# QUALITY AND STABILITY OF SHELF-STABLE PULP-RICH FRUIT JUICE

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by
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# ABSTRACT

Tart cherries, Concord grapes, and apples are known for their health benefits due to high phenolic content and antioxidant capacity. Apples are also a rich source of fiber, helping to reduce the risk of some types of cancer. However, current juice processing leads to significant losses of these compounds through degradation heating and poor extraction from fruit. Pomace, a byproduct of pressing, is a rich source of total phenols, antioxidants, and dietary fiber. Therefore, alternative processing approaches which promote the preservation of these compounds are essential.

Our objective was to develop pulpy juices from tart cherries, Concord grapes, and apples with maximum retention of fruit components and to evaluate storage quality of pulpy juices against clear juices.

The following fruits were used in this study: Concord grape; tart cherry cv. Balaton and Montmorency; three varieties of red apple: Cortland, Empire, and McIntosh; and one variety of yellow apple: Golden Delicious. Fruits were harvested from the New York State Agricultural Experiment Station Orchards, Geneva, NY during the 2007 harvesting season.

Juices were processed as clarified/clear (depectinased) and pulpy. A turbo extractor with two screen sizes, and a high shear mixer, were employed in pulpy tart cherry and Concord grape juice processing. A turbo extractor was used with or without a blanching and/or enzymatic treatment in pulpy apples juice processing. Juices were pasteurized by hot-filling at 85°C in 10-oz glass bottles.

Whole fruit and juices were analyzed for pH, acidity, soluble solids, and dry and pectin content. Juice viscosity was also measured. Shelf-life studies at 18°C were conducted at 0, 12, and 24 weeks to determine changes over time in color, percent settled solids, turbidity, total phenolics content, antioxidant capacity, anthocyanin content and polymeric color (only in tart cherry and Concord grape). Total phenolic and anthocyanin content, antioxidant capacity, and percent polymeric color in whole fruits were also measured in extracts prepared by methanol extraction of freeze-dried powdered fruit. Sensory evaluations were conducted at 0 and 24 weeks to determine an acceptance of color, flavor, mouthfeel, and overall acceptability using a 7-point hedonic scale. The ranking test was used for flavor intensity and preference.

Pulpy juices had higher phenolic and anthocyanin content, and antioxidant capacity than clear juices of the same fruit type; the content was comparable to that of whole fruits. These compounds in pulpy juices were 73 to 87% of whole tart cherry, 95 to 100% of whole Concord grapes, and 60 to 100% of whole apples. The percent loss over time of these compounds was similar in clear and pulpy juices from tart cherry and Concord grapes; however, the content in pulpy tart cherry juices was 13 to 41% higher than that of clear juices, and 50 to 134% higher in Concord grape juices. Even though the percent loss of total phenols and antioxidant capacity over 24 weeks in clear apple juices was lower (0 to 11%) than that of pulpy juices (6 to 22%), pulpy juices had 1.7 to 3.6 times higher total amounts of these compounds than clear juices.

Dry content of pulpy juices were 0.3 to 11.8% higher than clear juices. Pectin content of pulpy juices was comparable to that of whole fruits. There was almost no pectin in clear juices. Pulpy juices represented a rich source of soluble fiber and one serving contained 0.7 to 11.6 g pectin. Sensory evaluation confirmed that overall acceptability and preference of pulpy juices were as equally acceptable as clear juices at 0 weeks storage but was lower at 24 weeks. However, pulpy juices were rated positively in all attributes and thus were acceptable from a consumer view point.

Pulpy juices could be a healthy shelf-stable fruit juice product if the processing is optimized.

# BIOGRAPHICAL SKETCH

Passaporn Siricururatana was born on July 19th 1983 in Bangkok, Thailand. She received early education at Kasetsart University Laboratory School, Bangkok, Thailand. After high school, she attended Science Department at Chulalongkorn University, Bangkok, Thailand, where she obtained her Bachelor of Science Degree in Food Science and Technology and graduated with 1st class honors.

In 2006, Passaporn received the Fulbright Scholarships and started her Master program in Food Science and Technology at Cornell University under the supervision of Dr. Olga Padilla-Zakour. Upon completion of her master's degree, Passaporn will continue working with Dr. Olga Padilla-Zakour for her Ph.D. degree.

To my beloved family:

Dad, Mum, On, and Oy

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# CHAPTER 1

# LITERATURE REVIEW

## Dietary Guidelines

Major causes of morbidity and mortality in the US are related to poor diet and sedentary lifestyle. Specific diseases linked to poor diet and physical inactivity include cardiovascular disease, type 2 diabetes, hypertension, osteoporosis, and certain cancers. Furthermore, poor diet and physical inactivity are the most important factors contributing to the increase in the overweight and obese population in the US. The Dietary Guidelines for Americans (2005) provides science-based advice to promote health and reduce the risk of or prevent major chronic diseases through diet and physical activity. According to the dietary guidelines, the key recommendation is to consume adequate nutrients within calorie needs and engage in regular physical activity. People should consume a variety of nutrient-dense foods and beverages within and among the basic food groups while choosing foods that limit the intake of saturated and trans-fats, cholesterol, refined grains, added sugars, sweeteners, salt, and alcohol. (Dietary Guideline for Americans, 2005)

Encouragement of fruit and vegetable consumption is key. Two cups of fruit and two and a half cups of vegetables per day are recommended for a reference 2,000-calorie intake. However, the loss-adjusted food availability data suggested that Americans consumed only 0.9 cup of fruits and 1.7 cups of vegetables per person per day in 2005 (The Food Institute Report, 2008). Thus Americans would need to consume more fruits and vegetables to be consistent with the recommended intakes. Also, consumption of whole fruits rather than fruit juice is suggested to ensure adequate fiber intake. A variety of fruits and vegetables as well as fiber-rich fruits, vegetables, and whole grains are strongly suggested.

Other foods to encourage are fat-free or low-fat milk or milk products. Three cups of milk and milk products per day are recommended as part of a 2,000-calorie-per-day diet; however, the loss-adjusted food availability data showed that Americans consumed only 1.8 cups of milk or mild products per day (The Food Institute Report, 2008).

## Fruits and Vegetables Consumption

Per capita consumption of fruits and vegetables in the US increased 1 percent, from 347 pounds in 2005 to 350 pounds in 2006. In 2006, each American consumed 141 pounds of fruit, 3 percent increased from 2005 while the consumption of vegetables (210 pounds) remained stable. (PMA, 2007)

As Americans increasingly embrace national health recommendations for consuming at least five fruits and vegetables a day, their array of choices continues to widen. Fresh-cut fruits and vegetables, prepackaged salads, locally grown items, and exotic produce, as well as hundreds of new varieties and processed products, have been introduced or expanded since the early 1980s (Putnam and Allshouse, 1999). Retailers, on the average, carried 290 produce items per store in 2006, an increase of 10 items from previous year (The Food Institute Report, 2007).

While the overall market for fruits and vegetables has expanded, the mix has changed. Traditional varieties have lost market share to specialty varieties, and exotic produce has gained favor (Putnam and Allshouse, 1999). Despite bigger price increases for fresh fruits and vegetables than for processed, consumers wanted fresh and minimally processed products as opposed to canned or frozen (The Food Institute Report, 2006). The fresh produce department experienced a steady sales growth since 1999 and the retail produce sales ($58.9 billion) increased almost 5 percent from 2006 to 2007 (PMA, 2008). Better quality, increased variety, year-round availability, and more convenient were the factors boosting consumption of fresh fruits and vegetables (Putnam and Allshouse, 1999).

According to the Fruit and Tree Nuts Situation and Outlook Yearbook 2007 (Pollack and Perez, 2007), per capita fresh fruit consumption was 100.9 pounds in 2006, 1 percent above the previous year. Americans ate slightly more fresh noncitrus fruit, but slightly less citrus. Noncitrus fruit consumption averaged 79.3 pounds per person in 2006, 2 percent above 2005. Strong demand for apples and pears, blueberries, strawberries, cherries, kiwifruit, and tropical fruit helped offset weak demand for fresh table grapes, peaches and nectarines, and plums and prunes. Consumption of fruit juices in 2006 increased 2 percent more than in 2005; however, consumption of other processed fruits namely, canned, frozen, and dried fruits declined 5 to 8 percent. The demand for most canned fruit products has been declining since 2000/01 while the demand for frozen fruit products appeared to continue to grow as it has throughout the 2000s. The demand for raisins, accounting for almost 70% of total dried fruit in 2006, has stabilized over the past 5 years but much of the decline in dried fruit consumption was due to the weak demand for prunes (dried plums).

Despite the increased consumption of fruits and vegetables, Americans consume only half as much fruit as is recommended. One argument for not consuming fruits and vegetables is that they are too expensive, especially when fresh. Among 154 fruits and vegetables, more than half were estimated to cost 25 cents or less per serving (Reed and others, 2004). Consumers can meet the food guide pyramid recommendation of 3 servings of fruits and 4 servings of vegetables daily for only 64 cents.

## Juice Market

The total fruit juice and juice drink market was valued at $14.7 billion in 2007 displaying 16 and 27 percent decline in current and constant process during 2002 to 2007. Juice drinks accounted for 42% of the total sales while the remains 58 percent came from fruit juices. According to the Fruit Juice and Juice Drink-US Report from Mintel (2008), total US sales are expected to decrease annually at an inflation-adjusted rate of 5 percent during 2007 to 2012. The market share of fruit juice and juice drinks (excluding Wal-Mart) declined 4 percent during 2003 to 2007. This was due to the high-calories image of fruit juice and juice drinks and an increasing fruit juice prices. Also, the consumer had shifted to other beverages that provide the perception of better health and functional benefits and excitement such as ready to drink tea, enhanced water, sport drinks, and energy drinks. (Mintel, 2008)

Although the overall market declined, juices with health-forward positioning—functional, organic, all natural, low sugar—experienced growth during 2002 to 2007. Similarly, innovation focused on health and new flavors found popularity among consumers. Juice based smoothies would gain significant growth in demand on the premium, functional, and meal replacement categories. Furthermore, the single-serve fruit juice segment, especially in bottled packaging, exhibited growth which could be explained by the consumer need for on-the-go convenience. (Mintel, 2008)

According to the Fruit and Tree Nuts Situation and Outlook Yearbook 2007 (Pollack and Perez, 2007), Americans consumed 7.8 single-strength equivalent (sse) gallons of fruit juices in 2006, 2 percent more than in 2005, but below any other year since 1991/92. Citrus juices accounted for 59 percent of juice consumption with orange juice accounting for the largest component. Orange juice consumption fell by 6 percent to 4.13 sse gallons per person, the third consecutive annual decline. However, noncitrus juice consumption increased 12 percent in 2006 to an average of 3.21 sse gallons per person, with apple juice accounting for 69 percent of the total.

## Health Benefits of Fruits

Fruits provide an array of nutrients and other compounds that may have beneficial effects on health. Epidemiological studies have established a positive correlation between the intake of fruits and vegetables and the slowing prevention of aging and diseases like atherosclerosis, cancer, diabetes, and arthritis (CDC, 2008; Kaur and Kapoor, 2001). Among the phytonutrients cited as potentially providing the protection were polyphenols, lycopene, carotenoids, tocopherols, vitamin C, isoflavones, glucosinolates, and dietary fiber (Dillard and German, 2000).

Aging is a complex multifactorial process in which free radical oxidative damage plays an important role, but may not be the exclusive mechanism. Reactive oxygen species are associated with many age-related diseases such as cancers, atherosclerosis, trauma, stroke, asthma, dermatitis, retinal damage, hepatitis, liver injury, and asthma (Lee and others, 2003). As aging proceeds, the efficiency of the antioxidant defense systems is reduced, and the ability to remove deleterious reactive oxygen species and free radicals decreases. The prevalent free radical state, oxidative stress, causes lipid, protein, and sterol oxidation, DNA strand break and base modification, and modulation of gene expression (Lee and others, 2003). Consumption of fruits and vegetables containing high amounts of antioxidative compounds has been associated with the balance of free radicals, which helps to minimize the oxidative stress in the body and reduce the risk of cancers and cardiovascular disease (Liu and others, 2000). Epidemiological studies also reported the relevance of antioxidative compounds to health issues and the prevention of age-related diseases (Lee and others, 2003).

Another health promoting phytochemical is dietary fiber which is associated with alterations of the colonic environment that protect against colorectal diseases. Fiber may also provide protection by increasing fecal bulk, which dilutes the increased colonic bile acid concentrations that occur with a high-fat diet (Jensen and others, 1982). Different dietary fibers have different cancer-preventing effects, and the differences may be related to the differential bacterial fermentation of fiber in the colon to short-chain fatty acids, especially butyric acid (Smith and others, 1998; Smith and German, 1995). Butyric acid has been shown to suppress cholesterol synthesis in rat liver and intestine models (Hara and others, 1999).

Dillard and German (2000) categorized the way which these phytochemicals could act to provide health benefits as:

(1) Substrates for biochemical reactions
(2) Cofactors of enzymatic reactions
(3) Inhibitors of enzymatic reactions
(4) Absorbents or sequestrants that bind to and eliminate undesirable constituents in the intestine
(5) Ligands that agonize or antagonize cell surface or intracellular receptors
(6) Scavengers of reactive or toxic chemicals
(7) Compounds that enhance the absorption and or stability of essential nutrients
(8) Selective growth factors for beneficial gastrointestinal bacteria
(9) Fermentation substrates for beneficial oral, gastric or intestinal bacteria
(10) Selective inhibitors of deleterious intestinal bacteria.

## Tart Cherry

Tart or sour cherry (*Prunus cerasus* L.) cultivars are classified in three major groups: Amarelles, Morellos, and Marasca. Montmorency, a clear-fleshed Amarelle cultivar, is a major tart cherry grown in the US and is used extensively for the production of cherry pies (McLellan and Padilla-Zakour, 2004b). Despite the high

**Table 1.1**. Tart cherry: production, utilization, and value in United States, 2003-2007

| Year | Production (thousand tons) | | Utilization (thousand tons) | | Value of Production (million dollars) | | |
|---|---|---|---|---|---|---|---|
| | Total | Utilized | Fresh | Processed | Fresh | Processed | All |
| 2003 | 102.7 | 102.7 | 0.45 | 102.3 | 0.74 | 79.5 | 80.3 |
| 2004 | 96.7 | 96.7 | 0.59 | 96.1 | 1.19 | 68.8 | 70 |
| 2005 | 122.8 | 121.9 | 0.54 | 121.3 | 1.07 | 62.9 | 63.9 |
| 2006 | 131.9 | 125.2 | 0.64 | 113 | 1.39 | 52.6 | 54 |
| 2007 | 126 | 125.2 | 0.73 | 113 | 1.68 | 65.3 | 67 |

*Source*: NASS, 2008; Pollack and Perez, 2007.

content of polyphenols and antioxidant capacity in Montmorency, the anthocyanin content is low compared to other cultivars, resulting in low natural color (Chantanawarangoon, 2005; Chandra and other, 1992). This has led to interest in identifying tart cherry cultivars with higher anthocyanin content. Balaton, a new Hungarian cultivar, was then introduced due to the higher anthocyanin content. Studies have shown that Balaton has two to six times higher anthocyanin content than that of Montmorency (Chantanawarangoon, 2005; Wang and others, 1997).

Total commercial production of tart cherry, ranging from 0.10 to 0.18 million tons (Table 1.1), has been stable since 1980 except for the shortfall in 2002 due to unusual spring weather (Pollack and Perez, 2007; McLellan and Padilla-Zakour, 2004b). The five largest producing states, Michigan, Utah, Washington, New York, and Wisconsin, accounted for 98 percent of utilized production in 2007 in the US; Michigan alone was responsible for 77 percent (Table1.2). In 2007, the US produced 0.13 million tons of tart cherries having a value of 67 million dollars (NASS, 2008). Most tart cherries are used exclusively for processing. About 73 percent of tart cherries are frozen, 19 percent are canned, and 8 percent are used for juice, wine, brined, or dried (NASS, 2008).

The nutrient data for tart cherries is presented in Table 1.4. Cherries are rich in vitamins C and E, and provide potassium, magnesium, iron, folate and fiber. Tart cherries are also excellent sources of beta carotene (vitamin A). In fact, they contain 19 times the beta carotene of blueberries and strawberries (Cherry Marketing Institute, 2007). Tart cherries are one of the nutrient-rich fruits that contain natural compounds shown to have potential disease-fighting properties. Tart cherries are rich in antioxidants and contain potent phytonutrients including anthocyanins – plant pigments that have been linked to a variety of health benefits (Cherry Marketing Institute, 2007). Furthermore, tart cherries are one of the few known food sources of melatonin, which may help regulate circadian rhythms and natural sleep patterns (Burkhardt, 2001). A recent study found that tart cherries ranked 14 in the top 50 foods for highest antioxidant content per serving size, surpassing well-known leaders such as red wine, prunes, dark chocolate and orange juice (Halvorsen 2006).

**Table 1.2**. Tart cherry: total production by State and United States, 2005-2006 and Forecasted 2007

| State | Total Production ( thousand tons) | | |
|---|---|---|---|
| | 2005 | 2006 | 2007 |
| Michigan | 94.3 | 86.2 | 104.3 |
| New York | 3.4 | 4.7 | 5.9 |
| Oregon | 0.14 | 1.5 | 0.36 |
| Pennsylvania | 1.2 | 2.4 | 2.0 |
| Utah | 12.7 | 12.7 | 7.3 |
| Washington | 7.5 | 10.1 | 8.2 |
| Wisconsin | 3.4 | 2.0 | 5.3 |
| United State | 122.7 | 119.7 | 133.3 |

*Source*: NASS, 2007.

Emerging studies suggest that cherries may offer protection against heart disease and certain cancers, reduce the risk of diabetes and insulin resistance syndrome, reduce inflammation and ease the pain of arthritis and gout, and aid in the treatment and possible prevention of memory loss (Cherry Marketing Institute, 2007).

### Grape and Concord Grape

There are three distinct broad classes of grapes grown in the three principle grape growing areas of the US: the northeastern or native euvitis or bunch grape (*Vitis lubrusca*), the western grape common to the California area (*Vitis vinifera*), and the southeastern Muscadian grape (*Vitis rotundifolia*) (Pederson, 1961). The species *Vitis vinifera* cannot stand the severe winters and the attacks of insects and diseases while many native grapes thrive despite the insects or the relatively cold climate (Pederson, 1961). Therefore, the selection of hybrids of *Vitis lubrusca* crossed with American species has been studied. The Concord grape variety was one of the hybrids.

In 2007, the utilized production and the value of utilized production of grapes were 6.7 million tons and 3.38 billion dollars respectively, which were the highest values among noncitrus fruits in the US (NASS, 2008). Also, grapes have had the highest cash receipt in the US for more than a decade (Pollack and Perez, 2007).

California is the largest grape producing State, responsible for almost 90 percent of total grape utilized production (NASS, 2008). On the other hand, the largest producing states for Concord grapes are Washington, New York, Pennsylvania, and Michigan. Concord grape was the major variety grown in these states, accounting for 55 to 87 percent of total processed utilization of all grapes (NASS, 2008). The processed utilization of grapes accounted for almost 90 percent of total utilized production with the remaining in fresh utilization. Processed utilization of grapes and Concord grapes is shown in Table 1.3.

**Table 1.3**. Grapes and Concord grapes: processed utilization by State and total United States, 2005-2007

| State | Processed Utilization (thousand tons) | | |
|---|---|---|---|
| | 2005 | 2006 | 2007 |
| Michigan | 102.0[1] (66.5)[2] | 27.4 (15.35) | 100.0 (61.0) |
| New York | 175.0 (137.0) | 150.0 (108.6) | 176.0 (131.0) |
| Ohio | 8.4 (6.8) | 3.0 (1.6) | 7.5 (5.8) |
| Pennsylvania | 89.5 (77.5) | 81.7 (71.4) | 83.5 (71.5) |
| Washington | 415.0 (275.0) | 316.0 (175.0) | 399.0 (249.0) |
| Other States | 3.4 (0.46) | 4.3 (0.92) | 3.4 (0.17) |
| United State | 6,814.9 (563.3) | 5,568.3 (372.9) | 5,840.4 (518.5) |

*Source*: NASS, 2007.
1: The processed utilization of grapes
2: The processed utilization of Concord grapes

The nutrient data of American type (slip skin) grapes (*Vitis* spp.) is shown in Table 1.4. Most grape cultivars reach full size and color several days before they are ripe for consumption. The ripening process stops as soon as the grape is harvested. The total soluble solids consist mainly of sugar. The sugar of berries consists of glucose and fructose (1:1), and small amount of sucrose, maltose and various other mono- and oligo-saccharides. The predominant acid in grapes is tartaric acid. Pectin is an important constitute. (Konja and Lovric, 1993)

Anthocyanin pigments, which are responsible for the color (red/blue) of grapes and their products, are located in and adjacent to the skin (Konja and Lovric, 1993; Pederson, 1961). Grapes contain several types of anthocyanin which varies among species. Anthocyanidin oligoglucoside is found frequently in American species, but not in *Vitis vinifera*. (Konja and Lovric, 1993). Anthocyanins in Concord were not only responsible for juice color, but their antioxidant activity was comparable to that of red wines and also inhibited in vitro oxidation of human low density lipoprotein and (Frankel and others, 1998).

**Table 1.4**. Nutrient data for tart cherries and grapes (American type; slip skin) (*Vitis* spp.)

| Nutrients | Unit | Amount in 100 g edible portion | |
|---|---|---|---|
| | | Tart Cherries | Grapes |
| Food energy | kJ | 208 | 263 |
| Water | g | 86.13 | 81.30 |
| Proteins | g | 1.00 | 0.63 |
| Lipid | g | 0.30 | 0.35 |
| Fatty acids; Saturated, total | g | 0.068 | 0.114 |
| Fatty acids; Monounsaturated, total | g | 0.082 | 0.014 |
| Fatty acids; Polyunsaturated, total | g | 0.09 | 0.102 |
| Fatty acids; Cholesterol | mg | 0 | 0 |
| Carbohydrates | g | 12.18 | 17.15 |
| Fiber | g | 0.2 | 0.76 |
| Ash | g | 0.4 | 0.57 |
| Vitamins | | | |
| Ascorbic Acid | mg | 10 | 4 |
| Thiamin | mg | 0.03 | 0.092 |
| Riboflavin | mg | 0.04 | 0.057 |
| Niacin | mg | 0.4 | 0.3 |
| Pantothenic acid | mg | 0.143 | 0.024 |
| Vitamin B6 | mg | 0.044 | 0.11 |
| Folacin | µg | 7.5 | 3.9 |
| Vitamin B12 | µg | 0 | 0 |
| Vitamin A | IU | 1283 | 100 |
| Minerals | | | |
| Calcium | mg | 16 | 14 |
| Iron | mg | 0.32 | 0.29 |
| Magnesium | mg | 9 | 5 |
| Phosphorus | mg | 15 | 10 |
| Potassium | mg | 173 | 191 |
| Sodium | mg | 3 | 2 |
| Zinc | mg | 0.1 | 0.04 |
| Copper | mg | 0.104 | 0.04 |
| Manganese | mg | 0.112 | 0.718 |

*Source*: Konja and Lovric, 1993.

Concord grapes are the main variety used in the American grape juice industry. Relatively few grapes produce juices having the balance of sugar, acid, flavor, and astringent constituents comparable to Concord grape juice (Pederson, 1961). The flavor and aroma of Concord grapes is characterized by methyl anthranilate which occurs in very large quantities (Konja and Lovric, 1993). When hot pressed, Concord grapes yield rich purple-red colored and flavored juices that present a good appearance without clarification. Of all fruit juices, it is one of the most stable juices for heat processing and storage (Pederson, 1961). The chemical composition of grape juices is similar to that of whole grapes except that crude fiber and oils, which are primarily present in the seed, are removed (Morris and Striegler, 2004). According to Robinson and others (1949), the quality of grape juice largely depends on sugar level, acid content, and flavor constituents. Acidity above 0.85 percent results in juice that is too tart. The Concord juice industry usually uses 15 percent soluble solids as the minimum level of acceptable quality and pays a premium for grapes based on each increase in percentage soluble solids up to 18 percent (Morris and Striegler, 2004).

### Apple

There are hundreds of apple cultivars grown in the US but only about 20 cultivars are grown commercially (Root and Barrett, 2004). The recent trend is to plant newer cultivars, which are appearing in fruit markets. Gala, Fuji, and Jonagold are relatively new varieties that consumers have accepted as an alternative to traditional varieties. Some of the characteristics of popular varieties are listed in Table 1.5.

