.6 ± 0.6	22.0 ± 1.0
Blanching	0	1.1 ± 0.2^{a}	9.2 ± 0.2^{a}	ND	21.9 ± 1.3^{a}	5.0 ± 0.4^{a}	25.0 ± 3.9^{a}
	3	1.1 ± 0.1^{a}	7.5 ± 1.1^{b}	ND	14.1 ± 2.1^{b}	4.1 ± 0.3^{b}	24.4 ± 2.3^{a}
	6	0.9 ± 0.0^{b}	7.1 ± 0.4^{b}	ND	13.3 ± 1.6^{b}	3.4 ± 0.3^{b}	22.1 ± 1.2^{a}
Rhubarb juice+ blanching	0	1.3 ± 0.0^{a}	7.4 ± 0.7^{a}	ND	22.5 ± 1.8^{a}	5.2 ± 0.5^{a}	22.2 ± 2.6^{a}
	3	1.4 ± 0.1^{a}	7.7 ± 0.5^{a}	ND	17.6 ± 0.9^{b}	4.9 ± 0.4^{a}	23.8 ± 1.9^{a}
	6	1.1 ± 0.1^{b}	7.4 ± 0.8^{a}	ND	13.9 ± 1.3^{c}	3.5 ± 0.4^{b}	23.5 ± 2.0^{a}
Rhubarb juice-only	0	0.6 ± 0.0	9.8 ± 0.8^{a}	ND	15.0 ± 1.3^{a}	4.1 ± 0.4^{b}	22.6 ± 1.7^{a}
	3	ND	6.6 ± 0.1^{b}	ND	13.2 ± 3.0^{a}	4.3 ± 0.3^{b}	21.4 ± 1.1^{a}
	6	ND	6.6 ± 0.4^{b}	ND	9.8 ± 2.4^{a}	6.5 ± 0.4^{a}	21.5 ± 1.9^{a}
Sulfites	0	1.2 ± 0.2^{ab}	8.3 ± 0.3^{a}	ND	27.2 ± 2.5^{b}	7.1 ± 0.1^{c}	23.3 ± 2.4^{b}
	3	1.3 ± 0.0^{a}	9.5 ± 0.5^{a}	ND	34.4 ± 0.4^{a}	15.6 ± 0.8^{a}	30.9 ± 2.1^{a}
	6	1.1 ± 0.0^{b}	8.7 ± 0.5^{a}	ND	29.7 ± 3.4^{ab}	11.6 ± 1.2^{b}	26.1 ± 1.2^{b}

ND: Not detected. Unknown 1 and 2: flavan-3-ols. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Table 5.3. (Continued).

	Mo	Quercetin-3-glucoside	Quercetin derivative	Rutin	Unknown 1	Unknown 2	**Total**
Fresh		1.2 ± 0.0	1.3 ± 0.0	12.7 ± 0.8	17.5 ± 1.8	11.6 ± 0.3	**106.0 ± 7.3**
Blanching	0	2.9 ± 0.1^{a}	3.0 ± 0.0^{ab}	16.2 ± 1.2^{ab}	26.2 ± 2.6^{a}	12.2 ± 1.4^{a}	**122.7 ± 11.3^{a}**
	3	2.9 ± 0.1^{a}	3.0 ± 0.1^{a}	18.0 ± 2.2^{a}	9.2 ± 0.4^{b}	10.6 ± 0.8^{a}	**94.9 ± 9.5^{b}**
	6	2.9 ± 0.0^{a}	2.9 ± 0.0^{b}	13.5 ± 1.4^{b}	6.0 ± 0.6^{c}	9.8 ± 1.0^{a}	**81.9 ± 6.5^{b}**
Rhubarb juice+ blanching	0	2.9 ± 0.1^{a}	2.9 ± 0.2^{a}	11.5 ± 0.9^{a}	26.8 ± 1.7^{a}	12.7 ± 1.7^{a}	**115.4 ± 10.2^{a}**
	3	2.9 ± 0.1^{a}	2.9 ± 0.1^{a}	14.1 ± 1.4^{a}	10.1 ± 1.0^{b}	12.6 ± 1.0^{a}	**98.0 ± 7.4^{ab}**
	6	2.9 ± 0.1^{a}	2.9 ± 0.1^{a}	11.8 ± 1.1^{a}	6.8 ± 0.5^{c}	10.9 ± 0.8^{a}	**84.7 ± 7.2^{b}**
Rhubarb juice-only	0	3.2 ± 0.0^{c}	2.8 ± 0.1^{a}	17.4 ± 1.9^{a}	10.1 ± 0.7^{a}	10.9 ± 0.8^{a}	**96.5 ± 7.7^{a}**
	3	3.5 ± 0.1^{b}	3.0 ± 0.1^{a}	12.2 ± 1.3^{b}	7.4 ± 0.5^{b}	11.1 ± 0.5^{a}	**82.7 ± 7.0^{a}**
	6	3.7 ± 0.0^{a}	2.8 ± 0.0^{a}	11.9 ± 0.9^{b}	11.6 ± 1.2^{a}	7.8 ± 0.8^{b}	**82.2 ± 8.0^{a}**
Sulfites	0	3.1 ± 0.1^{a}	2.9 ± 0.0^{b}	13.8 ± 1.1^{b}	32.6 ± 2.5^{b}	14.1 ± 1.1^{b}	**133.6 ± 10.3^{b}**
	3	3.2 ± 0.0^{a}	3.0 ± 0.0^{a}	16.0 ± 1.0^{ab}	41.4 ± 1.1^{a}	17.3 ± 0.5^{a}	**172.6 ± 6.4^{a}**
	6	3.1 ± 0.0^{a}	2.9 ± 0.0^{b}	17.8 ± 1.0^{a}	18.2 ± 2.4^{c}	19.0 ± 0.8^{a}	**138.2 ± 10.5^{b}**

ND: Not detected. Unknown 1 and 2: flavan-3-ols. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Table 5.4. Mean values of carotenoid compounds (µg / 100 g) in fresh and dried 'Harlayne' apricot post-drying after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

		β-carotene	β-cryptoxanthin	Lutein	Zeaxanthin	**Total**
Fresh		18000 ± 1340	140 ± 11	27 ± 2	ND	**18200 ± 1400**
Blanching	0	16100 ± 840^{a}	140 ± 7^{a}	30 ± 1^{a}	360 ± 18^{b}	**16700 ± 870^{a}**
	3	5200 ± 230^{b}	33 ± 2^{b}	25 ± 2^{b}	460 ± 8^{a}	**5800 ± 240^{b}**
	6	3800 ± 305^{c}	21 ± 0.4^{c}	23 ± 1^{b}	320 ± 10^{c}	**4200 ± 320^{c}**
Rhubarb juice+ blanching	0	17400 ± 1600^{a}	150 ± 5^{a}	33 ± 3^{a}	360 ± 23^{a}	**18000 ± 1600^{a}**
	3	5500 ± 160^{b}	33 ± 2^{b}	26 ± 1^{ab}	370 ± 13^{a}	**6000 ± 180^{b}**
	6	5100 ± 200^{b}	26 ± 2^{b}	26 ± 2^{b}	320 ± 14^{b}	**5500 ± 220^{b}**
Rhubarb juice-only	0	16300 ± 660^{a}	120 ± 10^{a}	32 ± 1^{a}	420 ± 14^{b}	**16900 ± 680^{a}**
	3	6700 ± 400^{b}	30 ± 1^{c}	30 ± 0.2^{ab}	506 ± 45^{a}	**7300 ± 440^{c}**
	6	7800 ± 170^{b}	50 ± 2^{b}	27 ± 2^{b}	350 ± 19^{c}	**8200 ± 190^{b}**
Sulfites	0	14900 ± 1430^{a}	105 ± 12^{a}	32 ± 2^{a}	407 ± 17^{b}	**15500 ± 1500^{a}**
	3	10300 ± 310^{b}	47 ± 2^{b}	31 ± 2^{b}	560 ± 17^{a}	**11000 ± 330^{b}**
	6	10400 ± 240^{b}	61 ± 5^{b}	27 ± 2^{b}	350 ± 19^{c}	**10900 ± 270^{b}**

ND: Not detected. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

The drying process uniformly eliminated the anthocyanin cyanidin-3-glucoside from the final product, but made available (or measurable) zeaxanthin, which had been undetected in fresh fruit. β-carotene was again identified as the predominant carotenoid, comprising greater than 90% of total carotenoid content in both fresh and dried apricots and being the key determinant of TC. Blanching also had noticeable effects on xanthophylls, as the two treatments with blanching had greater β-cryptoxanthin content while those without had higher zeaxanthin content.

Treatment type had a distinct influence on phenolic compounds in storage. Rhubarb juice+blanching and blanching flavan-3-ol concentration decreased sharply while hydroxycinnamic acid and flavonol glycoside content remained relatively stable. Rhubarb juice-only showed little consistency in its effect on compounds over time. In sulfited samples, an apparent increase in 3 mo followed by a decrease by 6 mo was found in flavan-3-ols and hydroxycinnamic acids while flavonol glycosides did not change significantly with storage. This resulted in a peaking of sulfited samples HPLC-TP at 3 mo, similar to the increase at this point as determined by the Folin-Ciocalteu assay. Contrary to that test, a decrease was seen by 6 mo to levels similar to those post-drying. Comparing this to the significantly reduced HPLC-TP values of other treatments by this point, sulfited samples still had a substantially greater HPLC-TP by the end of the shelf life study with those for the others approximately equivalent.

Carotenoid compound degradation with storage was most severe in β-carotene, by 6 mo reduced by 30% (sulfites) to 80% (blanching). Zeaxanthin increased at 3 mo in all

treatments, although this did not significantly impact TC. By 6 mo, significant differences could be seen in TC of the different treatment types, ranking in the order sulfites> rhubarb juice-only > rhubarb juice+blanching ≥ blanching, with rhubarb juice-only demonstrating even greater capacity here than in peaches to benefit carotenoid content. It was proposed that in apricots, while blanching initially made carotenoid compounds more measurable, it later had a detrimental effect as these compounds were more susceptible to and available for lipid oxidation, resulting in a greater degree of carotenoid loss during storage.

Nutritional content and phytochemical retention

Nutritional content was calculated at the end of the shelf life study as an estimation of what was realistically available to the consumer 6 mo after production. A major appeal of dried peaches and apricots is their provitamin A status. Considering a 40 g serving of dried fruit (FDA 2012) and the dietary reference intake of 900 µg RAE for males 14 years or older, dietary provitamin A compounds β-carotene and β-cryptoxanthin from the different treatments were evaluated (USDA FNC 2011; NIH 2012). A serving of dried peaches provided 1.1% (rhubarb juice+blanching), 1.3% (blanching), 1.8% (rhubarb juice-only) and 3.6% (sulfites) of the recommended dietary allowance (RDA) for vitamin A while apricots supplied 14.1% (blanching), 19.1% (rhubarb juice+blanching), 29.0% (rhubarb juice-only) and 38.7% (sulfites). The sulfite-free treatments in apricots therefore still resulted in products that are good (blanching and rhubarb juice+blanching) or excellent (rhubarb juice-only) sources of vitamin A.

Nutrient retention was calculated by comparing the HPLC-determined phenolic and carotenoid content of dried products with fresh fruit on a 100 g dry weight basis (Table 5.5). Retention was compared after drying and at 6 mo to assess losses due to the drying treatment and storage, respectively. The effect of sucrose uptake during the pre-drying soak on fruit soluble solids content as well as initial and final moisture content in fruits and products were taken into consideration. In both fruits, phenolic retention at the end of the 6 mo period was better than that of carotenoids, under the treatment conditions used. Dried peaches had better retention of phenolic and carotenoid compounds after both drying and storage. However, while carotenoid retention was as good or better than phenolics post-drying, losses were more severe during storage. Dried apricots experienced similarly significant losses in carotenoids during storage that were likely to decrease further or eventually plateau with time. The non-linear progression in phenolics made it difficult to accurately predict their response with prolonged storage. The effectiveness of the sulfite-free treatments mirrored previous observations, with the two blanching treatments better for phenolic retention and the rhubarb juice-only more effective in carotenoid retention.

Table 5.5. Phenolic and carotenoid retention in dried ‘Redhaven’ peach and ‘Harlayne’ apricot post-drying and after storage for 6 months at 18 – 20 ˚C.

