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PHYSICO-CHEMICAL CHARACTERISITCS AND
ANTIOXIDANT ACTIVITY OF TART CHERRY POWDER AS
AFFECTED BY VARIOUS DRYING METHODS

presented by

MEGAN K. SCHWANNECKE

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Major Professor's Signature

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# PHYSICO-CHEMICAL CHARACTERISTICS AND ANTIOXIDANT ACTIVITY OF TART CHERRY POWDER DRIED BY VARIOUS DRYING METHODS

By

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## ABSTRACT

## PHYSICO-CHEMICAL CHARACTERISTICS AND ANTIOXIDANT ACTIVITY OF TART CHERRY POWDER DRIED BY VARIOUS DRYING METHODS

**By**

**Megan K. Schwannecke**

Raw tart cherry pomace (*Prunus cerasus)* was dried using three drying methods (vacuum drying, cabinet drying, and infrared drying) at four different temperatures (50, 70, 90, and 110°C). The cherry pomace was also freeze dried for use as a "gold standard." The dried pomace from each drying method was ground into a powder and the following physical characteristics were measured: pH, titratable acidity, Hunter Color CIE L*a*b*, water solubility, and water absorption index. The cherry powder was analyzed for total antioxidants (Oxygen Radical Absorbance Capacity assay), phenolics (Folin-Ciocalteu assay), and anthocyanins (pH-differential assay). The freeze dried, vacuum dried, cabinet dried, and infrared dried samples contained 477, 356-455, 348-463, and 307-425 umol TE/g cherry powder db, respectively. The freeze dried, vacuum dried, cabinet dried, and infrared dried samples contained 28.02, 17.89-20.88, 18.49-20.93, and 15.92-17.86 mg GAE/g cherry powder db, respectively. The freeze dried, vacuum dried, cabinet dried, and infrared dried samples contained 25.02, 13.20-13.93, 13.85-15.73, and 10.00-12.35 mg cyn-3-glu/100g cherry powder db, respectively. In general, the dried cherry pomace in this research compared favorably to commercial cherry powders in levels of phenolics and total antioxidants, but was lower in levels of total anthocyanins.

## DEDICATION

To my supporting family and loving husband.

## ACKNOWLEDGEMENTS

I would first like to thank my advisor Dr. Kirk Dolan for being an outstanding mentor. A good mentor not only guides their student academically but shares life lessons along the way and Dr. Dolan has done just this. Thank you for teaching me that I have to look at the forest and not get lost in the trees. I also thank my committee members Dr. Maurice Bennink and Dr. James Steffe for their academic guidance. Thank you, Dr. Bennink, for your help with the antioxidant extraction process and anthocyanin assay. Dr. Steffe, thank you for sharing your expertise with food drying technologies. I would also like to thank Dr. Muhammed Siddiq for the original ideas for this research project, for the use of his lab equipment, and his mentorship. I would like to thank Mr. Phil Hill for his help with the construction of drying trays for the vacuum dryer and for his help with devices such as the current probe. In addition I would like to thank Dr. John Foss from the Department of Mechanical Engineering for the use of his anemometer and Mr. Doug Neal for his instruction on the use and theory of this device. I would like to thank my lab mates and fellow graduate students for your support and life long friendship. Last but certainly not least I would like to thank Cherry Growers Inc. for the donation of the experimental samples. Hopefully the results of my research will end up benefiting your business.

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## INTRODUCTION

Michigan supplies the United States with approximately 75% of the nation's supply of tart cherries. After the fresh tart cherries are pressed for juice the cherry pomace (skins, flesh, and stems) remains. Cherry juice processors in northern Michigan consider the tart cherry pomace to be a waste (Personal Communication, 2008). In 2008 approximately three million pounds of tart cherry pomace were disposed of in Michigan by composting or spreading on fields. However, the cherry pomace has potential to be dried, ground into a powder, and used as a functional food ingredient. The tart cherry powder may be used in extruded and baked products, confectionaries, agglomerated granola bars, dairy products such as yogurt, et cetera. For example, fruit powders are currently used in extruded products (Berry Burst Cheerios® Cereal and Gerber® Graduates® Fruit Puffs), baked products (Hip Bones™ dog treats by Overby Farms), and dry mix fruit drinks (Clif Kid™ Splashers™).

The benefits of the tart cherry powder are the nutritional properties. Tart cherry powder contains antioxidants such as phenolic acids and anthocyanins that have been shown to have health benefits. These health benefits include the suppression of cancer cells (Kamei and others 1995), reduced formation of LDL cholesterol (Arai and others 2000), reduced risk of coronary heart disease (Hertog 1995) and anti-inflammatory benefits (Dai and others 2007). There are various drying methods that may be applied to remove most of the moisture from the raw tart cherry pomace such as freeze drying, cabinet drying, vacuum drying, and infrared drying. Not all drying methods are created equal; these methods vary in capital cost, energy utilization, production rate, labor requirements, and

heat application to the foodstuffs. The nutritional properties of the tart cherry powder will vary depending on the drying method used. It is important for a food manufacturer to choose an economically feasible drying process that will protect the nutritional properties of the tart cherry powder from being degraded.

The objectives of this research were:

**(i)** To compare the effects of freeze drying, cabinet drying, vacuum drying, and infrared drying on the physical characteristics (Color, pH, titratable acidity, water absorption index, and water solubility) of the tart cherry powder.

**(ii)** To compare the effects of freeze drying, cabinet drying, vacuum drying, and infrared drying on the nutraceutical content (total antioxidants, total anthocyanins, and total phenolics) of the tart cherry powder.

**(iii)** To compare the nutraceutical content and the physical characteristics of the tart cherry powder produced from raw tart cherry pomace to two commercially available tart cherry powders manufactured from the whole cherry fruit and one manufactured from raw tart cherry pomace.

# 1 LITERATURE REVIEW

## 1.1 Tart Cherry Pomace and Powder

The climate of western Michigan is ideal for growing tart cherries (*Prunus cerasus)* which are harvested June to late August (Pollack and Perez 2002). There were approximately 214.4 million pounds of tart cherries grown in the United States in 2008. Michigan alone provided 165 million pounds of tart cherries to the nation's supply in 2008, which was valued at $64.7 million (Boriss and others 2009). The three major varieties of tart cherries in Michigan are Montmorency, Balaton, and Galaxy. The Montmorency variety accounts for 94.8 percent of the total acreage of the sour cherries in Michigan (USDA 2007). Of the 214.4 million pounds of tart cherries produced in the U.S., 213.2 million pounds of tart cherries were available for use. Of this amount 212.2 million pounds were processed into other goods while the remaining 1.0 million pounds of tart cherries were kept for fresh use (USDA 2009). Tart cherries are commonly processed into pie filling, frozen sugar packs, dried fruit, liquor, wine, juice, and juice concentrate.

During the production of tart cherry juice and concentrate cherry pomace, which consists of the cherry skins, flesh, stems, and sometimes pits and pressing aids such as rice hulls is generated. In 2008 approximately 10 million pounds of tart cherries in Michigan were used for the production of cherry juice and cherry juice concentrate (Personal Communication 2009). The production of cherry juice from Montmorency cherries using a hot press method will give a 32-38% pomace yield (Luh and others 1986). Using a conservative estimate of a 32% pomace yield, the annual pomace generated in Michigan may be as high as 3.2

million pounds. Personal communications with cherry processors in Northern Michigan confirmed that the cherry pomace is considered a manufacturing waste. The cherry pomace is considered a low-grade material and therefore is used as a fertilizer on land near the processing plants or is hauled to a landfill.

However, tart cherry pomace has the potential to be dried, ground into a powder, and used as a value-added ingredient in food product development. Dried cherry powder is already used as an ingredient in dry drink mixes, extruded, and baked products. Confectionaries and agglomerated granola bars are other possibilities for this ingredient, as these types of products already contain other dried fruit solids. Dried tart cherry powder has potential beyond human food product development; it also has potential in products developed for animals. Extruded and baked pet food products with real fruit solids already exist. Using real fruit solids in food products sheds a positive light on the product in the eye of the consumer. Another advantage of using dried cherry powder as an ingredient is gaining the benefits of the nutrients naturally found in the plant tissue. These nutrients include antioxidants such as phenols and anthocyanins. Identifying natural sources of phenols is especially important since these compounds cannot be chemically synthesized and therefore must be extracted from plant material if desired for use as a separate ingredient (Schieber and others 2001).

Other fruit industries, such as the apple and wine industry, already practice waste management with the solid waste generated during the processing of fruit juice and wine. The bioactive polyphenolic composition of the apple and grape pomace has been extensively studied and apple pomace is

further valued for its source of pectin (Schieber et al. 2001; Makris and others 2007; Sriram and others 1999; Ju and Howard 2003). Phenolic compounds and other antioxidants have also been identified in raspberry (McDougall and Beames 1994) and cranberry pomace (Vattem and Shetty 2003).

The antioxidant and physical properties of tart cherry pomace have not been studied as extensively as these other fruit industries. Adil and others (2008) have studied the extraction process of total phenolics through high pressure liquid extraction and subcritical fluid extraction from tart cherry pomace. The antioxidant as well as pro-oxidative effects of extracts from cherry liquor pomace were studied by Rodtjer and others (2006). Moreira and others (2009) have studied the effects of spray drying on the physical properties of acerola cherry pomace including water solubility, hydroscopicity, and flowability of the powder. The dietary fiber content of cherry pomace has been classified (Nawirska and Kwasniewska 2005).