Apple has the third highest cash receipts of all fruits in the US followed by grape and orange, a trend which has remained the same for more than a decade (Pollack and Perez, 2007). The United States, the second largest apple producing country in the world after China, produced 4.67 million ton of apples having a value of 2.4 billion dollars (NASS, 2008). Apples are grown throughout the US with the largest producing state being Washington which accounted for almost 60 percent of the total utilized production in the US. In addition to Washington State, primary apple producers are New York, Michigan, Pennsylvania, California, and Virginia. These

**Table 1.5**. Fruit characteristics of leading apple varieties

| Variety | Fruit size$^1$ | Fruit color$^2$ | Fruit shape$^3$ | Flesh | Acidity$^4$ | Uses$^5$ |
|---|---|---|---|---|---|---|
| Cortland | M | MR | Ob | White, highly resistant to browning, tender, moderately firm, juicy | M | FCP |
| Delicious | M-L | MRB | Ob-Co | Creamy white, crisp, juicy, tender | L | FJ |
| Empire | M | R | Ro-Ob | Cream, juicy, firm, crisp | M | FC |
| Fuji | M | RSD | Ro-Co | White, juicy, firm, crisp | M | F |
| Gala | S-M | RSB | Ro-Co | Yellow, juicy, very firm,fine-texture | M | F |
| Golden Delicious | M-L | Y | Co | White to cream, firm, crisp, tender | M | FP |
| Granny Smith | M-L | G | Ob-Ro | Greenish to yellowish white, juicy, crisp, firm, fine-grained | M-H | FP |
| Jonathan | S-M | UBR | Ro-Co | Whitish, tender, crisp, juicy | M-H | FP |
| McIntosh | M | MRBl | Ro-Ob | White, very tender, juicy | M | FPC |
| Northern Spy | L | BSR | Ro-Co | Yellowish white, firm, fine-grained, very tender and juicy | M-H | FP |
| Rhode Island Greening | S-M | GY | Ro-Ob | Greenish yellow, firm, crisp, tender, very juicy | M-H | FP |
| Rome Beauty | L | MRB | Ro-Ob | Near white, firm, crisp to mealy | M-H | P |

*Source:* Smock and Neubert, 1950b; Childers and others, 1995; Khanizadeh and Cousineau, 1998

1: S-small; M-medium; L-large

2: B-bright; Bl-blush; D-dull; M-medium; R-red; S-striped; U-niform; Y-yellow

3: C-conic; Ob-oblate; R-round

4: L-low; M-medium; H-high

5: F-fresh; J-juices; C-cider; P-processing (cooking, baking, sauce, pie, drying, canning, and freezing)

**Table 1.6**. Apples: production, utilization, and value in United States, 2001-2007

| Year | Production (million tons) | | Utilization (thousand tons) | | Value of Utilized Production (billion dollars) | | |
|---|---|---|---|---|---|---|---|
| | Total | Utilized | Fresh | Processed | Fresh | Processed | All |
| 2001 | 4.27 | 4.18 | 2.48 | 1.70 | 1.25 | 4.04 | 5.29 |
| 2002 | 3.87 | 3.80 | 2.43 | 1.36 | 1.38 | 3.91 | 5.29 |
| 2003 | 3.99 | 3.95 | 2.48 | 1.47 | 1.61 | 4.25 | 5.85 |
| 2004 | 4.74 | 4.70 | 3.01 | 1.69 | 1.45 | 3.98 | 5.43 |
| 2005 | 4.47 | 4.43 | 2.80 | 1.62 | 1.71 | 3.76 | 5.46 |

*Source*: Pollack and Perez, 2007.

states produce over three quarter of the total US production (Root and Barrett, 2004).

In 2005, the percentage of apples marketed fresh was 63 percent of the total and 37 percent was processed (Table 1.6). Of the processed apples, 50 percent was utilized in juice and cider, 34 percent was canned, 7 percent was frozen, 5 percent was dried, 2 percent was marketed as fresh slices, and 2 percent was used in other products such as vinegar, wine, and jelly (Pollack and Perez, 2007). The utilization of apples has changed to a higher percentage of fresh apples and a lower percentage of processed apple products (Pollack and Perez, 2007).

Apples are also an excellent source of fiber while low in fat and sodium (Root and Barrett, 2004). The nutrient composition of apples and apple products is presented in Table 1.7. Whole apples contain more fiber than oranges, bananas, apricots, or grapefruits. Apples are also a natural source of health-promoting phytonutrients, including plant-based antioxidants which may help prevent various chronic diseases (USApple, 2008). Based on apples' nutrition facts, the US FDA has approved health claims for apple such as: may reduce the risk of some types of cancer, coronary heart disease, and high blood pressure (USApple, 2008).

**Table 1.7**. Proximate composition of apples and apple products

| Apple products | Energy (kcal/100g) | Water (%) | Protein (%) | Lipid (%) | Carbo hydrate (%) | Fiber (%) | Ash (%) |
|---|---|---|---|---|---|---|---|
| Fresh with skin | 59 | 83.9 | 0.19 | 0.36 | 15.3 | 0.77 | 0.26 |
| Fresh without skin | 57 | 84.5 | 0.15 | 0.31 | 14.8 | 0.54 | 0.24 |
| Canned, sweetened | 67 | 82.4 | 0.18 | 0.49 | 16.7 | 0.54 | 0.27 |
| Dehydrated (low-moisture) | 346 | 3.0 | 1.32 | 0.58 | 93.5 | 4.1 | 1.6 |
| Dehydrated | 243 | 31.8 | 0.93 | 0.32 | 65.9 | 2.9 | 1.1 |
| Frozen | 48 | 86.9 | 0.28 | 0.32 | 12.3 | 0.54 | 0.24 |
| Canned juice | 47 | 87.9 | 0.06 | 0.11 | 11.7 | 0.21 | 0.22 |
| Sauce, unsweetened | 43 | 88.4 | 0.17 | 0.05 | 11.3 | 0.53 | 0.15 |
| Sauce, sweetened | 76 | 79.6 | 0.18 | 0.18 | 19.9 | 0.46 | 0.14 |

*Source*: Lee and Mattick, 1989.

## Juice Processing

Freshly harvested fruits or refrigerated or frozen fruits are washed thoroughly to remove dirt. The sanitation step may be used to decrease the load of contaminants. This process is essential for minimally processed juices to ensure the safety of perishable products. Sorting is necessary to remove decay fruits so that the finished product will not have a high microbial load, undesirable flavors, or mycotoxin contamination. For most fruits, preparation steps such as pitting and grinding are required prior to juice extraction. Heating and enzyme addition might be included before the extraction to increase the yield and quality of juices. The treatment after extraction depends on the characteristics of the final product. For cloudy juices, further clarification might not be necessary or may involve a coarse filtration or a controlled centrifugation to remove only large insoluble particles. For clear juices, depectinization step by adding enzyme, fine filtration, or high-speed centrifugation are required to achieve the visual clarity. After that, juices are subjected to heat treatment or equivalent nonthermal process to achieve safe and stable single-strength juices. (McLellan and Padilla-Zakour, 2004a)

### *Disintegration*

Fruits are crushed prior to the pressing to break down the cell tissue, enhance ease of pressing, and allow the higher yield. Diverse types of equipment are available such as hammer mills, grinding mills, grating mills, stemmer/crushers, stone fruit mills, or turbo extractors (McLellan and Padilla-Zakour, 2004a). The choice of crushing equipment depends on types of fruits and finished products, i.e. clear, cloudy, or nectar (Konja and Lovric, 1993). For instance, the hammer mills are widely used in the apple juice industry while the stemmer/crushers are used in the grape juice industry (McLellan and Acree, 1993; Bump, 1989)

### *Hot Break Process*

Hot break process is common used in red fruits such as grapes, cherries, and berries to maximize juice yield and color-flavor extraction. Crushed fruit or mash is heated to 50 to 60°C using a tubular heat exchanger (McLellan and Padilla-Zakour, 2004a; McLellan and Acree, 1993). This stage is called hot break process and is aimed to extract a large amount of color from the skin into juices. The heating also improves the extraction of both phenols and anthocyanins (McLellan and Acree, 1993). The pectolytic enzyme can be added into hot fruit to ease the pressing. The type of enzyme used is critical since some enzymes may have some side effects that could destroy the juice color (Helbig, 2001).

### *Mash Enzymatic Treatment*

Fruit mash is heated to 45 to 50°C and then the pectolytic enzyme is added at the dosage recommended by the enzyme supplier. The reaction time can take up to 1 to 2 hours (McLellan and Padilla-Zakour, 2004a). Soluble pectin in fresh juice, a result of physical breakup of cells and the activity of pectolytic enzymes in fruit, causes difficulty in extraction. Soluble pectin increases juice viscosity and helps lubricate the press cake and thus reduces the effectiveness of the extraction (McLellan and Acree, 1993). The added pectinase enzyme will break down structure of pectin molecules. Consequently, it will reduce the viscosity and slipperiness of the pulp and thus permit the effective use of decanters and presses. Treatment of the mash with enzymes is expected to increase the yield, reduce the processing time, and improve the extraction of important or valued components of the fruit (Will and other, 2000; Bump, 1989). However, if the preservation of the fresh flavor is essential in the finished product, this step might not be used.

### *Extraction*

After the preparation steps, fruits are extracted in juices by either pressing or decanting depending on the type of fruits. Juice extraction should be done as rapidly as possible to minimize oxidation of juices by naturally present enzymes. Pome fruit and small stone fruit can be used for extraction without the peeling step. Some small stone fruits might have to be pitted (destoned) such as apricots or plums depending on the extraction equipment used. In some cases such as cherries, the aroma compound after the breakage of pit is desirable and thus, they may be pressed with the pit intact. (McLellan and Padilla-Zakour, 2004a)

Several types of extractors are available namely rack and frame hydraulic press, horizontal piston press, bladder press, belt press, screw press, and decanter centrifuge (McLellan and Padilla-Zakour, 2004a). The selection of equipment should depend on the desired outcome such as the type of operation (batch or continuous), the batch size, and the availability of labor (Bump, 1989).

### *Clarification*

Clarification is required for the production of clear juices and could be done by three general ways: physical (mechanical separation), biochemical (enzymatic treatment), and chemical (fining) processes (Binnig and Possmann, 1993). The addition of pectinase enzyme will break semistable emulsion of colloidal plant carbohydrates which support insoluble cloud material of freshly processed juices and changes the opacity of cloudy juice to an open clear look (McLellan and Padilla-Zakour, 2004a). Other methods for nonenzymatic clarification are heating or addition of gelatin, casein, or tannic acid-protein combinations (Kilara and Van Buren, 1989, Smock and Neubert, 1950a). The mechanical separation includes decanters and finishers, centrifugation, diatomaceous earth filtration and cross-flow membrane filtration (McLellan and Padilla-Zakour, 2004a). One of the specific processes in grape juice processing is the removal of tartaric acid to avoid their subsequent precipitation in the final product (Konja and Lovric, 1993). This process is called cold stabilization and carried out by the storage of partially clear juices at low temperature, close to the freezing point (about 2°C).

### *Pasteurization and Nonthermal Process*

Hot-filling or bottled juice pasteurization is used to produce the shelf-stable juices in which the high-quality retention can range from 9 to 12 months. Juices are heated using a heat exchanger such that the temperature after juice filling the container reaches 88 to 95°C. A holding time of at least 3 min is normally used before juices are cooled down. This whole process is called hot filling and it is adequate for highly acidic beverages such as apple, cherry, and grape juices. The maximum pH allowed for the hot-fill process is normally 4. (McLellan and Padilla-Zakour, 2004a)

In aseptic juice processing, juices and containers are sterilized separately. Juices are filled into containers under the sterile environment at room temperature and the product can be kept at room temperature with an extended shelf-life (at least 2 to 3 months and preferably for 6 months). (Hotchkiss, 1989)

Since refrigerated juices are minimally processed or unheated, juices have a fresh flavor profile and better retention of nutrients with limited refrigerated shelf life. Juices are pasteurized at 70 to 90°C for a few seconds to eliminate microorganisms and contaminants that could cause health risk to consumers (McLellan and Padilla-Zakour, 2004a).

Nonthermal processing have the advantage of fresh-like characteristic with extended shelf life. The techniques include high-pressure processing, pulsed electric field, electron beam irradiation, high carbon dioxide processing, and chemical sterilants (McLellan and Padilla-Zakour, 2004a).

### Nectars or Pulpy Juices

Another type of fruit product is fruit nectar or pulpy juice which is a blend of sugar syrup, fruit acid, and very high-solids juice or puree. Nectar is produced with fruit that are either low in flavors as a single-strength, clarified juice, or too strong in flavor and needed dilution. (McLellan and Padilla-Zakour, 2004a)

Nectars contain most of the solids from the fruit and certain amount of colloids, the most important of which is pectin. The products are based on fruit puree that contains all the edible parts of fruits that is as homogenous and as stable as possible. The key operations for this product are straining (pulping) at the puree preparation stage and homogenization at the final stage. The enzymatic maceration might be required to breakdown the intercellular layer and release the colloid pectin which is important for the polydispersion system. The small soft fruits that are usually processed into nectars are strawberries, raspberries, blackberries, and sour cherries. These fruits contain a relatively small amount of pulp and thus a stabilizer (pectin or alginate) may be added to increase the viscosity and stability of the product. (Konja and Lovric, 1993)

To produce fruit nectars, fruit flesh is softened or cooked before pulping or finishing to obtain fruit puree. Acidified sugar syrup is added and mixed thoroughly. The mixer is then hot-filled into the appropriated containers (McLellan and Padilla-Zakour, 2004a). Commercial fruit nectars consist chiefly of apricot and peach nectars with small amounts of pear and plum nectars (Luh and El-Tinay, 1993). (Konja and Lovric, 1993)

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# CHAPTER 2

# TART CHERRIES AND CONCORD GRAPES JUICES

## Abstract

Two cultivars of tart cherries (Montmorency and Balaton) and Concord grapes were used to produce pulp-rich juices using a turbo extractor and a high shear mixer. Quality of fruits and juices were evaluated and juices were compared to traditional clear juices during the 24-week storage at 18°C. The juice processing decreased the total phenolic and anthocyanin content and vitamin C equivalent antioxidant capacity (VCEAC) in tart cherry juices and Concord grape clear juice, but not in Concord grape pulpy juices. Tart cherry pulpy juices had 13 to 25% higher total phenolics, VCEAC, and anthocyanins compared to clear juices, while Concord grape pulpy juices had 50 to 55% higher total phenolics and VCEAC, and two times the anthocyanin content versus clear juice over the shelf-life study. Pectin content in pulpy juices was comparable to that of whole fruits, but clear juices had almost none. Sensory evaluation showed that there was no difference in overall acceptability and preference for freshly prepared juices, but after 6 months of storage, clear juices were preferred over pulpy juices.

## Introduction

Grapes were the second leading fruit for cash receipts after apples in both the US and in New York State (ERS, 2007). According to reports from NASS (2008), national utilized production of grape in 2007 was 6.7 million tons. Utilized production of grapes in New York State, the third largest producing state, was 180,000 tons. Only

2 percent of utilized grapes in New York State went into the fresh utilization; the rest (98 percent) were used in the processing industry. Of all processed utilization, 23 percent was in the wine industry and 75 percent was in the juice industry. Concord grape (*Vitis labrusca* L.), the native American cultivar, is the major cultivar in New York State accounting for 74 percent of grapes grown (NASS, 2008). Concord grapes are extensively used for the production of grape juice.

Tart cherry (*Prunus cerasus* L.) cv. Montmorency is the major and most important tart cherry cultivar grown in the US and is used extensively for the production of cherry pie filling (McLelland and Padilla-Zakour, 2004b). Despite the high content of polyphenols and antioxidant capacity, Montmorency has a low anthocyanin content and thus, low natural color compared to other varieties (Chantanawarangoon, 2005; Chandra and other, 1992). A new cultivar, Balaton, has been introduced due to its higher anthocyanin content. In 2007, the national utilized production of tart cherry was 250 million pounds (NASS, 2008). New York State, the fourth largest producing state after Michigan, Utah, and Washington, was expected to produce 13.0 million pounds of tart cherries in 2007 which is 25 percent higher than 2006 (NASS, 2007).

Consumption of cherries and cherry products has been reported to be particularly useful in alleviating arthritic pain and gout, and to reduce the incidence of cancer (Cherry Marketing Institute, 2007). Studies have shown that the anthocyanin and cyanidin isolated from tart cherries exhibit in vitro antioxidative and anti-inflammatory activities (Gonçalves and others, 2004; Wang and others, 1999a, 1999b). Frankel and others (1998) also reported that anthocyanins in Concord grape juice inhibited the in vitro oxidation of human low-density lipoprotein and that antioxidant activity was comparable to that of red wines. Regardless of the increasing interest in the health benefits of tart cherries and Concord grapes, the annual price of tart cherries and Concord grapes received in the past couple of years (2005-2007) was very stable (0.216 to 0.268 dollars per pound for tart cherry and 216 to 273 dollars per ton for Concord) (NASS, 2008).

Anthocyanins and polyphenolics are not uniformly distributed in fruit tissue. Studies show that total phenolics and anthocyanins in tart cherries and Concord grapes were located in and adjacent to the skin (Chaovanalikit and Wrolstad, 2004a, 2004b; Konja and Lovric, 1993; Pederson, 1961. This was consistent with the report by Will and others (2007) that sour cherry juices obtained from mash enzymatic treatment had higher anthocyanin content and color intensity compared to juices from direct hot pressing. Although the clear tart cherry juice is rich in anthocyanin and polyphenolic content, the pomace after pressing is also rich in these nutrients and could be a potential source for natural antioxidants (Mazza, 1995). Therefore, incorporating tart cherry and Concord grape skins into juices could increase natural antioxidants in juices than traditional clear juices.

The objective of our study was to develop a pulp-rich fruit product, pulpy juice, from tart cherries and Concord grapes that incorporate as much of the whole fruit components as possible so that the nutrition of this new product would be comparable to that of whole fruit. Processing methods, in terms of the type of extractors and the screen size, as well as shelf-life stability were also evaluated. The quality of pulpy juices was determined and compared to that of clear juices.

## Materials

### A. Chemicals

Folin-Ciocalteu reagent, 2,2’-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) as diammonium salt, 85% m-hydroxydiphenyl, galacturonic acid, and gallic acid were obtained from Sigma-Aldrich, Inc. (St. Louis, MO, USA). AAPH (2,2’-

azobis(2-amidino-propane) dihydrochloride) was obtained from Wako Chemicals USA, Inc. (Richmond, VA, USA). All other chemicals used were analytical or high performance liquid chromatography (HPLC) grade.

### B. Raw Materials

Tart cherry cultivars, Balaton and Montmerency, and Concord grapes were harvested (at maturity as determined by a horticulture specialist) from the New York State Agricultural Experiment Station Orchards, Geneva, NY, during the harvesting season (summer, 2007). Fruit was kept at 2°C until ready to process.

## Methods

### A. Processing

All fruit was processed into both clear and pulpy juices and two batches of juice were prepared for each processing treatment. A high shear mixer was used to process pulpy tart cherry juices while a turbo extractor was used for pulpy Montmorency and Concord juice processing. Two different screen sizes, 0.8 and 0.4 mm, for the turbo extractor were used in pulpy Concord juice processing; while only the 0.8 mm screen size was used for pulpy Montmorency juice processing. All juices were pasteurized at 85°C using a UHT/HTST Lab-25 HV heat exchanger (Micro Thermics Inc., Raleigh, NC) and hot packed into 10 fluid ounce bottles with 2 minutes hot-hold, water cooled to room temperature. Juice samples were stored at 18°C and protected from light until ready for analysis.

#### ***Clear Juice Processing***

Tart cherries and Concord grapes were processed into juices following the modified standard laboratory procedures that simulate industrial processing (McLellan and Padilla-Zakour, 2004a, 2004b; Konja and Lovric, 1993). The hot breaking step was done by heating whole fruits in a steam kettle (Design 20CD, Lee Metal Products Co. Inc., Philipsburg, PA) until the temperature reached 80°C to extract the color from fruit skins to juices and to inactivate polyphenol oxidase enzyme which also help prevent the browning and oxidation of phenolic compounds. Blanched fruits were cooled down to 50°C in the steam kettle using ice and running water. Pectinase enzyme, Rapidase® ADEX-G, (DSM Food Specialties USA, Inc., Charlotte, NC) was added to cherry and grape puree at the ratio of 100 g/ton of cherries or 20 g/ton of Concord grapes. The puree was held at room temperature for an hour for complete depectinization and color extraction.

Juice was obtained by pressing the puree using a small hydraulic rack and frame press (Orchard Equipment Co., Conway, MA) with layer of press and cheese cloth at 1250 psi. The cherry juice was allowed to sit for sedimentation and the clear part of the juice was then filtered by Shriver Plate and Frame Filter size 7 (T. Shriver & Co., Inc., Harrison, NJ) using a Celite® Diatomite Grades Filter Aid no. 503 (World Minerals Inc., Santa Barbara, CA). The cloudy part of the remaining juice was centrifuged at 9000 rpm for 15 minutes using a DuPont Instruments Sorvall RC-5B Refrigerated Superspeed Centrifuge with GS-3 Head (DuPont Co., Wilmington, DE). The supernatant was added to the filtered clear juice and mixed thoroughly. For Concord juices, cold stabilization was conducted first by adding tartaric acid to juices to initiate the tartrate precipitation, and juices were kept refrigerated at 2°C for 2 days before filtration.

Clear juice from each type of fruit was pasteurized at 85°C, hot packed, and kept at 18°C until ready for analysis.

### *Pulpy Juice Processing using Turbo Extractor*

Fruits were processed into pulpy juice using modified standard laboratory procedures (McLellan and Padilla-Zakour, 2004a). Fruits were heated to 80°C, and then cooled to 50°C using ice and running water in a steam kettle (Design 20CD, Lee Metal Products Co. Inc., Philipsburg, PA). Heated fruits were finely ground and seeds and some skins were separated from the pulpy juice using a Turbo extractor (Bertocchi model CX5, Bertocchi SLR., Parma, Italy) with three-quarter turn gap and 1500 rpm for Concord and 800 rpm for Montmorency. The pulpy juice was pasteurized, hot packed, and stored at 18°C until ready for analysis.

### *Pulpy Juice Processing using High Shear Mixer*

Tart cherries were pitted using a Dunkley Cherry Pitter Style SP no. 549 (Dunkley Co., Kalamazoo, MI). Subsequently, cherries were heated at 80°C with a steam kettle (Design 20CD, Lee Metal Products Co. Inc., Philipsburg, PA,) and cooled to 50°C. Cherries were coarsely ground into puree in a commercial food processor Robot Coupe® model R6VN (Robot Coupe USA Inc., Ridgeland, MS) at medium speed for 30 seconds. Cherry puree was then ground with a LSK High Shear Mixer model HSM-100LSK (Charles Ross & Son Co., Hauppauge, NY) at the maximum speed using the round hole disintegrating head for 5 minutes and then using the clotted head for another 20 minutes to obtain the pulpy juice. These grinding steps were applied to stimulate the homogenizing procedure used in the food industry. The pulpy juice was pasteurized, hot packed, and kept at 18°C until ready for analysis.

## B. Chemical Analysis

pH, titratable acidity (TA), soluble solids (°Brix), percent dry content, and pectin were determined in whole fruits and juices. Viscosity of juices was also measured. During the shelf-life study, turbidity, percent settled solids, color, total phenolic and anthocyanin contents, antioxidant capacity, and percent polymeric color were determined in all juices at 0, 12, and 24 weeks of storage. Total phenolic and anthocyanin content, antioxidant capacity, and percent polymeric color in whole fruits were also measured using freeze-dried powdered fruit extracts. The measurements for all analyses were conducted in duplicate or triplicate, as appropriate, to represent the experimental units for each batch of processing treatments.

### ***Total Soluble Solids, pH, and Titratable Acidity***

Total soluble solids content (TSS) of juices was measured with a Leica Auto ABBE refractometer (Leica Inc., Buffalo, NY) and reported as ºBrix. pH of juices were measured using a pH meter model Orion 3 Star Series pH Benchtop (Thermo Electron Corp., Beverly, MA).

Titratable acids (TA) of juices were measured following the AOAC titration method 37.1.37B (AOAC International, 2000a) using 0.1 N NaOH as a titrant to an endpoint at pH 8.10. TA was calculated as an equivalent weight of g malic acid per 100 g juices for tart cherries, and using an equivalent weight of g tartaric acid per 100 g juices for Concord grape.

Whole fruits were analyzed as fresh juices for TSS, pH, and TA following the same procedures as described for juice analysis. After seeds were removed, Concord grapes were ground using Robot Coupe® R302V (Robot Coupe USA. Inc., Ridgeland, MS) to obtain the juice. Tart cherries were squeezed through a cheese cloth to obtain fresh juice. Juices were then analyzed immediately for total soluble solids, pH, and TA.

### *Percentage Dry Content*

Moisture content in juices was measured following the AOAC vacuum drying method 44.1.03A (AOAC, 2000b). Juices were dried using Lab-Line Squaroid Model 3608 vacuum oven (Lab-Line Instruments, Inc., Melrose Park, IL) at 60°C and 26 in Hg (88 kPa). Juices were weighed and re-dried until the changes in weight were less than 2 mg. The percent moisture content and dry content were calculated using weight loss and total weight of juices. The corrected dry content was obtained by standardizing the TSS of juices with the TSS of whole fruit.

To calculate percent dry content in whole fruits, fruits were randomly selected and weighed before being frozen at -40°C for one day and then lyophilized using VirTis® Model 50-SRC (Virtis Co., Gardiner, NY) for 2 days to obtain freeze-dried whole fruits. The percentage dry content was calculated based on fresh and dried weight.