Fruit	Treatment	Phenolic retention (%)		Carotenoid retention (%)	
		Drying	Storage	Drying	Storage
Peach	Blanching	61.9	57.0	73.0	29.7
	Rhubarb juice+blanching	59.8	49.0	80.2	25.5
	Rhubarb juice-only	46.5	44.2	78.5	35.0
	Sulfites	71.2	60.5	103.0	53.7
Apricot	Blanching	43.3	28.9	35.1	8.8
	Rhubarb juice+blanching	35.2	25.9	32.8	10.0
	Rhubarb juice-only	26.7	22.7	27.9	13.6
	Sulfites	36.9	38.2	25.6	17.9

Conclusion

This study allowed for an assessment of various pre-drying treatments and a comparison of their efficacy. The commercial practice of sulfiting did prove to produce the most appealing final product in terms of color and phytochemical value. Two of the alternative treatments, blanching and rhubarb juice+blanching, have potential as inexpensive, easily reproducible, natural alternatives to sulfited dried fruit, although products would require storage at refrigerated temperatures to maintain their bright color for more than a month. They also proved comparable to sulfiting, particularly in apricots, for yielding products of significant phenolic and antioxidant content; modifications will be required to sustain these levels in storage. The rhubarb juice-only treatment, although incapable of producing the desired color in dried products, was most effective in the retention of carotenoid compounds and pro-vitamin A constituents after drying and in storage. Treatments had varying effects on bioactive compounds; notably, anthocyanins were most affected by drying in apricots and storage in peaches. Time of consumption after storage may also be pertinent as phenolic content was observed to peak at 3 mo after drying, under the conditions of our study. Dried peaches had better retention of phenolic and carotenoid compounds after both drying and storage; in both fruits, storage was most detrimental to carotenoid content. Overall, the study contributes to the search for alternative antibrowning treatments, supplying useful information on the effects of such treatments on phytochemicals.

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CHAPTER 6: THE EFFECT OF PROCESSING AND STORAGE ON THE PHENOLIC, ANTIOXIDANT AND CAROTENOID CONTENT OF PEACH AND APRICOT JAMS AND NECTARS.

Introduction

The peach (*Prunus persica*) and apricot (*Prunus armeniaca*) are sources of phenolic and carotenoid compounds, phytochemicals found to have various health benefits (Tomas-Barberan and others 2001; Gil and others 2002; Kader and Barrett 2005; Ruiz and others 2005a; Ruiz and others 2005b). Antioxidants, which include both phenolic and carotenoid compounds, have been found to reduce the risk of cardiovascular diseases and some cancers while carotenoids play a role in vision (Ames and others 1993; Paiva and Russell 1999; Fraser and Bramley 2004).

Postharvest storage is challenging for these fruit since, being climacteric, they can ripen off the tree, limiting their shelf life (Kader and Mitchell 1989; Kader 1999; Payasi and Sanwal 2008). Processing is a means to add value to these fruits by extending shelf life or developing products which ensure year-round fruit availability.

A small proportion of peaches and apricots produced in the United States are channelled into puree and related products. Puree is used in the production of fillings, baby food or as an oil substitute (Siddiq 2006a; Siddiq 2006b). It can also serve as a starting material for secondary products including jam and beverages (Barta and others 2005). While peach and apricot jam are relatively simple to make, beverage production is challenging because of the difficulty involved in juice extraction and clarification due to high pulp and suspended solids content of

these fruits. Peach and apricot beverages are therefore often in the form of nectars (diluted juice beverages), pulpy juices or ingredients in less turbid beverages produced in combination with other fruits (Beveridge and Harrison 1995; Beveridge and Rao 1997; FDA 2003; McLellan and Padilla-Zakour 2005; Siddiq 2006b; Santin 2008).

Growing public concern about obesity and other diet-related diseases has created a market for lower sugar or low calorie versions of these products (Sloan 2010). However, sucrose reduction or substitution causes changes in taste, consistency and color which may negatively affect the marketing, perception and consumption of low or reduced sugar products (Costell 1993; Somogyi 2005). There is currently little information available on the effect of these formula modifications on the phytochemical and nutritional value of these products. Furthermore, the extensive thermal treatment involved in the processing of jams and nectars as well as storage temperatures and conditions may have detrimental effects on compounds susceptible to degradation by heat, light or oxidation (Sabry 1961; Hamama and Nawar 1991).

Our study investigated the composition and concentration of phenolic, antioxidant and carotenoid compounds in peach and apricot jam and nectar with varying sucrose and fruit content. Phytochemical content and product quality were evaluated post-processing and over a 6-month storage period. Drawing on knowledge gained about varietal characteristics, we also assessed the suitability of the selected varieties for jam and nectar production.

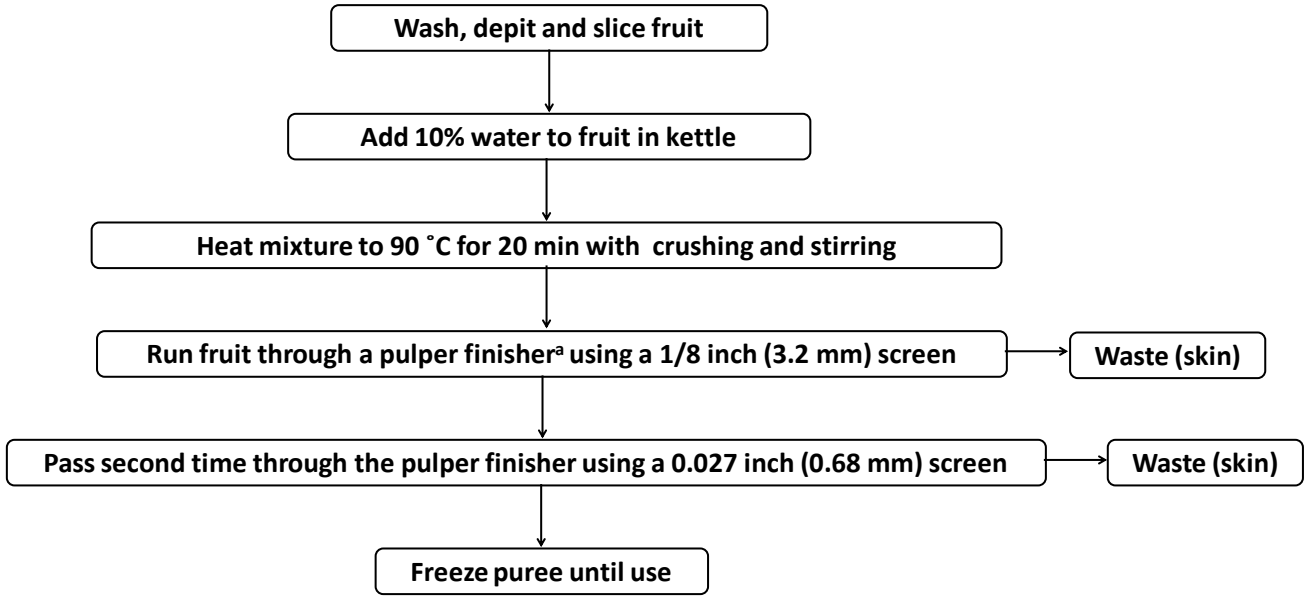
Materials and methods

Harvest

'Redhaven' peach and 'Harlayne' apricot were selected for this study because of their economic importance to the Northeast based upon their cold hardiness (Lamb and Terry 1973; Layne 1996; Scorza and Sherman 1996; Monet and Bassi 2008). Fruits were harvested from local Northeast orchards at the 'tree ripe' stage (ready-to-eat) to ensure good sugar-to-acid balance and full development of flavor and aroma, as well as a softening of flesh tissue to facilitate pureeing (Bureau 2006; Horvath-Kerkai 2006; Ramina and others 2008).

Processing

Figures 6.1 outlines the procedure for the production of puree, which was then used as a starting material for jam (Figure 6.2) and nectar (Figure 6.3); yield from the pureeing process was 60%. Jam production followed typical protocols as well as formulations recommended by the brand of pectin used (Reynolds and others 1993; Pacific Pectin 2010). Reduced sucrose jams contained at least 25% less sucrose than standard jams. To avoid exceeding the target brix, reduced sucrose jams underwent a slower heating process over a slightly longer time. Nectar ingredients and formulation were in line with USDA Commercial Item Description A-A-20118B (Luh 1980; FDA 2003; USDA AMS 2012). Standard nectar was developed to have a final Brix of 16 and a sugar-to-acid ratio of 20 – 30 for apricot and 30 – 40 for peach nectars. Reduced sucrose nectars were formulated in order to have a final product containing 100 calories per serving (240 mL). Pictures of the final products are shown in Illustrations A.7 and A.8.

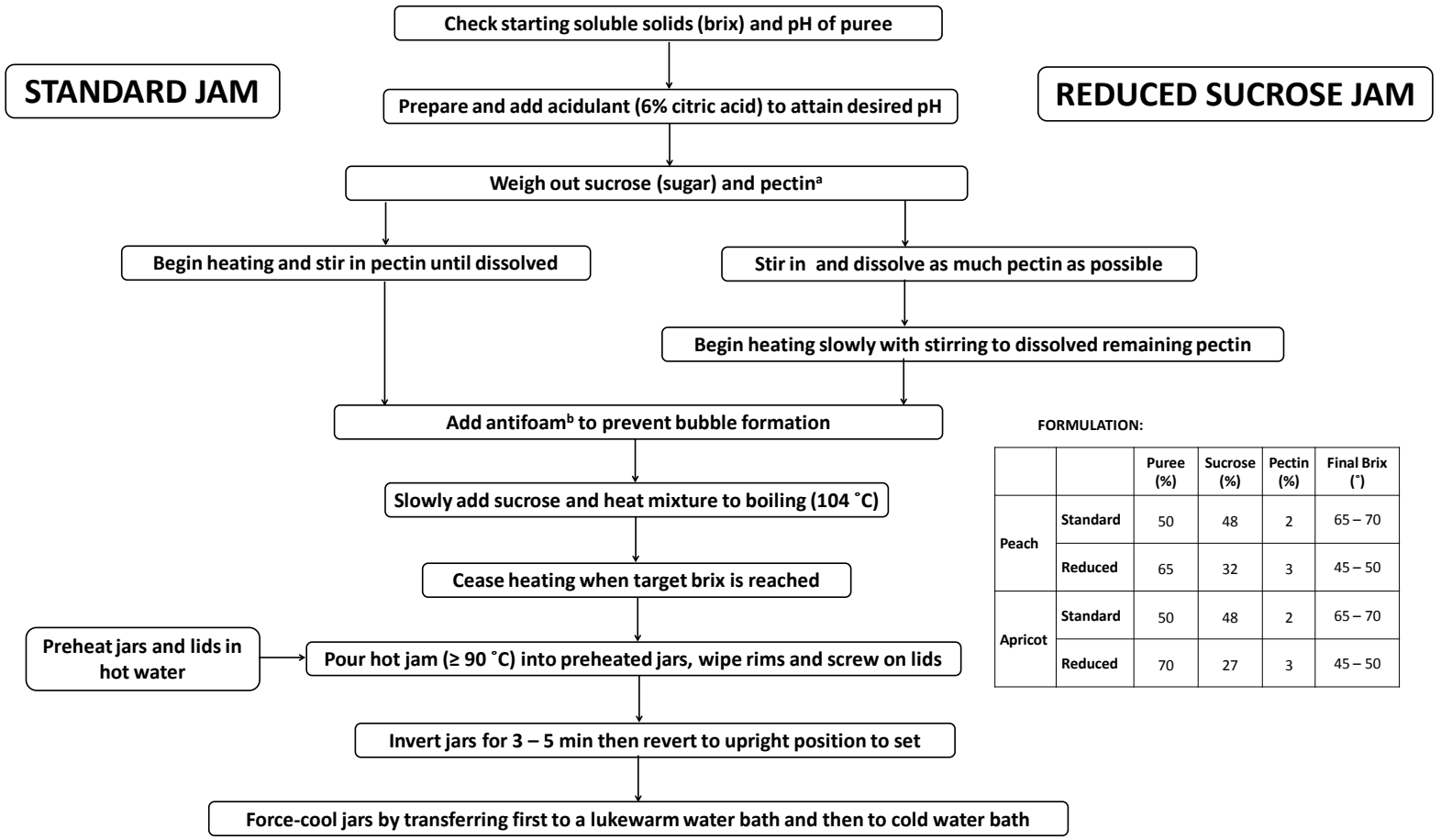


PUREE CHARACTERISTICS

	Brix (˚)	pH	Titratable acidity (g malic acid/100 g)	Sugar-to-acid ratio
Peach	8.5	3.91	0.302	28.1
Apricot	20	3.77	0.831	24.1

[a] Model 1858; Langsenkamp Manufacturing, Indianapolis, IN

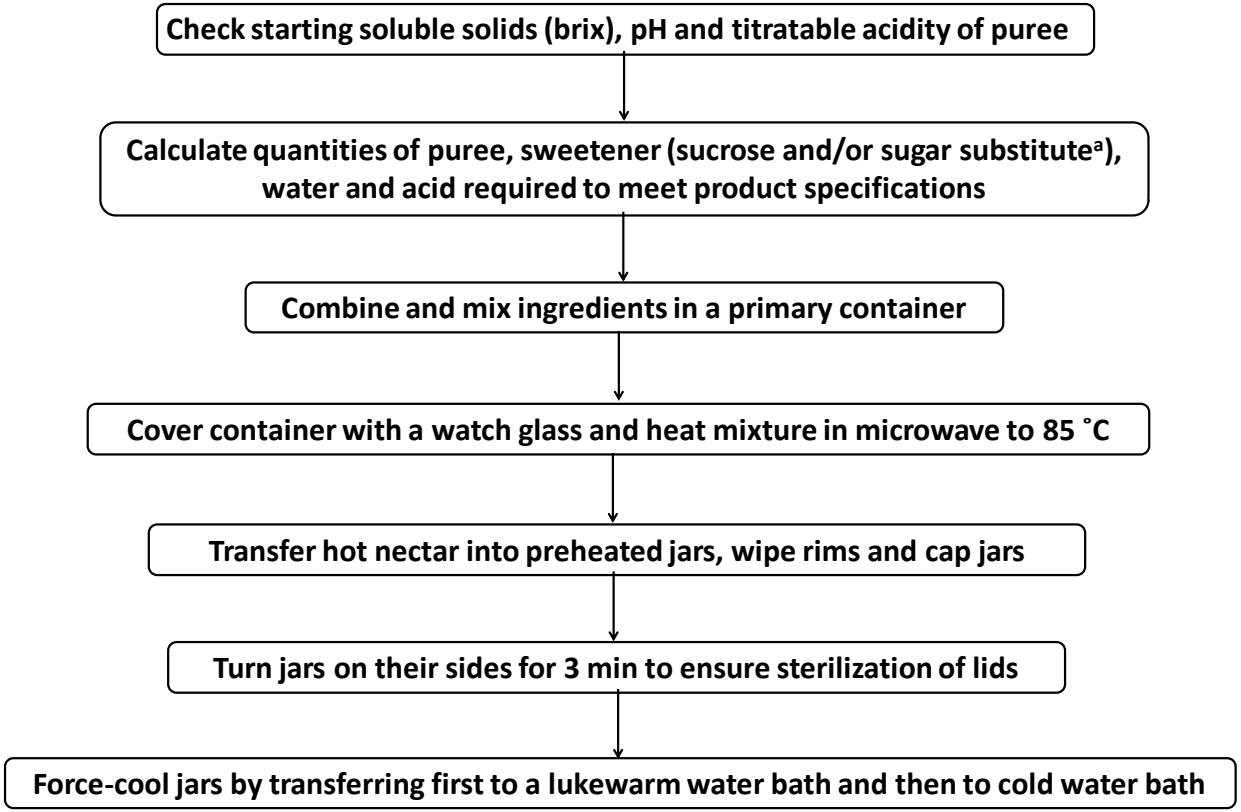
Figure 6. 1. Flow chart for the production of peach and apricot puree.