## 1.2 Impact of Antioxidants on Health

Antioxidants are a group of compounds that have the ability to delay, prevent, or remove oxidative damage to a target molecule (Halliwell and Gutteridge 2007). Antioxidants have the ability to prevent damage caused by reactive species to biological systems by quenching these free radicals. There are many types of reactive species including reactive nitrogen species (RNS), reactive chlorine species (RCS), reactive oxygen species (ROS), and reactive bromine species (RBS) (Halliwell and Gutteridge 2007). Reactive species are formed during exposure to smog, ozone, chemicals, drugs, radiation, and during

normal physiological processes (Gropper and others 2005). Reactive species (or free radicals) are characterized by one ore more unpaired electron in an orbital, and can cause oxidation of DNA, proteins, lipids, and uric acid (Halliwell and Gutteridge 2007). The antioxidant has the ability to quench free radicals by donating a hydrogen atom to the reactive species, which yields a stable compound with paired electrons that is able to slow the rate of oxidative stress in the body. Figure 1 illustrates the scavenging activity of a phenolic antioxidant for a peroxyl free radical (Belitz and Grosch 2004). Equation 1 and 2 demonstrate the donation of a hydrogen atom from the antioxidant (AH) to the free radical (RO2• and RO•). The free radical has transformed into a compound (ROOH and ROH) that is unable to seize a hydrogen atom from another source such as an unsaturated fatty acid to cause lipid oxidation. The antioxidant that has donated a hydrogen atom is in a stable state due to the resonance delocalization of the unpaired electron around the aromatic ring and the lack of available sites for molecular oxygen to attack (Nawar 1996). Equation 3 and 4 demonstrate the end products (ROOA and ROA) that are formed which are relatively stable causing the autoxidation of the free radicals to shorten (Belitz and Grosch 2004).

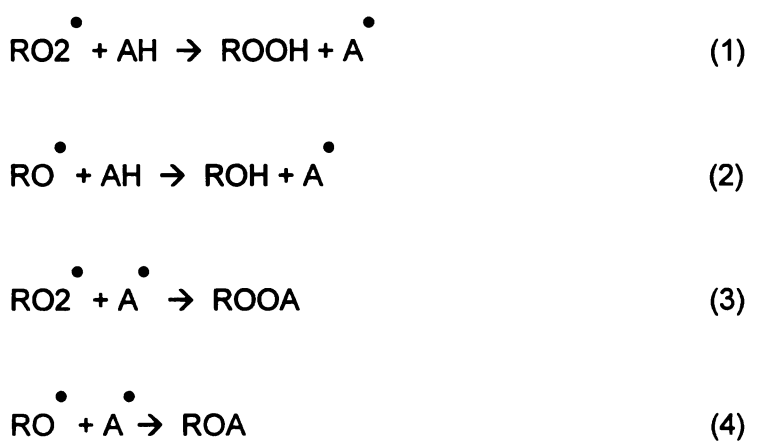


**Figure 1. The scavenging activity of an antioxidant compound (AH) for a free radical**

Oxidative stress is defined by a system that contains too many reactive species in comparison to available antioxidants. One results from oxidative stress is oxidative damage which is the biomolecular damage to living organisms caused by the attack of reactive species (Halliwell and Gutteridge 2007). Excessive oxidative stress results in a variety of health problems including diabetes and atherosclerosis (Baynes and Thorpe 1999), hypertension (Alexander 1995), rheumatoid arthritis (Jasin 1993).

Phenols are secondary metabolites derived in plants from phenylalanine and in some cases from tyrosine (Van Sumere 1989). Phenols exhibit antioxidant properties and are found in tea, wine, fruits, vegetables, herbs and spices, and dark chocolate (Bravo 1998). Phenolic compounds contain an aromatic ring with one or more hydroxyl groups, including their functional groups. There are numerous phenolic compound derivatives including simple phenols,

phenylpropanoids, benzoic acid derivatives, flavonoids, stilbenes, tannins, lignans, and lignins (Shahidi and Naczk 2004). Anthocyanins are a group of compounds found naturally in various plant tissues and are a part of a larger group of compounds called flavonoids. Anthocyanins also display antioxidant behavior and are responsible for the red, blue, and purple color of many fruits, vegetables, and flowers. Anthocyanins (Figure 2) are water soluble and exist as glycosides of polyhdroxy and polymethoxy derivatives of 2-phenylbenzophrylium otherwise known as flavylium salt (Mazza and Miniati 1993).

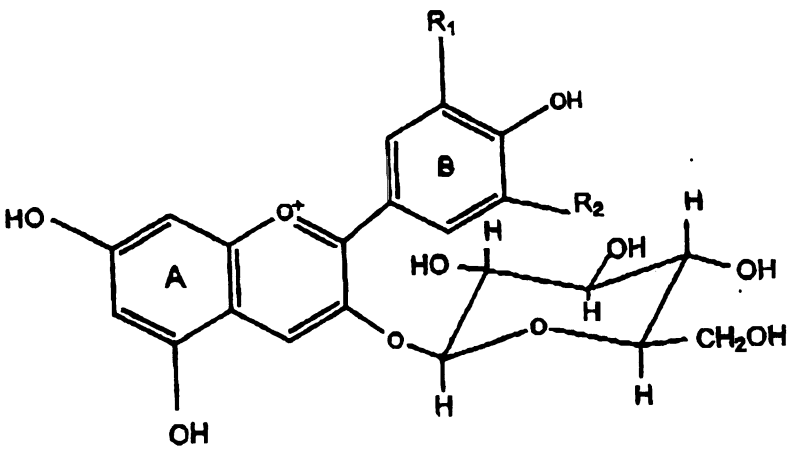


**Figure 2. Generalized structure for anthocyanin pigments (Wrolstad 2000)**

The flavylium cation may be substituted with glycosyl groups at position C-3 and C-5 may include glucose, arabinose, xylose, galactose, rhamnose, fructose, rutinose, sophorose, gentobiose, sambubiose, xylosylrutinose, or glycoylrutinose. Positions R-1, R-2, R-3, and R-4 may be substituted with hydroxyl or methoxyl groups which influences the color of the compound (Shahidi

and Naczk 2004). In addition sugar substituents may be esterified with organic acids such as cinnamic or aliphatic acids. Esterification of sugar hydroxyls does not influence the color of the compound but it may affect the stability (Wrolstad 2000). The six most frequently identified anthocyanins in plants are pelargonidin, cyanidin, peonidin, delphinidin, petunidin, and malvidin (Timberlake and Bridle 1975). Diets rich in phenolic acids and anthocyanins have been shown to be beneficial for human health.

Anthocyanins have been shown to suppress the growth of cancer cells (Kamei and others 1995). Anthocyanins have shown a role in the suppression of colon (Renis and others 2007), liver (Meyers and others 2003), lung (Chen and others 2005), breast (Singletary and others 2007), and skin cancer (Afaq and others 2007). Katsube and others (2003) demonstrated the suppression of the growth of HL60 human leukemia cells in vitro from the induction of apoptosis through the consumption of bilberry extracts. Phenolic compounds such as flavonoids and more specifically anthocyanins have been shown to reduce the concentration LDL (low-density lipoprotein) cholesterol in the blood. Arai and others (2000) showed an inverse correlation between intake of total flavonoids and the concentration of LDL cholesterol in the Japanese population. Lui and others (2008) demonstrated the ability of anthocyanins extracted from mulberry fruit to lower the formation of oxidative LDL that helps to reduce the risk of atherosclerosis. These results agree with earlier work published by Laplaud and others (1997) which showed a decrease in LDL upon the consumption of anthocyanins. Flavonoid compounds have been shown to reduce heart

problems such as coronary heart disease (Hertog 1995). There is also evidence to show that anthocyanins help reduce the risk of developing cardiovascular disease (Visioli and others 2000; Feldman 2001; Leifert and Abeywardena 2008). Anthocyanins such as those found in blackberry extracts were found to inhibit interleukin release from mouse bone marrow-derived dendritic cells in vitro, and therefore may contain anti-inflammatory effects (Dai et al. 2007). Subarnas and Wagner (2000) showed the anti-inflammatory effects in an animal study by reducing the intensity of edema found in rats.

The anthocyanins from tart cherries have been evaluated in vivo and in vitro. Anthocyanins from tart cherries have been shown to inhibit lipid peroxidation and cyclooxygenase enzymes (Wang and others 1999b; Seeram and others 2001; Mulabagal and others 2009). These findings are important since these reactions have been shown to promote inflammation, carcinogenesis, apoptosis, cell proliferation, and angiogenesis (Marnett and DuBois 2002). Bobe and others (2006) used an animal model to show that consumption of anthocyanin extracts from tart cherries reduced the total tumor burden on mice when compared to sulindac. These results agree with previous studies conducted to test the ability of anthocyanins to inhibit tumor development in human and animal cells (Mahmoud and others 2000; Kang and others 2003). The anthocyanins found in cherries may also provide protection against gout (Blau 1950; Jacob and others 2003).

## 1.3 Drying Methods

Dehydration of foodstuffs is perhaps the oldest method of food preservation, and is used for fruits, vegetables, spices, tea, coffee, dairy products, fish, and meat. The process involves the removal of water from a food material, which inhibits the growth of microorganisms and the activity of enzymes in order to extend the shelf life of the product beyond the timeline of the fresh material. The extension of a product's shelf life is advantageous since it allows the product to be handled, transported, and consumed conveniently and especially during non-seasonal times. Important consideration should be made in the selection of a dehydration method. The fresh material's characteristics (size, shape, color, texture, nutritional content) may be drastically changed during the dehydration process depending on the method chosen.

### 1.3.1 Economic Impact

Many factors should be considered when selecting a drying method for foodstuffs including the physical form of the product, the desired quality of the final product, the heat sensitivity of the product, the product production rate required, and the energy efficiency of the drying process (Sztabert and Kudra 1995). These factors contribute to the economic impact of a particular drying method for the food manufacturer.