### *Percent Settled Solids*

Percentage settled solids in juices was determined using the spin solids method described by Padilla-Zakour and McLellan (1993). Juice samples were centrifuged using IEC Centra-4B Centrifuge (International Equipment Company, Division of Damon, Needham Heights, MA) at 3600-3800 rpm (2200g-2400g) for 15 min and the percent settled solids was calculated.

### *Turbidity of Clear Juice*

Turbidity of clear juices was measured with a Hach 2100P Turbidimeter (Hach Co, Loveland, CO) and reported in Nephelometric Turbidity Units (NTU).

***Viscosity***

The viscosity of clear juices was measured in triplicate for each sample using the Cannon-Fenske Routine Capillary Viscometer (Cannon Instrument Company Inc., State College, PA) at 25°C and reported in Centipoise (cp).

Viscosity of pulpy juices was determined using the flow test of Vane yield method (Genovese and Rao, 2003; Rao and Cooley, 1984; Rao, 1975) and expressed in Centipoise (cp). All tests were conducted at 25°C. Juice was poured into a stainless steel vessel (7.2 cm diameter and 11.7 cm height) with a jacket connected to a water bath (HAAKE DC30-K20, Paramus, NJ, USA) to control the temperature at 25°C. An 8-blade impeller (4.4 cm height, 5.8 cm diameter, each vane 0.079 wide, Qui and Rao, 1988) attached to a HAKKE Rotovisco RV30 viscometer (Karlsruhe, Germany) was then immersed into the sample at a fixed depth. The sample was allowed to stand for half an hour to build structure and reach the measurement temperature.

The flow test was performed by applying a continuous average shear rate ($\dot{\gamma}$) from 0 to 25 $s^{-1}$ and back to 0 $s^{-1}$. The shearing time was 5 min each for the ascending and descending shear cycles. Vane shear rate values were calculated based on the assumption that $\dot{\gamma}$ around the vane is directly proportional to the rotational speed (N), $\dot{\gamma} = k_s \frac{N}{60}$, (Rao and Cooley, 1984). The value of $k_s$ is a constant for each impeller and the value of $k_s$ for the 8-blade impeller used in this work was determined earlier to be 19.7 (Rao and Cooley, 1984). The magnitudes of torque ($T$) were recorded on a computer using HAAKE software (HAAKE Rotation Version 3.0, Karlsruhe, Germany). Since the shear stress ($\sigma$) is directly proportional to $T$, $\sigma = A*T$, the shear stress was calculated using factor $A$. The constant $A$ was calculated by measuring $T$ against $\dot{\gamma}$ at 4 different Brookfield Viscosity Standards (Brookfield Engineering Laboratories, Inc., Stoughton, MA) with magnitudes ranging from 50.5 to 976 Centipoise (cp).

To calculate the viscosity of pulpy juices, the Casson model ($\sqrt{\sigma} = \sqrt{\sigma_{0-C}} + \sqrt{\eta_\infty \dot{\gamma}}$; where $\sqrt{\sigma_{0-C}}$ is Casson yield stress and $\eta_\infty$ is Casson viscosity) was used with the shear rate-shear stress data obtained during the ascending cycle of the flow test.

### *Pectin Content*

Pectin content in all juices was measured by the colorimetric assay using m-hydroxydiphenyl (Kintner and Buren, 1982) with a slight modification, and reported as mg galacturonic acid per 100 g juice (mg GA/100 g).

Prior to analysis, pectin in juices was precipitated out by isopropanol precipitation (Kravtchenko and others, 1999; May, 1990). Juices were refluxed with 50 ml of 80% isopropanol for one hour and filtered on a glass fiber filter type A/E (PALL Corp, Ann Arbor, MI), followed by a washing step with 50 ml of 80% isopropanol to remove the mono and disaccharides. The glass filter was placed in a beaker and the precipitate was dissolved in hot distilled water. The volume was adjusted to 50 ml in a volumetric flask. The solution was centrifuged at 10,000 rpm for 10 min and the supernatant was used for analysis. For whole fruits, freeze-dried powder was used instead of juices. The freeze-dried powder was rehydrated with distilled water before isopropanol precipitation.

Galacturonic acid at concentrations of 20-100 ppm was used for a standard curve. Four hundred microliters of standard solution or samples were pipetted into test tubes and placed in an ice-water bath. After allowing to cool, 2.4 ml of $H_2SO_4$/ tetraborate solution (0.0125 M solution of sodium tetraborate in concentrated sulfuric acid) was added and the test tubes were capped. Each test tube was mixed thoroughly using a Vortex mixer. The test tubes were then heated in a 100°C waterbath for 5 min and immediately placed in ice-water to cool. Then 40 µl of m-hydroxydiphenyl solution (0.15% solution of m-hydroxydiphenyl in 0.5% sodium hydroxide) was added to each sample. The test tubes were mixed thoroughly using a Vortex mixer and allowed to stand for 20 min to develop color. The absorbance at 520 nm versus blank (using 0.5% NaOH instead of m-hydroxydiphenyl solution) was measured using a Barnstead Turner SP830 Spectrophotometer (Barnstead International, Dubuque, IA). The reagent blank containing 0.4 ml of distilled water, 2.4 ml $H_2SO_4$/ tetraborate solution, and 40 µl m-hydroxydiphenyl solution were used to zero the spectrophotometer.

### *Color*

The Hunter L, a', and b' color components of clear and pulpy juices were measured in 2 cm glass cuvette with HunterLab Ultra Scan XE colorimeter (Hunter Associates Laboratory, Inc., Reston, VA) with a reflectance setting (RSIN mode).

### *Whole Fruit Sample Preparation*

Whole fruits were analyzed as whole fruit extracts for total phenolic content, antioxidant capacity, total anthocyanin content, and percent polymeric color. Freeze-dried fruits were ground into powder in a PB-5A Waring blender (Waring Products Co., New York, NY) and stored in sealed bags protected from light at 2°C until the extraction.

Phenolic compounds were extracted from freeze-dried fruit powder using the method from Kim and Lee (2002) with some modifications. The 80% methanol was added to 1 g of freeze-dried sample in a 50 ml plastic centrifuge tube. The tubes were then flushed with nitrogen gas and sonicated for 20 min with ice in a Branson 2200 sonicator (Fisher Scientific, Agawam, MA). Samples were centrifuged using DuPont Instruments Sorvall RC-5B Refrigerated Superspeed Centrifuge with SS-34 Head

(DuPont Co., Wilmington, DE) at 10,000 rpm for 20 min. Supernatants were decanted into glass vials. Sonication and centrifugation steps were repeated again. All supernatants were collected into glass vials flushed with nitrogen gas. The extracts were stored at -30°C and protected from light until ready for analysis. Two batches of whole fruit extract were prepared to represent two experimental units.

### *Total Phenolic Content*

Total phenolic content in juices and whole fruit extracts was determined using the protocol for Folin-Ciocalteu (FC) reagent in colorimetric analysis described by Singleton and Rossi (1965) with some modifications. Samples were diluted prior to analysis with distilled deionized water and total phenolic content was expressed as mg gallic acid equivalent (GAE) per 100 g sample.

Gallic acid solutions at concentrations of 20-100 ppm were used to produce a standard curve. Samples were diluted prior to analysis with distilled deionized water so that the absorbance was within the range of the standard curve. Two hundred microliters of standard solution or diluted samples were mixed with 2.8 ml of distilled deionized water in the test tube followed by the addition of 200 µl of FC reagent. The mixtures were mixed and allowed to stand for 6 min before 2 ml of 7% $Na_2CO_3$ was added. Samples were allowed to stand for 90 min before the absorbance at 750 nm versus blank (using 200 µl of distilled deionized water instead of samples) was measured using a Barnstead Turner SP830 Spectrophotometer (Barnstead International, Dubuque, IA).

### *Antioxidant Capacity*

Antioxidant capacity in juices and whole fruit extracts was determined using the 2,2’-azino-bis (3-ethylbenzthiazoline-6-sulfonic acid) diammonium salt (ABTS) assay (Van den Berg and other, 1999) with some modifications and expressed as mg Vitamin C Equivalent Antioxidant Capacity (VCEAC) per 100 g sample.

Ascorbic acid solution at concentrations of 20-100 ppm was used as a standard and samples were diluted before the analysis. The radical solution of 2.5 mM ABTS with 1.0 mM AAPH in phosphate-buffered saline (PBS; pH 7.4; 0.1 M $K_2HPO_4/KH_2PO_4$ buffer; 150 mM NaCl) was heated in a water bath at 70°C for 20 min. The absorbance of radical solutions was adjusted to 0.065 ± 0.02. Twenty microliters of sample, or distilled deionized water for control, was added to 980 µl of the radical solution. The mixture was incubated at 37°C in a water bath for 10 min before the reduction in absorbance between sample and control was measured at 734 nm using a Barnstead Turner SP830 Spectrophotometer (Barnstead International, Dubuque, IA).

### *Total Anthocyanin Content*

Total anthocyanin content was measured using a pH-differential method for total monomeric anthocyanin (Giusti and Wrolstad, 2001; Niketic-Aleksic and Hrazdina, 1972). Total anthocyanin content was expressed as mg cyaniding-3-glucoside equivalent (CGE) per 100 g sample for tart cherries and mg malvidin-3-glucoside equivalent (MGE) per 100 g sample for Concord grapes.

Samples were diluted in 0.025 M potassium chloride buffer pH 1.0 and 0.4 M sodium acetate buffer pH 4.5 with the same dilution factor for both buffers. The mixture was allowed to stand for 15 min and the absorbance of samples was measured using a Barnstead Turner SP830 Spectrophotometer (Barnstead International, Dubuque, IA) at 510 nm for tart cherries and at 520 nm for Concord grapes. All sample mixtures were also measured for absorbance at 700 nm to correct for haze. The differences in absorbance of samples at pH 1.0 and pH 4.5 were used to calculate total anthocyanin content.

### *Percent Polymeric Color*

Polymeric color in juices and whole fruits was determined using the sodium bisulfite bleaching method as described by Giusti and Wrolstad (2001) and expressed as percentage polymeric color.

Samples were diluted before the analysis. Diluted samples were transfered into 2 cuvettes each of 2.8 ml. Two hundred microliters of distilled water or bisulfite solution were added into each cuvette and the mixtures were allowed to equilibrate for 15 min. The absorbance of samples was measured using a Barnstead Turner SP830 Spectrophotometer (Barnstead International, Dubuque, IA) at 420 nm, 700 nm, and 510 nm for tart cherries or 520 nm for Concord grapes. The color density was calculated from water treated samples as the sum of absorbance at 420 nm and 510 or 520 nm, the wavelength producing the maximum absorbance for samples. Polymeric color was calculated from bisulfite bleached samples as the sum of absorbances at 420 nm, serving as the browning index, and 510 or 520 nm. The percentage polymeric color is the ratio between the polymerized color and the color density.

## C. Sensory Evaluation

Sensory evaluation of juices was conducted at 0 and 24 weeks storage using an acceptance and a ranking test. Prior to both tests, juices from the same processing treatment were mixed. Juices were served at room temperature in the random order. Twenty-four panelists were asked to test and evaluate all juices from the same variety.

### *Acceptance Test*

The 7-point hedonic scale (Lawless and Heymann, 1999c) was used to assess the acceptability of juices in four attributes: color, flavor, mouthfeel, and overall acceptability.

#### *Ranking Test*

Panelists were asked to rank the flavor intensity and preference of different type of juices from the same fruit.

### D. Statistical Analysis

Results were reported in means ± standard deviation for each cultivar, each processing treatment, and each storage time. All data were subjected to analysis of variance (ANOVA) and means were compared with the Tukey Significant Difference test at 95% confidence interval using the JMP® 7.0 statistical software package (SAS institute Inc., Cary, NC).

For the sensory evaluation, means of each attribute in the acceptance test were also subjected to ANOVA and compared using the Tukey Significant Difference test at 95% confidence interval using the JMP® 7.0 statistical software package. Since the data obtained from the ranking test is nonparametric, the Friedman test was used to analyze the data and the mean comparison was made using the Least Significant Ranked Difference (LSRD) test at 95% confidence interval (Lawless and Heymann, 1999a, 1999b).

## Results and Discussion

### A. Juice and Whole Fruit Characteristics

#### *Total Soluble Solids, pH, and Titratable Acidity*

Table 2.1 shows total soluble solids (TSS), pH, and titratable acidity (TA) of whole fruits and juices from tart cherry cv. Montmorency and Balaton, and Concord grapes. TSS of clear juices is lower than that of pulpy juices of the same cultivar. Montmorency had a higher TSS than Balaton and TSS for both cultivars was in line with the TSS for tart cherries previously reported (Kaack and other, 1996; Tressler, 1961; Marshall, 1954). Compared to the values previously reported by Chaovanalikit and Wrolstad (2004a) and Kim and Padilla-Zakour (2004), TSS of Montmorency and Balaton whole fruits was 16% and 38% higher, respectively. TSS of Montmorency clear juices was 14% higher than values reported by Chantanawarangoon (2005) and 7% higher for Balaton clear juices.

TA of tart cherry cv. Montmorency and its juices was lower than that of Balaton which was consistent with the higher pH. Within the same cultivar, whole fruit had a higher acidity than juices. TA of Montmorency and Balaton whole fruits were similar to those reported by Kaack and other (1996). TA of Balaton clear juices was similar to value reported by Chantanawarangoon (2005), while TA of Montmorency clear juice was 14% lower. pH of Montmorency whole fruit was in the same range of values previously reported by Marshall (1954) but 2% lower than values reported by Chaovanalikit and Wrolstad (2004a). pH of Balaton whole fruit was 9% lower than the value reported by Kim and Padilla-Zakour (2004). Compared to the value previously reported (Chantanawarangoon, 2005), pH was 4% and 2% higher in Montmorency and Balaton clear juices, respectively. The variation in TSS, pH, and TA of the same fruit may be the result of differences in growing locations, harvesting seasons, and other horticulture practices (Chantanawarangoon, 2005; Poll and others, 2003).

Concord grape juices had a similar pH and a slightly lower TA in clear juices than in pulpy juices. This was due to the cold stabilization during the clear juice processing which took out some of the tartaric acid. Konja and Lovric (1993) explained that the depectinization step was an essential process in removing the

**Table 2.1**. pH, titratable acidity, soluble solids, and percent dry content of whole fruits and juices from tart cherry cv. Montmorency and Balaton, and Concord grapes

| Variety | Treatment | pH | Titratable acidity[1] | Soluble solids (°Brix) | % Dry content[2] |
|---|---|---|---|---|---|
| Tart cherry cv. Balaton | Whole fruit | 3.32 ± 0.03 | 2.24 ± 0.02 | 18.15 ± 0.04 | 20.57 ± 0.00 a |
| | Clear juice | 3.26 ± 0.01 | 1.77 ± 0.04 | 16.83 ± 0.30 | 15.68 ± 0.17 c |
| | Shear mixer | 3.26 ± 0.01 | 1.94 ± 0.57 | 18.99 ± 0.17 | 16.43 ± 0.01 b |
| Tart cherry cv. Montmorency | Whole fruit | 3.45 ± 0.03 | 1.69 ± 0.03 | 16.74 ± 0.03 | 18.94 ± 0.00 a |
| | Clear juice | 3.41 ± 0.00 | 1.31 ± 0.05 | 16.88 ± 0.27 | 15.24 ± 0.23 c |
| | Shear mixer | 3.42 ± 0.00 | 1.03 ± 0.41 | 18.36 ± 0.01 | 16.92 ± 0.81 b |
| | Turbo extractor | 3.35 ± 0.00 | 1.49 ± 0.00 | 17.52 ± 0.45 | 15.98 ± 0.39 b |
| Concord grapes | Whole fruit | 3.16 ± 0.00 | 1.11 ± 0.01 | 16.81 ± 0.08 | 20.14 ± 0.00 a |
| | Clear juice | 3.14 ± 0.00 | 0.97 ± 0.02 | 15.51 ± 0.05 | 13.85 ± 0.01 c |
| | 0.8mm turbo extractor | 3.12 ± 0.04 | 1.17 ± 0.04 | 18.07 ± 0.58 | 16.01 ± 0.14 b |
| | 0.4mm turbo extractor | 3.18 ± 0.02 | 1.15 ± 0.01 | 17.58 ± 0.20 | 16.17 ± 0.02 b |

1: Reported as g malic acid, for tart cherries, and g tartaric acid, for Concord grape, per 100 g sample
2: For each fruit, the values followed by different letters are significantly different

tartrate since this treatment lowered the viscosity of clear juices which was one of the main factors affecting the rate of precipitation for tartrate. Total soluble solids and TA of Concord juices were consistent with the values reported (Pederson, 1961). pH of Concord juice was also in good agreement with values previously reported (McLellan and Acree, 1993; Ingalsbe and others, 1963; Ingram and Lüthi, 1961).

### *Percent Dry Content*

Percentage dry content of whole fruits and juices from tart cherry cv. Montmorency and Balaton, and Concord grapes are presented in Table 2.1. The dry content of Montmorency and Balaton whole fruit was 16.7% and 18.1% respectively which was 6% and 28% lower than values reported by Lenartowicz and other (1985) but was 13.6% and 5.8% higher compared to values reported by Wang and others (1997). The differences in dry content might be due to the variety and harvesting season. Whole fruits had higher dry content than juices of the same variety (17 to 24% higher for tart cherries and 26 to 32% higher for Concord grapes). Also, pulpy juices had higher dry content than clear juices of the same variety. Montmorency and Balaton pulpy juices had dry content values 3.6 and 4.8% higher than those for clear juice while dry content of Concord pulpy juices was 8% higher than Concord clear juices.

### ***Viscosity***

Viscosity of tart cherries and Concord grape juices are presented in Table 2.2. Clear juices had a significantly lower viscosity than pulpy juices of their counterparts. Viscosity of clear juices for all varieties ranged from 1.09 to 1.11 cp which was 15% lower than the viscosity of clear apple juices reported by Bonsi (2005). The low viscosity of clear juice was due to the depectinization using pectinase enzyme during processing. Treatments with pectinase enzyme before the filtration led to the decomposition of pectin, acting as the protective colloid for suspended particles; thus, reduced the viscosity of juices (Konja and Lovric, 1993; Luh and El-Tinay, 1993; Tressler, 1961).

The viscosity of pulpy juices ranged from 15.82 to 35.09 cp which was in the same magnitude of viscosity of tomato juices (13.0 to 25.0 cp) reported by Kaur and others (2007). Compared to the viscosity of apple sauces (240 cp) reported by Bonsi (2005), the viscosity of pulpy juice was 85 to 93% lower. This indicated that the pulpy juice studied could be categorized as juice rather than sauce. When pulpy juices from the two types of extractors were compared, pulpy juices made from a high shear mixer had a significantly higher in viscosity than from a turbo extractor. This result

**Table 2.2**. Viscosity of juices from tart cherries and Concord grapes

| Fruits | Treatments | Viscosity (cp) |
|---|---|---|
| Tart cherry cv. Balaton | Clear juice | 1.11 ± 0.01 b |
| | Shear mixer | 35.09 ± 0.17 a |
| Tart cherry cv. Montmorency | Clear juice | 1.11 ± 0.01 c |
| | Shear mixer | 22.06 ± 0.43 a |
| | Turbo extractor | 15.82 ± 0.22 b |
| Concord grape | Clear juice | 1.09 ± 0.00 b |
| | 0.8mm Turbo extractor | 34.69 ± 5.27 a |
| | 0.4mm Turbo extractor | 27.29 ± 1.30 a |

For each fruit, the values followed by different letters are significantly different

corresponded well with percentage settled solids (data described later). Since bigger particle size could lead to higher juice viscosity (Schijvens and others, 1998), this could indicate that pulpy juices made from the high shear mixer contained a higher amount of bigger particles. On the other hand, the screen size of the turbo extractor did not make a difference in the viscosity of pulpy juices.

## B. Effect of Processing

### *Total Phenolic Content*

Total phenolic content of whole fruits and juices at 0 weeks of storage are presented in Figures 2.1 and 2.2. For tart cherries, juices had a significantly lower phenolic content than that of whole fruits and clear juices had a significantly lower value than that of pulpy juices. The phenolic content of Montmorency whole fruit was in good agreement of value reported by Chaovanalikit and Wrolstad (2004a), while the phenolic content in Balaton whole fruit was 33% higher than value reported by Kim and Padilla-Zakour (2004). Phenolic content in Montmorency and Balaton clear juice were 301.6 and 225.0 mg GAE/100g, respectively, which were 58% and 2% higher than the value reported by Chantanawarangoon (2005). Montmorency had higher total

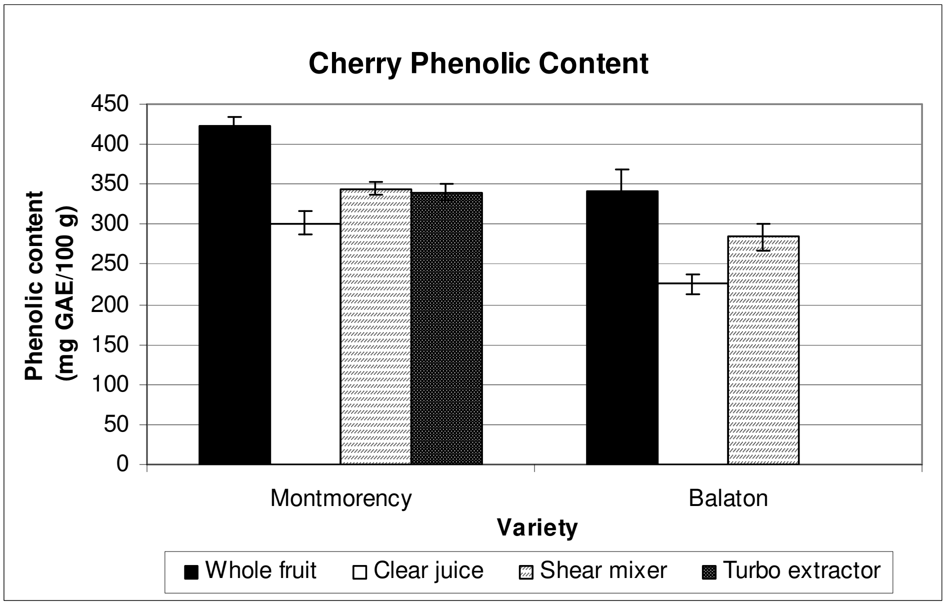

**Figure 2.1**. Phenolic content of tart cherries and their juices

pheonolic content than Balaton when samples from the same treatment were compared. In whole fruit, Montmorency had a 24% higher phenolic content than Balaton. The type of extractors, a turbo extractor and a high shear mixer, did not make a difference in total phenolic content of pulpy juices. (Figure 2.1)

The phenolic content in the pulpy Concord grape juices was not significantly different than that in whole fruit but was significantly higher than in clear juices. Phenolic content in clear juice was consistent with values previously reported (Frankel and others, 1998; Huang and others, 1988; Niketic-Aleksic and Hrazdina, 1972), but was 50% lower than values reported by Montgomery and others (1982). When looking at the effect of screen size, the total phenolic content of pulpy juices made from two different screen sizes was not significantly different. (Figure 2.2)

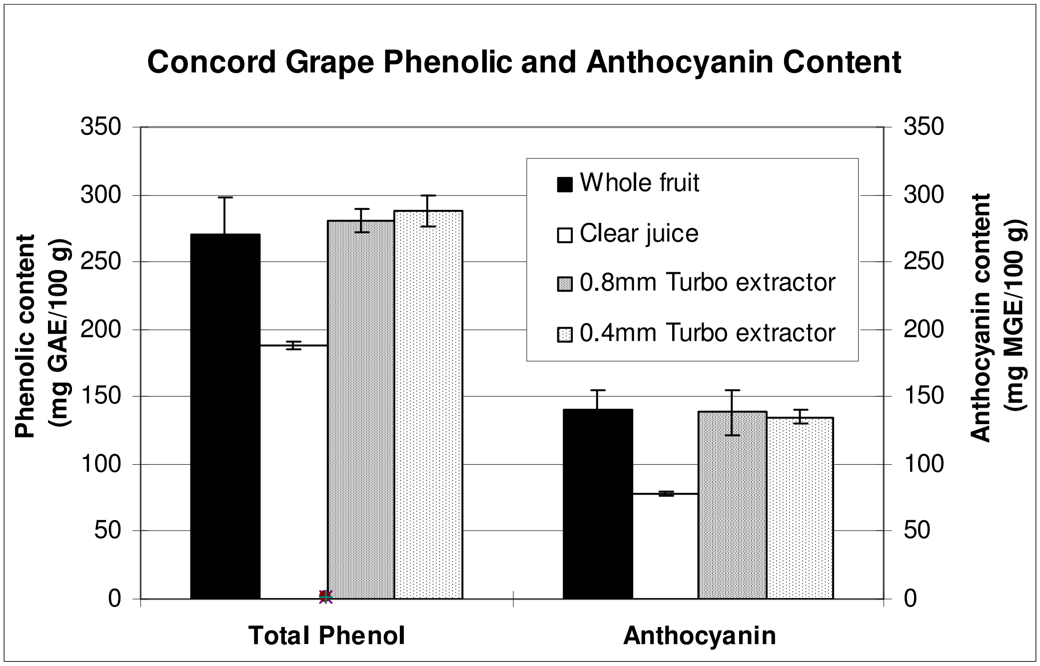

**Figure 2.2**. Phenolic and anthocyanin content of Concord grapes and their juices

### *Antioxidant Capacity*

The antioxidant capacity of whole fruit and juices at 0 weeks of storage was evaluated using ABTS assay (Figures 2.3 and 2.4). Antioxidant capacity followed the same trend as the phenolic content. Chantanawarangoon (2005) reported a good relationship ($r^2 = 0.83$) between total phenolic content and antioxidant capacities measured by the ABTS assay in tart cherries. Other studies also reported high correlations between antioxidant activities and phenolic content in fruits and their products (Alasalvar and others, 2005; Kader and Barrett, 2004; Wang and others, 1996).