		Puree (%)	Sucrose (%)	Pectin (%)	Final Brix (˚)
Peach	Standard	50	48	2	65 – 70
	Reduced	65	32	3	45 – 50
Apricot	Standard	50	48	2	65 – 70
	Reduced	70	27	3	45 – 50

[a] Pacific pectin mix and Pacific LM-3 pectin (Pacific Pectin Mix; Pacific Pectin Inc, Oakhurst, CA) were used for standard and reduced sucrose jams, respectively.
[b]Antifoam (Double strength antifoam, Pacific Pectin Inc).

Figure 6. 2. Flow chart for the production of peach and apricot standard and reduced sucrose jam.



FORMULATION:

		Puree (%)	Sucrose (%)	Water (%)	Stevia (%)
Peach	Standard	90	5.03	4.97	-
	Reduced	90	2.77	7.23	-
Apricot	Standard	60	4	36	-
	Reduced	50	0.2	49.6	0.2

[a] (Good&Sweet Stevia, Life Concepts Inc., Rancho Santa Margarita, CA)

Figure 6. 3. Flow chart for the manufacture of peach and apricot standard and reduced sucrose nectar.

Phenolic analysis

Extraction of phenolic compounds followed the method described in chapter 2 with 100% methanol used to extract 5 g of jam and nectar. Total phenolic content and HPLC phenolic analysis were also performed as in chapter 2.

Total antioxidant capacity assay

This was performed as described in chapter 2.

Carotenoid analysis

This was performed as described in chapter 2; 5 g jam and nectar were extracted and analysed.

Shelf life study

Samples were stored at 18 - 20 ˚C for six months (mo) under dark conditions. Phenolic, antioxidant and carotenoid analyses were conducted at 3 mo and again at 6 mo and results compared to those obtained post-processing. Lightness (*L),* *a* and *b* color values were measured post-processing and on a monthly basis over the course of the shelf life study with a HunterLab UltraScan XE (Hunter Associates Laboratory Inc., Reston, VA).

Statistical analysis

Data was analysed as described in chapter 2, with the respective weights for bioactive data stated as required

Results and discussion

Quality indices

The reduction of sucrose and caloric content in fruit products while maintaining good flavor is currently accomplished by the use of sugar substitutes (Somogyi 2005). Sugar is nevertheless critical for the formation of hydrophobic bonds required for gelation and the prevention of syneresis in jam (Oakenfull and Scott 1984; Baker 2006). The amount of sugar present also affects the color and texture of products (Costell and others 1993; Benamara and others 1999). Although low methoxyl pectin, such as the one used in this study, allows for gel formation using less sugar (Baker 2006), the effect of sucrose reduction on quality indices of our products was evaluated for all these reasons.

Visually, standard jams were darker than reduced sucrose jams. This was corroborated instrumentally, with standard jam having lower *L* values post processing and during storage (Table 6.1); differences were more pronounced in apricots than in peaches. The disparity between treatments was attributed to a greater concentration of Maillard reaction products in standard jam due to its higher sucrose content (Abers and Wrolstad 1979; Joslyn 1941; Siddique 2006a). This was confirmed by HPLC, with standard jams of both fruits having four- to five-fold greater hydroxymethylfurfural (HMF) content than reduced sucrose jam.

Table 6. 1. Color of peach and apricot jam and nectar post-processing and after storage for 3 and 6 months at 18 – 20 ˚C.

Fruit	Treatment	Mo	Jam			Nectar		
			L	*a*	*b*	*L*	*a*	*b*
Peach	Standard	0	27.6 ± 0.3[b]	0.41 ± 0.04[a]	-0.10 ± 0.28[a]	35.3 ± 0.5[a]	0.90 ± 0.04[a]	5.08 ± 0.23[a]
		3	28.1 ± 0.2[b]	0.13 ± 0.06[b]	-0.61 ± 0.23[a]	35.5 ± 0.5[a]	0.66 ± 0.10[b]	4.41 ± 0.47[ab]
		6	28.7 ± 0.5[a]	-0.14 ± 0.03[c]	-0.80 ± 0.50[a]	35.1 ± 0.3[a]	0.50 ± 0.05[c]	4.26 ± 0.39[b]
	Reduced sucrose	0	30.2 ± 0.5[a]	1.06 ± 0.08[a]	0.80 ± 0.30[a]	36.1 ± 0.7[a]	0.88 ± 0.02[a]	5.15 ± 0.57[a]
		3	30.7 ± 0.7[a]	0.59 ± 0.03[b]	0.73 ± 0.54[a]	36.5 ± 0.4[a]	0.62 ± 0.07[b]	4.11 ± 0.41[b]
		6	30.6 ± 0.2[a]	0.28 ± 0.01[c]	1.09 ± 0.20[a]	36.3 ± 0.2[a]	0.48 ± 0.08[c]	4.41 ± 0.29[ab]
Apricot	Standard	0	28.9 ± 0.3[b]	2.57 ± 0.05[a]	2.85 ± 0.25[a]	40.1 ± 0.9[a]	7.65 ± 0.38[a]	15.0 ± 1.01[a]
		3	29.4 ± 0.2[ab]	2.40 ± 0.10[b]	2.58 ± 0.40[a]	40.0 ± 0.4[a]	6.83 ± 0.24[a]	13.4 ± 0.60[b]
		6	29.9 ± 0.6[a]	2.20 ± 0.09[c]	2.12 ± 0.51[a]	39.3 ± 0.7[a]	6.46 ± 0.20[b]	13.2 ± 0.50[b]
	Reduced sucrose	0	34.5 ± 0.7[a]	6.60 ± 0.23[a]	10.6 ± 0.98[a]	39.7 ± 0.5[a]	6.91 ± 0.29[a]	14.5 ± 0.30[a]
		3	35.5 ± 1.0[a]	6.68 ± 0.24[a]	10.4 ± 0.93[a]	39.7 ± 0.7[a]	6.13 ± 0.23[b]	13.1 ± 0.40[b]
		6	35.9 ± 1.2[a]	6.44 ± 0.29[a]	9.98 ± 0.78[a]	40.0 ± 0.5[a]	5.75 ± 0.27[b]	12.3 ± 0.71[b]

Means not connected by the same letter indicate a significant difference between time points for that parameter (alpha = 0.05).

While *L* remained relatively stable, *a* (red color) decreased in storage in both jam and nectar and *b* (yellow color) in nectar. These changes, particularly the loss of redness, have been observed with storage of strawberry products and attributed to non-enzymatic browning and Maillard product formation, as well as phenolic – mainly anthocyanin – degradation or polymerization with other fruit components (Wesche-Ebeling and Montgomery 1990; Garcia-Viguera and others 1999; Rababah and others 2011).

Sucrose content also affected consistency, assessed visually, with standard jam being thicker with better spread. Syneresis was observed in reduced sucrose peach jam by 6 mo, implying that the variety used, 'Redhaven', was not suitable for this product unless in combination with other varieties or with the addition of other ingredients to aid and/or maintain gelation (e.g. gum). The set of apricot reduced sucrose jam was facilitated by the high fruit soluble solids content of 'Harlayne'.

Peach nectars did not differ in consistency since both had the same fruit content. Apricot reduced sucrose nectar was unique in that less fruit had to be used than in their standard version due to the high soluble solids content and thus high caloric content of 'Harlayne' puree. Nonetheless, the reduced sucrose nectar had acceptable taste and consistency.

Jam

Final Brix and pH for peach jams were 66.0 and 3.05 for standard and 46.5 and 3.08 for reduced sucrose jams. For apricot jams, final values were 68.4 and 3.14 for standard and 49.4 and 3.21 for reduced. The difference in sucrose content also implied differences in water activity (a_w). The dissolution of sucrose molecules in

water decreases vapor pressure, lowering the relative humidity of the air around the food product in relation to pure water (which has a a_w of 1). Increasing sucrose concentration therefore lowers a_w, affecting a range of factors including chemical stability, enzyme activity and microbial growth (Pintauro 1990). The implications of this phenomenon, particularly how it contrasted with fruit content, were evaluated in standard and reduced sucrose jams.

The Folin-Ciocalteu test showed no difference in total phenolic content (TP) between peach standard and reduced sucrose jam after processing or during storage despite the reduced sucrose version containing 30% greater fruit content (Figure 6.4). Reduced sucrose apricot jam, having 40% more fruit than the standard version, had slightly higher TP ($p < 0.05$) after processing, although the disparity became more obvious during storage (Figure 6.5).

In both treatments, decreases were observed in TP during storage. While the different peach jams remained indistinguishable even at 6 mo (30% loss in both), reduced sucrose apricot jam performed better in storage than standard jam, suffering a 25% decrease in TP compared to 50% in the standard. This was in agreement with work by Howard and others (2010) who reported better performance in storage by sugar-free jam, with higher fruit content, compared to jams with sugar. These results imply better stability of phenolic compounds in the reduced sucrose medium over time although a putative mechanism is yet to be determined.

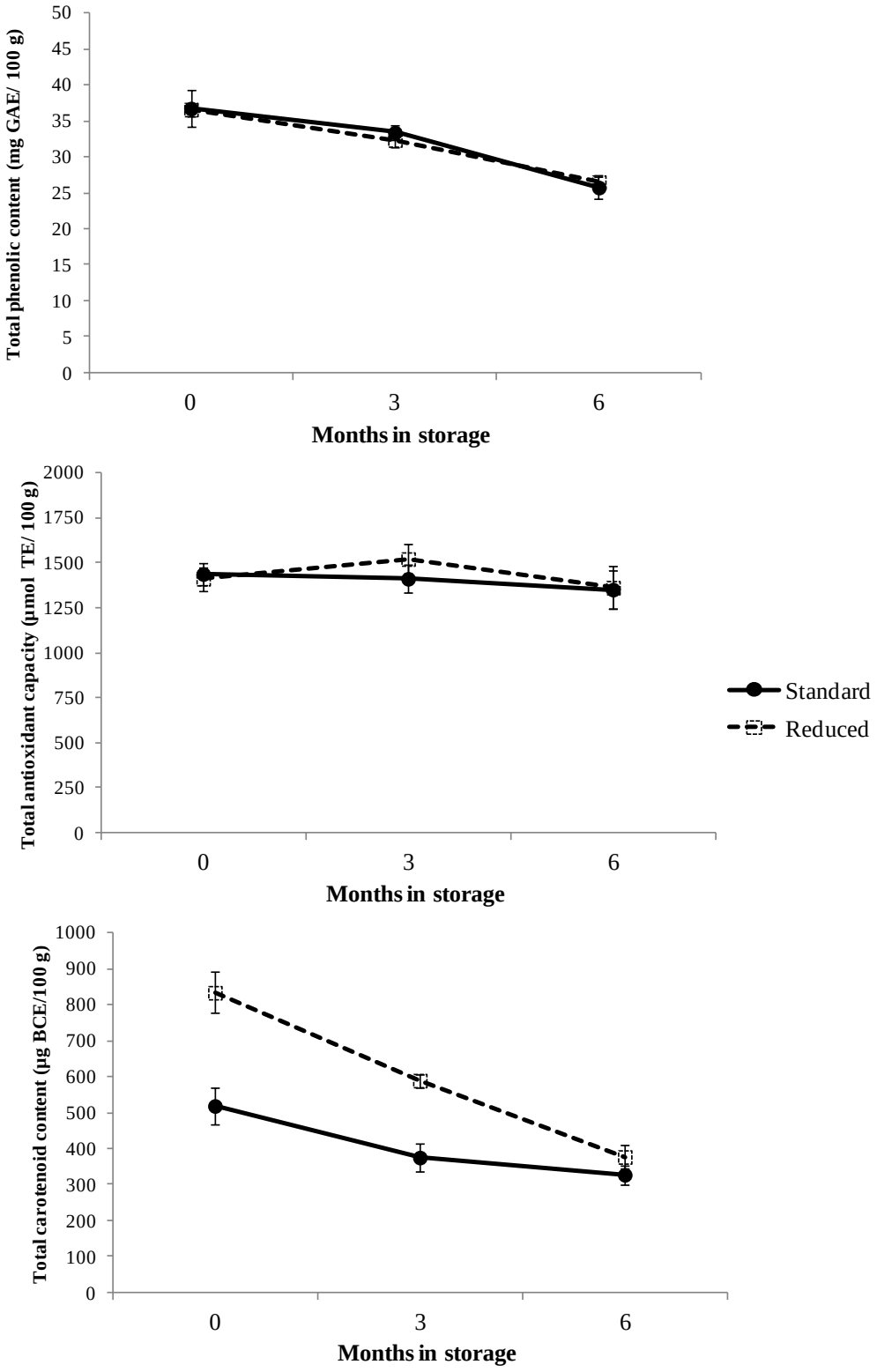


Figure 6. 4. Total phenolic content, total antioxidant capacity and total carotenoid content of 'Redhaven' peach standard and reduced sucrose jam post-processing and after 3 and 6 months storage at 18 – 20 ˚C (GAE: Gallic acid equivalents, TE:Trolox equivalents, BCE: β-carotene equivalents).