The cost of drying foodstuffs is a main concern for food manufactures. Estimating the cost of drying methods is a difficult task since there are numerous variables involved. The capital cost of the dryer itself varies due to the size of the dryer, the construction material, and the cost of an accompanying controller,

which may include a computer with specialized software. The Marshall and Stevens Index is a tool that is used to adjust the current cost of drying equipment in the U.S. based on reference values from 1926. However the best estimate of capital cost should be obtained directly from the equipment manufactures. The capital cost of investing in a new drying system goes beyond the capital cost of the dryer itself. When a dryer is installed in a processing plant it is important to consider the floor space required, cost of building renovations, new piping or wiring, and additional service and storage facilities. Another challenge for calculating an accurate cost estimation of a new drying method is the effect of economic inflation on the cost of the drying equipment (Sztabert and Kudra 1995).

There are several operating costs associated with the cost estimation of drying. These include depreciation of the dryer, buildings, warehouses, or another facilities used during the operation, the cost of energy and other utilities, maintenance costs, and the type and amount of labor needed to operate the equipment. Along with the capital and operation costs the product rate should be factored into the cost estimate (Sztabert and Kudra 1995).

### 1.3.2 Principles of Freeze Drying

Freeze drying (otherwise referred to as lyophilisation or sublimation drying) has a long history of use. One original use for this method was for the preservation of biological samples such blood plasma during World War II (Flosdorf 1949). Soon afterwards freeze drying was applied to foods and gained momentum in the food industry starting in the 1950's. Freeze drying has successfully been applied to meat and seafood, fruit and vegetables, legumes,

herbs, cheese, and juice concentrate (Bermudez-Aguirre and others 2008). Freeze drying is a process that has high capital and operating costs which makes this drying method less common (Jayaranman and Das Gupta 1992). However the foodstuff is exposed to lower temperatures as compared to other drying methods, which preserve the qualities of the sample. The advantages of freeze drying include superior aroma, flavor, and structure retention of the final product (King 1971). The structure of a freeze-dried product remains intact because the cells of the product are not disrupted during sublimation, as opposed to normal thawing, where the ice transforms to a liquid and injures the cells. Freeze drying is a preferred method for the production of retail fruit powders due to the high quality of the final product (Holdsworth 1986).

The equipment for a batch freeze dryer consists of a sample chamber with heated shelves, a refrigerated condenser, and a vacuum pump. The process of freeze drying has three main stages, the freezing stage, the primary drying stage, and the secondary drying stage. The freezing stage involves freezing the sample, the primary drying stage refers to the removal of the solvent in the sample through sublimation, and the secondary drying stage refers to the desorption of water bound to the solids in the sample (Liapis and Bruttini 1995).

During the freezing stage the food sample is brought to a temperature -10°C or lower prior to placing it in the sample chamber of the freeze-dryer. At this stage the water is withdrawn from the hydrated components of the sample to form ice crystals. The rate of freezing affects the rate of drying. Food samples that are frozen at a slow rate produce large ice crystals, which allow for faster

drying rates when compared to samples frozen at fast rates that produce small ice crystals (Brennan and others 1990).

The primary drying stage follows and is characterized by the sublimation of the ice crystals from the sample. In order for the ice crystals to sublime the pressure inside of the sample chamber is reduced below the equilibrium vapor pressure of the frozen sample. The absolute pressure inside the chamber is often reduced to a range of 13.5 – 270.0 Pa (Brennan 2006). The ice crystals sublime from the outermost layer of the sample to the inside portion of the sample, therefore a freeze-dried layer forms on the outside layer of the sample and recedes inward. The vaporized water is continuously removed from the sample chamber by a vacuum pump into a refrigerated condenser, which re-freezes the water vapor. The dried portion of the sample has a porous structure and the tissue cells experience little or no shrinkage. The remaining liquid in the food system remains intact and does not redistribute or equalize in the freeze-dried layer. As more ice crystals vaporize they diffuse through the freeze dried layer and this process continues until all of the ice crystals have lyophilized (Liapis and Bruttini 1995). The drying rate in the primary drying stage is fairly constant (Williams-Gardner 1971).

Water in the sample that was bound tightly to solid particulates may not have frozen during the freezing stage. This water is removed from the sample during the secondary drying phase. To remove the bound water, the sample is heated under vacuum. The heat may be supplied by convection, conduction and

or radiation (Liapis and Bruttini 1995). The process is complete when the desired moisture level of the sample has been reach.

### 1.3.3 Principles of Cabinet Drying

Cabinet drying (or hot air drying) is one of the most commonly used drying methods for food products including fruits, vegetables, herbs and spices, and pasta (Zhao 2007). The process is characterized as a parallel or cross flow of warm air that passes over a layer of foodstuff and is expelled out of the drying chamber. A batch cabinet drying system consists of an insulated cabinet with a sample-drying chamber filled with shelves, a fan, and steam coils that are used to indirectly heat the air. The heated air is transferred to the surface of a food sample through convection. The water vapor formed from the sample is carried away in the air stream and is expelled from dryer through side vents.

When the temperature, humidity, and air velocity of the system are held constant the sample is dried in three stages. The first stage is the equilibrium period. This stage is relatively short lasting compared to the remaining stages and is the period at which the surface of the wet solid sample comes into equilibrium with the air stream flowing over it. The second stage is the constant rate period where the water within the food sample is constantly moving towards the surface of the sample to keep the vapor pressure of the surface saturated. The air temperature, humidity, and surface area of the sample affect the rate of drying during the constant rate period. As the water from the surface evaporates, it is replaced with additional water that has migrated from the inside of the sample. Therefore the rate of drying during this stage remains constant. Near

the end of the constant rate period there is not enough water in the sample to maintain saturation at the surface. This point is called the critical point and it is at this point where the rate of drying declines. The third stage of drying occurs after the critical point and it is called the falling rate period. During the falling rate period the surface temperature of the sample rises to the dry bulb temperature of the air. Some foodstuffs have more than one falling rate period before the sample has finished drying (Brennan 2006).

### 1.3.4 Principles of Vacuum Drying

Vacuum drying tends to yield fruit products that have a higher quality than those dried by cabinet drying. However the capital cost of vacuum drying is higher and the production throughput is low compared to cabinet hot air drying (Brennan 2006). During the vacuum drying process the water inside the foodstuff is vaporized after being exposed to a heat source and the vapor is removed from the sample chamber under partial vacuum. The equipment for a batch vacuum dryer consists of a sample chamber with multiple shelves, a moisture condenser, and a vacuum pump.

After the sample is placed inside the sample chamber the cavity is sealed and the internal pressure is reduced by the vacuum pump. The absolute pressure inside of the sample chamber may range from 5-30 kPa for temperatures ranges of 35-80°C. In some styles of vacuum dryers the heat is supplied to the samples by conduction through the hollow shelves on which they rest. The shelves may be heated with circulating steam, heated water, or a thermal fluid. The samples may also receive additional heat through radiation

from the hot surfaces in the sample chamber. In other vacuum drying systems heat is delivered to the sample through convection using hot air (Brennan 2006).

Using excessive heat to removal moisture from a foodstuff may damage the quality of the final product. The advantage of using a vacuum dehydration method is that the boiling point of water is reduced below 100°C through the reduction of pressure. Thus the moisture in the sample is removed at a faster rate (Noomhorm and Ahmad 2008) and therefore the samples may be dried in 4-20 hours depending on the size and shape of the product (Brennan 2006).

### 1.3.5 Principles of Infrared Drying

Infrared drying is not a heavily utilized method using for drying food. Infrared drying has been applied to products such as breadcrumbs, tea, flour, and spices (Brennan et al. 1990). It is less common to apply infrared drying to wet products where the bulk water needs to be removed. Nonetheless infrared drying has been successfully applied to fruit, vegetables, meat, and fish (Ginzburg 1969). The advantages to infrared dehydration are that the processing times are short and the energy utilization is minimal (Sakai and Hanzawa 1994).

Infrared drying utilizes electromagnetic radiation of wavelengths between 0.7 – 1,000 microns, which are longer than visible light energy but shorter than radio waves. There are three subgroups of infrared drying divided by the wavelengths used during drying. The three subgroups are near infrared (0.76 – 2 μm; 1200 - 3800°C surface temperature), medium infrared (2 - 4 μm; 450 – 1200°C surface temperature), and far infrared (4 - 6 μm; 450 °C surface temperature or less). Water has a peak absorption of 3 μm, therefore for efficient

water removal from a foodstuff sample, the emitter output should satisfy this specification (Cenkowski and others 2008).

The basic equipment necessary for a batch infrared dryer involves an infrared oven with a product shelf, reflector, and a radiator that is either electrically heated or gas-fired. The thermal radiation may be reflected, absorbed, or transmitted through the foodstuff. The thermal radiation applied to foodstuffs is often absorbed into the sample and is influenced by the surface characteristics of the sample as well as the wavelength of the radiation (Williams-Gardner 1971). As the radiation comes into contact with the surface of the product, the radiant energy is absorbed into the outer most layer of the product and turned into heat. Infrared drying is therefore best applied to products that are spread into thin layers on samples trays to obtain a large surface area (Brennan 2006). The temperature of the product may be measured with a radiometer or a thermocouple shielded from ambient air conditions (Williams-Gardner 1971).

The drying model developed by Hasatani and others (1988) for infrared drying is similar to the drying model described for cabinet drying. There are three drying stages with the first being a constant drying period. It is during this stage where the water vapor pressure on the surface of the product is equal to the saturated vapor pressure at the surface temperature. The second drying stage is the falling rate drying period. At this stage in the drying process dry patches begin to form on the sample's surface and this leads to a decrease in the drying rate. As the water levels in the sample decreases, the reflectivity of the sample

increases and the absorption of radiation decreases (Nowak and Lewicki 2004). The third drying stage occurs when the surface of the sample forms a dry layer and the layer of water evaporation has migrated towards the center of the sample. The residual water vapor must travel through the dry layer in order to escape the sample.