For tart cherries, juices had a significantly lower antioxidant capacity than that of whole fruits, and antioxidant capacities in clear and pulpy juices were not significantly different (Figure 2.3). This means that both clear and pulpy juice processing lowered the antioxidant capacity in tart cherry juices at the same magnitude

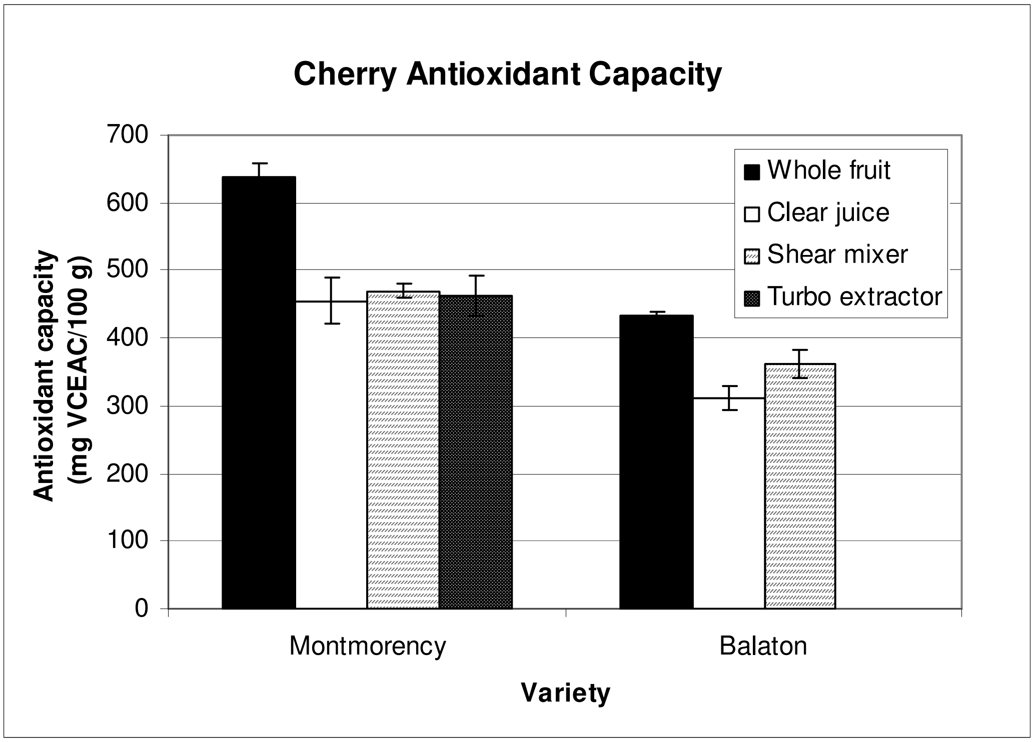

**Figure 2.3**. Antioxidant capacity of tart cherries and their juices

and the decrease may be due to the destruction of active antioxidant compounds such as vitamin C and anthocyanins by the heating process. The antioxidant capacity of Montmorency and Balaton clear juices was 32% and 12% higher than values reported by Chantanawarangoon (2005). However, the antioxidant capacity in Balaton clear juices was 12% lower than values reported by Kim and Padilla-Zakour (2004). The differences could due to the growing location, harvesting seasons and other horticulture practices (Chantanawarangoon, 2005).

Pulpy juices from Concord grapes, on the other hand, did not have significantly different antioxidant capacities than that of whole fruits, and had significantly higher antioxidant capacities than clear juices. The screen size of the turbo extractor did not affect the antioxidant capacity in Concord grape pulpy juices.

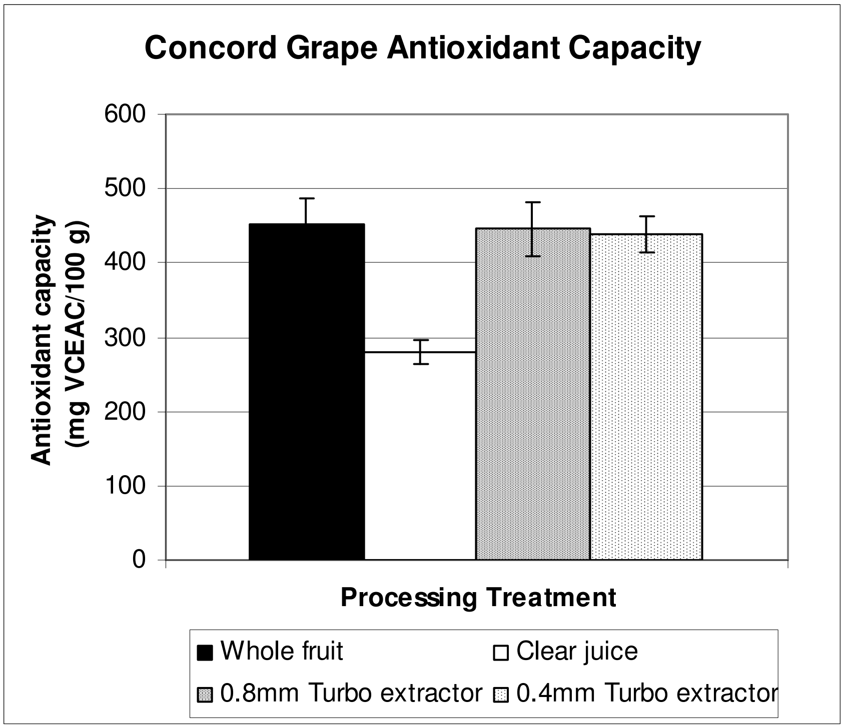

**Figure 2.4**. Antioxidant capacity of Concord grapes and their juices

***Total Anthocyanin Content***

Figures 2.2 and 2.5 show the total anthocyanin content of whole fruits and juices at 0 weeks of storage from tart cherry cv. Montmorency and Balaton, and Concord grapes. The same pattern from total phenolic content and antioxidant capacities was exhibited in anthocyanin content. This coincided with the findings of Kalbasi and Cisneros-Zevallos (2007) that the antioxidant capacity related linearly to anthocyanin content.

Anthocyanin content in Montmorency was 23 to 79% higher than values previously reported (Chantanawarangoon, 2005; Wang and others, 1997a). Anthocyanin content in Balaton clear juices was in good agreement with values reported by Kim and Padilla-Zakour (2004), but was 17% lower than values reported by Chantanawarangoon (2005). The differences in anthocyanin content could due to

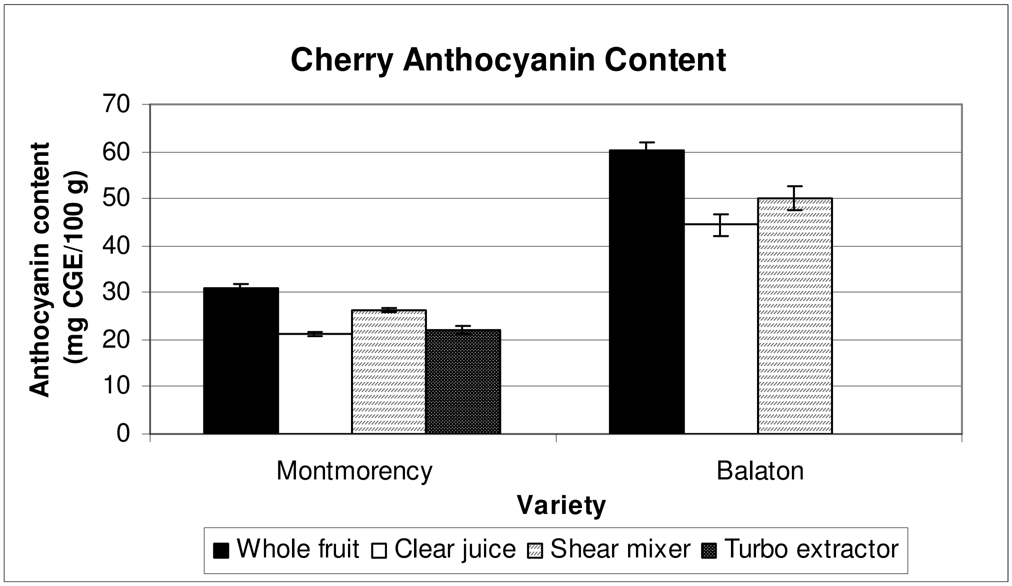

**Figure 2.5**. Anthocyanin content of tart cherries and their juices

the maturity, geographic location, and environmental factors such as light, temperature, and various stresses (Kalt and others, 1999; Tomás-Barberán and Espín, 2001). Anthocyanin content in Balaton was two times higher than in Montmorency. Chantanawarangoon (2005) and Wang and others (1997) also reported that Balaton had three to six times higher anthocyanin content than Montmorency. Montmorency juices made from a shear mixer resulted in significantly higher anthocyanin content than clear juices or juices from a turbo extractor. However, anthocyanin content in Balaton pulpy juices made from a shear mixer was not different than clear juices.

Concord clear juices had significantly lower anthocyanin content than pulpy juices due to the filtration and the pigment precipitation during detartration (cold stabilization) rather than the decomposition of anthocyanins (Sistrunk and Cash, 1974; Ingalsbe and others, 1963). Anthocyanin content in Concord clear juices were comparable to values reported by Mazza (1995); however, we could not compare this to the value reported by Montgomery and others (1982) and Niketic-Aleksic and

Hrazdina (1972) because of the difference in reference anthocyanin. Pulpy juices made from two different screen sizes did not have significantly different anthocyanin content.

### *Polymeric Color*

Polymeric color of whole fruits and juices is presented in Figures 2.6 and 2.7. For tart cherries, the percentage polymeric color of clear juices and whole fruits was not different, but was significantly lower than that of pulpy juices. In contrast, the percent polymeric color of Concord clear juices was significantly lower than that of whole fruits and pulpy juices. Percentage polymeric color of Montmorency and Balaton whole fruit was 16.5% and 11.9% which was comparable to values in fresh Bing cherry (12.5%) reported by Chavanalikit and Wrolstad (2004a).

Polymeric color could be formed from the polyphenoloxidase (PPO) activity (Chavanalikit and Wrolstad, 2004a); therefore, percentage polymeric color of whole fruit could be due to the lack of PPO inhibition while the low percentage polymeric color in clear juice was the result of the inhibition of PPO during the heating step (Montgomery, 1982). The lower polymeric color of clear juices could also be explained by the loss during filtration and cold stabilization. According to Kalbasi and Cisneros-Zevallos (2007), the polymeric color loss (11 to 28%) occurred during Concord juice filtration. Furthermore, polymerized pigments in Concord clear juices could co-precipitate with tartrates during cold stabilization.

The higher percent polymeric color of pulpy juices indicated that anthocyanin degradation occurred during processing. The type of extractors, a shear mixer and a turbo extractor, and the screen sizes of the turbo extractor did not affect the level of polymeric color.

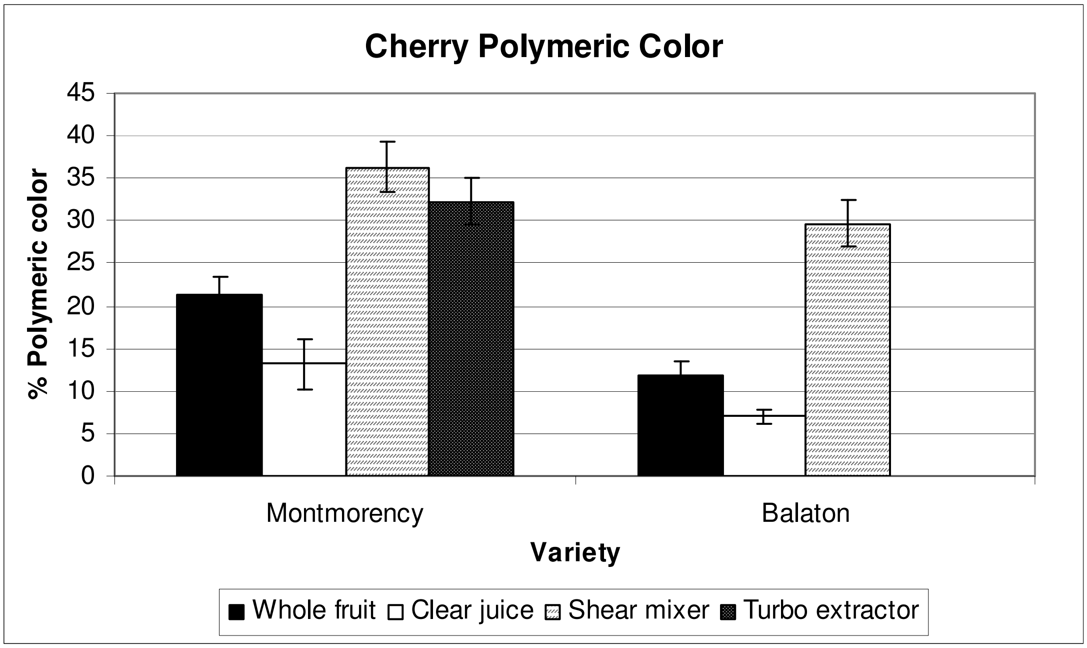

**Figure 2.6**. Polymeric color of tart cherries and their juices

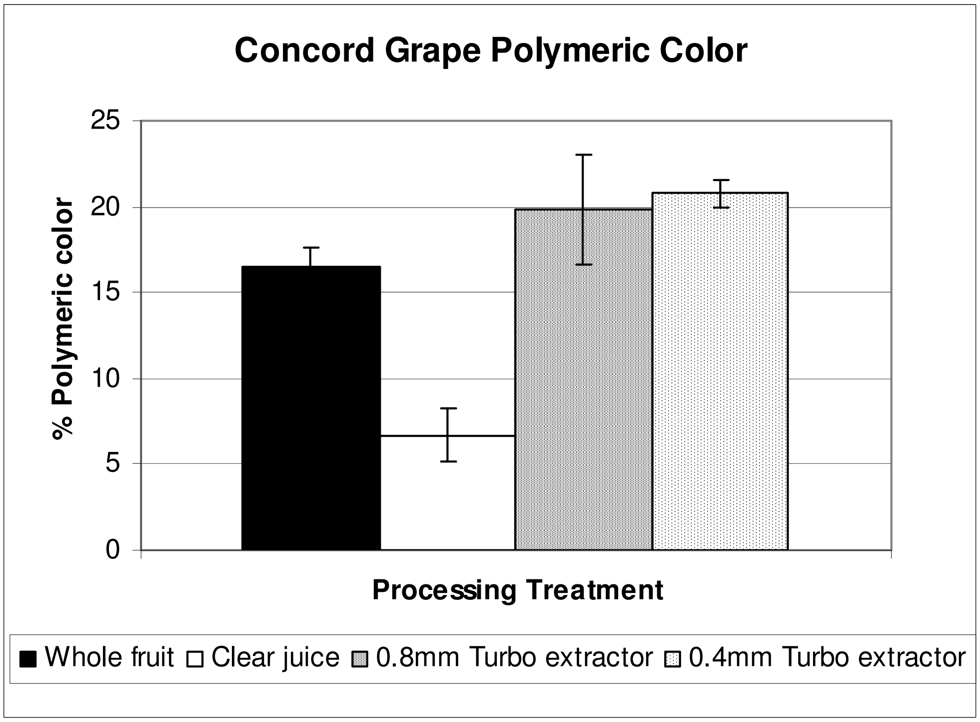

**Figure 2.7**. Polymeric color of Concord grapes and their juices

### *Pectin content*

Pectin content in juices and whole fruits are shown in Table 2.3. Pectin content in pulpy juices was comparable to that of whole fruits. Clear tart cherries and Concord grape juices had the least pectin content indicating the depetinization step during clear juice processing. Balaton had higher pectin content than Montmorency but both cherry cultivars had lower pectin contents than Concord grapes. Juices made from a high shear mixer resulted in a significantly higher pectin content than those from a turbo extractor. Even though juices made from a 0.8 mm screen size had higher pectin content than juices from 0.4 mm screen size, there was no significant difference in pectin content.

Since pectin is a major soluble fiber in fruits and it contains 60% galacturonic acid (Constenla and others, 2002), 1 serving (8 fl. oz.) of pulpy juices from Balaton, Momemorency, or Concord grapes may contain up to 0.75, 0.68, or 0.85 g pectin respectively. Therefore, they could carry the claim "may reduce the risk of coronary heart disease" (FDA, 2008).

**Table 2.3**. Pectin content, described as galacturonic acid, of tart cherries and Concord grapes, and their juices

| Variety | Treatment | Galacturonic acid (mg/100 g) |
|---|---|---|
| Tart cherry cv. Balaton | Whole fruit | 184.0 ± 1.8 a |
| | Clear juice | 1.61 ± 0.74 b |
| | Shear mixer | 181.0 ± 7.7 a |
| Tart cherry cv. Montmorency | Whole fruit | 169 ± 13 a |
| | Clear juice | 0.75 ± 0.47 c |
| | Shear mixer | 165 ± 11 a |
| | Turbo extractor | 124.21 ± 0.88 b |
| Concord grape | Whole fruit | 209 ± 19 a |
| | Clear juice | 2.4 ± 2.6 b |
| | 0.8mm Turbo extractor | 207 ± 17 a |
| | 0.4mmTurbo extractor | 181 ± 12 a |

For each fruit, the values followed by different letters are significantly different

## C. Shelf-life Study of Juices

### *Turbidity*

The turbidity of clear juices during the shelf-life study is shown in Figure 2.8. The turbidity of all clear juices was higher than the turbidity of clear apple juices (12 to 36 NTU) reported by Bonsi (2005). This confirms that clear juices still retains color pigments with the filter aid used in this study (Celite® Diatomite Grades Filter Aid no. 503). The turbidity of clear Montmorency juices increased significantly over the 24-week storage, as opposed to that of clear Balaton and Concord juices. Even though the turbidity of clear Concord juices increased over the shelf-life study, there was no significant difference due to the large difference between the two experimental units. The trend of increasing turbidity in clear juices during the storage, indicating the instability of juices, was a result of tannin hazes which formed slowly from polymerized polyphenolic molecules (McLelland and Padilla-Zakour, 2004a). Therefore, the changes in turbidity over time followed the same trend as the changes in polymeric color (described later). Clear Concord juices started with a lower turbidity than clear tart cherry juices. This could be explained by the lower polymeric color of clear Concord juices as a result of an additional cold stabilization step that.

### *Settled Solids*

There was no significant difference in percentage settled solids over the shelf life study for any variety, but processing treatments had a significant effect on the juices' percent settled solids (Table2.4). Clear juices had a significantly lower percent settled solids than pulpy juices. Pulpy juices made from a shear mixer had a significantly higher percent settled solids than juices from a turbo extractor and pulpy juices made from a 0.8 mm screen size showed a significantly higher settled solids than those from a 0.4 mm screen size.

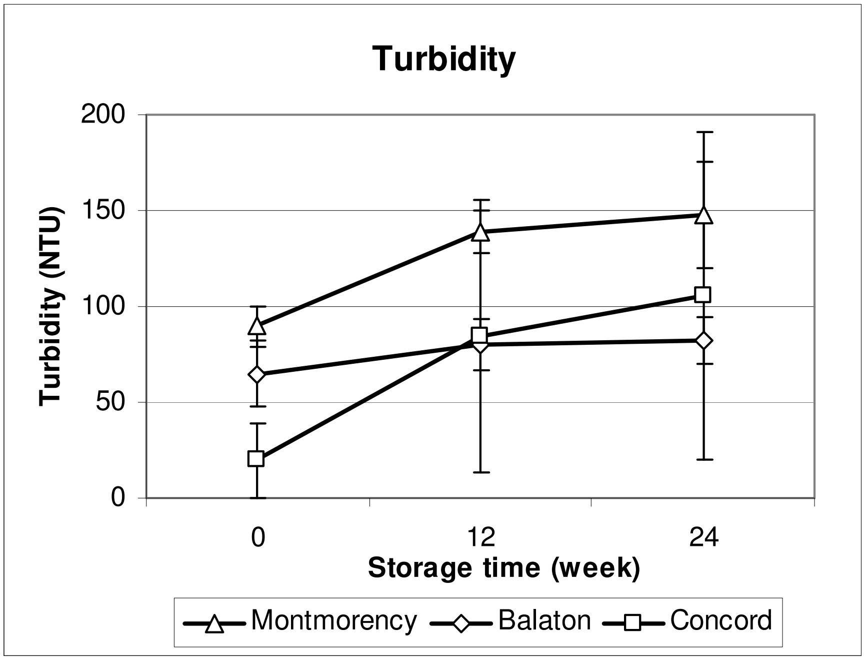

**Figure 2.8**. Turbidity of tart cherry and Concord grape clear juices during the shelf-life study at 18°C

***Total Phenolic Content***

The changes in phenolic content in juices during the shelf life study are presented in Figures 2.9 and 2.10. Total phenolic content generally decreased during the storage. For Concord juices and clear tart cherry juices, there was a significant difference between the 0 and 12 weeks of storage but not between 12 and 24 weeks. This indicated that the loss of phenolic content was higher early in storage time. In contrast, phenolic content of pulpy tart cherry juices decreased significantly at every point in storage due to the steady rate of loss over the entire shelf-life study.

When compared at the same storage time, pulpy Balaton and Concord juices had significantly higher phenolic content than their clear counterparts. For Montmorency, this significant difference between pulpy and clear juices was noted only at 0 weeks of storage. This was due to the difference in percentage loss of

**Table 2.4**. Percent settled solids of tart cherry and Concord grape juices during the shelf-life study at 18°C

| Variety | Treatment | % Settled Solids | | |
|---|---|---|---|---|
| | | 0 Week | 12 Week | 24 Week |
| Tart cherry cv. Balaton | Clear juice | 0.15 ± 0.04 b | 0.15 ± 0.04 b | 2.73 ± 0.88 b |
| | Shear mixer | 49.38 ± 0.42 a | 48.09 ± 2.66 a | 53.21 ± 3.35 a |
| Tart cherry cv. Montmorency | Clear juice | 0.31 ± 0.17 c | 0.13 ± 0.05 c | 2.45 ± 0.65 c |
| | Shear mixer | 36.25 ± 1.08 a | 35.18 ± 2.64 a | 37.52 ± 2.78 a |
| | Turbo extractor | 21.88 ± 1.72 b | 23.46 ± 1.80 b | 24.21 ± 1.66 b |
| Concord grapes | Clear juice | 0.00 ± 0.00 b | 0.26 ± 0.08 c | 0.26 ± 0.04 c |
| | 0.8mm Turbo extractor | 39.35 ± 2.70 a | 39.58 ± 1.51 a | 38.06 ± 3.94 a |
| | 0.4mm Turbo extractor | 34.62 ± 3.36 a | 34.87 ± 1.81 b | 31.72 ± 1.72 b |

For each fruit in each column, the values followed by different letters are significantly different

phenols in clear and pulpy juices which were 10% and 20%, respectively. The percentage loss in clear Concord and pulpy Concord juices was the same, 13%, and since pulpy juices started with higher phenolic content than clear juices, they ended up with a higher content (50% higher through out the shelf-life study).