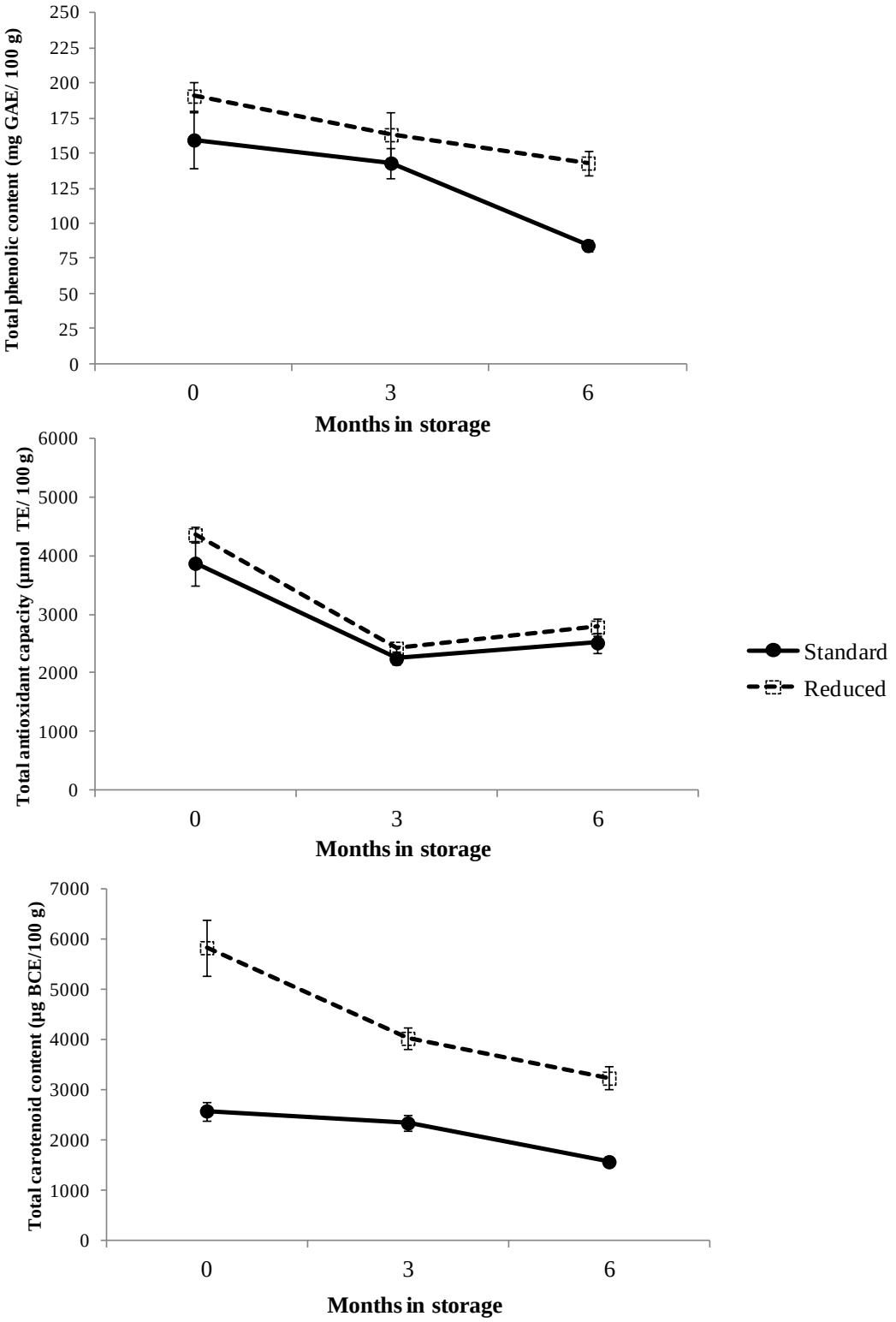


Figure 6. 5. Total phenolic content, total antioxidant capacity and total carotenoid content of 'Harlayne' apricot standard and reduced sucrose jam post-processing and after 3 and 6 months storage at 18 – 20 ˚C (GAE: Gallic acid equivalents, TE:Trolox equivalents, BCE: β-carotene equivalents).

These observations were attributed to the complex interactions of jam constituents with heat treatment (Joslyn 1941; Hubberman 2006). Studies on the effect of heat concentration on phenolic compounds are focused mainly on anthocyanin content. Sucrose has been found to provide a protective effect in some studies (Wrolstad and others 1990; Cemeroglu 1994) while being implicated in anthocyanin degradation in others (Hubberman 2006). In light of previous studies, our observations would suggest that phenolic retention involves more than just fruit or sucrose content, being affected by additional factors such as fruit type, processing and storage conditions including time and temperature.

Standard and reduced sucrose jams of both fruits were similar in antioxidant capacity (AOX) post-processing. As with TP, AOX is influenced by factors other than fruit content; a number of studies have demonstrated that Maillard reaction products, formed during heat treatment as well as storage and typically enhanced by higher sucrose content, possess antioxidant properties (Lingnert and Lundgreen 1980; Bolin and Steele 1987; Elizalde and others 1991). Thus the greater sucrose concentration of standard jams resulted in AOX comparable to that of reduced sucrose jams, despite the difference in fruit content.

In both peach jam treatments, antioxidant capacity remained stable during storage. Contrarily, a sharp decrease (35%) was observed in the two apricot jam treatments by 3 mo, remaining relatively stable thereafter. The results for peach jam were consistent with those by Howard (2010) while those for apricot jam agreed better with other studies (Wicklund and others 2005; Rababah and others 2011). All relevant studies however stressed the importance of storage temperature on AOX because this could affect the hydroxylation and glycolysation of compounds,

resulting in gradual decline in antoxidant activity (Srivastava and others 2007).

HPLC analysis allowed for a better evaluation of treatment impact on specific phenolic compounds (Tables 6.2 and 6.3). For both fruits, HPLC-determined total phenolic content (HPLC-TP) of reduced sucrose jam was greater than that of standard jam. The difference was more pronounced in apricot jams, where reduced sucrose jam surpassed standard jam in all phenolic classes studied. In peach jams, the reduced sucrose versions were greater in all but flavonol glycoside content.

Our results differed from the study by Howard and others (2010) in which levels of anthocyanins but not chlorogenic acid or flavonol glycosides were affected by both jam type (with or without sugar) and storage of blueberry jam. The difference in phenolic composition and stability of blueberries versus stone fruits as well as the formulation of model jams may explain the disparities in these experimental results. Losses in peach jams by 6 mo were similar (20%) and less severe than in apricot jams, with a 47% loss in reduced sucrose jam and 51% in standard jam.

The treatment types differed most significantly in carotenoid content. Given that this parameter was analyzed directly by HPLC, differences were better detected. Fruit content proved vital as in both fruits, reduced sucrose jams had higher carotenoid content post-processing. Carotenoid content decreased in all cases with storage, with reduced sucrose apricot jam maintaining a higher TC ($p < 0.01$) throughout storage. No comparable studies were found for changes in carotenoid concentration with jam formulation or storage, although carotenoid content in other heat-treated products has been found to decrease over time due to oxidation and geometrical isomerization (Abushita and others 2000; Britton and Khachik 2009).

Table 6. 2. Phenolic compounds (mg / 100 g) in 'Redhaven' peach standard and reduced sucrose jam post-processing and after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

	Mo	Catechin	Chlorogenic acid	Cyanidin-3-glucoside	Epicatechin	Epigallocatechin	Kaempferol-3-rutinoside
Standard	0	1.48 ± 0.05^{a}	3.15 ± 0.14^{a}	1.37 ± 0.03^{a}	2.91 ± 0.18^{a}	0.71 ± 0.05	6.82 ± 0.01^{a}
	3	0.44 ± 0.03^{b}	3.11 ± 0.17^{a}	1.17 ± 0.04^{b}	2.52 ± 0.05^{b}	ND	6.73 ± 0.04^{b}
	6	0.31 ± 0.04^{b}	2.82 ± 0.14^{a}	1.11 ± 0.01^{c}	2.00 ± 0.13^{c}	ND	6.67 ± 0.01^{c}
Reduced sucrose	0	1.37 ± 0.16^{a}	3.65 ± 0.05^{a}	1.51 ± 0.01^{a}	3.69 ± 0.16^{a}	1.07 ± 0.12^{a}	6.91 ± 0.03^{a}
	3	0.44 ± 0.02^{b}	3.52 ± 0.09^{a}	1.23 ± 0.00^{b}	2.83 ± 0.15^{b}	0.47 ± 0.02^{b}	6.72 ± 0.01^{b}
	6	0.47 ± 0.11^{b}	3.21 ± 0.14^{b}	1.13 ± 0.01^{c}	2.75 ± 0.16^{b}	ND	6.69 ± 0.02^{b}

	Mo	Neochlorogenic acid	Quercetin-3-glucoside	Rutin	Unknown 1	Unknown 2	**Total**
Standard	0	2.87 ± 0.19^{a}	1.12 ± 0.00^{a}	1.13 ± 0.01^{a}	0.44 ± 0.02^{a}	1.14 ± 0.00^{a}	**23.32 ± 0.68^{a}**
	3	2.71 ± 0.10^{ab}	1.11 ± 0.01^{a}	1.06 ± 0.01^{b}	0.35 ± 0.04^{b}	1.13 ± 0.01^{a}	**20.35 ± 0.52^{b}**
	6	2.52 ± 0.10^{b}	1.10 ± 0.00^{a}	1.05 ± 0.01^{b}	0.40 ± 0.01^{ab}	1.12 ± 0.00^{a}	**19.08 ± 0.46^{b}**
Reduced sucrose	0	3.24 ± 0.12^{a}	1.12 ± 0.01^{a}	1.10 ± 0.04^{a}	0.82 ± 0.04^{a}	1.14 ± 0.01^{a}	**25.62 ± 0.75^{a}**
	3	3.04 ± 0.06^{b}	1.12 ± 0.01^{a}	1.07 ± 0.01^{a}	0.35 ± 0.01^{b}	1.14 ± 0.00^{a}	**21.94 ± 0.37^{b}**
	6	3.11 ± 0.01^{ab}	1.11 ± 0.00^{a}	1.07 ± 0.01^{a}	0.39 ± 0.02^{b}	1.14 ± 0.00^{a}	**21.06 ± 0.47^{b}**

ND: Not detected. Unknown 1: flavan-3-ol; Unknown 2: flavonol glycoside. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Table 6. 3. Phenolic compounds (mg / 100 g) in 'Harlayne' apricot standard and reduced sucrose jam post-processing after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

	Mo	Catechin	Chlorogenic acid	Cyanidin-3-glucoside	Epicatechin	Epigallocatechin	Neochlorogenic acid
Standard	0	0.37 ± 0.01^{a}	2.9 ± 0.2^{a}	ND	6.1 ± 0.4^{a}	2.2 ± 0.1^{b}	8.4 ± 1.0^{a}
	3	0.25 ± 0.01^{b}	2.6 ± 0.2^{b}	ND	3.9 ± 0.4^{b}	3.1 ± 0.3^{a}	7.2 ± 0.4^{a}
	6	0.20 ± 0.01^{c}	2.0 ± 0.1^{c}	ND	2.4 ± 0.1^{c}	2.0 ± 0.1^{b}	5.0 ± 0.2^{b}
Reduced sucrose	0	0.61 ± 0.06^{a}	3.3 ± 0.2^{a}	ND	11.1 ± 0.5^{a}	3.0 ± 0.4^{a}	14.8 ± 0.6^{a}
	3	0.24 ± 0.02^{b}	3.3 ± 0.3^{a}	ND	6.0 ± 0.5^{b}	0.9 ± 0.1^{b}	10.4 ± 0.8^{b}
	6	0.17 ±0.02^{c}	2.8 ± 0.2^{b}	ND	6.0 ± 0.5^{b}	1.4 ± 0.2^{b}	9.7 ± 0.5^{b}