## 1.4 Analysis of Antioxidant Capacity

### 1.4.1 Oxygen Radical Absorbance Capacity

Currently there are no standardized methods for measuring the total antioxidant capacity of foodstuffs. One reason for a lack of standardization is that there is no one method that accounts for all possible free radical or antioxidant sources (Prior and others 2005). The Oxygen Radical Absorbance Capacity ($ORAC_{FL}$) is one method for analyzing the total antioxidant capacity that has become common. The $ORAC_{FL}$ method has been used to study the antioxidant capacity of several foodstuffs including fruits, vegetables, legumes, cereal grains, herbs and spices, dairy products, and nuts.

The development of the $ORAC_{FL}$ method is accredited to Ghiselli and others (1995),Glazer (1990)and Cao and others (1993) and is classified as a Hydrogen Atom Transfer Assay (HAT). In HAT reactions, the antioxidant will quench free radicals through the donation of a hydrogen atom. The $ORAC_{FL}$ method measures the ability of the antioxidant to scavenge for peroxyl radicals using a fluorescent probe (fluorescein sodium salt) for detection. The peroxyl radicals will oxidize the fluorescent probe causing a decrease in the intensity of the fluorescence that can be quantified over time using a fluorometer.

Antioxidants in the system will quench the peroxyl radicals preventing the loss of intensity in the fluorescence. One advantage of the $ORAC_{FL}$ method is that the mechanism is based on peroxyl radicals which are biologically relevant and are the predominate free radical found in lipid oxidation in foods and biological systems. The peroxyl radicals in the system are thermally generated through the addition of an azo compound, AAPH (2,2'–azobis(2-amidinopropane) dihydrochloride). The interaction between the antioxidants, free radicals, and the fluorescent probe is illustrated in Figure 3 (Zulueta and others 2009):

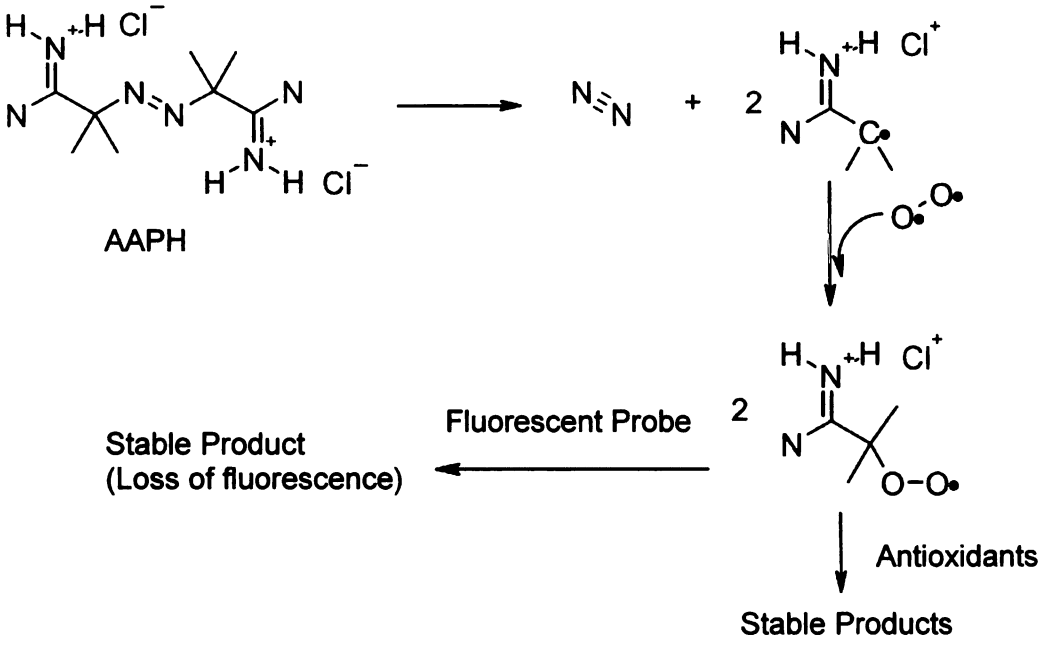


**Figure 3. Formation of radicals through the addition of AAPH**

The relative fluorescence intensity is measured over time to build a decay curve for each sample and a blank sample. The $ORAC_{FL}$ assay reactions will be allowed to run for an extended period of time to account for the potential effects

of secondary antioxidant products. To date this is the only method that combines both the degree and time of antioxidant reaction (Zulueta et al. 2009). Once the decay curve the area under the curve (AUC) is calculated using the following trapezoidal equation 5 . Here R1 is defined as the fluorescence measurement at the initial time of the oxidation reaction, Rn is the final fluorescence measurement, and $\Delta t$ is the difference of time between the two measurements:

$$AUC = (R1/2 + R2 + R3 + \ldots Rn/2)\ \Delta t \qquad (5)$$

The antioxidant capacity is quantified by calculating the net area under curve:

$$\text{Net AUC} = AUC_{\text{Sample}} - AUC_{\text{Blank}} \qquad (6)$$

The net AUC of each sample is then compared to a standard calibration curve. The calibration curve is constructed by plotting the net AUC of a compound called Trolox (6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid) against five standard concentrations in micromoles of Trolox, a water soluble vitamin E analog (Prior and others 2005). Therefore the $ORAC_{FL}$ value of a sample is expressed as micromoles of Trolox equivalents per gram or liter of sample (μmol TE/g or μmol TE/L).

An additional advantage of the ORACFL procedure is that the principles may be applied to free radicals other than peroxyl radicals (Ou and others 2002). Some of the disadvantages of using the ORACFL procedure for measuring total antioxidants is that it requires the use of expensive equipment, the assay is pH sensitive, and the assay requires a long time period to quantify results (Zulueta et al. 2009).

### 1.4.2 Folin-Ciocalteu's Assay

The Folin-Ciocalteu assay is a colormetric spectroscopy method used to measure the concentration of phenols. It is based on the original work of Folin and Ciocalteau (1927) who used this method to measure the tyrosine and tryptophane concentrations in protein. This method was adapted by Singleton and Rossi (1965) to measure the total phenolics in wine. Now the Folin-Ciocalteu method is used to measure the total phenolics in many foodstuffs such as tea, fruit, vegetables, cereal grains, and olive oil (Singleton and others 1999). The specific phenols found in tart cherries are flavonoids such as 7-dimethoxy-5,8,4'-trihydoxyflavone, quercetin 3-rhamnoside, genistein, chlorogenic acid, naringenin, and genistin (Wang and others 1999a).

To begin the assay an aqueous antioxidant extract of the foodstuff is diluted to the appropriate concentration with distilled water. A commercially available reagent called the Folin-Ciocalteau Reagent is added to the samples; the samples are mixed, and then incubated at room temperature for one to eight minutes. Afterwards a twenty percent sodium carbonate solution is added to the samples, the samples are mixed, and then incubated at room temperature for two hours before quantifying the color development on a spectrophotometer.

The basis of this assay involves the oxidation of a phenolate ion from the antioxidant extract of the foodstuff sample and the reduction of the phosphotungstic-phosphomolybdic reagent, otherwise known as the Folin-Ciocalteu reagent. The result of this reduction turns the chromophore moiety from a yellow complex to a blue phosphotungstic-phoshomolybdic complex (Bravo and Mateos 2008). The reaction must take place under alkaline

conditions in order to aid with the uptake of oxygen by the phenol, which occurs most efficiently near the pKa (approximately pH 10) of the phenol. The pH of the system is controlled through the addition of sodium cyanide, sodium hydroxide, or more commonly with sodium carbonate. The blue color produced is relatively stable and has a broad light absorption peak that can be measured on a spectrophotometer (Singleton and others 1999). The concentration of phenols is proportional to the intensity of the light absorption near 760 nm where other biological species do not absorb at this wavelength (Waterhouse 2005). The absorbance values of the samples are then compared to a standard such as tannic acid, catechin, tyrosine, and gallic acid (Singleton and others 1999). Gallic acid is commonly used as the standard and has the advantage of being inexpensive in pure form and is stable in dry form (Waterhouse 2005). Thus the total phenolics values for the samples are expressed in gallic acid equivalents per gram or liter of sample (GAE/g or GAE/L).

The procedure is simple, rapid, utilizes common laboratory equipment, and the method is standardized allowing for comparison of results found in literature (Bravo and Mateos 2008). Another advantage of this method is that the chemical reaction has a relatively equivalent response to various phenolic substances making this assay suitable for determination of the total phenolics in a sample. Reducing agents such as ascorbic acid, amino acids, and sugars may act as interferences to this method and may cause overestimation. The interference of sugar may be easily adjusted in wine samples. However in other high sugar foodstuffs such as fruit, it is uncertain whether a correction factor can

be applied. Another approach is to prepare the standards in the same sugar concentration as the samples. One final consideration is that the Folin-Ciocalteu method measures all compounds that are oxidized under the reactions mentioned above. Therefore substances such as proteins that are less typically thought of as phenols need to be considered during quantification (Singleton 1999).

### 1.4.3 Detection of Anthocyanins by the pH-differential Assay

The pH differential assay is a method that is used to quantify the total amount of monomeric anthocyanins found in foodstuffs. Sondheimer and Kertesz (1948) originally developed the concept for this method to study the anthocyanins founds in fruit jam and the method was further modified by Fuleki and Francis (1968) to analyze the anthocyanins found in cranberries. The pH differential method has been used to analyze foodstuffs including fruits, vegetables, cereal grains, and legumes (Mazza and Miniati 1993).

The foundation of this assay is dependent on the structural changes made to the anthocyanin chromophore as affected by the pH of the system. Anthocyanins represent a variety of colors found in nature ranging from red to purple and blue. The color of anthocyanins is reversible and depends on their structure, which is influenced by the pH of the system. Anthocyanins exist as flavylium cations at pH 2 or less and are found to display red or yellow. The anthocyanins transform into hemiketals around pH 4-6 and their color fades. A further increase in pH will yield anthocyanins that display colors of purple, blue, and sometimes yellow upon heat treatment (Mazza and Miniati 1993). In the pH

differential assay antioxidant sample extracts are diluted with two aqueous buffers, one with pH 1.0 and the other with pH 4.5. Figure 4 demonstrates the structural changes during the pH-differential assay (Wrolstad and others 2005).