### *Antioxidant Capacity*

Figures 2.11 and 2.12 present the antioxidant capacity of juices during the shelf-life study. There was a significant difference in antioxidant capacity due to storage time in Concord and Montmorency juices but not in Balaton juices. Even though the percentage loss of Montmorency and Concord juices compared at 0 and 24 weeks storage was of the same magnitude (7 to 12%), manner in which each decreased was different. For Montmorency, the loss of antioxidant capacity was high late in the shelf-life study (from 12 to 24 weeks) while it was high early in the shelf-life study (from 0 to 12 weeks) for Concord. Because the percentage loss between clear and pulpy juices was the same, pulpy Concord juices had a 55% higher

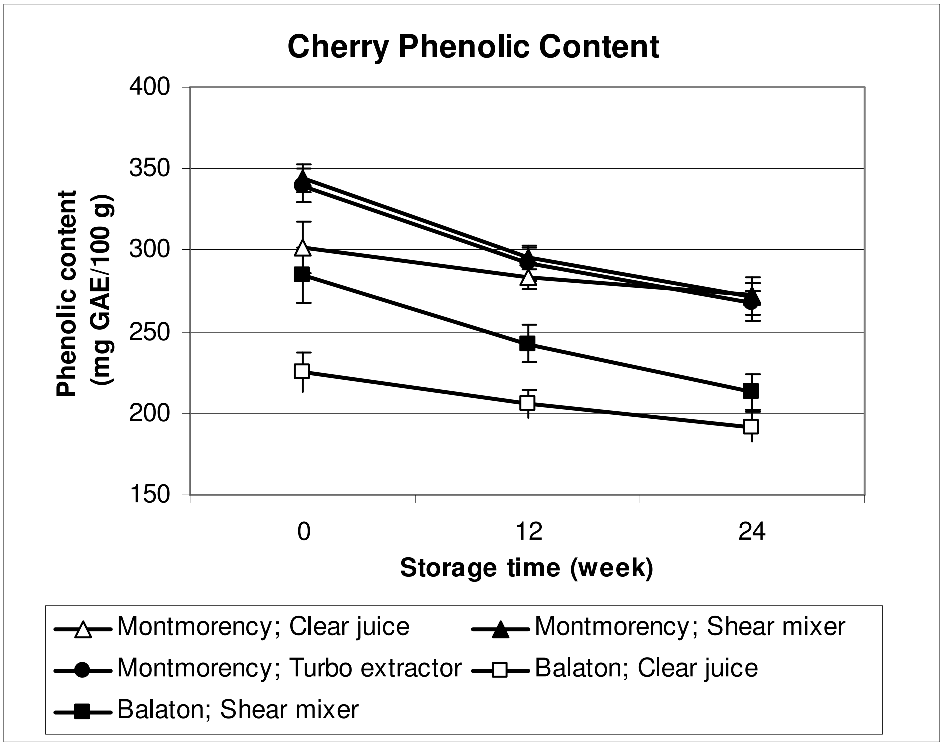

**Figure 2.9**. Phenolic content of tart cherry juices during the shelf-life study at 18°C

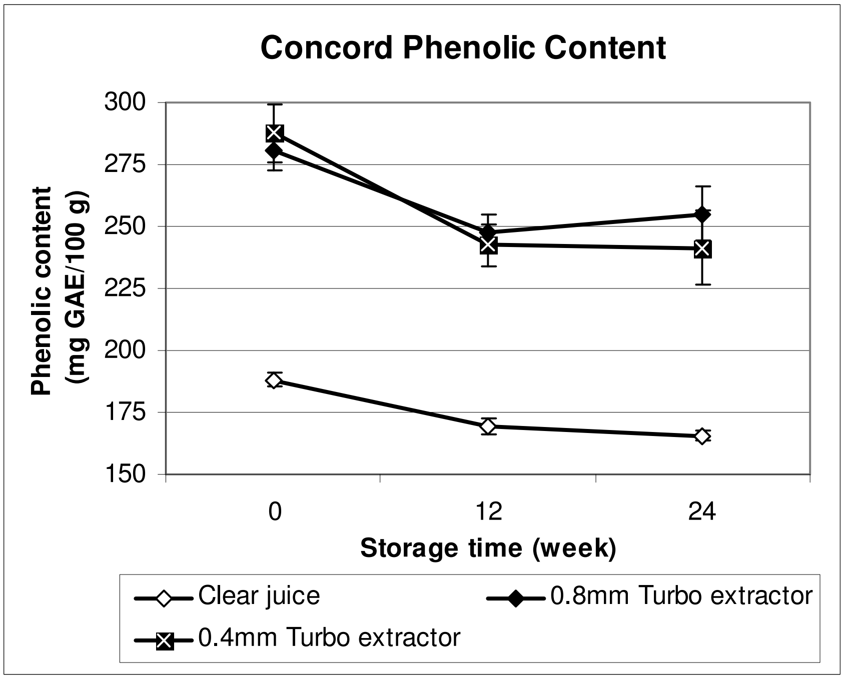

**Figure 2.10**. Phenolic content of Concord grape juices during the shelf-life study at 18°C

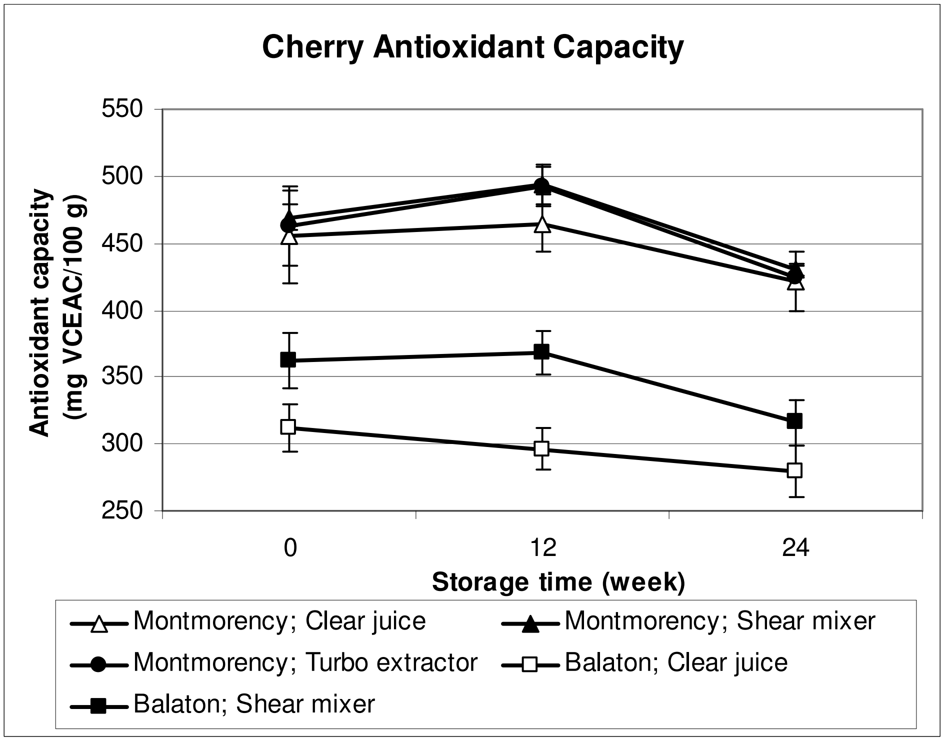

**Figure 2.11**. Antioxidant capacity of tart cherry juices during the shelf-life study at 18°C

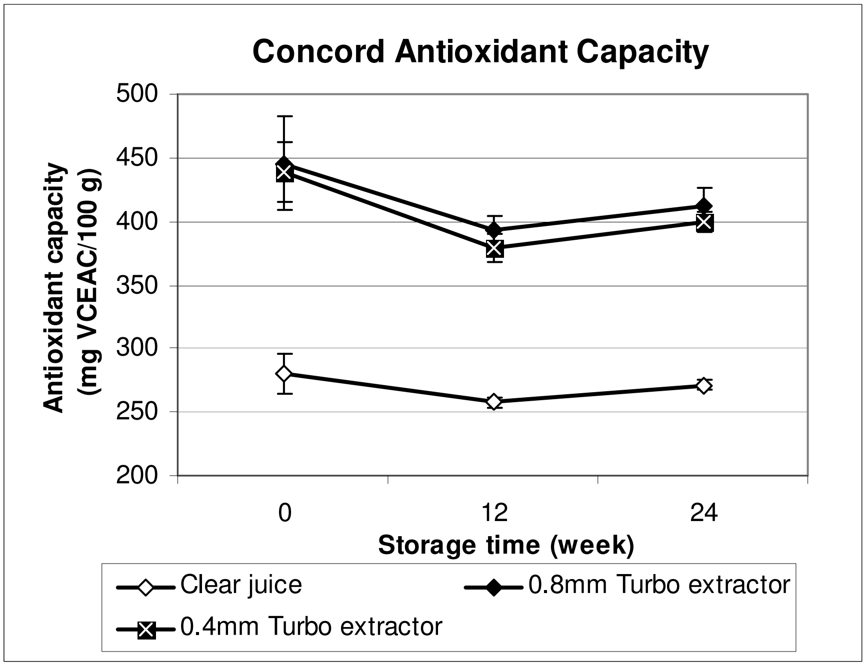

**Figure 2.12**. Antioxidant capacity of Concord grape juices during the shelf-life study at 18°C

antioxidant capacity than clear juices through out the shelf-life study. In contrast, differences in antioxidant capacity in Montmorency clear and pulpy juices over the shelf-life study were not significant.

According to Figures 2.11 and 2.12, it was clear that throughout the shelf-life study, clear Balaton and Concord juices were significantly lower in antioxidant capacity than pulpy juices of their counterparts. For the entire study, pulpy Balaton juices had a 15% higher antioxidant capacity than clear juices, and both clear and pulpy juices had a 10% loss from 0 to 24 weeks storage. Percentage loss of antioxidant capacity was lower compared to that of phenolic and anthocyanin content. This suggests that degraded phenolics and anthocyanins still had antioxidant activities and might have higher antioxidant capacity compared to their original compounds (Kalbasi and Cisneros-Zevallos, 2007; Plumb and others, 1998).

### *Total Anthocyanin Content*

Total anthocyanin content in juices during the shelf-life study are presented in Figures 2.13 and 2.14. For tart cherry juices, the degradation rate of anthocyanin compounds was almost stable (50 to 60% loss), resulting in significantly lower anthocyanin content during the study. Chaovanalikit and Wrolstad (2004b) also reported a substantial loss of anthocyanin (42%) in canned cherries after 5-month storage at 22°C. In contrast, the degradation rate was higher at early storage points for Concord juices, resulting in a significant decrease in anthocyanin content between 0 and 12 weeks but not between 12 and 24 weeks storage. This result was consistent with the report of Sistrunk and Cash (1974). Montgomery (1982) also reported a decrease in anthocyanin content during the storage of clear Concord juices.

All pulpy juices had a significantly higher anthocyanin content than clear juices. Pulpy tart cherry juices were 15 to 25% higher than clear juice at 0 weeks and ended 40% higher at 24 weeks storage. Pulpy Concord juices had almost 1.5 times the anthocyanin content of clear juices for the entire study. It is also worth noting that Montmorency pulpy juices made from a shear mixer had significantly higher anthocyanins than those from a turbo extractor, but there was no significant difference in anthocyanin content between pulpy Concord juices made from different screen sizes of turbo extractor.

The reduction of antioxidant capacity and phenolic content (7 to 25%) was not nearly as great as the loss of anthocyanins (31 to 62%) which may result in color or quality loss in juice. One possible explanation is that degraded anthocyanins and other phenolic compounds still had some phenolic structure and retained antioxidant capacity.

### ***Polymeric Color***

Percentage polymeric color of juices at 0, 12, and 24 weeks storage is shown in Figures 2.15 and 2.16. The pattern of change over storage time was different between clear and pulpy juices. The percentage polymeric color was almost stable in pulpy tart cherry juices whereas the polymeric color in pulpy Concord juices was significant different between 0 and 12 weeks storage but not between 12 and 24 weeks.

The percent polymeric color in clear tart cherry juices increased significantly over the storage time, as opposed to those in Concord clear juices which increased significantly from 0 to 12 weeks but remained constant after that. The percent polymeric color in pulpy juices was significantly higher than clear juice at 0 and 12 weeks for tart cherries and at 0 weeks for Concord; however, at the end of shelf-life study, there was no significant difference between clear and pulpy juices of the same fruits. This was due to the differences in changing pattern over storage time between clear and pulpy juices.

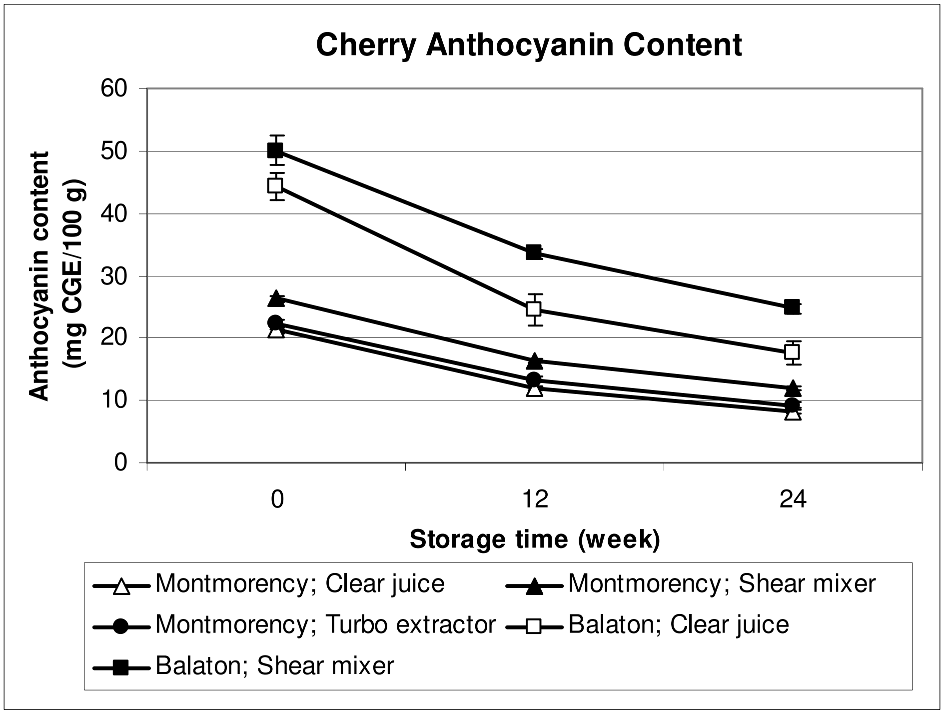

**Figure 2.13**. Anthocyanin content of tart cherry juices during the shelf-life study at 18°C

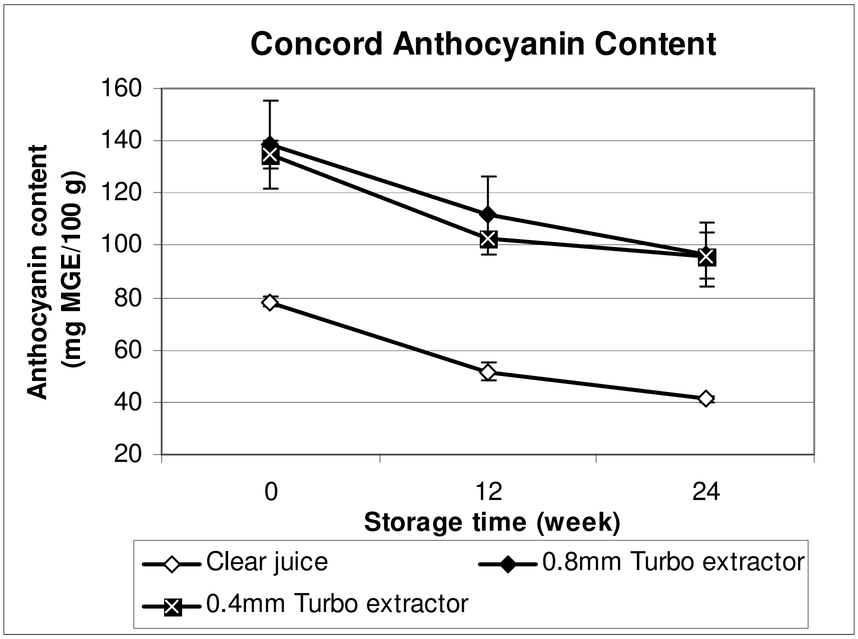

**Figure 2.14**. Anthocyanin content of Concord grape juices during the shelf-life study at 18°C

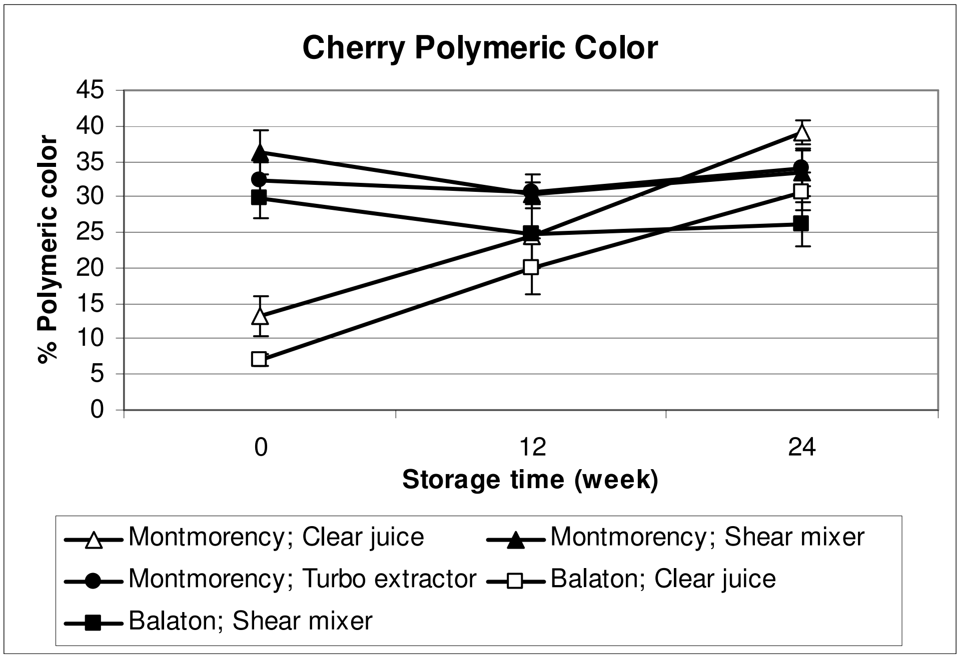

**Figure 2.15**. Polymeric color of tart cherry juices during the shelf-life study at 18°C

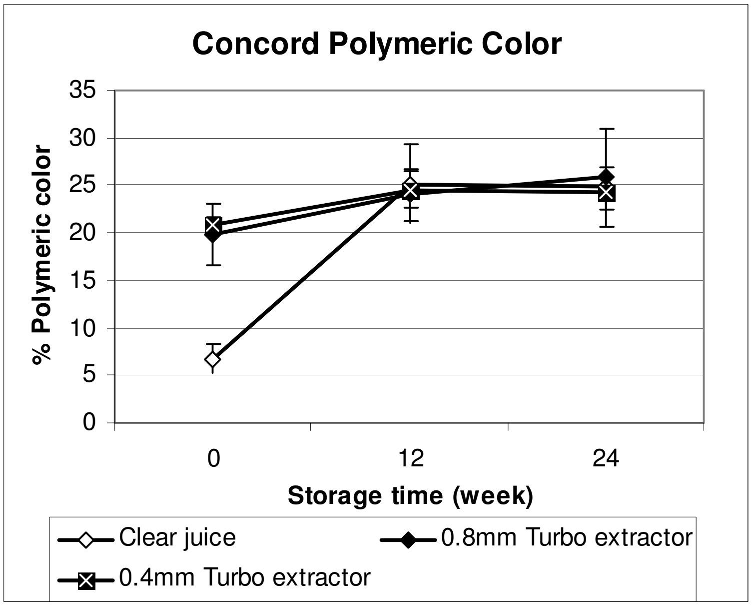

**Figure 2.16**. Polymeric color of Concord grape juices during the shelf-life study at 18°C

### *Color*

The changes in the L value of juices during the shelf-life study ar shown in Figure 2.17. Pulpy juices had a significantly higher L value compared to that of clear juices of their counter part, indicating that clear juices were darker than pulpy juices. When looking at processing treatments, type of extractors, a high shear mixer or a turbo extractor, and screen sizes of a turbo extractor all had a significant effect on L value. There was an increasing trend of the L value over time in all pulpy juices and this could due to color loss from anthocyanin degradation over time. Kalbasi and Cisneros-Zevallos (2007) reported that lightness in color related linearly to monomeric anthocyanin content. There was no significant change of the L value in any clear juices even though the anthocyanin content lowered over time. One possible explanation is that the significant increase in percent polymeric color might mitigate the loss of L value from anthocyanin degradation in clear juices.

The Hunter color a' and b' values are shown in Table 2.5. Pulpy juices had a significantly higher a' and b' value than clear juices but there was no significant difference in a' and b' values among pulpy juices from the same fruit. The data is in agreement with the visual color. Pulpy juices were more reddish and less bluish than clear juices. There was no significant change over time in the a' value of juices made from Montmorency tart cherry and Concord grape. The a' value of Balaton clear juices decreased over time, but an increasing trend was observed in pulpy juices.

The changes in b' value of clear juices were opposite to those of pulpy juices. The b' value decreased over the storage time in clear juices while an increasing trend was observed in pulpy juices. The changes in the color of pulpy juices could be attributed to polymeric pigments. Rentzsch and others (2007) reported that formation of polymeric pigments had the highest impact (>80%) on the overall color of aged tart cherry juices, compared to anthocyanins and 5-carboxy-pyranoanthocyanins.

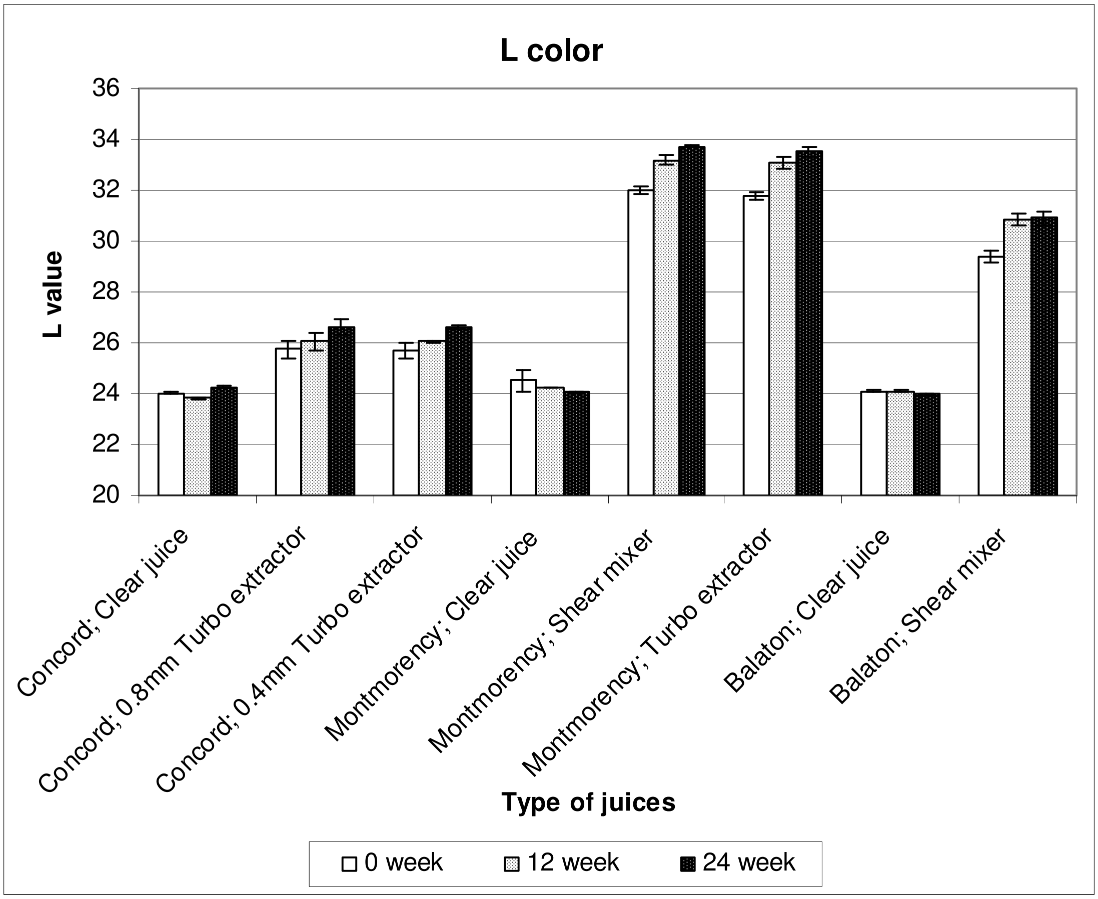

**Figure 2.17**. L value of tart cherry and Concord grape juices during the shelf-life study at 18°C

### D. Sensory Evaluation

Sensory evaluation results from the acceptance and ranking tests are shown in Tables 2.6 to 2.7. There was no significant difference in acceptance for any attributes of Montmorency juices at 0 weeks of storage; however, clear juices became better accepted in color, mouthfeel, and overall acceptability at 24 weeks storage. Clear Balaton juices had significantly higher acceptance scores for all attributes at both 0 and 24 weeks of storage. There was no difference in the acceptance of any attribute, except color, among Concord juices at 0 weeks, but at 24 weeks storage, clear juices got a better acceptance for all attributes compared to pulpy juices.