	Mo	Quercetin-3-glucoside	Quercetin derivative	Rutin	Unknown 1	Unknown 2	**Total**
Standard	0	1.15 ± 0.02^{a}	1.18 ± 0.01^{a}	4.9 ± 0.5^{a}	8.3 ± 1.0^{a}	4.8 ± 0.5^{a}	**40.3 ± 3.8^{a}**
	3	1.13 ± 0.01^{a}	1.13 ± 0.01^{b}	4.2 ± 0.2^{b}	2.6 ± 0.1^{b}	2.8 ± 0.1^{b}	**28.9 ± 1.8^{b}**
	6	1.11 ± 0.00^{b}	ND	3.2 ± 0.1^{c}	1.8 ± 0.2^{b}	1.8 ± 0.2^{c}	**19.5 ± 1.0^{c}**
Reduced sucrose	0	1.19 ± 0.01^{a}	1.22 ± 0.01^{a}	7.2 ± 0.2^{a}	14.1 ± 0.7^{a}	7.3 ± 0.5^{a}	**63.9 ± 3.3^{a}**
	3	1.18 ± 0.02^{ab}	1.17 ± 0.01^{b}	6.3 ± 0.5^{b}	3.9 ± 0.5^{b}	5.2 ± 0.5^{b}	**38.6 ± 3.2^{b}**
	6	1.16 ± 0.01^{b}	1.14 ± 0.01^{c}	5.5 ± 0.4^{c}	2.1 ± 0.2^{b}	4.2 ± 0.1^{c}	**34.2 ± 2.2^{b}**

ND: Not detected. Unknown 1 and 2: flavan-3-ols. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Decreases occured in all carotenoid compounds (Tables 6.4 and 6.5). With both fruit types, losses were greater in reduced sucrose jams (47% in peach and 48% in apricot) compared to standard jams (30% in peach and 36% in apricot). This demonstrated the effect of a_w on lipid oxidation, a complex interaction that has been explained in part by Nelson and Labuza (1992). The formation of lipid free radicals, which initiate and propagate oxidation, is catalyzed by trace metals. Within the a_w of jam (approximately 0.75), greater water or moisture availability increases mobility of catalysts in the aqueous phase, including metal ions and oxygen, and allows them to move closer to the lipid/water interface. This positioning brings them in contact and allows them to react with lipid compounds, resulting in free radical formation which facilites lipid oxidation. The reduction of water activity by dehydration (up to ~ 0.4) or introduction of water-binding solutes like sucrose therefore slows the rate of oxidation (Leung 1987; Bell 2007).

From our study, fruit type and varietal characteristics influenced product formulation (fruit versus sucrose content), and processing conditions (time and temperature). All these factors influenced the phytochemical content of the final product. The type of assay employed was also important, since more sensitive analyses (HPLC) detected differences less evident with more generalized tests (Folin-Ciocalteu and ORAC assays).

Table 6. 4. Mean values of carotenoid compounds (µg / 100 g) in 'Redhaven' peach standard and reduced sucrose jam post-processing and after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

	Mo.	β-carotene	β-cryptoxanthin	Lutein + Zeaxanthin	**Total**
Standard	0	460 ± 46[a]	9.3 ± 0.9[a]	160 ± 2.3[b]	**630 ± 49[a]**
	3	290 ± 18[b]	8.7 ± 0.8[a]	210 ± 21[a]	**510 ± 40[b]**
	6	270 ± 24[b]	7.0 ± 0.2[b]	160 ± 2.6[b]	**440 ± 26[b]**
Reduced sucrose	0	750 ± 49[a]	13 ± 0.8[a]	180 ± 7.2[a]	**940 ± 57[a]**
	3	530 ± 12[b]	8.3 ± 0.1[b]	160 ± 6.2[b]	**700 ± 18[b]**
	6	320 ± 28[c]	6.7 ± 0.6[c]	160 ± 4.2[b]	**490 ± 33[c]**

Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Table 6. 5. Mean values of carotenoid compounds (µg / 100 g) in 'Harlayne' apricot standard and reduced sucrose jam post-processing after 3 and 6 months storage at 18 – 20˚C (n = 4).

	Mo	β-carotene	β-cryptoxanthin	Lutein + Zeaxanthin	**Total**
Standard	0	2400 ± 190[a]	36 ± 0.9[a]	9.1 ± 0.5[b]	**2500 ± 190[a]**
	3	2200 ± 140[a]	26 ± 5.6[b]	16 ± 1.0[a]	**2200 ± 150[a]**
	6	1500 ± 95[b]	6.1 ± 0.2[c]	ND	**1600 ± 95[b]**
Reduced sucrose	0	5600 ± 550[a]	74 ± 0.2[a]	ND	**5700 ± 550[a]**
	3	3800 ± 220[b]	53 ± 6.1[b]	8.8 ± 0.1	**3900 ± 220[b]**
	6	3100 ± 230[c]	28 ± 2.8[c]	ND	**3100 ± 230[c]**

Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Nectar

Nectars are defined as diluted juice beverages that contain fruit juice or puree, water and may contain sweeteners (FDA 2003). They vary in consistency, ranging from almost-clear liquid to beverages with high suspended solids, depending on the type of fruit and fruit content (Luh 1980). While this definition is relatively flexible, the USDA has supplied a commercial item description (CID A-A-20118B) which details the ingredient, analytical and regulatory requirements for a product to attain this classification.

The nectar study investigated the effect of the current trend of sucrose reduction and the use of sugar substitutes to produce lower calorie beverages on phytochemical content (Somogyi 2005; Sloan 2010; Gibeson 2011). 'Harlayne' puree had high fruit soluble solids content which allowed for product formulation with less than 5% added sucrose. Despite the low soluble solids content of 'Redhaven' puree, its low titratable acidity and consequently high sugar-to-acid ratio, allowed for the manufacture of a peach beverage with high fruit content and less than 6% added sucrose. The low titratable acidity of peach puree (0.302 g malic acid/100 g) negatively affected taste and necessitated an adjustment of pH with malic acid (0.487 g malic acid/100 g).

Quality indices of the final products are presented in Table 6.6. The standard nectar fulfilled CID requirements while the reduced sucrose versions (particularly in apricot) did not meet some of the stipulations. These products still served their purpose, experimentally, and in practice could be marketed as 100-calorie fruit beverages with high fruit content (>50%). Standard peach nectar had 130 calories while standard apricot nectar had 160 calories per 240 mL serving.

Table 6. 6. Quality indices of ‘Redhaven’ peach and ‘Harlayne’ apricot standard and reduced sucrose nectars.

Fruit	Treatment	Brix (˚)	pH	Titratable acidity (g malic acid/100 g)	Sugar-to-acid ratio
Peach	Standard	14.2	3.85	0.44	32.6
	Reduced	11.7	3.86	0.43	27.2
Apricot	Standard	17.4	3.65	0.70	24.8
	Reduced	11.4	3.68	0.61	18.7

The two peach nectar treatments did not differ in TP, AOX or TC (Figure 6.6). Little difference was expected since that the fruit content was equal and the relative differences in added sucrose (5.03% and 2.77% in peach and 4% and 0.2% in apricot standard and reduced sucrose, respectively) were considered too slight to significantly impact phytochemical stability. AOX remained stable with storage in both treatments while TP decreased, as observed in grape and apple juice studies (Spanos and others 1990; Spanos and Wrolstad 1990). The phenolic profile remained similar to that of peach jam (Dragovic-Uzelac 2005). In this instance, HPLC phenolic data agreed with the observations from the Folin-Ciocalteu test (Table 6.7). There were no clear patterns in storage losses of phenolic compounds, although hydroxycinnamates experienced the least decrease in storage. Reduced sucrose nectar suffered greater losses at 6 mo (21%) than standard nectar (14%).

As TC was an expression of the various individual carotenoid compounds in β-carotene equivalents, HPLC profiles matched the observations in TC (Table 6.8). Carotenoid compounds typically declined in storage, with degradation most evident in the provitamin A compounds. Losses were significantly greater in reduced sucrose (32%) as compared to standard (24%) nectar. The effect of water and sucrose content could be the reason behind this although, given how small the differences between treatments were, other factors were more likely to be involved.

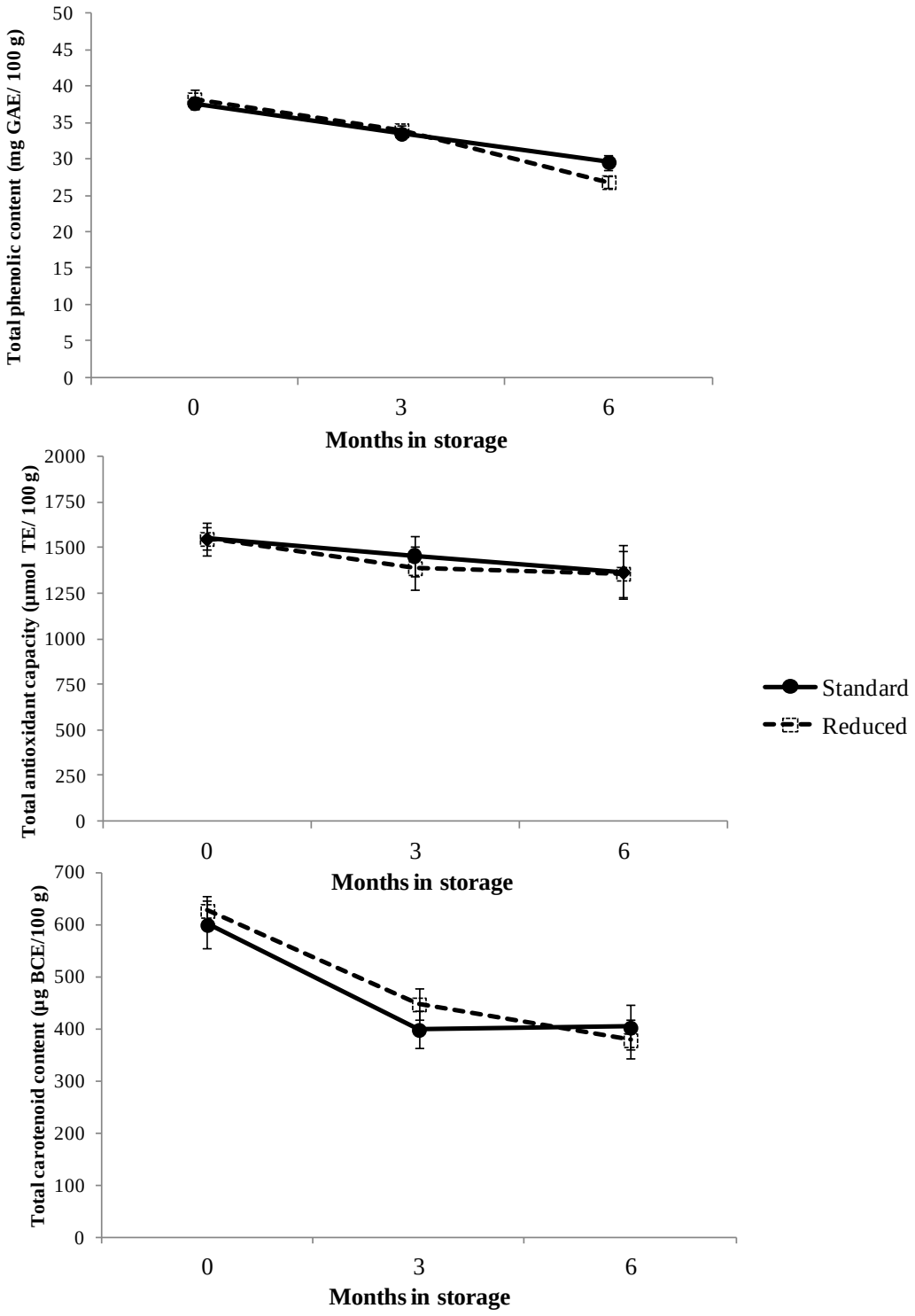


Figure 6. 6. Total phenolic content, total antioxidant capacity and total carotenoid content of 'Redhaven' peach standard and reduced sucrose nectar post-processing and after 3 and 6 months storage at 18 – 20 ˚C (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents).