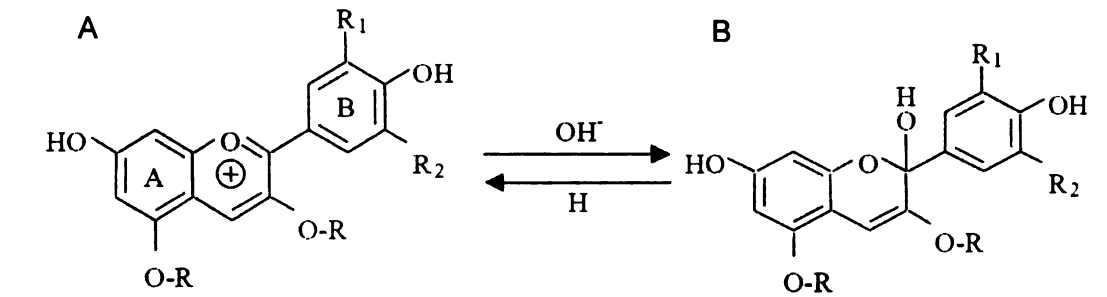


**Figure 4. Structural changes of an anthocyanin at pH 1.0 (A) and pH 4.5 (B)**

The absorbance of the samples are read on a spectrophotometer at λvis-max and at 700 nm, which is used to correct for haze caused by some colloidal substances (Giusti and Wrolstad 2005). The λvis-max is chosen based upon the type of anthocyanins found in the sample and a wavelength near 520 nm is often chosen since cyanidin-3-glucoside is the most common anthocyanin found in nature (Giusti and Wrolstad 2005; Francis 1989). The difference of absorbance between the two buffered samples represents the monomeric anthocyanins present in the system. Any polymerized anthocyanins or non-enzymatic browning pigments that are present in the system do not undergo reversible structural transformations with pH (Wrolstad and others 2005). The total monomeric anthocyanin concentration is reported as milligrams of the specific

anthocyanin such as cyanidin-3-glucoside per 100 grams or liter of foodstuffs (mg cyn-3-glu/100 g or mg cyn-3-glu/L).

The pH differential assay is an accurate, rapid and, easy procedure (Giusti and Wrolstad 2005). This method is applied widespread in the industry and scientific community, which allows for comparison of results between laboratories (Lee and others 2005). The pH differential method has shown high correlation with HPLC (high performance liquid chromatography) methods for determining the concentration of anthocyanins in foodstuffs (Lee and others 2008). Substances that have been found to interfere with the pH-differential method include FD&C Red Number 40, FD&C Red Number 3, cochineal, and beet powder (Giusti and Wrolstad 2005).

# 2 MATERIALS AND METHODS

## 2.1 Plant Material

### 2.1.1 Tart Cherry Pomace

Montmorency tart cherry pomace was obtained from Cherry Growers Inc. (Grawn, Michigan) in July 2008. The pomace had been processed within the same morning the samples were acquired. The pomace consisted of skins, flesh, stems, and pits. The average initial moisture content was 78.43 ± 0.72% wet basis (wb) and the average water activity was 0.996 at 23°C. The pomace was stored in five gallon plastic buckets in the Michigan State University Food Science Pilot Plant Freezer at -15°C until the sample preparation for drying.

### 2.1.2 Commercial Tart Cherry Powder Samples

Three commercial tart cherry powder samples were obtained for comparison to the tart cherry powder produced in these laboratory experiments. The first sample was a drum dried tart cherry powder supplied by Van Drunen Farms (Momence, Illinois). It was manufactured from the whole cherry fruit and contains 10% (w/w) rice flour. The second sample was a freeze dried tart cherry powder also supplied by Van Drunen Farms. It was manufactured from the whole cherry fruit and contains 3% (w/w) silicon dioxide. The final sample was a freeze dried tart cherry powder supplied by Shoreline Fruit (Traverse City, Michigan). It was manufactured from cherry pomace and does not contain any additives.

### 2.1.3 Sample Preparation

The raw cherry pomace was removed from the pilot plant freezer and was thawed at refrigeration temperatures (4°C). The stems and pits were manually removed from the cherry pomace sample. The cherry pomace was blended with 10% (w/w) maltodextrin (Maltrin M100, Grain Processing Corp., Muscatine, Iowa) using a KitchenAid Mixer KSM90 (St. Joseph, MI) to increase the glass transition temperature of the carbohydrates within the pomace. The cherry pomace sample prepared for the freeze dryer was spread into a thin even layer onto a wire mesh tray (20" length x 10" width) and refrozen (-15°C) before drying. The thawed cherry pomace samples for the vacuum, cabinet, and infrared dryer were evenly distributed in a thin layer onto a wire mesh tray. Separate cherry pomace samples were dried to an equilibrium dry bulb temperature of 50°C, 70°C, 90°C, and 110°C in each type of dryer except for the freeze dryer. The temperature of the pomace during the constant rate drying period is equal to the wet bulb temperature of the air. As the product dries it reaches its critical moisture point and enters the falling rate period where the temperature of the pomace approaches the dry bulb temperature of the air. Thus at the end of the drying process the pomace temperature had reached the dry bulb temperature of the air. However the surface temperature of the pomace is higher (450 – 1200°C) than the dry bulb temperature of the air in the infrared drying method (Cenkowski and others 2008).

The target final moisture content of the cherry pomace was 4±1% (wb). The target final moisture content of the cherry powder was chosen based on the specifications of tart cherry powder currently commercially available. The

moisture content of the samples was measured using a Denver Instrument Moisture Analyzer IR-200 (Denver, Colorado).

## 2.2 Drying Methods

### 2.2.1 Freeze Drying

The freeze dryer used for these experiments was a Unitop 600SL Freeze Mobil 12 batch dryer manufactured by The Virtis Company (Gardiner, NY). The dryer system consisted of a sample chamber (10" width, 10.5" height) with three shelves, a Cenco Hyvac 7 vacuum oil pump (Chicago, Illinois) and a refrigerated condenser chamber. The sample chamber was cooled with dry ice for one hour prior to drying and the condenser chamber was turned on to reach and maintain a temperature between –66.0°C to -70.0°C. The frozen cherry pomace sample was placed on the middle shelf of the sample chamber. The vacuum oil pump was turned on and a proper seal formed around the door of the sample chamber. The absolute pressure inside the chamber ranged from 0.026 – 0.042 torr. The air temperature within the sample chamber came to room temperature within a few hours from the start of the test and remained at that temperature until the test was completed. The total length of time taken to freeze-dry the samples was up to 96 hours.

### 2.2.2 Cabinet Drying

The cabinet dryer used for these experiments was a Proctor and Schwartz Inc. K12395 batch dryer (Philadelphia, Pennsylvania). The dryer consisted of a centrifugal fan, a sample chamber (30" width, 45" height) with 10 shelves, and

steam-fueled heat exchangers. The cabinet dryer was preheated to a stable specific temperature monitored by an alcohol thermometer mounted on the front side of the dryer. The sample tray was placed on the fifth shelf from the top, the cabinet door was closed, and the centrifugal fan was turned on. Every one to two hours the sample was rotated on the wire mesh tray. The air velocity was measured over the product surface and held constant using a handheld Omega Temperature and Air Velocity Meter HHF52 (Stamford, Connecticut) at 1.9 ± 1 m/s. The total length of time taken to cabinet-dry the samples ranged one to three hours.

### 2.2.3 Vacuum Drying

The vacuum dryer (VWR 1430, West Chester, PA) used for these experiments consisted of a dry air inlet maintained with desiccant, a convection oven with three shelves, an ethanol and dry ice moisture trap, and a vacuum oil pump (Gast 0523-V4F-G582DX, Benton Harbor, MI). The oven was preconditioned to the specified temperature monitored by a mercury thermometer placed in the front of the dryer in the lower left corner. The sample tray was placed on the middle shelf of the sample chamber in the oven, the door was properly sealed, and the vacuum pump was turned on to create a vacuum (75 kPa) inside the sample chamber. Every one to two hours the vacuum pump was turned off in order to empty the moisture trap and rotate the sample on the tray to ensure even drying. The total length of time taken to vacuum-dry the samples ranged from two to eight hours.

### 2.2.4 Infrared Drying

The dryer used for these experiments was a bench top infrared dryer (Michigan State University, concept by Mark A. Uebersax, design by Muhammad Siddiq, built by Richard Wolthuis) The stainless steel dryer consisted of a two medium infrared bulbs (R40 Heat, 120 volts, 240 watts), two product sample shelves (19.5" length, 9.75" width), and two separate manual dials to control the current of the infrared bulbs. The cherry pomace samples were placed on the bottom product sample shelf, which was placed 10.5" below the infrared bulbs. The temperature of the system was controlled with a Cole Parmer Digi-Sense Dual JTEK thermocouple thermometer (Vernon Hills, Illinois) shielded with aluminum foil. Every 30 to 60 minutes the sample was rotated on the sample tray. The total length of time taken to infrared dry the samples ranged from one to two and a half hours.

## 2.3 Cherry Powder Preparation

### 2.3.1 Particle Size Reduction, Selection, and Storage

The dried cherry pomace was ground into a powder using a Krups F203 coffee grinder (Millville, New Jersey). The cherry powder was sifted using a stainless steel Tyler test sieve, 250 um (Mentor, Ohio) to obtain a more uniform sample size. All particles smaller than 250 microns were vacuum packed (Multivac Inc. Kansas City, Missouri) in polyethylene bags and stored in the Michigan State University Food Science Pilot Plant Freezer at -15°C.