**Table 2.5**. Hunter color a' and b' value of tart cherry and Concord grape juices during the shelf-life study at 18°C

| Variety | Treatment | Time (week) | Color a | Color b |
|---|---|---|---|---|
| Tart cherry cv. Balaton | Clear juice | 0 | 1.10 ± 0.03 | -0.49 ± 0.05 |
| | | 12 | 0.47 ± 0.11 | -0.64 ± 0.05 |
| | | 24 | 0.65 ± 0.08 | -0.88 ± 0.04 |
| | Shear mixer | 0 | 14.29 ± 0.40 | 2.67± 0.15 |
| | | 12 | 17.22 ± 0.27 | 3.88 ± 0.22 |
| | | 24 | 16.37 ± 0.24 | 3.36 ± 0.07 |
| Tart cherry cv. Montmorency | Clear juice | 0 | 1.05 ± 0.12 | -0.48 ± 0.05 |
| | | 12 | 1.00 ± 0.05 | -0.43 ± 0.05 |
| | | 24 | 0.80 ± 0.07 | -0.85 ± 0.05 |
| | Shear mixer | 0 | 16.55 ± 0.44 | 4.50 ± 0.20 |
| | | 12 | 16.97 ± 0.37 | 5.41 ± 0.17 |
| | | 24 | 16.69 ± 0.22 | 5.63 ± 0.06 |
| | Turbo extractor | 0 | 17.18 ± 0.24 | 4.72 ± 0.15 |
| | | 12 | 17.26 ± 0.81 | 5.45 ± 0.30 |
| | | 24 | 15.73 ± 0.28 | 5.25 ± 0.14 |
| Concord grape | Clear juice | 0 | -0.03 ± 0.08 | -0.69 ± 0.10 |
| | | 12 | 0.13 ± 0.03 | -1.01 ± 0.04 |
| | | 24 | 0.00 ± 0.04 | -1.13 ± 0.05 |
| | 0.8 mm Turbo extractor | 0 | 5.72 ± 0.63 | -0.20 ± 0.08 |
| | | 12 | 6.44 ± 0.80 | 0.03 ± 0.10 |
| | | 24 | 6.36 ± 0.82 | -0.34 ± 0.10 |
| | 0.4 mm Turbo extractor | 0 | 5.52 ± 0.14 | -0.23 ± 0.11 |
| | | 12 | 6.22 ± 0.20 | 0.04 ± 0.05 |
| | | 24 | 6.20 ± 0.18 | -0.26 ± 0.06 |

The ranking test gave a very promising result for pulpy juices. For both Balaton and Concord juices, panelists ranked clear juices the same as pulpy juices in both flavor intensity and preference. This suggested that the acceptance test for clear

**Table 2.6**. Acceptance test results of tart cherry and Concord grape juices at 0 and 24 weeks of storage at 18°C

| Variety/ Treatment | Attribute Score | | | |
|---|---|---|---|---|
| | Color | Flavor | Mouthfeel | Overall Acceptability |
| Tart cherry cv. Balaton | | | | |
| *0 Week* | | | | |
| Clear juice | 6.3 ± 0.9 a | 5.2 ± 1.5 a | 5.3 ± 1.4 a | 5.4 ± 1.4 a |
| Shear mixer | 5.7 ± 1.3 b | 5.0 ± 1.4 a | 4.3 ± 1.9 b | 4.8 ± 1.5 a |
| *24 Week* | | | | |
| Clear juice | 6.4 ± 0.8 a | 5.5 ± 1.4 a | 5.6 ± 1.2 a | 5.5 ± 1.3 a |
| Shear mixer | 4.8 ± 1.5 b | 4.2 ± 1.9 b | 3.6 ± 1.7 b | 3.9 ± 1.6 b |
| Tart cherry cv. Montmorency | | | | |
| *0 Week* | | | | |
| Clear juice | 6.0 ± 1.6 a | 5.3 ± 1.6 a | 5.3 ± 1.5 a | 4.8 ± 1.7 a |
| Shear mixer | 5.3 ± 1.6 a | 5.4 ± 1.9 a | 5.0 ± 1.6 a | 5.1 ± 1.9 a |
| Turbo extractor | 5.4 ± 1.4 a | 5.4 ± 1.2 a | 4.8 ± 2.0 a | 4.9 ± 1.4 a |
| *24 Week* | | | | |
| Clear juice | 6.5 ± 0.8 a | 5.3 ± 1.3 a | 5.7 ± 1.2 a | 5.5 ± 1.1 a |
| Shear mixer | 4.5 ± 1.4 b | 4.7 ± 1.3 a | 3.8 ± 1.9 b | 4.2 ± 1.4 b |
| Turbo extractor | 4.3 ± 1.5 b | 4.9 ± 1.5 a | 4.5 ± 1.6 b | 4.4 ± 1.2 b |
| Concord grapes | | | | |
| *0 Week* | | | | |
| Clear juice | 6.5 ± 0.9 a | 5.8 ± 1.1 a | 5.8 ± 1.4 a | 5.6 ± 1.3 a |
| 0.8mm Turbo extractor | 5.3 ± 1.5 b | 5.4 ± 1.6 a | 5.0 ± 1.7 a | 4.7 ± 1.7 a |
| 0.4mm Turbo extractor | 5.2 ± 1.4 b | 5.1 ± 1.8 a | 4.8 ± 2.1 a | 4.7 ± 1.9 a |
| *24 Week* | | | | |
| Clear juice | 6.2 ± 1.1 a | 6.1 ± 0.8 a | 6.2 ± 1.0 a | 5.9 ± 1.0 a |
| 0.8mm Turbo extractor | 5.0 ± 1.4 b | 4.5 ± 1.4 b | 4.2 ± 1.8 b | 4.7 ± 1.3 b |
| 0.4mm Turbo extractor | 5.3 ± 1.3 b | 4.8 ± 1.5 b | 4.6 ± 1.8 b | 4.2 ± 1.4 b |

For each fruit in each column at each storage time, the values followed by different letters are significantly different

**Table 2.7**. Ranking test results of tart cherry and Concord grapes juices at 0 and 24 weeks of storage at 18°C

| Variety | Time (week) | Treatment | Flavor intensity | Preference |
|---|---|---|---|---|
| Tart cherry cv. Balaton | 0 | Clear juice | 1.4 ± 0.5 a | 1.4 ± 0.5 a |
| | | Shear mixer | 1.5 ± 0.5 a | 1.6 ± 0.5 a |
| | 24 | Clear juice | 1.4 ± 0.5 a | 1.2 ± 0.4 a |
| | | Shear mixer | 1.4 ± 0.5 a | 1.8 ± 0.4 a |
| Tart cherry cv. Montmorency | 0 | Clear juice | 1.8 ± 0.8 a | 1.9 ± 0.8 ab |
| | | Shear mixer | 1.9 ± 0.8 a | 1.8 ± 0.9 b |
| | | Turbo extractor | 1.9 ± 0.9 a | 2.4 ± 0.7 a |
| | 24 | Clear juice | 1.7 ± 0.9 a | 1.4 ± 0.7 b |
| | | Shear mixer | 2.0 ± 0.9 a | 2.6 ± 0.7 a |
| | | Turbo extractor | 1.8 ± 0.7 a | 2.2 ± 0.7 a |
| Concord grape | 0 | Clear juice | 2.4 ± 1.3 a | 2.0 ± 0.9 a |
| | | 0.8 mm Turbo extractor | 2.0 ± 1.2 a | 2.1 ± 0.8 a |
| | | 0.4 mm Turbo extractor | 2.3 ± 1.2 a | 1.9 ± 0.8 a |
| | 24 | Clear juice | 1.8 ± 0.9 a | 1.6 ± 0.8 b |
| | | 0.8 mm Turbo extractor | 2.2 ± 0.7 a | 2.3 ± 0.7 a |
| | | 0.4 mm Turbo extractor | 1.8 ± 0.8 a | 2.2 ± 0.8 a |

For each fruit in each column at each storage time, the values followed by different letters are significantly different

and pulpy juices was not a good indicator of preference. Only clear Montmorency juices showed better preference results compared to pulpy juices. The acceptance and ranking test imply that mouthfeel was one of the main factors affecting overall acceptability and preference. When clear juices received higher scores in mouthfeel than pulpy juices, they also had better overall acceptability and preference.

It is also worth noting that pulpy juices made from a high shear mixer and a turbo extractor were rated equally in both acceptance and ranking tests. Also, pulpy juices made from different screen sizes were rated equally in all attributes of the acceptance and ranking tests.

## Conclusion

The pattern of quality changes in juices over time was different depending on processing treatments and fruit varietal. In general, pulpy juices had higher phenolic and anthocyanin content, and antioxidant capacity than clear juices. In pulpy Concord grape juices, the phenolic and anthocyanin content, and antioxidant capacity was comparable to those of whole fruits. Furthermore, the pectin content in pulpy juices was comparable to that of whole fruits, and there was almost none in clear juices. From the sensory point of view, there was no difference between clear and pulpy in overall acceptability and preferences at 0 weeks, but after 6 months of storage, clear juices had a higher overall acceptability than pulpy juices. Pulpy Balaton and Concord juices were preferred equally to clear juice after the shelf-life study. It is also worth noting that the quality, both in terms of chemical analysis and sensory evaluation, of pulpy juices made from different type of extractors or screen sizes of turbo extractor was the same. In all, pulpy juices could be a healthy fruit juice product if the processing is optimized.

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# CHAPTER 3

# APPLE JUICES

## Abstract

Three varieties of red apples, Cortland, Empire, and McIntosh, and one variety of yellow apples, Golden Delicious were selected to produce a pulp-rich apple juice (pulpy juices) using a turbo extractor with different treatments. Quality of fruits and juices were evaluated and pulpy juices were compared to traditional clear juices during the 24-week storage at 18°C. The processing slightly decreased total phenolic content and antioxidant capacity of pulpy juices but considerably decreased these compounds in clear juices. Pulpy juices with a blanching treatment retained 80 to 100% of phenolic compounds and antioxidant capacity whereas pulpy juices without a blanching treatment retained up to 95%. In contrast, the percent retention was only 27 to 59% in clear juices. Compared to clear juices, total phenolic content and antioxidant capacity in pulpy juices was 1.4 to 3.6 times that of clear juices during the 24-week storage study at 18°C. The pectin content of pulpy juices was also comparable to that of whole fruits, but there was almost none in the clear juices. Sensory evaluation showed that pulpy juices were considered acceptable products from the consumer's viewpoint. Pulpy juices could provide a healthy fruit juice option if the processing is optimized.

## Introduction

According to the Noncitrus Fruits and Nuts 2007 Preliminary Summary (NASS, 2008), apples were the second leading noncitrus fruit in the US after grapes. In 2007, the utilized production of apples was 4.65 million tons, accounting for 28% of the nation's utilized production for noncitrus crops. The value of utilized production of apple was 2.4 billion dollars, 22% of the total value for noncitrus crops. New York State was the second leading apple producing state after Washington. The utilized production of apples in New York State was 4.65 billion tons, 12.3% of the nation's utilized production. Apples were ranked third in New York State based on cash receipts for commodities in 2006 (ERS, 2007).

The health benefits of apples and apple products have been known for many years. Recently, apples' healthy attributes have received considerable renewed interest, following the publication of several studies linking apple nutrients to an impressive range of health benefits. Research has shown that apples helped reduce the risk of cancer and coronary heart disease, control weigh loss, and improve memory and learning (USApple, 2008).

Clear apple juice processing considerably decreases the phenolic content and antioxidant capacity of the fruit (Oszmianski and others, 2007; Will and others, 2002). Moreover, apple products in general had lower antioxidant activity and phenolic content than fresh fruit (Sacchetti and others, 2008). Apple peels were richer in polyphenolic compounds and antioxidant capacity than flesh (Drogoudi and others, 2008; Chinnici and others, 2004; Schieber and others, 2003). Pectin content, a major soluble fiber in fruit, was high in apple pomace (Schieber and others, 2003). Therefore, apple pomace, a by-product of apple juice processing, is a rich source of fiber, polyphenols, and antioxidants (Sudha and other, 2007; Lu and Foo, 2000, 1997). Studies have suggested apple pomace as a potential food ingredient to increase the nutrition value to food products (Sudha and other, 2007; Carson and others, 1994). Moreover, Will and others (2000) reported that apple juices subjected to a pomace liquefaction using pectinase enzyme showed a 30 to 50% increase in phenolic content without any increase in browning.

However, there have not yet been any studies of apple juices processed to retain a high percent of apple peel and pulp. Our study was aimed at producing a healthy shelf-stable juice, pulpy juice, that retained nutritious compounds in amounts comparable to those found in whole fruits. A turbo extractor with fine screens and enzymatic treatment were used to incorporate apple peel and pulp. In this study, we developed pulpy juices from four varieties of apple: Cortland, Empire, Golden Delicious, and McIntosh, and evaluated storage quality of pulpy juices against clear juices for 24 weeks of storage at 18°C.

## Materials

### A. Chemicals

Folin-Ciocalteu's phenol reagent, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) as diammonium salt, 85% m-hydroxydiphenyl, galacturonic acid, and gallic acid were obtained from Sigma-Aldrich, Inc. (St. Louis, MO). AAPH (2,2'-azobis(2-amidino-propane) dihydrochloride) was obtained from Wako Chemicals USA, Inc. (Richmond, VA). All other chemicals used were analytical or high performance liquid chromatography (HPLC) grade.

### B. Raw Material

Apples cv. Cortland, Empire, Golden Delicious, and McIntosh were obtained from the New York State Agricultural Experiment Station Orchards, Geneva, NY,. Apples were harvested (at maturity as recommended by a horticulture specialist) during each cultivar's harvesting season and then kept at 2°C until ready to process.

## Methods

### A. Processing

Apples from each cultivar were made into clear juices (CJ) and three different types of pulpy juices, control (PC), blanching (PB), and blanching with enzymatic treatment (PE). Prior to processing, apples were sliced using an apple slicer (Dicer, Strip cutter, and Slicer Model G, Urschel Laboratories Inc., Valparaiso, IN) and dipped into an acid solution (1.3% w/w citric acid and 0.2% w/w ascorbic acid) for 30 seconds to prevent browning. Two batches of juice were prepared for each processing treatment. The °Brix of juices from different batches of the same processing treatment were adjusted with water so that the °Brix difference was in the range of ± 0.5 before pasteurization. All juices were pasteurized at 87°C using a UHT/HTST Lab-25 HV heat exchanger (Micro Thermics Inc., Raleigh, NC) and hot packed into 10 fluid ounce bottles. Juices were held hot for 3 minutes before cooling. Juice samples were stored at 18°C and protected from the light until ready for analysis.

#### Juice Processing: prior to pasteurization and bottling

***Clear Juice***

Apples were processed into juices following standard laboratory procedures that simulate industrial processing (McLellan and Padilla Zakour 2004). Apple slices were ground by a hammer mill (Comminuting Machine Model D, the W.J. Fitzpatrick Co., Chicago, IL) using a half inch screen size (fit no.5) at the maximum speed. Cloudy apple juices were obtained by pressing the puree using a small hydraulic rack and frame press (Orchard Equipment Co., Conway, MA) with press cloth at 1250 psi. A mixture of pectinase and hemicellulase enzymes (Rapidase® ADEX-D, DSM Food Specialties USA, Inc., Charlotte, NC) was added to cloudy juices at the rate of

150 g/ton of apple. Juices were held at room temperature for an hour for complete depectinization before being filtered by a Shriver Plate and Frame Filter size 7 (T. Shriver & Co., Inc., Harrison, NJ) using a Celite® Diatomite Grades Filter Aid no. 503 (World Minerals Inc., Santa Barbara, CA) as a filter aid.

### *Pulpy Juice: Control Processing (Without Blanching)*

Apple slices were finely ground to obtain pulpy juices using a turbo extractor, Bertocchi model CX5 (Bertocchi SLR., Parma, Italy), at 1500 rpm with 0.4 mm screen size and three-quarter turn gap.

### *Pulpy Juice: Blanching Processing*

Apple slices were blanched at 110°C with a customized steam blancher (NYSAES Machine Shop, Cornell University, Geneva, NY) setting the speed at 2.5 to achieve a final apple slice temperature of 87°C. Blanched apples were finely ground to obtain pulpy juices using a turbo extractor, Bertocchi model CX5 (Bertocchi SLR., Parma, Italy), at 1500 rpm with 0.4 mm screen size and three-quarter turn gap.

### *Pulpy Juice: Blanching Processing with Enzymatic Treatment*

Apple slices were blanched and finely ground using a turbo extractor, Bertocchi model CX5 (Bertocchi SLR., Parma, Italy) following the same procedure for blanched pulpy juice processing. A mixture of the enzymes pectinase and hemicellulase (Rapidase® ADEX-D, DSM Food Specialties USA, Inc., Charlotte, NC) was added to pulpy juices at the rate of 500 g/ton of apple. Juices were held at room temperature for an hour to allow for the depectinization process and the mixture of enzyme alpha-amylase and amyloglucosidase (Hazyme® C, DSM Food Specialties

USA, Inc., Eagleville, PA) was then added to the juice at the rate of 10 g/ton of apple. Apple juices were held at room temperature for another hour before pasteurization.

## B. Chemical Analysis

### *Juice Analysis*

Freshly prepared juices were analyzed for total soluble solids (TSS), pH, titratable acidity (TA), percent dry content, viscosity, and pectin content. All analyses were conducted following procedures described in chapter 2 and measurements were done in duplicate to represent the experimental units for each batch of processing treatments. The TA of juices was measured following the AOAC titration method 37.1.37B (AOAC International, 2000a) and expressed as g malic acid per 100 g sample. The dry content in juices was measured using the AOAC vacuum drying method 44.1.03A (AOAC, 2000b).

The viscosity of clear juices was measured using the Cannon-Fenske Routine Capillary Viscometer (Cannon Instrument Company Inc., State College, PA) while the viscosity of pulpy juices was determined by Vane yield method (Genovese and Rao, 2003; Rao and Cooley, 1984; Rao, 1975) explained in chapter 2. All tests were conducted at 25°C and the viscosity was reported in Centipoise (cp). During the flow test of Vane yield method, a continuous average shear rate ($\dot{\gamma}$) from 0 to 20 $s^{-1}$ was applied. The magnitudes of shear stress ($\sigma$) and shear rate ($\dot{\gamma}$) were recorded on the computer and the Casson model was used to calculate the viscosity.

Pectin content was measured by the colorimetric assay using m-hydroxydiphenyl (Kintner and Buren, 1982) with a slight modification including the precipitation of pectin with 80% isopropanol (May, 1990) (details in chapter 2) and reported as mg galacturonic acid (mg GA) per 100 g juice.

### *Whole Fruit Analysis*

The dry content of whole fruits was determined using the lyophilization process explained in chapter 2. Freshly prepared juices from whole fruits (procedures described in chapter 2) were analyzed for TSS, pH, and TA. Prior to the analysis of total phenolic contents and antioxidant capacities, apple whole fruits were subjected to the extraction with methanol (Kim and Lee, 2002) following procedures described in chapter 2.

Total phenolic content was measured using the Folin-Ciocalteu (FC) reagent assay (Singleton and Rossi, 1965) with some modifications and reported as mg gallic acid equivalent (GAE) per 100 g fruit. The antioxidant capacity was determined from whole fruit extracts using the 2,2'-azino-bis (3-ethylbenzthiazoline-6-sulfonic acid) diammonium salt (ABTS) assay (Van den Berg and other, 1999) as described in chapter 2. Antioxidant capacity was expressed as mg Vitamin C Equivalent Antioxidant Capacity (VCEAC) per 100 g fruit. Pectin content of whole fruit was measured by the m-hydroxydiphenyl assay (Kintner and Buren, 1982) and reported as mg galacturonic acid (mg GA) per 100 g fruit (details in chapter 2).

The measurements for all analyses were conducted in duplicate or triplicate, as appropriate, to represent the experimental units for each batch of processing treatments.

### *Shelf-life Study of Juices*

The shelf-life study of juices was conducted over 24 weeks at 18°C and all analyses were conducted at 0, 12, and 24 weeks of storage. Only clear juice was measured for turbidity using a Hach 2100P Turbidimeter (Hach Co, Loveland, CO) and reported in Nephelometric Turbidity Units (NTU).

All juices were measured for color, total phenolic content, and antioxidant capacity following procedures described in chapter 2.

The percent settled solids of all juices, except juices with a blanching treatment (PB), was determined using the spin solids method described by Padilla-Zakour and McLellan (1993) (details in chapter 2).

All measurements were conducted in duplicate or triplicate, as appropriate, for each batch of processing treatments.

## C. Sensory Evaluation

The sensory evaluation of apple juices was conducted at 0 and 24 weeks storage using the acceptance and ranking test. For each variety, 24 panelists were asked to test three different types of juices; CJ, PC, and PE. Prior to both tests, juices from the same processing treatment were mixed and juices were served at room temperature in random order.

### *Acceptance Test*

The 7-point hedonic scale (Lawless and Heymann, 1999c) was used to assess the acceptability of juices in 4 attributes; color, flavor, mouthfeel, and overall acceptability.

### *Ranking Test*

Panelists were asked to rank apple flavor intensity and preference for different types of juices from the same apple variety.

## D. Statistical Analysis

Results were reported in means ± standard deviations of each apple variety, each processing treatment, and each storage time. All data were subjected to analysis of variance (ANOVA) and means were compared with the Tukey Significant Difference test at 95% confidence interval using JMP® 7.0 statistical software package (SAS institute Inc., Cary, NC).

For sensory evaluation, means of each attribute in the acceptance test were also subjected to ANOVA and compared using the Tukey Significant Difference test at 95% confidence interval using JMP® 7.0 statistical software package. Since the data obtained from the ranking test is nonparametric, the Friedman test was used to analyze the data and the mean comparison was made using the Least Significant Ranked Difference (LSRD) test at a 95% confidence interval (Lawless and Heymann, 1999a, 1999b).

## Results and Discussion

### A. Juice and Whole Fruit Characteristics

#### *Total Soluble Solids, pH, Titratable Acidity, and Percent Dry Content*

Table 3.1 shows TSS, pH, TA, and percent dry content of whole fruit and apple juices. Compared within the same variety, the percent dry content of whole fruits was highest followed by PB, PE, PC, and CJ. The same trend was also observed in the TSS value. This not only indicated that pulpy juices had more solid material than clear juices, but also showed that pulpy juices from blanching treatments (both PB and PE) had higher solid content than those without blanching treatments (PC).

The pH, TA, and TSS of whole fruits and juices were in the same range for all varieties. The pH ranged from 3.14 to 3.67 while the TA was in the range of 0.52 to 0.92. The TSS was in the range of 11.4 to 16.9 °Brix. All of pH, TA, and TSS values were in consistent with values previously reported (Drogoudi and others, 2008; Lee and Mattick, 1989; Way and McLellan, 1989; Smock and Neubert, 1950a, 1950b).

**Table 3.1**. pH, titratable acidity, soluble solids, and percent dry content of whole apples and apple juices

| Variety | Treatment[1] | pH | Titratable acidity[2] | Soluble solids (°Brix) | % Dry content[3] |
|---|---|---|---|---|---|
| Cortland | WF | 3.39 ± 0.02 | 0.77 ± 0.12 | 15.79 ± 0.03 | 17.54 ± 0.00 a |
| | CJ | 3.27 ± 0.00 | 0.73 ± 0.00 | 12.63 ± 0.23 | 14.86 ± 0.03 d |
| | PC | 3.21 ± 0.01 | 0.65 ± 0.01 | 12.96 ± 0.05 | 15.35 ± 0.07 c |
| | PE | 3.20 ± 0.01 | 0.72 ± 0.00 | 14.45 ± 0.08 | 15.62 ± 0.21 b |
| | PB | 3.37 ± 0.02 | 0.61 ± 0.04 | 13.52 ± 0.04 | 16.61 ± 0.02 b |
| Empire | WF | 3.40 ± 0.01 | 0.65 ± 0.07 | 14.63 ± 0.09 | 16.24 ± 0.00 a |
| | CJ | 3.23 ± 0.04 | 0.85 ± 0.00 | 11.91 ± 0.09 | 13.84 ± 0.07 d |
| | PC | 3.14 ± 0.01 | 0.77 ± 0.02 | 11.92 ± 0.09 | 13.88 ± 0.21 d |
| | PE | 3.19 ± 0.02 | 0.78 ± 0.01 | 14.02 ± 0.37 | 14.46 ± 0.04 c |
| | PB | 3.32 ± 0.00 | 0.66 ± 0.05 | 13.06 ± 0.05 | 14.89 ± 0.11 b |
| Golden Delicious | WF | 3.67 ± 0.00 | 0.63 ± 0.05 | 16.87 ± 0.05 | 17.99 ± 0.00 a |
| | CJ | 3.34 ± 0.05 | 0.65 ± 0.02 | 13.62 ± 0.21 | 15.84 ± 0.02 c |
| | PC | 3.33 ± 0.01 | 0.63 ± 0.01 | 13.95 ± 0.44 | 16.22 ± 0.10 c |
| | PE | 3.33 ± 0.00 | 0.65 ± 0.02 | 16.11 ± 0.09 | 16.46 ± 0.03 b |
| | PB | 3.58 ± 0.01 | 0.52 ± 0.02 | 15.03 ± 0.34 | 17.32 ± 0.04 b |
| McIntosh | WF | 3.40 ± 0.01 | 0.87 ± 0.09 | 13.75 ± 0.03 | 15.94 ± 0.00 a |
| | CJ | 3.20 ± 0.01 | 0.80 ± 0.05 | 11.36 ± 0.10 | 12.73 ± 0.11 d |
| | PC | 3.27 ± 0.02 | 0.63 ± 0.01 | 11.71 ± 0.08 | 13.22 ± 0.04 c |
| | PE | 3.14 ± 0.00 | 0.92 ± 0.02 | 13.07 ± 0.32 | 13.68 ± 0.21 b |
| | PB | 3.26 ± 0.02 | 0.77 ± 0.03 | 12.69 ± 0.18 | 14.22 ± 0.04 b |

1: WF- whole fruit, CJ- clear juice, PC- pulpy control, PE-pulpy enzyme, PB- pulpy blanch
2: Titratable acidity was expressed as g malic acid per 100 g
3: For each variety, the values followed by different letters are significantly different

### *Viscosity*

The viscosity of apple juices is presented in Table 3.2. McIntosh juices had the highest viscosity while Empire juices had the lowest. Processing treatments had a significant effect on viscosity. Clear juices had the lowest viscosity followed by PC and PE, and PB. The difference in viscosity for juices was a result of the concentration, size, and shape of suspended particles (Saravacos, 1970). Also, Genovese and Lozano (2000) reported that viscosity of apple juices increased as the soluble solids or the soluble pectin content increased. The viscosity of clear juices ranged from 1.18 to 1.25 cp which was in agreement with values for McIntosh clear juices reported by Bonsi (2005) but was lower than values (1.5 to 1.7 cp) reported by Smock and Neubert (1950a).