Table 6. 7. Phenolic compounds (mg / 100 g) in 'Redhaven' peach standard and reduced sucrose nectar post-processing and after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

	Mo	Catechin	Chlorogenic acid	Cyanidin-3-glucoside	Epicatechin	Epigallocatechin	Kaempferol-3-rutinoside
Standard	0	1.44 ± 0.13^{a}	4.69 ± 0.06^{a}	1.58 ± 0.01^{a}	4.30 ± 0.06^{a}	1.86 ± 0.06^{a}	7.06 ± 0.02^{a}
	3	0.53 ± 0.04^{b}	4.67 ± 0.10^{a}	1.22 ± 0.00^{b}	3.93 ± 0.18^{a}	0.77 ± 0.05^{c}	6.85 ± 0.01^{b}
	6	0.53 ± 0.07^{b}	4.02 ± 0.19^{b}	1.11 ± 0.01^{b}	4.31 ± 0.29^{a}	1.01 ± 0.08^{b}	6.78 ± 0.02^{c}
Reduced sucrose	0	1.37 ± 0.10^{a}	4.81 ± 0.08^{a}	1.59 ± 0.01^{a}	4.38 ± 0.11^{a}	2.01 ± 0.04^{a}	7.07 ± 0.01^{a}
	3	0.54 ± 0.06^{b}	4.63 ± 0.01^{a}	1.23 ± 0.01^{b}	3.75 ± 0.06^{b}	1.00 ± 0.07^{b}	6.86 ± 0.01^{b}
	6	0.41 ± 0.02^{b}	4.10 ± 0.15^{b}	1.11 ± 0.01^{c}	3.25 ± 0.22^{c}	0.95 ± 0.18^{b}	6.77 ± 0.03^{c}

	Mo	Neochlorogenic acid	Quercetin-3-glucoside	Rutin	Unknown 1	Unknown 2	**Total**
Standard	0	4.09 ± 0.01^{a}	1.14 ± 0.01^{a}	1.10 ± 0.00^{a}	1.23 ± 0.16^{a}	1.18 ± 0.00^{a}	**29.68 ± 0.52^{a}**
	3	4.11 ± 0.02^{a}	1.13 ± 0.00^{a}	1.10 ± 0.01^{a}	0.84 ± 0.02^{b}	1.17 ± 0.00^{b}	**26.33 ± 0.44^{b}**
	6	3.58 ± 0.04^{b}	1.13 ± 0.00^{a}	1.09 ± 0.00^{b}	0.94 ± 0.07^{b}	1.16 ± 0.00^{c}	**25.67 ± 0.78^{b}**
Reduced sucrose	0	4.16 ± 0.18^{a}	1.14 ± 0.01^{a}	1.11 ± 0.01^{a}	1.42 ± 0.02^{a}	1.19 ± 0.01^{a}	**30.26 ± 0.57^{a}**
	3	4.04 ± 0.17^{a}	1.14 ± 0.01^{a}	1.10 ± 0.01^{a}	0.86 ± 0.04^{b}	1.18 ± 0.00^{b}	**26.33 ± 0.50^{b}**
	6	3.55 ± 0.08^{b}	1.13 ± 0.00^{b}	1.09 ± 0.00^{b}	0.48 ± 0.00^{c}	1.16 ± 0.01^{c}	**24.00 ± 0.70^{c}**

Unknown 1: flavan-3-ol; Unknown 2: flavonol glycoside. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Table 6. 8. Mean values of carotenoid compounds (µg / 100 g) in 'Redhaven' peach standard and reduced sucrose nectar post-processing and after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

Treatment	Mo	Beta-carotene	Beta-cryptoxanthin	Lutein + Zeaxanthin	**Total**
Standard	0	490 ± 37[a]	18 ± 0.7[a]	200 ± 7.1[a]	**700 ± 45[a]**
	3	320 ± 19[b]	10 ± 0.4[b]	194 ± 16[a]	**520 ± 35[b]**
	6	340 ± 23[b]	6.7 ± 0.4[c]	190 ± 20[a]	**530 ± 43[b]**
Reduced sucrose	0	520 ± 24[a]	19 ± 0.6[a]	200 ± 2.7[a]	**730 ± 27[a]**
	3	370 ± 22[b]	11 ± 1.0[b]	184 ± 7.4[b]	**570 ± 30[b]**
	6	320 ± 29[c]	7.0 ± 0.9[c]	170 ± 7.3[b]	**500 ± 37[c]**

Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

The high sucrose content of 'Harlayne' necessitated the use of stevia as well as a reduction in fruit content to attain the target caloric content in the reduced sucrose nectar. The strong taste profile of apricot sufficiently masked the aftertaste associated with sugar substitutes (Somogyi 2005). The lower fruit content was however disadvantageous to nutraceutical value (Figure 6.7). As with peach nectar, and in contrast to jams, fruit content was the determining factor in nectar phytochemical content; this was evident even in the more generalized Folin-Ciocalteu and ORAC tests. This observation was attributed to less interference by sucrose or browning reaction products (HMF was not detected in nectar) given the less intensive heat treatment as well as the relatively simpler formulation of nectars (Dragovic-Uzelac and others 2005).

Standard nectar had higher TP and TC ($p < 0.01$) after processing and in storage while AOX, though higher in standard nectar post-processing, was similar to reduced sucrose levels after 6 mo storage. TP and AOX decreased relatively uniformly with storage in both treatments. HPLC analyses showed that standard nectar was higher in almost all phenolic compounds after processing (Table 6.9). The disparity between treatments decreased with time with standard nectar at 6 mo having only slightly higher phenolic content (30%) than its reduced sucrose counterpart (26%).

Carotenoid loss in storage was more pronounced in reduced sucrose (32%) than standard nectar (24%). This was attributed to starting fruit content, although the greater water content in reduced sucrose nectar (30%) could have some effect on the rate of lipid oxidation. Lutein and zeaxanthin, which had been stable in all other products during storage, were lost within the first 3 mo (Table 6.10).

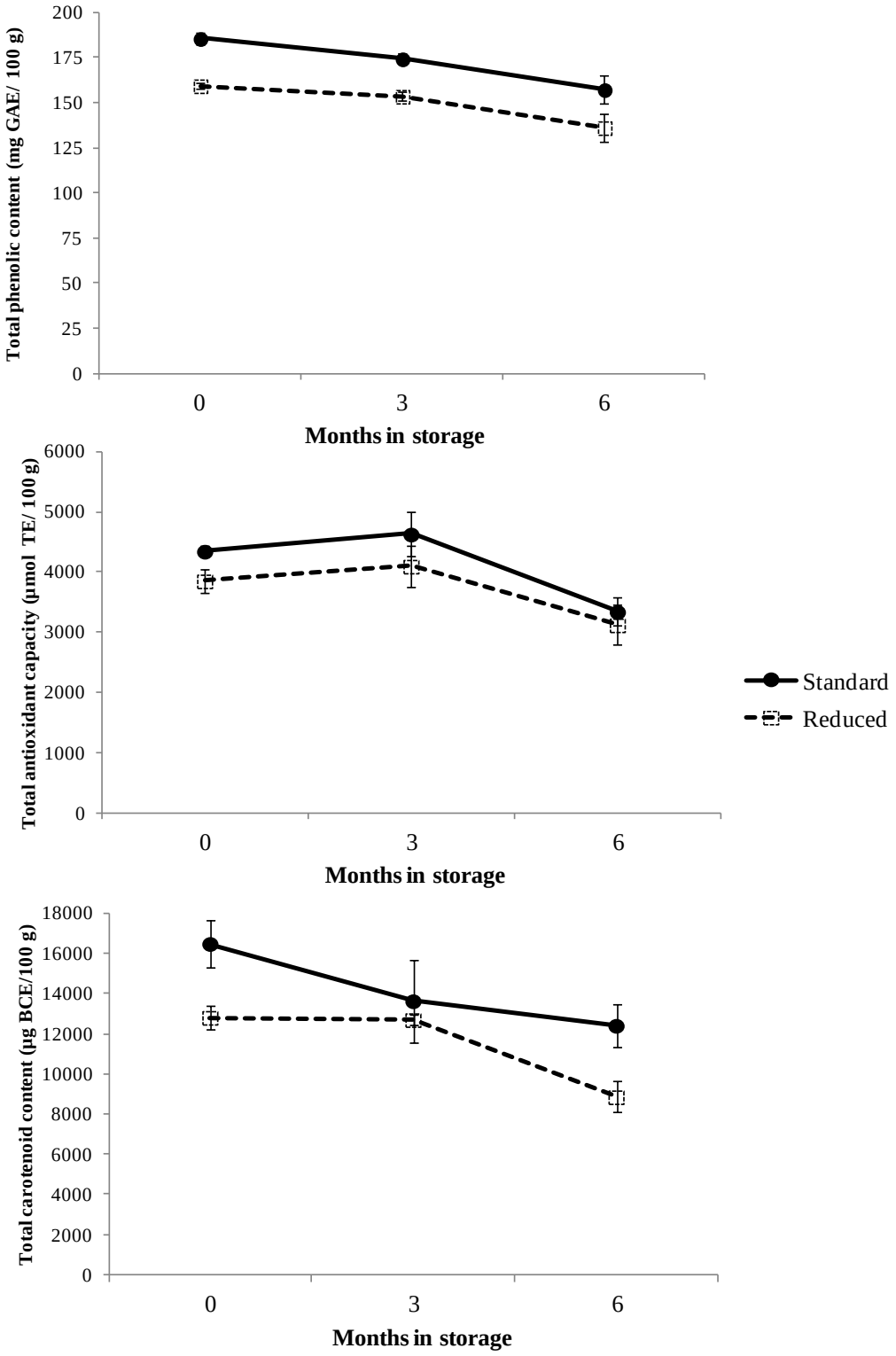


Figure 6.7. Total phenolic content, total antioxidant capacity and total carotenoid content of 'Harlayne' apricot standard and reduced sucrose nectar post-processing and after 3 and 6 months storage at 18 – 20 ˚C (GAE: Gallic acid equivalents, TE: Trolox equivalents, BCE: β-carotene equivalents).

Table 6. 9. Phenolic compounds (mg / 100 g) in 'Harlayne' apricot standard and reduced sucrose nectar post-processing after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

	Mo	Catechin	Chlorogenic acid	Cyanidin-3-glucoside	Epicatechin	Epigallocatechin	Neochlorogenic acid
Standard	0	0.35 ± 0.03[a]	4.1 ± 0.0[a]	ND	11.8 ± 0.3[a]	3.2 ± 0.3	13.4 ± 0.3[a]
	3	0.21 ± 0.01[b]	3.9 ± 0.1[b]	ND	10.3 ± 0.3[b]	ND	12.3 ± 0.1[b]
	6	0.20 ± 0.04[c]	3.3 ± 0.1[c]	ND	8.4 ± 0.3[c]	ND	11.6 ± 0.3[c]
Reduced sucrose	0	0.32 ± 0.03[a]	3.7 ± 0.0[a]	ND	9.9 ± 0.2[a]	2.5 ± 0.2	11.6 ± 0.2[a]
	3	0.17 ± 0.00[b]	3.3 ± 0.1[b]	ND	8.9 ± 0.2[b]	ND	10.7 ± 0.1[b]
	6	0.18 ± 0.06[b]	3.0 ± 0.0[c]	ND	7.1 ± 0.3[c]	ND	10.5 ± 0.1[c]

	Mo	Quercetin-3-glucoside	Quercetin derivative	Rutin	Unknown 1	Unknown 2	**Total**
Standard	0	1.19 ± 0.01[a]	1.22 ± 0.01[a]	7.4 ± 0.1[a]	14.8 ± 0.5[a]	8.0 ± 0.2[a]	**65.4** ± 1.7[a]
	3	1.19 ± 0.01[a]	1.20 ± 0.01[b]	7.2 ± 0.1[b]	9.5 ± 0.8[b]	6.2 ± 0.2[b]	**52.0 ± 1.7[b]**
	6	1.19 ± 0.01[a]	1.18 ± 0.01[c]	7.0 ± 0.1[c]	7.3 ± 0.3[c]	5.9 ± 0.6[b]	**46.0 ± 1.7[c]**
Reduced sucrose	0	1.17 ± 0.00[a]	1.20 ± 0.01[a]	6.4 ± 0.0[a]	12.3 ± 0.2[a]	6.4 ± 0.2[a]	**55.5** ± 1.1[a]
	3	1.17 ± 0.00[a]	1.18 ± 0.00[b]	6.2 ± 0.1[b]	8.0 ± 0.4[b]	5.6 ± 0.2[b]	**45.2 ± 1.2[b]**
	6	1.17 ± 0.01[a]	1.16 ± 0.00[c]	6.1 ± 0.1[b]	6.6 ± 0.3[c]	5.2 ± 0.6[c]	**41.0 ± 1.5[c]**

ND: Not detected. Unknown 1 and 2: flavan-3-ols. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Table 6. 10. Carotenoid compounds (µg / 100 g) in 'Harlayne' apricot standard and reduced sucrose nectar post-processing after 3 and 6 months storage at 18 – 20 ˚C (n = 4).

	Mo	β-carotene	β-cryptoxanthin	Lutein+ Zeaxanthin	**Total**
Standard	0	16000 ± 1200[a]	120 ± 9.5[a]	200 ± 15[a]	**16300 ± 1200[a]**
	3	13300 ± 2040[ab]	85 ± 2.2[b]	150 ± 10[b]	**13500 ± 2050[ab]**
	6	12100 ± 1060[b]	96 ± 6.2[b]	ND	**12200 ± 1070[b]**
Reduced sucrose	0	12500 ± 580[a]	91 ± 3.7[a]	150 ± 8.6[a]	**12700 ± 600[a]**
	3	12400 ± 250[a]	91 ± 0.5[a]	9.6 ± 0.4[b]	**12500 ± 250[a]**
	6	8600 ± 770[b]	71 ± 6.6[b]	ND	**8700 ± 780[b]**

ND: Not detected. Means not connected by the same letter indicate a significant difference between time points for that compound (alpha = 0.05).