### 2.3.2 Extraction of Antioxidants

Antioxidants from the raw cherry pomace were extracted using a modified procedure by Chaovanalikit and Wrolstad (2004). Raw pomace was blended with 70% (v/v) aqueous acetone (Sigma-Aldrich, St. Louis, Missouri) with 0.01% hydrochloric acid (EMD Chemicals, Gibbstown, New Jersey) in a stainless steal Waring Blender (Torrington, Connecticut) until a smooth pureed consistency. The use of aqueous acidified acetone creates a low pH environment where the antioxidants are more stable (Rodriguez-Saona and Wrolstad 2005). The pomace slurry was stored in sealed glass jars wrapped in aluminum foil to protect the sample from sun light and placed in a freezer (-15°C) for 15 hours to achieve an equilibrium state.

The antioxidant filtrate was then collected into clean glass containers by filtering and squeezing the pomace slurry through nylon mesh. Equal volumetric parts of chloroform (EMD Chemicals, Gibbstown, New Jersey) were added to the antioxidant filtrate and the mixture was allowed to rest at refrigeration temperatures (4°C) until a clear partition had formed between the two layers. The chloroform is added to the filtrate in order to remove the lipophilic contaminants (Rodriguez-Saona and Wrolstad 2005). After a clear partition had formed, the top layer which contained the hydrophilic antioxidant substances was transferred to a 50 mL sealed plastic centrifuge tube (Corning, Corning, New York) and stored at freezer conditions until the chemical analysis.

The procedure for the extraction of antioxidants from the dried cherry powder was similar to that of the raw cherry pomace with a few exceptions. The cherry powder was placed in a 50-mL centrifuge tube wrapped in aluminum foil

along with the 70% (v/v) aqueous acetone with 0.01% hydrochloric acid and placed on a shaker table (Model G76, New Brunswick Scientific, Edison, New Jersey) for 30 minutes. The centrifuge tubes containing the cherry slurry were then placed in freezer conditions for 15 hours. Afterwards the samples were then centrifuged in a Sorvall RC-5B Refrigerated Superspeed Centrifuge (Waltham, Massachusetts) for 10 minutes at 3,000 x g to remove the cherry solid particulates. The supernatant was mixed with equal volumetric parts of chloroform and allowed to rest at refrigeration temperatures until a clear partition has formed. The top layer from the partitioned mixture was transferred to a centrifuge tube and stored in freezer conditions until the chemical analysis.

## 2.4 Physico-Chemical Characterizations

### 2.4.1 Hunter Color CIE

Hunter CIE L*, a*, b* ΔE* parameters were determined using a Hunter Color LabScan XE Colorimeter (Reston, Virginia) and the EasyMatch® QC software. The colorimeter was operated in the reflectance mode where, L* is the lightness or darkness (black, L=0; white, L=100), +a* is redness, -a* is greenness, +b* is yellowness, and –b* is blueness. The total color difference (ΔE*) is a single value that takes L*, a*, and b* into account. The instrument was calibrated using two calibrations tiles, a black tile and a white standard calibration tile #LX17582 provided by the manufacturer (X=80.37, Y=85.26, Z=89.86). For the Hunter Color CIE measurements the raw cherry pomace or dried cherry powder samples were spread into a continuous layer across the bottom of a 1.75 inch glass sample cup provided by the manufacturers.

### 2.4.2 pH and Titratable Acidity

The pH and the titratable acidity of the samples were measured according to the AOAC Official Method 942.15 (AOAC 2000). The pH of the raw pomace and dried cherry powder was measured using a Corning 1430 meter (Corning, New York). The cherry powder samples were prepared by blending five grams of cherry powder with 50 mL of distilled water and the raw cherry pomace samples were prepared by blending 10 grams of pomace with 100 mL of distilled water in a stainless steel Waring Blender. The measurements were conducted with a pH combination electrode (Pinnacle, Woburn, Massachusetts). The samples were by neutralized with 0.1N sodium hydroxide (Mallinckrodt Baker, Phillipsburg, New Jersey) until a pH of 8.1 was reached. The titratable acidity was calculated using the following equation and was expressed as a percentage of malic acid:

Percent malic acid =
mL of NaOH x 0.1N NaOH x 0.067 meq x (100/weight of sample) (7)

### 2.4.3 Water Absorption Index

The water absorption index (WAI) of the dried cherry powder was measured using a procedure adapted from Anderson and others (1969). Two and a half grams of dried cherry powder were weighed into a pre-weighed centrifuged tube. Next 30 mL of distilled water (30°C) was added to the centrifuge tube, mixed thoroughly, and placed on a shaker table for 30 minutes. The slurry was then centrifuged at 3,000 x g for 10 minutes. The filtrate was removed from the tube and set aside for the water solubility assay. The centrifuge tube was inverted for 10 minutes to allow for additional draining. The

remaining sediment was weighed and the water absorption index was calculated using the following equation:

$$WAI = (\text{Weight of sediment} / \text{Weight of dry sample}) \quad (8)$$

### 2.4.4 Water Solubility

The water solubility index (WS) of the dried cherry powder was measured using a procedure adopted from Anderson and others (1969). The filtrate from the water absorption index was poured into a pre-weighed aluminum weigh dish (VWR, Westchester, Pennsylvania) and oven dried in a convection incubator (Thermo Scientific, Waltham, Massachusetts) at 110 °C. The water solubility index was calculated using the following equation:

$$WS\ (\%) = \frac{(\text{Weight of dry solids in filtrate}) \times 100}{(\text{Weight of original dried sample})} \quad (9)$$

## 2.5 Determination of Total Antioxidants: Oxygen Radical Absorbance Capacity

### 2.5.1 Sample and Reagent Preparation

The $ORAC_{FL}$ procedure was adopted from Huang and others (2005). The chemicals for the assay including the fluorescein sodium salt, 2,2'-Azobis(2-amidinopropane) dihydrochloride (AAPH), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox®), and dibasic sodium phosphate were purchased from Sigma-Aldrich (St. Louis, Missouri). The monobasic monohydrate sodium phosphate was purchased from Mallinckrodt Baker (Phillipsburg, New Jersey).

The fluorescein stock solution (4 x $10^3$ mM) was prepared by dissolving 0.1 g of fluorescein in 50 mL of sodium phosphate buffer (75 mM, pH 7.4) to make a fluorescein solution with a concentration of 5.31 x $10^{-3}$ M. Then 0.752 mL of the 5.31 x $10^{-3}$ M fluorescein solution was placed into a one liter volumetric flask and the total volume was adjusted to one liter using the sodium phosphate buffer. The Trolox stock solution (2.0 mM) was prepared by combining 0.25 g Trolox with 500 mL of sodium phosphate buffer. The fluorescein and Trolox stock solutions were stored in sealed glass containers wrapped in foil and stored at refrigerator conditions.

For each ORAC analysis a fluorescein working solution, the Trolox dilutions, and the AAPH solution were prepared fresh. The fluorescein solution was prepared by diluting the stock solution (1:1000) in the sodium phosphate buffer. The Trolox dilutions (6.25, 12.5, 25, 50, 100 µM) were prepared with the sodium phosphate buffer. The AAPH solution (153 mM) was prepared by dissolving 0.414 g of AAPH into 10 mL of the sodium phosphate buffer. The antioxidant extract samples were prepared by diluting the extract sample (1:4 or 1:2.3) in sodium phosphate buffer.

### 2.5.2 Experimental Procedure

Black polystyrene 96-well, round bottom plates were obtained from Corning (Corning, New York). The exterior wells of the plate were filled with 300 µL of distilled water to prevent variations is measurements between wells due to low conductivity of the polystyrene plates (Zulueta et al. 2009). All of the interior wells used for the experimental analysis were filled with 150 µL of the fluorescein

working solution. Twenty-five micro liters of sodium phosphate buffer were added to the wells, representing the blank samples. The remaining experimental samples wells were filled either with 25 µL of the Trolox dilutions or 25 µL of the extract sample dilutions. The 96-well plate was then placed in the FLx800 Multi-Detection Microplate Reader (Biotek Instruments, Winooski, Vermont) and incubated for 30 minutes at 37ºC. After the incubation period, 25 µL of the AAPH solution was added to all of the experimental wells. The accompanying software to the Biotek Microplate Reader was Gen 5. The detection parameters were set at 485 nm, 20 nm bandpass, excitation filter and a 528 nm, 20 nm bandpass, emission filter. The relative fluorescence intensity was monitored and recorded every two minutes for five hours.

The relative fluorescence intensity was plotted against time to build a decay curve for each sample and the blank. The antioxidant capacity is quantified by calculating the net area under curve:

$$\text{Net AUC} = \text{AUC}_{\text{Sample}} - \text{AUC}_{\text{Blank}} \qquad (10)$$

The net AUC of each sample is then compared to a standard calibration curve. The calibration curve is constructed by plotting the net AUC of Trolox against five standard concentrations in micromoles. Therefore the $ORAC_{FL}$ value of a sample is expressed as micromoles of Trolox equivalents per gram or liter of sample (µM TE/g or µM TE/L).

## 2.6 Determination of Total Phenolics: Folin-Ciocalteu's Assay

### 2.6.1 Sample and Reagent Preparation

The total phenolics procedure was followed as prescribed by Singleton and Rossi (1965). The anhydrous sodium carbonate, gallic acid, and the Folin-Ciocalteu reagent were obtained from Sigma-Aldrich (St. Louis, Missouri). The sodium carbonate solution was prepared by dissolving 200 g of anhydrous sodium carbonate in 800 mL of distilled water and bringing the solution to a boil. After the solution had cooled, a few crystals of sodium carbonate were added, and the solution was allowed to rest at room temperature for 24 hours. The next day the solution was filtered through Whatman No. 1 paper (Whatman Inc., Clifton, New Jersey) into a one liter volumetric flask where the volume was adjusted to one liter and stored at room temperature.