**Table 3.2**. Viscosity of clear and pulpy apple juices

| Variety | Viscosity (cp) | | | |
|---|---|---|---|---|
| | Clear juice | Pulpy control | Pulpy enzyme | Pulpy blanch |
| Cortland | 1.20 ± 0.00 d | 31.8 ± 3.1 c | 30.9 ± 4.2 b | 217.0 ± 3.7 a |
| Empire | 1.21 ± 0.03 c | 13.9 ± 1.5 b | 22.3 ± 1.7 b | 165.1 ± 2.1 a |
| Golden Delicious | 1.25 ± 0.03 b | 19.8 ± 4.1 b | 21.3 ± 1.7 b | 213.2 ± 0.8 a |
| McIntosh | 1.18 ± 0.02 c | 29.7 ± 4.3 b | 35.7 ± 0.2 b | 246 ± 17 a |

For each variety, the values followed by different letters are significantly different

Furthermore, the viscosity of PE was not significantly different than that of PC for any variety except Empire. The viscosity of PB for all varieties ranged from 165.1 to 246.5 cp which was in the range of apple sauce viscosity (240 cp) reported by Bonsi (2005). Kaur and others (2007) reported the viscosity of tomato juices ranging from 13.0 to 25.0 cp. The viscosity of PC and PE made from Empire and Golden Delicious (13.9 to 22.3 cp) was consistent with values reported by Kaur and others (2007), while the viscosity of PC and PE made from Cortland and McIntosh (29.7 to 35.7 cp) was slightly higher. Based on the viscosity, PC and PE treatments gave products that had a viscosity similar to that of tomato juices while products from PB treatments was more similar to apple sauces.

## B. Effect of Processing

### *Total Phenolic Content*

Figure 3.1 shows total phenolic content in whole fruit and juices at 0 weeks of storage. Samples from McIntosh had the highest phenolic content followed by those from Cortland, Golden Delicious, and Empire. Clear juices had significantly lower phenolic content than the pulpy juices and whole fruit of their counterparts. The loss of phenolic compounds in clear juices could due to depectinization. Total phenols in all clear juices except Empire clear juices were higher than that of commercial apple juices (34 mg GAE/100 g) (Gardner and others, 2000).

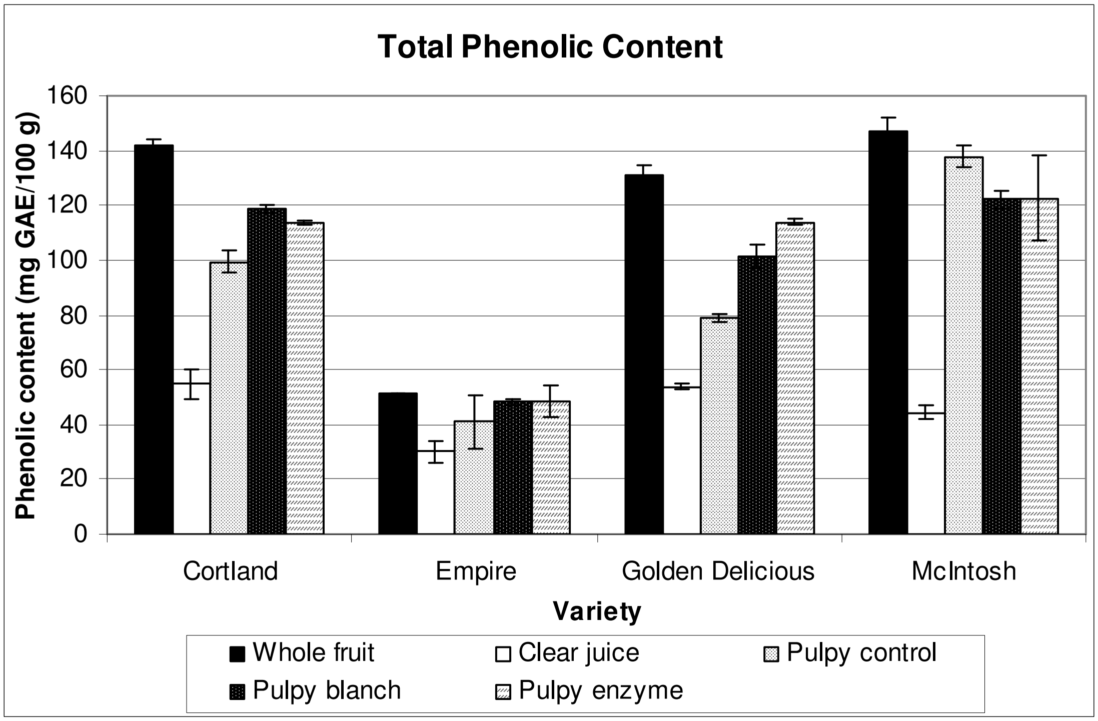

**Figure 3.1**. Phenolic content of apples and their juices

The effects of processing were different depending on variety. McIntosh clear juice processing reduced phenolic content by 70% while pulpy juice processing did not significantly change phenolic content. Empire PB and PE juices retained almost 95% of phenolic content while PC and clear juice processing significantly reduced (20% loss) phenolic content. Phenolic content of Empire whole fruit and clear juices were 29 to 38% higher than values reported by Bonsi (2005) and were 10% higher for McIntosh samples.

Total phenolic content of each type of Golden Delicious juice were significantly different. Phenolic content was highest in Golden Delicious PE followed by PB, PC, and CJ, and the percentage loss was 13, 23, 40, and 59% respectively. Phenolic content of Cortland PE was not significantly different than that of PB and PC, but phenolic content of PC was significantly lower than that of PB. The percent retention of phenolic content in Cortland PB, PE, PC, and CJ was 84, 80, 70, and 38% respectively.

Compared to clear juices, pulpy juices retained a higher amount of phenolic content, especially in the PE and PB processing. Since phenolic content in PE and PB was higher than that of PC, the implication is that the blanching process helped retain more phenolic compounds in the resulting juice. The results coincided with a report from Bonsi (2005) that blanching apples with skins could prevent the loss of total phenolic content.

### ***Antioxidant Capacity***

The antioxidant capacity of apple juices followed the same trend as phenolic content (see Figure 3.2). Bonsi (2005) reported a good relationship ($r^2 = 0.81$ to 0.99) between total phenolic content and antioxidant capacity measured by the ABTS assay in apple products. Other studies also reported a high correlation between phenolic content and antioxidant activity in fruits and their producgts (Kader and Barrett, 2004; Kalt and others, 1999; Wang and others, 1996). Cortland and McIntosh juices had the highest antioxidant capacity while Empire juices had the lowest. Even though Empire juices had the lowest antioxidant capacity, the percent retention after processing was higher than other varieties. Empire and McIntosh whole fruits had 10 to 14% lower antioxidant capacities than values reported by Bonsi (2005).

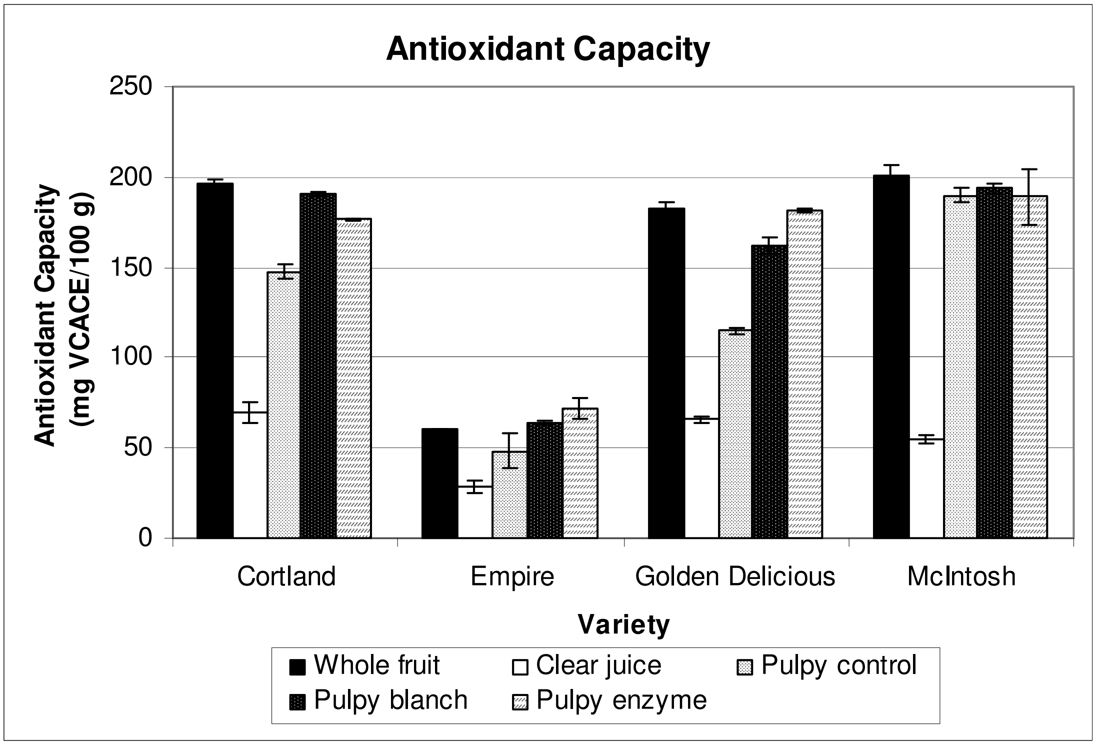

**Figure 3.2**. Antioxidant capacity of apples and their juices

The antioxidant capacity of clear juices of all varieties was significantly lower than that of pulpy juices and whole fruits. This loss of antioxidant was due to the clarification step (Oszmianski and Wojdylo, 2006). PB and PE juices were not significantly different in antioxidant capacities to those of whole fruits, and these finding were consistent with previous study (Bonsi, 2005). The percent loss of antioxidant capacity in McIntosh, Cortland, Golden Delicious, and Empire clear juices was 73, 65, 64, and 53% respectively while the percent loss in PB and PE juices ranged from 0.5 to 11% for all varieties except Empire.

Antioxidant capacities of PC juices were significantly higher than those of clear juices, but were lower than those of PB and PE juices, except in McIntosh juices. The antioxidant capacity of McIntosh PC juices was not significantly different than that of PB and PE juices. The percent retention of antioxidant capacity in PC juices made from McIntosh, Empire, Cortland, and Golden Delicious was 95, 80, 75, and 63% respectively.

### *Pectin Content*

Pectin content, described in mg galacturonic acid per 100 g, is shown in Table 3.3. Cortland and McIntosh had significantly higher pectin content than Empire and Golden Delicious. It is worth noting that pectin content in PB juices were comparable to that of whole fruits in all varieties. The clear juices did not have any pectin at all and this confirmed that the depectinization during processing was complete. There was a significant difference in pectin content between PB and PE juices which implied that the enzymatic treatment significantly reduced the amount of pectin. For Cortland and McIntosh, the PC juices had significantly higher pectin content than PE juices while the opposite trend was observed in Empire and Golden Delicious juices. This implied that the effect of pectin reduction from enzymatic treatment was more pronounced in Empire and Golden Delicious juices.

**Table 3.3**. Pectin content, expressed as galacturonic acid, of apples and their juices

| Treatment | Galacturonic acid (mg/100 g) | | | |
|---|---|---|---|---|
| | Cortland | Empire | Golden Delicious | McIntosh |
| Whole fruit | 279 ± 15 a | 186 ± 18 a | 179 ± 28 a | 273 ± 15 a |
| Clear juice | 0.00 ± 0.00 d | 0.00 ± 0.00 d | 0.00 ± 0.00 d | 0.00 ± 0.00 d |
| Pulpy control | 92.0 ± 4.6 b | 18.1 ± 2.2 c | 32.1 ± 1.2 c | 87.2 ± 2.3 b |
| Pulpy enzyme | 44.9 ± 1.1 c | 28.3 ± 2.4 b | 46.0 ± 2.1 b | 51.9 ± 3.3 c |
| Pulpy blanch | 273.9 ± 4.2 a | 195.1 ± 1.5 a | 160.9 ± 8.9 a | 290.9 ± 2.9 a |

For each variety, the values followed by different letters are significantly different

Since pectin is a major soluble fiber in fruits and it contains 60% galacturonic acid (Constenla and others, 2002), 1 serving (8 fl. oz.) of PB contains 6.4 to 11.6 g pectin contributing to 26 to 46% of recommended dietary fiber intake (25 g). Therefore, PB is an excellent source of dietary fiber and could carry the claim "may reduce the risk of heart disease and some types of cancer" (FDA, 2008). On the other hand, PC and PE contained 0.7 to 3.7 g pectin per 1 serving depending on the variety and processing. Since PC and PE contained more than 0.6 g of soluble fiber, they could carry the claim "may reduce the risk of coronary heart disease" (FDA, 2008). Only Cortland and McIntosh PC were a good source of dietary fiber (contained 14 to 15% of recommended dietary fiber intake); thus, they could also carry the claim "may reduce the risk of some types of cancer" (FDA, 2008).

## C. Shelf-life Study of Juices

### *Turbidity*

The changes in turbidity of clear juices during the shelf-life study were different depending on the variety (Figure 3.3). For all varieties except Empire, the turbidity increased significantly over time at an almost constant rate; however, the turbidity of Empire clear juices was very stable over 24 weeks. One explanation was that the turbidity of Empire clear juices was in the range (2 NTU or less) generally required to produce stable clarified juices while the turbidity of other clear juices was high enough (10 NTU or more) to have a turbidity problem (Van Buren, 1989). The turbidity of clear apple juices was 45 to 70% higher than values reported by Oszmianski and Wojdylo (2006).

The percent increase of turbidity from 0 to 12 weeks storage in McIntosh, Golden Delicious, and Cortland was 59, 64, and 67% respectively, while the percent increase from 12 to 24 storage weeks was 37, 33, and 21%. The increasing trend of

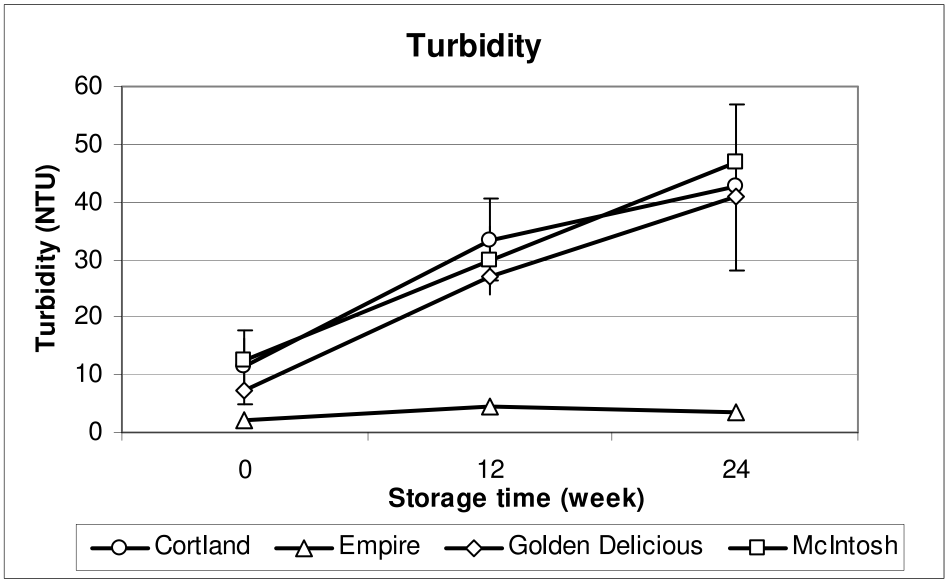

**Figure 3.3**. Turbidity of clear apple juices during the shelf-life study at 18°C

turbidity in clear juices after storage could be a result of tannin hazes which formed slowly from polymerized polyphenolic molecules (McLelland and Padilla-Zakour, 2004). Bonsi (2005) reported that the turbidity of McIntosh clear juices at 0, 12, and 24 weeks of storage was 12, 15, and 36 NTU respectively. Compared to values previously reported, the turbidity of clear juices from all varieties except Empire was in the same magnitude at 0 weeks storage, but was 80 to 100% higher at 12 weeks and 11 to 28% higher at 24 weeks. The differences could be due to apple varieties, harvesting times, and processing methods.

### *Settled Solids*

The percent settled solids of CJ, PC, and PE juices is presented in Table 3.4 but the percent settled solids of PB juices is 100% (data not shown in the table) since there was no separation in any of PB juices after the spin solid method. There was no significant change of percent settled solids over the storage time in any variety.

**Table 3.4**. Percent settled solids of apple juices during the shelf-life study at 18°C

| Variety | Treatment | % Settled Solids | | |
|---|---|---|---|---|
| | | 0 Week | 12 Week | 24 Week |
| Cortland | Clear juice | 0.27 ± 0.05 c | 0.19 ± 0.08 c | 0.31 ± 0.04 c |
| | Pulpy control | 15.9 ± 1.2 b | 15.7 ± 2.0 b | 16.0 ± 2.0 b |
| | Pulpy enzyme | 21.3 ± 1.5 a | 21.3 ± 1.4 a | 20.56 ± 0.93 a |
| Empire | Clear juice | 0.06 ± 0.04 c | 0.01 ± 0.01 c | 0.08 ± 0.00 c |
| | Pulpy control | 7.58 ± 0.64 b | 9.46 ± 0.32 b | 7.84 ± 0.23 b |
| | Pulpy enzyme | 17.58 ± 0.26 a | 16.18 ± 0.33 a | 15.9 ± 1.1 a |
| Golden Delicious | Clear juice | 0.23 ± 0.08 c | 0.35 ± 0.02 c | 0.49 ± 0.00 c |
| | Pulpy control | 9.07 ± 0.47 b | 9.21 ± 0.47 b | 10.8 ± 1.3 b |
| | Pulpy enzyme | 16.8 ± 1.5 a | 16.3 ± 2.2 a | 16.7 ± 1.2 a |
| McIntosh | Clear juice | 0.25 ± 0.07 c | 0.23 ± 0.04 c | 0.46 ± 0.05 b |
| | Pulpy control | 18.98 ± 0.44 b | 20.20 ± 0.84 b | 21.7 ± 1.0 a |
| | Pulpy enzyme | 23.5 ± 1.3 a | 23.8 ± 1.3 a | 21.11 ± 0.63 a |

For each variety in each column, the values followed by different letters are significantly different

Empire and Golden Delicious juices had the lowest percent settled solids while McIntosh juices had the highest.

Clear juices had the lowest settled solids while PE juices had the highest. This coincided with the dry content values. In other words, the higher the dry content, the higher the settled solids. PE juices had a significantly higher percent settled solids than PC juices except for McIntosh juice at 24 weeks of storage. The difference in percent settled solids between PC and PE juices varied depending on the variety. The least difference in settled solids between PC and PE juices was found in McIntosh juices (3 to 17% difference) followed by juices from Cortland (20 to 33%), Golden Delicious (38 to 44%), and Empire (44 to 60%).

### *Color*

The Hunter color L, a’, b’ values are presented in Table 3.5 and 3.6. The changes of L value over time, as an indicator of lightness, were the same for all varieties. The L values of clear juices decreased over time while the values were almost stable with a slight increase for pulpy juices. This indicates that clear juices got darker over time while the lightness of pulpy juices was stable or became lighter. Clear juices were darker (lower L value) than pulpy juices throughout the study. All juices had higher L values (lighter) than those of apple ciders reported by Bonsi (2005). Also, clear juices had different L, a’, and b’ values than clear apple juices reported by Bonsi (2005).

The L values of pulpy juices were similar to values (41.1) reported by Oszmianski and Wojdylo (2006). The order of lightness among pulpy juices varied by variety. Cortland PB had the highest L value (being lightest) while the lightness of Cortland PC and PE was not significantly different. Empire PB and PE were significantly lighter than Empire PC and CJ. The order of lightness of Golden Delicious juices from the maximum to minimum was PB, PE, PC, and CJ. It was interesting to note that, even though McIntosh PB and PE were significantly darker than McIntosh PC at 0 week, they were not significantly different after 24 weeks. This was a result of the increase in L values of PB and PE juices over time.

The values of a’ and b’ describes the color of juices in which a positive a’ value indicates a reddish tone while a negative number shows a greenish tone, and a positive b’ value indicates a yellowish tone while a negative value indicates a bluish tone. Both a’ and b’ values of pulpy juices coincided with the whole apple’s color. Cortland, Empire, and McIntosh were red varieties and Golden Delicious was a yellow variety. The a’ value was lowest in Golden Delicious pulpy juices and was highest in Empire pulpy juices. Golden Delicious pulpy juices had the highest b’ value followed

**Table 3.5**. Hunter L, a, b value of Cortland and Empire juices during the shelf-life study at 18°C

| Variety/ Treatment | Time (week) | Color | | |
|---|---|---|---|---|
| | | L | a' | b' |
| Cortland | | | | |
| Clear juice | 0 | 36.40 ± 0.67 | -0.10 ± 0.10 | 11.34 ± 0.70 |
| | 12 | 32.70 ± 0.71 | 1.83 ± 0.14 | 9.59 ± 0.58 |
| | 24 | 31.70 ± 0.89 | 2.72 ± 0.20 | 9.16 ± 0.84 |
| Pulpy control | 0 | 42.52 ± 0.28 | -2.16 ± 0.07 | 0.19 ± 0.11 |
| | 12 | 43.22 ± 0.14 | -2.22 ± 0.02 | 1.54 ± 0.29 |
| | 24 | 42.82 ± 0.02 | -2.10 ± 0.05 | 2.31 ± 0.29 |
| Pulpy enzyme | 0 | 42.65 ± 0.33 | -1.54 ± 0.04 | 2.27 ± 0.27 |
| | 12 | 43.56 ± 0.39 | -1.72 ± 0.06 | 3.84 ± 0.12 |
| | 24 | 43.29 ± 0.49 | -1.68 ± 0.08 | 4.54 ± 0.14 |
| Pulpy blanch | 0 | 42.78 ± 0.13 | 2.62 ± 0.12 | 2.46 ± 0.06 |
| | 12 | 44.58 ± 0.06 | -0.94 ± 0.05 | 4.55 ± 0.09 |
| | 24 | 44.53 ± 0.07 | -1.14 ± 0.09 | 5.34 ± 0.20 |
| Empire | | | | |
| Clear juice | 0 | 37.82 ± 0.04 | 0.31 ± 0.67 | 4.9 ± 1.6 |
| | 12 | 34.68 ± 0.25 | 1.43 ± 0.12 | 9.22 ± 0.19 |
| | 24 | 34.17 ± 0.36 | 2.42 ± 0.29 | 10.14 ± 0.36 |
| Pulpy control | 0 | 37.34 ± 0.04 | -1.36 ± 0.09 | 0.84 ± 0.04 |
| | 12 | 39.4 ± 1.1 | -1.99 ± 0.08 | 2.50 ± 0.73 |
| | 24 | 37.54 ± 0.37 | -1.60 ± 0.03 | 2.30 ± 0.35 |
| Pulpy enzyme | 0 | 43.56 ± 0.53 | 0.05 ± 0.07 | 4.68 ± 0.27 |
| | 12 | 44.30 ± 0.49 | -0.21 ± 0.08 | 6.20 ± 0.32 |
| | 24 | 43.64 ± 0.47 | -0.29 ± 0.10 | 6.80 ± 0.40 |
| Pulpy blanch | 0 | 41.47 ± 0.47 | 5.9 ± 1.2 | 2.93 ± 0.31 |
| | 12 | 43.09 ± 0.42 | 1.24 ± 0.47 | 4.84 ± 0.24 |
| | 24 | 43.44 ± 0.27 | 0.48 ± 0.49 | 5.81 ± 0.13 |

by McIntosh, Empire, and Cortland pulpy juices respectively. The a' value of Golden Delicious pulpy juices increased over time while the b' value was stable with a slight

**Table 3.6**. Hunter L, a, b value of Golden Delicious and McIntosh juices during the shelf-life study at 18°C

| Variety/ Treatment | Time (week) | Color | | |
|---|---|---|---|---|
| | | L | a’ | b’ |
| Golden Delicious | | | | |
| Clear juice | 0 | 36.60 ± 0.10 | 0.28 ± 0.04 | 10.35 ± 0.60 |
| | 12 | 31.80 ± 0.45 | 3.05 ± 0.16 | 9.15 ± 0.49 |
| | 24 | 31.12 ± 0.46 | 3.90 ± 0.16 | 8.96 ± 0.51 |
| Pulpy control | 0 | 39.52 ± 0.60 | -2.70 ± 0.05 | 5.05 ± 0.39 |
| | 12 | 39.45 ± 0.51 | -2.23 ± 0.03 | 4.69 ± 0.24 |
| | 24 | 40.52 ± 0.35 | -2.06 ± 0.03 | 6.15 ± 0.29 |
| Pulpy enzyme | 0 | 44.02 ± 0.05 | -2.94 ± 0.04 | 10.20 ± 0.11 |
| | 12 | 45.20 ± 0.19 | -2.39 ± 0.08 | 11.33 ± 0.09 |
| | 24 | 44.77 ± 0.09 | -2.20 ± 0.08 | 11.42 ± 0.14 |
| Pulpy blanch | 0 | 46.30 ± 0.61 | -2.76 ± 0.02 | 11.24 ± 0.38 |
| | 12 | 46.01 ± 0.13 | -2.39 ± 0.01 | 11.18 ± 0.06 |
| | 24 | 46.15 ± 0.10 | -2.04 ± 0.04 | 11.59 ± 0.17 |
| McIntosh | | | | |
| Clear juice | 0 | 36.06 ± 0.45 | 0.01 ± 0.23 | 12.19 ± 0.14 |
| | 12 | 33.35 ± 0.61 | 1.74 ± 0.34 | 9.92 ± 0.48 |
| | 24 | 32.52 ± 0.32 | 2.69 ± 0.23 | 9.64 ± 0.19 |
| Pulpy control | 0 | 45.26 ± 0.08 | -2.20 ±0.05 | 4.03 ± 0.03 |
| | 12 | 45.30 ± 0.05 | -1.95 ± 0.01 | 5.64 ± 0.10 |
| | 24 | 44.95 ± 0.20 | -1.76 ± 0.09 | 6.35 ± 0.46 |
| Pulpy enzyme | 0 | 44.36 ± 0.10 | -1.80 ± 0.06 | 7.36 ± 0.19 |
| | 12 | 45.70 ± 0.56 | -1.55 ± 0.07 | 8.99 ± 0.23 |
| | 24 | 45.20 ± 0.23 | -1.58 ± 0.14 | 8.92 ± 0.17 |
| Pulpy blanch | 0 | 44.66 ± 0.39 | -0.59 ± 0.10 | 7.29 ± 0.11 |
| | 12 | 43.86 ± 0.14 | -1.24 ± 0.18 | 7.88 ± 0.12 |
| | 24 | 44.72 ± 0.56 | -1.11 ± 0.09 | 9.04 ± 0.43 |

increase in PE juices. The b’ value of Cortland, Empire, and McIntosh pulpy juices increased over time while the a’ value decreased, except in McIntosh PC juices where the a’ value increased over time.