Nutritional content

Nutritional content was calculated at the end of the shelf life study as an estimation of what was realistically available to the consumer 6 mo after production. A major appeal of peach and apricot products is their provitamin A content. Considering the dietary reference intake of 900 µg RAE for males 14 years or older, dietary provitamin A compounds β-carotene and β-cryptoxanthin from the different treatments were evaluated per 20 g serving of jam and 240 mL for beverages (FDA 2012). Jams were generally poor sources of vitamin A, with peach standard and reduced sucrose jams supplying 0.5% and 0.6% RDA, while apricot standard and reduced sucrose jams supplied 2.9% and 5.8% RDA. Peach nectar was a better source of vitamin A, with a serving providing 7.2% in standard and 6.8% RDA in reduced sucrose versions. Apricot nectar was an excellent source, providing > 100% RDA in both standard and reduced sucrose forms.

Conclusion

The study provided information on the effect of jam and nectar formulations – mainly the reduction of sucrose and increase of fruit – on product quality and phytochemical content. Reduction of sucrose affected the color, taste, texture and long-term quality of products; varietal characteristics must be carefully considered in selection of varieties or blends for production. In jams, fruit content had a limited effect on phenolic and antioxidant compounds, but played a significant role in the levels of these compounds in nectar. Fruit content determined the carotenoid content in jams and nectars and products with greater fruit content maintained higher carotenoid and vitamin A content throughout the shelf life study. Sucrose content was found to influence the stability of

carotenoid compounds during product storage, with increased sucrose content protecting against carotenoid degradation particularly in jams. For both products, but more importantly in jams, the nutraceutical value of the final product was influenced by myriad factors including fruit and varietal type, processing and storage conditions as well as assay employed.

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CHAPTER 7: CONCLUSION, FUTURE WORK AND RECOMMENDATIONS

Summary of findings

The study generated qualitative and quantitative information on a significant number of Northeast peaches and apricots and their value-added products. It also produced information relevant to peach and apricot cultivation, handling and processing beyond this region. It contributes substantially to the limited literature available on apricots that, although hitherto receiving less public and scientific attention compared to peaches, were found to be richer in phytochemical, primarily carotenoid, content.

Allowing fruit to ripen on-tree, while beneficial to perceived fruit quality, negatively impacted phenolic and antioxidant content but increased carotenoid content, especially in apricots. These horticultural influences must be taken into consideration in the scheduling of harvests if fruit is to be promoted based on its nutraceutical value. The identification of selected varieties – 'Hargrand' apricot, 'PF 22-007' peach and 'Babygold 5' peach – as having high concentrations of healthful bioactive compounds may contribute to increased patronage by both growers and consumers of these two fruits.

The evaluation of processed products emphasized the need to find a balance between aesthetic appeal and nutraceutical value. The peeling of fruit for better visual appearance and mouthfeel was found to be detrimental to phytochemical content. While sulfited dried fruits had both good color and high concentrations of the

compounds of interest, the use of sulfiting agents continues to be viewed negatively by an increasingly health-conscious population. This study was successful in developing two promising alternative pre-drying treatments which produced dried fruits of good value. The effects of jam and nectar formulation were also assessed. Fruit content was the main indicator of jam carotenoid content, but its effect on phenolics and antioxidants was influenced by fruit type and variety. In nectars, fruit content determined overall phytochemical content post-processing although, other factors impacted compound stability in storage. This study showed that it was possible to develop reduced and low calorie products of good aesthetic and nutritive value by building on the knowledge of varietal characteristics.

With processed products, the importance of optimizing processing and storage conditions was demonstrated. Varietal selection was also important as it was noted that 'Redhaven' peach, which had relatively low to average concentrations of bioactive compounds in fresh form, was comparable to or outperformed other varieties after processing. Contrary to growing public perception about the negative effects of processing, the products evaluated remained significant sources of healthful compounds.

Results obtained from HPLC analysis of fresh and processed products showed the effects of different factors on specific phenolic and carotenoid compounds. Thermal treatments typically increased β-carotene content and decreased anthocyanin content. Flavanol glycosides tended to be most stable in storage while anthocyanin and β-

carotene suffered most degradation. Our findings highlight the need for better understanding of the actual nutraceutical properties of these compounds to allow for the development of production and processing procedures which best protect or augment beneficial compunds.

Future work

Future work to build on these findings should include studies on the changes in total and individual phenolic and carotenoid content of fruits with ripening; storage studies at different temperatures and for different time periods would also provide useful information. There is still a need for non-destructive methods to assess fruit ripeness and nutritive content and research in this area would be particularly beneficial to growers. Processing treatments evaluated in this study could be improved by the assessment of the effect of different processing and storage time and temperatures on product quality as well as bioactive compounds. The development of standard, product-specific formulae for calculating nutrient retention would be very welcome, as it would allow for more accurate comparison of different treatments and the improvement of current ones.

Given that the main appeal of these fruits remains their potential health benefits, research on the bioavailability of these compounds, *in vivo,* and their mechanisms of action would be most enlightening, since such work will advise on the production, handling and processing of these fruits for maximum nutraceutical value.

APPENDIX

Illustration A. 1. Peach (a) and apricot (b) flowers, and peach (c) and apricot (d) fruit on tree.

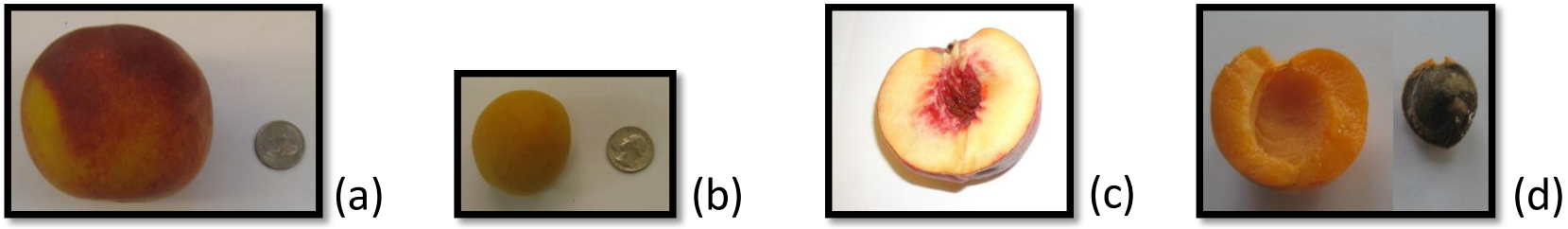

Illustration A. 2. Peach (a) and apricot (b) fruit pictured next to USA quarters for scale; halved peach (c) and apricot (d) fruit.

Illustration A. 3. Northeastern USA peach varieties evaluated in this study.

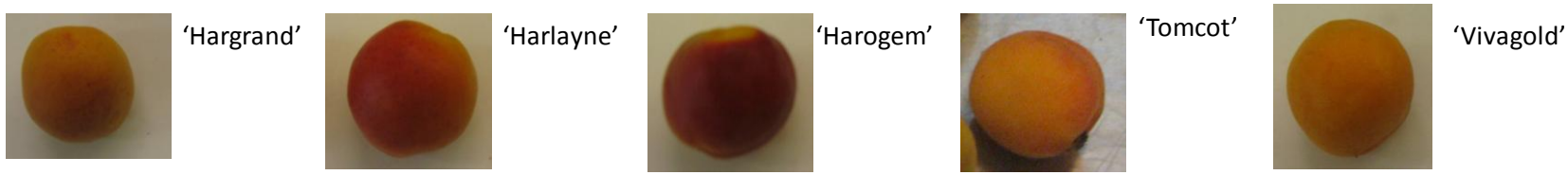

Illustration A. 4. Northeastern USA apricot varieties evaluated in this study.

Table A. 1. Firmness, weight, cross-sectional diameter and edible portion of selected Northeast peach varieties.

Variety	Firmness (N)	Weight (g)	Diameter (mm)	Edible portion (%)
Babygold 5	46.7 ± 4.1	220.7 ± 11	73.3 ± 1.4	93.2 ± 0.6
Bounty	24.6 ± 0.8	179.3 ± 10	69.0 ± 0.3	94.9 ± 0.4
Harrow Beauty	49.5 ± 14.4	96.0 ± 7.0	56.5 ± 2.3	94.8 ± 0.4
John Boy	45.2 ± 4.0	189.3 ± 4.7	71.5 ± 0.7	95.8 ± 0.2
John Boy II	34.3 ± 1.5	174.7 ± 10	70.5 ± 1.1	95.7 ± 0.2
PF 22-007	51.4 ± 6.2	296.3 ± 14	83.3 ± 1.5	96.6 ± 0.1
PF 23	30.9 ± 4.9	184.0 ± 6.1	70.2 ± 1.2	95.3 ± 0.7
PF Lucky 13	37.5 ± 3.9	198.3 ± 2.5	72.6 ± 0.7	96.1 ± 0.2
Redhaven	40.2 ± 5.4	121.3 ± 11	61.9 ± 1.5	93.6 ± 0.1
Vivid	49.1 ± 6.4	187.0 ± 9.5	72.3 ± 1.8	95.1 ± 0.5

Table A. 2. Color parameters *a*, *b*, *L*, hue angle (*H*) and chroma (*C*) of peel of selected Northeast peach varieties.

Variety	*a*		*b*		*L*	
	2009	2010	2009	2010	2009	2010
Babygold 5	24.1 ± 4.8	19.9 ± 2.3	27.0 ± 4.8	34.2 ± 3.3	49.1 ± 3.0	56.4 ± 2.1
Bounty	24.0 ± 1.5	20.0 ± 0.6	35.4 ± 2.8	24.5 ± 1.3	53.6 ± 3.1	47.5 ± 1.2
Harrow Beauty	31.8 ± 1.1	23.8 ± 0.4	35.7 ± 2.6	20.4 ± 1.7	51.2 ± 3.1	43.8 ± 0.8
John Boy	30.5 ± 1.2	25.5 ± 2.5	30.5 ± 2.1	18.9 ± 1.9	48.9 ± 2.4	43.9 ± 0.5
John Boy II	28.6 ± 2.0	21.0 ± 1.4	33.1 ± 3.7	20.1 ± 0.5	50.9 ± 4.8	44.6 ± 1.8
PF 22-007	30.0 ± 4.2	27.1 ± 4.2	33.0 ± 7.5	23.7 ± 1.3	50.7 ± 9.0	46.1 ± 1.2
PF 23	27.0 ± 0.9	20.9 ± 3.3	28.0 ± 4.9	19.4 ± 1.9	46.4 ± 6.2	42.6 ± 0.6
PF Lucky 13	29.4 ± 1.8	24.1 ± 1.2	30.3 ± 1.3	23.3 ± 2.2	49.9 ± 2.5	44.9 ± 1.9
Redhaven	25.3 ± 2.9	24.2 ± 2.2	28.8 ± 1.7	28.0 ± 2.8	55.5 ± 2.7	49.2 ± 2.5
Vivid	28.3 ± 2.3	25.1 ± 1.2	33.3 ± 3.7	31.4 ± 1.2	52.5 ± 4.1	51.2 ± 0.3

Variety	*H*		*C*	
	2009	2010	2009	2010
Babygold 5	45.0 ± 3.0	56.9 ± 3.9	36.2 ± 6.4	39.7 ± 2.7
Bounty	54.2 ± 2.9	45.3 ± 1.3	42.8 ± 2.8	31.6 ± 1.1
Harrow Beauty	47.6 ± 3.1	38.1 ± 1.6	47.9 ± 1.2	31.4 ± 0.9
John Boy	44.1 ± 2.9	35.5 ± 0.7	43.2 ± 1.6	31.7 ± 3.1
John Boy II	47.9 ± 4.9	41.9 ± 2.2	43.9 ± 2.4	29.1 ± 1.2
PF 22-007	46.4 ± 11	38.2 ± 1.5	45.0 ± 4.1	36.0 ± 3.9
PF 23	43.5 ± 6.5	40.9 ± 2.1	39.0 ± 3.6	28.5 ± 3.7
PF Lucky 13	45.0 ± 2.4	40.2 ± 2.5	42.3 ± 0.4	33.5 ± 1.8
Redhaven	47.8 ± 4.4	46.4 ± 0.9	38.4 ± 1.0	37.1 ± 3.5
Vivid	48.7 ± 5.8	48.6 ± 1.5	43.9 ± 1.4	40.1 ± 1.0

Table A. 3. Color parameters *a*, *b*, *L*, hue angle (*H*) and chroma (*C*) of flesh of selected Northeast peach varieties.