The gallic acid stock solution was prepared fresh for each analysis by dissolving 0.5 g of gallic acid with 0.5 mL of ethanol (EMD Chemicals, Gibbstown, New Jersey) and then the solution volume was brought to 100 mL with distilled water. The solution was sealed and stored in an amber colored glass container in refrigerator conditions. Five gallic acid standard dilutions (25, 50, 100, 150, 200 ppm) were prepared for each analysis using the gallic acid stock solution and distilled water. The antioxidant extract samples were prepared for the experimental procedure by diluting them (1:10) with the 70% (v/v) acidified aqueous acetone solution.

### 2.6.2 Experimental Procedure

Into separate glass test tubes 0.5 mL of each of the gallic acid standard dilutions, 0.5 mL of each extract sample, and 0.5 mL of distilled water used for the blank were placed. To each test tube 7.5 mL of distilled water was added to every test tube followed by 0.5 mL of the Folin-Ciocalteu reagent. All of the test tubes were mixed on the Fisher Scientific vortex mixer (Pittsburg, Pennsylvania) and incubated at room temperature for one to eight minutes. Then 1.5 mL of sodium carbonate was added to each of the test tubes and mixed a second time on the vortex mixer. The samples were incubated at room temperature for two hours before having the absorbance of each sample read at 765 nm on a Spectronic 21D Milton Roy spectrophotometer (Ivyland, Pennsylvania) using the blank sample to calibrate the meter.

The gallic acid standard dilution absorbance values were used to build a gallic acid standard curve that expressed the absorbance values versus the gallic acid standard concentrations (ppm). Using this standard curve the total phenolics value of the extract samples were calculated and expressed in gallic acid equivalents (GAE).

## 2.7 Determination of Total Anthocyanins: pH-Differential Assay

### 2.7.1 Sample and Reagent Preparation

The pH differential procedure was prescribed by Rodriguez-Saona and Wrolstad (2000). The chemicals for the assay included potassium chloride and sodium acetate provided by Mallinckrodt Baker (Phillipsburg, New Jersey) and hydrochloric acid. The potassium chloride buffer (0.025 M, pH 1.0) was prepared

by dissolving 1.86 g KCl into 980 mL of distilled water. The pH of the solution was measured and adjusted to pH 1.0 using concatenated HCl. The volume of the solution was then adjusted with distilled water to one liter using a volumetric flask.

The sodium acetate buffer (0.4M, pH 4.5) was prepared by dissolving 54.43 g $CH_3CO_2Na \cdot 3\ H_2O$ into 960 mL of distilled water. The pH of the solution was measured and adjusted to pH 4.5 using concentrated HCl. The volume of the solution was then adjusted with distilled water to one liter using a volumetric flask.

### 2.7.2 Experimental Procedure

The dilution factor for the antioxidant extract sample was determined by diluting it with the potassium chloride buffer until the absorbance of the sample at $\lambda_{vis\text{-}max}$ (510 nm) was within the linear range of the spectrophotometer. It is important to note while determining the dilution factor that the sample should not exceed the buffer's capacity and therefore the antioxidant extract sample should not exceed 20% of the total volume.

The Milton Roy Spectronic 21D spectrophotometer (Ivyland, Pennsylvania) was zeroed with distilled water at wavelength 510 nm and 700 nm. Two dilutions of the antioxidant extract sample were prepared separately with the potassium chloride buffer and the sodium acetate buffer using the previously determined dilution factor. These dilutions were mixed and allowed to equilibrate for 15 minutes at room temperature. The absorbance of each sample was measured at 510 nm and 700 nm.

The absorbance (A) of the samples was calculated using the following equation:

$$A = (A_{\lambda\ vis\text{-}max} - A_{700})_{pH1.0} - (A_{\lambda\ vis\text{-}max} - A_{700})_{pH4.5} \quad (11)$$

The monomeric anthocyanin pigment concentration was calculated using the following equation:

$$\text{Monomeric anthocyanin pigment (mg/liter)} = \quad (12)$$

$$(A \times MW \times DF \times 1000)/(\varepsilon \times 1)$$

In equation six, MW is the molecular weight of Cyanidin-3-glucoside (449.2 g/mol), DF is the dilution factor and ε is the molar absorptivity of Cyanidin-3-glucoside (26,900). The final monomeric anthocyanin pigment was converted and reported as mg/g cherry powder dry basis.

# 3 RESULTS AND DISCUSSION

The statistical analysis of these laboratory experiments was performed using SAS 9.1 (Raleigh, North Carolina).

## 3.1 Classification of the Physico-Chemical Characteristics of Tart Cherry Powder

### 3.1.1 Hunter Color CIE

The color of the raw tart cherry pomace and tart cherry powder was analyzed using the Hunter Color CIE L* a* b* system. All of the samples were analyzed under the D65/10 illuminant. In order to satisfy the normality assumption during the statistical analysis, a log transformation was applied to the data. The average L*, a*, b*, and ΔE* variables for the raw tart cherry pomace are located in Table 1 and the average values for the tart cherry powder for all four drying methods are shown in Figure 5 - Figure 8.

**Table 1. The average Hunter Color CIE variables for raw tart cherry pomace**

| | Average L* | Average a* | Average b* | Average ΔE* |
|---|---|---|---|---|
| Pomace Sample | 27.35 ± 0.37 | 15.95 ± 0.45 | 17.01 ± 0.76 | 70.53 ± 0.51 |

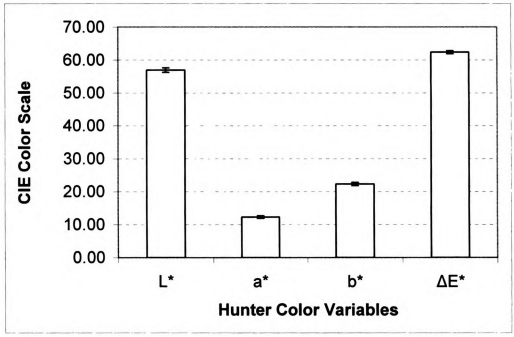


**Figure 5. The Hunter Color CIE variables of freeze dried tart cherry powder**

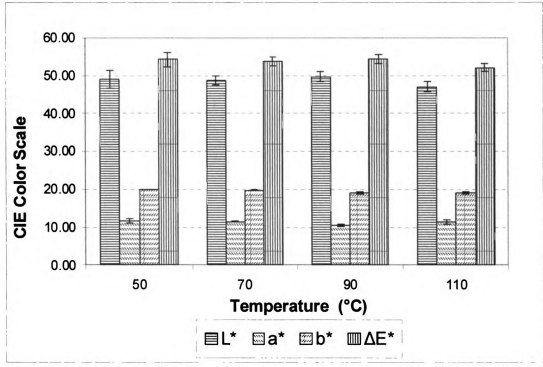


**Figure 6. The Hunter Color CIE variables of vacuum dried tart cherry powder**

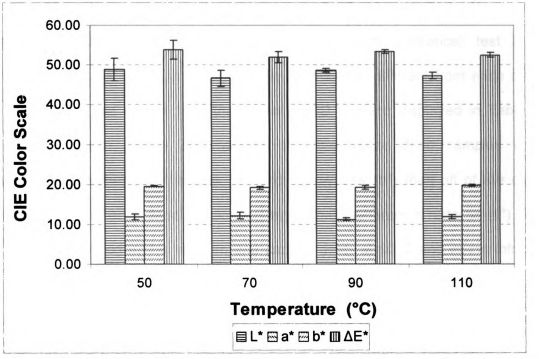


**Figure 7. The Hunter Color CIE variables of cabinet dried tart cherry powder**

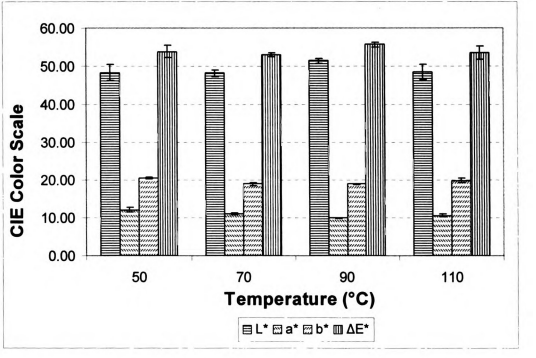


**Figure 8. The Hunter Color CIE variables of infrared dried tart cherry powder**

The differences of the means of the L*, a*, b*, and ΔE* values were analyzed using the Fisher's LSD (Least significant difference) test at a significance level of 5% and found to be significantly different from each other ($p<0.0001$). The results from the Fisher's LSD test are displayed in Table 2. From this table it may be observed that the freeze dried samples were significantly higher in whiteness (L*) and yellowness (b*) than all of the other samples. The freeze dried powder was significantly different in redness (a*) from the samples dried in the vacuum and cabinet dryer at 90°C and in the infrared dryer at 70°C, 90°C, and 110°C. The sample dried at 70°C in the cabinet dryer displayed the lowest average L* value. The sample dried at 90°C in the infrared dryer displayed the lowest average a* value. The samples dried at 70°C and 90°C in the infrared dryer displayed the lowest average b* values.