An increasing trend in a’ values was observed over time in all clear juices while the b’ values reduced over time in all varieties except Empire. Therefore, Empire clear juices were less yellowish (indicated by b’ value) than other varieties at the beginning but were more yellowish at the end of shelf-life study.

In all, pulpy juices had better quality than clear juices in terms of lightness (L value) since pulpy juices were more stable while clear juices darkened over time. Since the changes in a’ and b’ values in Golden Delicious pulpy juices were different than other varieties and it was the only yellow variety while the others were red varieties, we can conclude that the variety of apples was one of the main factors affecting changes of a’ and b’ values of pulpy juices over time.

### ***Total Phenolic Content***

The variety played an important role on the amount and changes of phenolic contents in each type of juices. Clear juices were significantly lower in phenolic content than the pulpy juices of their counterparts for the whole study. McIntosh pulpy juices had phenolic content almost three times the value of corresponding clear juices while pulpy juices from other varieties had 50 to 100% higher values. Phenolic content of Cortland PB and PE were not significantly different, but were significantly higher than Cortland PC and CJ. For Empire and Golden Delicious, PE contained the highest phenolic content followed by PB, PC, and CJ. It was also interesting to note that it was only in McIntosh that PC had the highest phenolic content compared to other treatments.

The changes in phenolic compounds over time were more stable in clear juice and the decreasing trend was more pronounced in all pulpy juices (Table 3.7). Empire clear juices lost almost 25% of their phenolic compounds over storage time while

**Table 3.7**. Phenolic content of apple juices during the shelf-life study at 18°C

| Variety | Treatment | Total phenolic Content (mg GAE/100 g juice) | | |
|---|---|---|---|---|
| | | 0 Week | 12 Week | 24 Week |
| Cortland | Clear juice | 54.8 ± 5.6 c1 | 55.0 ± 6.4 c1 | 49.3 ± 6.0 c1 |
| | Pulpy control | 99.5 ± 4.2 b1 | 91.0 ± 3.6 b2 | 84.0 ± 4.4 b2 |
| | Pulpy enzyme | 113.8 ± 0.6 a1 | 108.6 ± 1.0 a2 | 96.3 ± 3.0 a3 |
| | Pulpy blanch | 118.8 ± 1.4 a1 | 112.4 ± 1.8 a2 | 106.0 ± 4.7 a3 |
| Empire | Clear juice | 30.1 ± 3.6 b1 | 27.0 ± 1.3 d12 | 23.1 ± 1.1 d2 |
| | Pulpy control | 41.1 ± 9.6 ab1 | 38.4 ± 2.6 c1 | 33.4 ± 1.2 c1 |
| | Pulpy enzyme | 48.5 ± 5.7 a1 | 49.7 ± 1.2 a1 | 46.7 ± 1.1 a1 |
| | Pulpy blanch | 48.4 ± 1.1 a1 | 45.1 ± 0.4 b2 | 42.9 ± 0.7 b3 |
| Golden Delicious | Clear juice | 53.9 ± 1.4 d1 | 53.1 ± 0.6 d1 | 48.4 ± 0.8 d2 |
| | Pulpy control | 79.1 ± 1.6 c1 | 68.3 ± 1.1 c2 | 66.9 ± 1.5 c2 |
| | Pulpy enzyme | 113.9 ± 1.2 a1 | 106.4 ± 4.2 a12 | 100.1 ± 5.1 a2 |
| | Pulpy blanch | 101.2 ± 4.2 b1 | 96.1 ± 2.9 b12 | 92.6 ± 3.2 b2 |
| McIntosh | Clear juice | 44.4 ± 2.5 b1 | 42.6 ± 2.0 b1 | 39.3 ± 3.9 b1 |
| | Pulpy control | 137.6 ± 4.0 a1 | 120.8 ± 0.7 a2 | 111.5 ± 4.4 a3 |
| | Pulpy enzyme | 123 ± 16 a1 | 113 ± 12 a1 | 106.5 ± 7.3 a1 |
| | Pulpy blanch | 122.1 ± 3.2 a1 | 113.5 ± 4.4 a2 | 108.5 ± 2.1 a2 |

For each variety in each column, the values followed by different letters are significantly different
For each variety in each row, the values followed by different numbers are significantly different

Empire pulpy juices lost 4 to 20%. Empire CJ and PC juices had the highest percent loss compared to other varieties of the same treatment, and this was because the phenolic content in Empire juices was lower at 0 weeks of storage than that of other varieties. For all varieties except Empire, CJ and PB had the least percentage loss (9 to 11%) followed by PE (11 to 15%) and PC (15 to 19%). The percent loss was in agreement with the percent loss of total phenols (8 to 19%) in apple juices after 11 months of storage (Gliszczynska-Swiglo and Tyrakowska, 2003).

The results indicated that the blanching treatment not only helped retain more phenolic compounds in the resulting juices, but also retained more of these compounds over storage time. Both PE and PB juices resulted in a better retention of total phenolic content than PC juices; however, PE juices were less stable (lower phenolic content retention) than PB juices.

### *Antioxidant Capacity*

Antioxidant capacity of juices over 24-week storage is shown in Table 3.8. The antioxidant capacity decreased over time in all juices. However, the decreasing rate and the percent loss varied among varieties. Even though the antioxidant capacity in clear juices was significantly lower compared to other treatments, it was more stable over the storage time. Bonsi (2005) also reported the stability of antioxidant capacity in clear apple juices over 6 months of storage. In contrast, antioxidant capacities in pulpy juices decreased significantly at early storage (from 0 to 12 weeks) but there was no significant loss from 12 to 24 weeks storage.

For Empire and Golden Delicious varieties, the antioxidant capacity was highest in PE followed by PB, PC, and CJ respectively. This trend was also observed in Cortland juices with a slight difference. The antioxidant capacity in Cortland PB was not significantly different from that of PE, but was higher than that of PC and CJ. Antioxidant capacities in McIntosh pulpy juices, on the other hand, were the same but were significantly higher than that of clear juices.

Clear juices had the least percentage loss; 0% for Empire, 4% for Cortland, 6% for Golden Delicious, and 11% for McIntosh. This was lower than the percent loss of antioxidant capacity in apple juices (6 to 14%) reported by Gliszczynska-Swiglo and Tyrakowska (2003). The percentage loss over time was at the same magnitude (12 to 22%) for all pulpy juices. The antioxidant retention was highest in PB followed by PE, and PC. Even though the percentage loss in pulpy juices was higher than in clear juices, pulpy juices after 24 weeks of storage had 3 times the antioxidant capacity than clear juices for McIntosh, and 1.5 to 2.5 times for other varieties. Among pulpy juice

**Table 3.8**. Antioxidant capacity of apple juices during the shelf-life study at 18°C

| Variety | Treatment | Antioxidant Capacity (mg VCEAC/100 g juice) | | |
|---|---|---|---|---|
| | | 0 Week | 12 Week | 24 Week |
| Cortland | Clear juice | 69.8 ± 9.4 c1 | 70 ± 10 c1 | 67 ± 10 d1 |
| | Pulpy control | 147.6 ± 6.0 b1 | 127.7 ± 7.2 b2 | 124.9 ± 6.5 c2 |
| | Pulpy enzyme | 176.9 ± 5.1 a1 | 164.8 ± 3.2 a2 | 150.1 ± 4.4 b3 |
| | Pulpy blanch | 191 ± 13 a1 | 172.9 ± 3.8 a2 | 168.4 ± 2.3 a2 |
| Empire | Clear juice | 28.8 ± 2.4 d1 | 30.7 ± 1.3 d1 | 29.4 ± 1.5 c1 |
| | Pulpy control | 48.3 ± 2.2 c1 | 43.3 ± 4.1 c2 | 41.5 ± 2.0 d2 |
| | Pulpy enzyme | 71.7 ± 2.2 a1 | 66.5 ± 2.2 a2 | 62.7 ± 1.8 a3 |
| | Pulpy blanch | 64.4 ± 3.0 b1 | 57.2 ± 1.0 b2 | 56.2 ± 0.9 b2 |
| Golden Delicious | Clear juice | 65.8 ± 1.1 d1 | 65.3 ± 1.0 d1 | 62.0 ± 2.1 d2 |
| | Pulpy control | 114.8 ± 3.7 c1 | 95.1 ± 2.9 c2 | 90.4 ± 2.0 c3 |
| | Pulpy enzyme | 181.7 ± 4.1 a1 | 155.9 ± 6.9 a2 | 142.1 ± 5.3 a3 |
| | Pulpy blanch | 162.0 ± 6.9 b1 | 139.8 ± 5.4 b2 | 135.3 ± 4.1 b2 |
| McIntosh | Clear juice | 54.5 ± 3.6 b1 | 50.0 ± 3.4 b12 | 48.5 ± 4.4 b2 |
| | Pulpy control | 189.7 ± 2.5 a1 | 157.7 ± 4.1 a2 | 148.8 ± 5.6 a3 |
| | Pulpy enzyme | 189 ± 17 a1 | 160 ± 12 a2 | 149.0 ± 12.4 a2 |
| | Pulpy blanch | 193.6 ± 7.9 a1 | 166.6 ± 6.0 a2 | 154.3 ± 2.3 a3 |

For each variety in each column, the values followed by different letters are significantly different
For each variety in each row, the values followed by different numbers are significantly different

processing methods, juices from the blanching treatment (PB and PE) yielded a higher antioxidant activity, but the enzymatic treatment led to a higher loss over time.

### D. Sensory Evaluation

The acceptance test results of PC, PE, and PB at 0 and 24 weeks of storage are shown in Table 3.9. There was no significant difference in the acceptance of color, flavor, and overall acceptability for Empire juices at 0 weeks; however, Empire CJ had a more acceptable color and overall acceptability after 24 weeks. The mouthfeel acceptance for Empire CJ was no different than that of PC, but was significantly higher than that of PE in both 0 and 24 weeks of storage. In other varieties, even

**Table 3.9**. Acceptance test results of apple juices at 0 and 24 weeks of storage at 18°C

| Variety/ Treatment | Attribute Score | | | |
|---|---|---|---|---|
| | Color | Flavor | Mouthfeel | Overall Acceptability |
| Cortland | | | | |
| *0 Week* | | | | |
| Clear juice | 6.2 ± 0.9 a | 6.1 ± 0.6 a | 6.1 ± 0.7 a | 6.1 ± 0.6 a |
| Pulpy control | 4.1 ± 1.6 b | 4.2 ± 1.9 b | 4.6 ± 1.5 b | 4.0 ± 1.7 b |
| Pulpy enzyme | 4.1 ± 1.7 b | 5.2 ± 1.5 ab | 4.0 ± 2.0 b | 4.3 ± 1.7 b |
| *24 Week* | | | | |
| Clear juice | 5.9 ± 1.3 a | 5.6 ± 1.1 a | 6.0 ± 0.8 a | 5.6 ± 1.1 a |
| Pulpy control | 4.5 ± 1.3 b | 4.9 ± 1.6 a | 4.3 ± 1.4 b | 4.8 ± 1.4 ab |
| Pulpy enzyme | 4.2 ± 1.6 b | 4.8 ± 1.5 a | 4.0 ± 1.9 b | 4.2 ± 1.7 b |
| Empire | | | | |
| *0 Week* | | | | |
| Clear juice | 4.6 ± 1.7 a | 5.3 ± 1.4 a | 5.6 ± 1.2 a | 5.0 ± 1.5 a |
| Pulpy control | 4.3 ± 1.7 a | 4.4 ± 2.0 a | 4.6 ± 1.9 ab | 4.4 ± 1.8 a |
| Pulpy enzyme | 3.6 ± 1.7 a | 4.9 ± 1.6 a | 3.9 ± 2.1 b | 4.1 ± 1.9 a |
| *24 Week* | | | | |
| Clear juice | 6.0 ± 1.3 a | 5.5 ± 1.3 a | 6.0 ± 0.9 a | 5.5 ± 1.4 a |
| Pulpy control | 4.4 ± 1.5 b | 5.5 ± 1.3 a | 5.2 ± 1.1 ab | 5.1 ± 1.3 ab |
| Pulpy enzyme | 3.7 ± 1.8 b | 4.8 ± 1.5 a | 4.5 ± 1.6 b | 4.4 ± 1.6 b |
| Golden Delicious | | | | |
| *0 Week* | | | | |
| Clear juice | 6.0 ± 0.9 a | 5.8 ± 1.5 a | 6.0 ± 1.4 a | 5.8 ± 1.4 a |
| Pulpy control | 4.5 ± 1.6 b | 3.4 ± 1.6 b | 5.0 ± 1.6 ab | 4.0 ± 1.7 b |
| Pulpy enzyme | 4.2 ± 1.5 b | 3.8 ± 1.8 b | 4.3 ± 1.8 b | 4.2 ± 1.8 b |
| *24 Week* | | | | |
| Clear juice | 5.4 ± 1.2 a | 5.4 ± 1.1 a | 6.0 ± 1.2 a | 5.5 ± 1.2 a |
| Pulpy control | 5.0 ± 1.3 a | 5.1 ± 1.8 a | 5.4 ± 1.3 a | 5.1 ± 1.4 a |
| Pulpy enzyme | 5.0 ± 1.5 a | 5.0 ± 1.6 a | 5.1 ± 1.7 a | 4.9 ± 1.7 a |
| McIntosh | | | | |
| *0 Week* | | | | |
| Clear juice | 6.1 ± 1.0 a | 5.6 ± 1.3 a | 6.1 ± 1.3 a | 5.8 ± 1.4 a |
| Pulpy control | 3.6 ± 1.9 b | 4.2 ± 2.2 b | 3.8 ± 2.2 b | 4.0 ± 2.1 b |
| Pulpy enzyme | 3.6 ± 1.8 b | 4.7 ± 1.9 ab | 3.7 ± 2.0 b | 3.8 ± 1.9 b |
| *24 Week* | | | | |
| Clear juice | 5.8 ± 1.0 a | 5.5 ± 1.1 a | 5.7 ± 1.0 a | 5.5 ± 0.9 a |
| Pulpy control | 4.4 ± 1.4 b | 5.5 ± 1.3 a | 4.8 ± 1.5 a | 5.1 ± 1.2 a |
| Pulpy enzyme | 4.4 ± 1.3 b | 4.8 ± 1.4 a | 3.8 ± 1.7 b | 4.1 ± 1.4 b |

For each variety in each column at the same storage time, the values followed by different letters are significantly different

**Table 3.10**. Ranking test results of apple juices at 0 and 24 weeks of storage at 18°C

| Variety | Sensory attributes | Storage time (week) | Treatments | | |
|---|---|---|---|---|---|
| | | | Clear juice | Pulpy control | Pulpy enzyme |
| Cortland | Apple flavor intensity | 0 | 1.4 ± 0.6 a | 2.3 ± 0.7 b | 2.1 ± 0.8 b |
| | | 24 | 1.5 ± 0.7 a | 1.9 ± 0.7 a | 2.5 ± 0.8 b |
| | Preference | 0 | 1.6 ± 0.7 a | 2.2 ± 0.8 b | 2.2 ± 0.8 b |
| | | 24 | 1.5 ± 0.5 a | 2.0 ± 0.8 a | 2.6 ± 0.7 b |
| Empire | Apple flavor intensity | 0 | 2.2 ± 0.8 ab | 1.7 ± 0.7 a | 1.8 ± 0.8 a |
| | | 24 | 1.7 ± 0.8 a | 2.1 ± 0.7 ab | 2.2 ± 0.9 b |
| | Preference | 0 | 1.8 ± 0.8 a | 1.8 ± 0.8 a | 2.3 ± 0.8 b |
| | | 24 | 1.8 ± 0.8 a | 1.8 ± 0.6 a | 2.4 ± 0.9 b |
| Golden Delicious | Apple flavor intensity | 0 | 1.7 ± 0.9 a | 2.5 ± 0.7 b | 2.0 ± 0.7 ab |
| | | 24 | 1.6 ± 0.7 a | 2.0 ± 0.8 ab | 2.1 ± 0.9 b |
| | Preference | 0 | 1.5 ± 0.8 a | 2.4 ± 0.7 b | 2.2 ± 0.7 b |
| | | 24 | 1.8 ± 0.8 a | 2.1 ± 0.9 a | 2.0 ± 0.9 a |
| McIntosh | Apple flavor intensity | 0 | 1.5 ± 0.7 a | 2.3 ± 0.9 b | 2.1 ± 0.7 b |
| | | 24 | 1.8 ± 0.8 a | 1.7 ± 0.6 a | 2.4 ± 0.8 b |
| | Preference | 0 | 1.2 ± 0.5 a | 2.3 ± 0.6 b | 2.5 ± 0.7 b |
| | | 24 | 1.7 ± 0.9 a | 1.7 ± 0.6 a | 2.6 ± 0.6 b |

For each variety in each row, the values followed by different letters are significantly different

though CJ received a higher rating in flavor attributes than pulpy juices at 0 weeks, CJ was rated the same at 24 weeks of storage.

Golden Delicious CJ got a higher acceptance score in all attributes at 0 weeks but was not significantly different in any attributes from PC and PE at 24 weeks. Cortland CJ received a higher acceptance score for color, mouthfeel, and overall acceptability than PC and PE at both 0 and 24 weeks. McIntosh juices also exhibited these results at 0 weeks; however, after 24 weeks of storage, CJ and PC were rated the same in mouthfeel and overall acceptability but were higher than PE.

The ranking test results also varied according to variety (Table 3.10). Results from preference ranking were in agreement with the overall acceptability results from the acceptance test. Cortland and McIntosh juices showed similar results: clear juices were preferred over pulpy juices at 0 weeks but were preferred equally to PC at 24 weeks of storage. Empire CJ and PC were rated the same in preference and higher than PE at 0 and 24 weeks of storage. Even though, Golden Delicious clear juices were preferred over pulpy juices at 0 weeks, all juices were rated the same after 24 weeks. Clear juices had better flavor intensity than pulpy juices at 0 weeks storage; however, CJ and PC were rated equally in flavor intensity at 24 weeks of storage and were higher than that of PE.

## Conclusion

The quality of juices varied depending on the apple variety used. Empire has the lowest total phenolic content and antioxidant capacity, 3 to 4 times lower values than those of other varieties. Pulpy juices gave promising results in both sensory evaluation and chemical analysis compared to clear juices. Total phenolic and pectin content, and antioxidant capacity of pulpy juices from some varieties were significantly higher than that of clear juices, and were comparable to those of whole fruits. Based on the sensory result, even though pulpy enzyme treated juices (PE) were ranked lower in the overall acceptability and preference, pulpy control juices (PC) were rated equally to clear juices (CJ) in both attributes. Pulpy juices were more stable in terms of lightness compared to clear juices but the changes in color (a’ and b’ values) over the time were more pronounced than in clear juices. Therefore, based on the goal of incorporating more fruits into the daily diet as well as preserving more of the healthy compounds such as soluble fiber and phenolic compounds from whole fruits to juices, both pulpy control and pulpy enzyme treated juices could be successful juice products if the processing is optimized.

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# CHAPTER 4

# CONCLUSIONS AND FUTURE WORK

## Conclusion

The pattern of quality changes in juices over time was different depending on processing treatments and fruit varietals. Pulpy juices made from tart cherry cv. Balaton and Montmorency and Concord grapes had higher phenolic and anthocyanin content, and antioxidant capacity than the clear juices of their counterparts, especially in pulpy Concord grape juice whose nutrient contents were comparable to those of whole fruits. The difference between quantity of compounds due to the variety was more pronounced in apples. Empire apple has a third to half the phenolic content and antioxidant capacity found in other varieties studied. Total phenolic content and antioxidant capacity in pulpy apple juices were significantly higher than those in clear juices, and some were comparable to those in whole fruits. A decreasing trend of these compounds over storage was observed in all juices; however, at the end of shelf-life studies, pulpy juices were higher in phenolic and anthocyanin (if presented) content and antioxidant capacity.

Furthermore, the pectin content of pulpy juices was comparable to that of whole fruits, yet there was almost none in clear juices. One serving of pulpy juice represented a significant source of soluble fiber and could carry the claim “may reduce the risk of heart disease”. In addition, pulpy apple juices with the blanching treatment were an excellent source of dietary fiber and pulpy Cortland and McIntosh control juices were a good source of dietary fiber; thus they could carry the claim “may reduce the risk of some types of cancer”.

Based on the sensory evaluation, clear and pulpy juices from tart cherry cv. Balaton and Montmorency and Concord grape were rated the same in overall acceptability and preference at 0 weeks, but after 24 weeks of storage, clear juices had a higher overall acceptability than pulpy juices. Balaton and Concord pulpy juices were preferred equally to clear juices at the end of the shelf-life study. For apple, clear juices and pulpy control juices were rated equally in overall acceptability and preference but were higher than pulpy juices using enzymatic treatment.

It is also worth noting that the quality, both in term of chemical analysis and sensory evaluation, of pulpy juices made from different types of extractors or screen sizes of turbo extractor was the same. Pulpy apple juices with blanching treatments had higher phenolic content and antioxidant capacity than pulpy control juices; however, the pulpy juices with enzymatic treatment were less preferred than pulpy control juices.

The production of pulpy juices using a shear mixer or a turbo extractor with fine screens as well as the blanching and enzymatic treatments produced acceptable juices having quality comparable to clear juice but with higher nutritional quality.

## Future Work

Further studies are needed to identify and quantify phenolic compounds and anthocyanins in pulpy juices over storage time. According to the sensory evaluation, after 24 weeks storage, some of the pulpy juices gave off a barn-like smell which could come from an oxidized compound. Therefore, identifying compounds responsible for the odor is necessary. Since the particle size affected the viscosity and mouthfeel, analysis of particle size in pulpy juices would help explain the effect of the particle size on sensory aspects. Furthermore, optimized processing should be established so that the quality of pulpy juices remains stable over shelf-life, especially in term of sensory attributes.