Variety	*a*		*b*		*L*	
	2009	2010	2009	2010	2009	2010
Babygold 5	9.1 ± 0.7	10.1 ± 0.7	47.2 ± 0.9	47.2 ± 0.7	68.9 ± 0.9	63.3 ± 0.8
Bounty	7.8 ± 0.2	11.0 ± 0.5	45.1 ± 0.5	50.0 ± 0.8	67.9 ± 1.1	62.7 ± 1.5
Harrow Beauty	8.6 ± 0.3	9.8 ± 1.3	43.0 ± 1.0	45.5 ± 1.7	73.1 ± 1.6	64.8 ± 4.4
John Boy	11.9 ± 1.7	12.8 ± 0.8	40.7 ± 0.5	42.6 ± 1.2	62.8 ± 3.7	59.5 ± 2.4
John Boy II	11.6 ± 1.2	12.9 ± 0.7	46.1 ± 0.4	43.0 ± 1.0	65.9 ± 0.5	57.2 ± 1.0
PF 22-007	6.2 ± 1.3	10.0 ± 1.1	38.7 ± 0.2	42.4 ± 2.0	69.0 ± 0.3	63.5 ± 2.5
PF 23	9.2 ± 0.1	12.6 ± 1.4	45.3 ± 1.0	46.4 ± 0.7	68.7 ± 0.6	59.5 ± 0.7
PF Lucky 13	10.0 ± 1.1	10.9 ± 0.5	40.5 ± 1.2	43.3 ± 3.0	67.8 ± 2.0	60.2 ± 2.3
Redhaven	6.2 ± 0.4	9.6 ± 0.7	45.4 ± 1.1	46.2 ± 1.9	71.0 ± 0.9	66.0 ± 2.5
Vivid	7.6 ± 0.8	11.8 ± 1.1	46.0 ± 1.0	50.4 ± 0.5	67.5 ± 1.5	66.6 ± 0.6

Variety	*H*		*C*	
	2009	2010	2009	2010
Babygold 5	79.2 ± 0.7	77.9 ± 0.8	48.0 ± 1.0	48.2 ± 0.6
Bounty	80.2 ± 0.3	77.6 ± 0.3	45.8 ± 0.5	51.2 ± 0.9
Harrow Beauty	78.8 ± 0.3	77.2 ± 2.5	43.8 ± 1.0	46.5 ± 1.4
John Boy	73.6 ± 2.3	73.0 ± 1.0	42.4 ± 0.6	44.5 ± 1.3
John Boy II	75.7 ± 1.5	72.5 ± 1.7	47.5 ± 0.1	44.9 ± 0.9
PF 22-007	80.8 ± 1.8	76.7 ± 2.0	39.2 ± 0.4	43.6 ± 1.8
PF 23	78.4 ± 0.4	74.8 ± 1.5	46.2 ± 0.9	48.1 ± 1.0
PF Lucky 13	76.0 ± 2.0	75.3 ± 2.1	41.7 ± 0.9	44.7 ± 2.8
Redhaven	82.3 ± 0.3	78.3 ± 0.8	45.9 ± 1.2	47.2 ± 1.9
Vivid	80.6 ± 0.8	76.8 ± 1.3	46.6 ± 1.1	51.8 ± 0.3

Table A. 4. Soluble solids, titratable acidity, sugar-to-acid ratio, pH and moisture content of selected Northeast peach varieties.

Variety	Soluble solids (%)		Titratable acidity (g malic acid /100 g)		Sugar-to-acid ratio	
	2009	2010	2009	2010	2009	2010
Babygold 5	9.7 ± 0.4	11.8 ± 0.5	0.48 ± 0.03	0.42 ± 0.03	20.4 ± 0.4	28.1 ± 2.2
Bounty	8.6 ± 0.2	12.0 ± 0.6	0.48 ± 0.03	0.70 ± 0.03	17.8 ± 1.1	17.5 ± 0.3
Harrow Beauty	9.8 ± 0.1	10.2 ± 0.6	0.61 ± 0.02	0.54 ± 0.07	15.9 ± 0.6	19.2 ± 2.6
John Boy	10.3 ± 0.2	10.8 ± 0.3	0.47 ± 0.02	0.73 ± 0.01	22.1 ± 1.1	14.9 ± 0.4
John Boy II	12.2 ± 0.6	10.0 ± 0.8	0.65 ± 0.05	0.51 ± 0.04	18.8 ± 1.7	19.8 ± 0.7
PF 22-007	10.9 ± 0.2	11.9 ± 0.5	0.61 ± 0.05	0.62 ± 0.09	18.0 ± 1.4	19.3 ± 2.4
PF 23	10.9 ± 0.3	12.5 ± 0.8	0.70 ± 0.03	0.74 ± 0.10	15.4 ± 1.1	16.7 ± 0.4
PF Lucky 13	8.9 ± 0.5	11.1 ± 0.4	0.54 ± 0.02	0.69 ± 0.04	16.5 ± 0.5	16.1 ± 0.4
Redhaven	8.9 ± 0.5	9.2 ± 0.9	0.62 ± 0.06	0.44 ± 0.11	14.4 ± 1.6	22.0 ± 5.1
Vivid	9.7 ± 0.6	10.0 ± 0.3	0.60 ± 0.02	0.74 ± 0.03	16.1 ± 1.0	13.5 ± 0.1

Variety	pH		Moisture content (%)	
	2009	2010	2009	2010
Babygold 5	3.87 ± 0.08	3.96 ± 0.06	88.5 ± 0.1	85.4 ± 0.1
Bounty	3.79 ± 0.03	3.75 ± 0.02	89.9 ± 0.5	86.6 ± 0.5
Harrow Beauty	3.53 ± 0.02	3.66 ± 0.03	88.3 ± 0.2	88.2 ± 0.4
John Boy	3.65 ± 0.05	3.64 ± 0.02	88.4 ± 0.3	88.0 ± 0.6
John Boy II	3.45 ± 0.05	3.57 ± 0.04	86.4 ± 0.2	88.7 ± 0.7
PF 22-007	3.52 ± 0.06	3.48 ± 0.07	87.3 ± 0.3	86.9 ± 0.4
PF 23	3.51 ± 0.04	3.58 ± 0.08	87.6 ± 0.2	86.1 ± 0.5
PF Lucky 13	3.56 ± 0.02	3.50 ± 0.03	89.7 ± 0.0	88.1 ± 0.6
Redhaven	3.77 ± 0.03	3.64 ± 0.05	90.7 ± 0.2	89.4 ± 1.0
Vivid	3.59 ± 0.04	3.42 ± 0.03	89.2 ± 0.5	89.1 ± 0.5

Table A. 5. Firmness, weight, cross-sectional diameter and edible portion of selected Northeast apricot varieties.

Variety	Firmness (N)	Weight (g)	Diameter (mm)	Edible portion (%)
Hargrand	6.7 ± 1.6	48.9 ± 1.8	43.2 ± 1.2	94.2 ± 0.3
Harlayne	11.8 ± 2.1	49.6 ± 1.6	45.1 ± 0.7	94.4 ± 0.0
Harogem	10.5 ± 0.2	48.2 ± 2.8	47.8 ± 0.5	94.3 ± 0.3
Tomcot	11.6 ± 1.8	24.4 ± 2.6	35.1 ± 1.6	91.8 ± 0.6
Vivagold	17.7 ± 1.9	48.9 ± 3.4	41.8 ± 0.3	91.5 ± 0.2

Table A. 6. Color parameters *a*, *b*, *L*, hue angle (*H*) and chroma (*C*) of peel of selected Northeast apricot varieties.

Variety	*a*		*b*		*L*	
	2009	2010	2009	2010	2009	2010
Hargrand	20.3 ± 1.6	20.2 ± 2.3	41.9 ± 2.2	35.4 ± 1.9	56.2 ± 0.0	53.1 ± 1.8
Harlayne	28.8 ± 3.0	26.7 ± 0.9	40.8 ± 4.1	39.9 ± 2.2	55.0 ± 3.7	53.4 ± 2.1
Harogem	31.2 ± 3.3	28.6 ± 0.9	43.1 ± 5.2	34.4 ± 0.2	53.5 ± 4.5	50.8 ± 0.3
Tomcot	29.1 ± 1.9	24.7 ± 0.2	50.0 ± 0.7	41.7 ± 3.2	58.1 ± 1.2	56.5 ± 3.7
Vivagold	26.4 ± 2.4	30.7 ± 0.8	49.5 ± 1.3	40.4 ± 0.9	61.2 ± 0.5	58.6 ± 0.7

Variety	*H*		*C*	
	2009	2010	2009	2010
Hargrand	64.4 ± 1.1	60.0 ± 3.8	46.7 ± 2.5	41.0 ± 1.4
Harlayne	54.2 ± 5.5	56.0 ± 1.4	50.6 ± 2.2	48.3 ± 2.0
Harogem	52.9 ± 6.7	48.5 ± 0.5	54.5 ± 1.7	45.9 ± 0.6
Tomcot	59.7 ± 2.0	59.2 ± 1.9	58.3 ± 0.5	48.6 ± 2.6
Vivagold	61.9 ± 2.0	52.7 ± 0.6	56.3 ± 1.9	50.8 ± 1.2

Table A. 7. Color parameters *a*, *b*, *L*, hue angle (*H*) and chroma (*C*) of flesh of selected Northeast apricot varieties.

Variety	*a*		*b*		*L*	
	2009	2010	2009	2010	2009	2010
Hargrand	18.6 ± 1.3	21.0 ± 0.6	38.1 ± 2.4	31.6 ± 1.7	54.6 ± 1.1	42.8 ± 1.8
Harlayne	22.7 ± 0.5	19.6 ± 2.0	46.4 ± 0.8	37.3 ± 3.0	61.8 ± 0.5	51.7 ± 3.5
Harogem	23.7 ± 0.4	20.2 ± 1.6	45.8 ± 0.3	40.5 ± 1.2	59.9 ± 0.6	56.2 ± 1.7
Tomcot	23.1 ± 0.3	20.1 ± 1.5	43.6 ± 1.0	36.6 ± 3.0	61.6 ± 1.3	49.3 ± 3.8
Vivagold	23.7 ± 0.9	26.5 ± 0.4	43.7 ± 1.6	42.9 ± 0.9	58.4 ± 1.3	56.8 ± 0.7

Variety	*H*		*C*	
	2009	2010	2009	2010
Hargrand	64.1 ± 0.5	56.3 ± 0.8	42.4 ± 2.7	38.0 ± 1.8
Harlayne	64.0 ± 0.4	62.5 ± 1.0	51.7 ± 0.9	42.2 ± 3.5
Harogem	62.6 ± 0.3	63.7 ± 1.1	51.6 ± 0.4	45.3 ± 1.8
Tomcot	62.2 ± 0.2	61.2 ± 0.5	49.4 ± 1.0	41.8 ± 3.3
Vivagold	61.6 ± 0.1	58.4 ± 0.2	49.8 ± 1.8	50.5 ± 1.0

Table A. 8. Soluble solids, titratable acidity, sugar-to-acid ratio, pH and moisture content of selected Northeast apricot varieties.

Variety	Soluble solids (%)		Titratable acidity (g malic acid /100 g)		Sugar-to-acid ratio	
	2009	2010	2009	2010	2009	2010
Hargrand	13.2 ± 0.4	14.3 ± 0.3	2.46 ± 0.15	1.70 ± 0.10	5.4 ± 0.5	8.3 ± 0.3
Harlayne	11.5 ± 1.1	14.7 ± 0.3	1.65 ± 0.05	1.14 ± 0.04	7.0 ± 0.7	13.0 ± 0.2
Harogem	12.9 ± 0.7	14.5 ± 0.4	1.56 ± 0.02	1.01 ± 0.07	8.3 ± 0.5	14.5 ± 1.0
Tomcot	10.5 ± 0.5	11.2 ± 0.6	1.81 ± 0.05	1.25 ± 0.08	5.8 ± 0.3	9.0 ± 0.4
Vivagold	10.6 ± 0.9	14.1 ± 0.1	1.61 ± 0.08	0.91 ± 0.10	6.6 ± 0.8	15.7 ± 1.8

Variety	pH		Moisture content (%)	
	2009	2010	2009	2010
Hargrand	3.08 ± 0.04	3.68 ± 0.06	84.8 ± 0.2	80.9 ± 0.4
Harlayne	3.46 ± 0.03	3.67 ± 0.04	87.0 ± 0.1	83.9 ± 0.2
Harogem	3.18 ± 0.01	3.69 ± 0.04	85.6 ± 0.1	84.7 ± 0.4
Tomcot	3.40 ± 0.02	3.48 ± 0.03	87.9 ± 0.3	87.8 ± 0.5
Vivagold	3.35 ± 0.03	3.77 ± 0.01	88.2 ± 0.0	86.3 ± 0.2

‘Redhaven’ peach **‘Harlayne’ apricot**

Unpeeled Peeled Unpeeled Peeled

Illustration A. 5. Canned peaches and apricots (unpeeled and peeled).

‘Redhaven’ peach

Rhubarb juice-only Rhubarb juice+blanching Blanching Sulfites

‘Harlayne’ apricot

Rhubarb juice-only Rhubarb juice+blanching Blanching Sulfites

Illustration A. 6. Dried peaches and apricots (rhubarb juice-only, rhubarb juice+blanching, blanching and sulfites).

‘Redhaven’ peach **‘Harlayne’ apricot**

Standard Reduced sucrose Standard Reduced sucrose

Illustration A. 7. Peach and apricot jam (standard and reduced sucrose).

‘Redhaven’ peach **‘Harlayne’ apricot**

Standard Reduced sucrose Standard Reduced sucrose

Illustration A. 8. Peach and apricot nectar (standard and reduced sucrose).