**Table 2. The average Hunter Color CIE variables and the Fisher's LSD comparison results of the tart cherry powder**

| Tart Cherry Powder Sample | | | | | |
|---|---|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average L* (white)** | **Average a* (red)** | **Average b* (yellow)** | **Average ΔE*** |
| Freeze Dried | 23* | 56.96 ± 0.68 [a] | 12.26 ± 0.39 [a] | 22.30 ± 0.51 [a] | 62.39 ± 0.44 [a] |
| Vacuum Dried | 50 | 49.00 ± 2.25 [b,c,d] | 11.63 ± 0.68 [a,b,c] | 20.01 ± 0.05 [b,c] | 54.21 ± 1.88 [b,c] |
| | 70 | 48.66 ± 1.18 [b,c,d] | 11.50 ± 0.20 [a,b,c] | 19.73 ± 0.17 [c] | 53.76 ± 1.08 [b,c,d] |
| | 90 | 49.69 ± 1.31 [b,c] | 10.52 ± 0.24 [d,e] | 19.12 ± 0.19 [d,e,f] | 54.27 ± 1.22 [b,c] |
| | 110 | 47.09 ± 1.47 [c,d] | 11.44 ± 0.57 [a,b,c] | 19.10 ± 0.34 [e,f] | 52.10 ± 1.15 [c,d] |
| Cabinet Dried | 50 | 48.82 ± 2.80 [b,c,d] | 11.82 ± 0.73 [a,b,c] | 19.53 ± 0.12 [c,d,e] | 53.91 ± 2.36 [b,c,d] |
| | 70 | 46.66 ± 1.96 [d] | 12.12 ± 0.83 [a] | 19.13 ± 0.30 [d,e,f] | 51.88 ± 1.45 [d] |
| | 90 | 48.59 ± 0.48 [c,d] | 11.20 ± 0.37 [b,c,d] | 19.19 ± 0.40 [d,e,f] | 53.43 ± 0.46 [b,c,d] |
| | 110 | 47.25 ± 0.83 [c,d] | 11.80 ± 0.51 [a,b,c] | 19.64 ± 0.23 [c,d] | 52.51 ± 0.55 [c,d] |
| Infrared Dried | 50 | 48.35 ± 2.10 [c,d] | 12.03 ± 0.62 [a,b] | 20.39 ± 0.25 [b] | 53.85 ± 1.65 [b,c,d] |
| | 70 | 48.16 ± 0.80 [c,d] | 11.02 ± 0.33 [c,d] | 18.92 ± 0.44 [f] | 52.90 ± 0.52 [c,d] |
| | 90 | 51.38 ± 0.56 [b] | 9.88 ± 0.15 [e] | 18.89 ± 0.11 [f] | 55.63 ± 0.53 [b] |
| | 110 | 48.55 ± 1.96 [c,d] | 10.56 ± 0.42 [c,d] | 19.83 ± 0.58 [c] | 53.50 ± 1.79 [b,c,d] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

The Hunter Color CIE variables were separately analyzed using a two way ANOVA (Analysis of variance) to examine the main effects and the interaction of the type of drying method and the temperature at which the samples were dried. Through analysis of the L* variable, the main effect of the drying method was found to be non-significant (p=0.1823), the main effect of temperature was found to be significant (p=0.0318), and the overall interaction between the two variables was found to be non-significant (p=0.6027). In order to verify the absence of an interaction, a Simple Effects Test was performed by partitioning the data by the type of drying method and by the air temperature. The Simple Effects Test compares the estimates of the slopes of each drying method from the regression plot of analysis. In doing so, the effect of drying method can be tested within each temperature level and the effect of temperature can be tested within each drying method (Table 3). The Simple Effects Test is a more precise check of the interactions and this information is helpful for determining which interactions do and do not contribute to the overall interaction.

**Table 3.Summary of the p-values from the Simple Effects Test for the Hunter Color CIE L* values**

| Interaction Effect | Type of Drying | Air Temperature (°C) | Pr>F |
|---|---|---|---|
| Type*Temp | | 50 | 0.8868 |
| Type*Temp | | 70 | 0.3006 |
| Type*Temp | | 90 | 0.1519 |
| Type*Temp | | 110 | 0.5037 |
| Type*Temp | Vacuum | | 0.2863 |
| Type*Temp | Cabinet | | 0.3231 |
| Type*Temp | Infrared | | 0.0884 |

The first four lines in Table 3 test the hypothesis that each drying method is equal at each air temperature level in terms of producing the same effect on the L* variable. For example the first line will reveal whether the L* values of the samples dried using the vacuum, cabinet, and infrared dryer are equal when dried at 50°C. The last three lines in the table will test the hypothesis that all four air temperature levels (50°C, 70°C, 90°C, and 110°C) are equal within each drying method. For example the last line will reveal whether the L* values of the samples dried at the four air temperature levels were equal within the infrared drying method. Through partitioning by temperature it may be seen in that the null hypothesis is not rejected meaning there is not an effect of drying method at any of the temperature levels on the L* values of the samples. The null hypothesis is also not rejected for any of the temperature levels when the data is partitioned by drying method meaning that within each drying method the air temperature does not effect the L* values of the samples. Therefore it is confirmed that there is no interaction effect on the L* values. If the null hypothesis was rejected meaning there is an effect of drying method or temperature, then separate contrasts of the estimates of the slopes may be made to determine which comparisons contribute to the overall interaction.

Through analysis of the a* variable, the main effect of the drying method was found to be significant ($p=0.0010$), the main effect of temperature was also found to be significant ($p<0.0001$), and the overall interaction between the two variables was found to be non-significant ($p=0.1285$). To verify the absence of an interaction a Simple Effects Test was performed by partitioning the data by

type of drying method and by air temperature (Table 4). When the data is partitioned by temperature, it is seen that type of dryer is significant when the product is dried at 90°C (p=0.0075) and at 110°C (p=0.0144). When the data is partitioned by type of drying method, it is seen that there was a significant effect of the temperature level within the vacuum drying method (p=0.0390) and the infrared drying method (p=0.0001). These interactions were further analyzed through comparisons of individual slopes to determine which drying methods significantly affected the a* values at 90°C and 110°C as well as which temperatures within the vacuum and infrared drying methods significantly affect the a* values.

**Table 4. Summary of the p-values from the Simple Effects Test for the Hunter Color CIE a* values**

| Interaction Effect | Type of Drying | Air Temperature (°C) | Pr>F |
|---|---|---|---|
| Type*Temp | | 50 | 0.6388 |
| Type*Temp | | 70 | 0.0503 |
| Type*Temp | | 90 | 0.0075 |
| Type*Temp | | 110 | 0.0144 |
| Type*Temp | Vacuum | | 0.0390 |
| Type*Temp | Cabinet | | 0.2054 |
| Type*Temp | Infrared | | 0.0001 |

Table 5 and Table 6 display the results from the interaction comparisons. Table 5 demonstrates that when samples were dried at 90°C the only drying method comparison that yielded significantly different a* values was the cabinet drying method versus the infrared drying method (p=0.0019). At 110°C there were two drying method comparisons that yielded significantly different a* values.

Those drying methods were the vacuum dryer versus the infrared dryer (p=0.0358) and the cabinet dryer versus the infrared dryer (p=0.0050). Table 6 demonstrates that within the vacuum drying method the only temperature comparisons that produced significantly different a* values are 50°C versus 90°C (p=0.0108), 70° versus 90°C (p=0.199), and 90°C versus 110°C (p=0.0286). In the infrared drying method the all of the temperature comparisons except 70°C versus 110°C produced significantly different a* values.

**Table 5. Summary of the p-values from the Simple Effects Test partitioned by temperature for the Hunter Color CIE a* values**

| | 90°C | 110°C |
|---|---|---|
| **Method Drying Comparisons** | **Pr>F** | **Pr>F** |
| Vacuum versus Cabinet | 0.0939 | 0.3944 |
| Vacuum versus Infrared | 0.0959 | 0.0358 |
| Cabinet versus Infrared | 0.0019 | 0.0050 |

**Table 6. Summary of the p-values from the Simple Effects Test partitioned by drying method for the Hunter Color CIE a* values**

| | Vacuum Drying | Infrared Drying |
|---|---|---|
| **Air Temperature Comparisons (°C)** | **Pr>F** | **Pr>F** |
| 50 versus 70 | 0.7913 | 0.0234 |
| 50 versus 90 | 0.0108 | <0.0001 |
| 50 versus 110 | 0.6686 | 0.0014 |
| 70 versus 90 | 0.0199 | 0.0058 |
| 70 versus 110 | 0.8697 | 0.2453 |
| 90 versus 110 | 0.0286 | 0.0785 |

Through analysis of the b* variable, the main effect of the drying method was found to be non-significant (p=0.5392), the main effect of temperature was also found to be significant (p<0.0001), and the overall interaction between the two variables was found to be significant (p=0.0012). To analyze the interaction the Simple Effects Test was performed (Table 7). When the data were partitioned by temperature, it was seen that type of dryer significantly affected the b* values when the product was dried at 50°C (p=0.0096), 70°C (p=0.0085) and at 110°C (p=0.0207). When the data were partitioned by type of drying method, it was seen that there was a significant effect of the temperature level within the vacuum drying method (p=0.0021) and the infrared drying method (p<0.0001). These interactions were further analyzed through comparisons of individual slopes to determine which drying methods significantly affect the b* values at 50°C, 70°C, and 110°C as well as which temperatures within the vacuum and infrared drying methods significantly affect the b* values.

**Table 7. Summary of the p-values from the Simple Effects Test for the Hunter Color CIE b* values**

| Interaction Effect | Type of Drying | Air Temperature (°C) | Pr>F |
|---|---|---|---|
| Type*Temp | | 50 | 0.0096 |
| Type*Temp | | 70 | 0.0085 |
| Type*Temp | | 90 | 0.4597 |
| Type*Temp | | 110 | 0.0207 |
| Type*Temp | Vacuum | | 0.0021 |
| Type*Temp | Cabinet | | 0.1389 |
| Type*Temp | Infrared | | <0.0001 |

Table 8 and Table 9 display the results from the interaction comparisons. Table 8 demonstrates that when samples were dried at 50°C the only drying method comparison that yielded significantly different b* values was the cabinet drying method versus the infrared drying method (p=0.0026). At 70°C there were two drying method comparisons that yielded significantly different b* values, which were the vacuum dryer versus the cabinet dryer (p=0.0238) and the vacuum dryer versus the infrared dryer (p=0.0029). Table 9 demonstrates that within the vacuum drying method the only temperature comparisons that will produced non-significantly different b* values were 50°C versus 70°C (p=0.2819) and 90° C versus 110°C (p=0.9203). In the infrared drying method all of the temperature comparisons except 70°C versus 90°C will produced significantly different b* values.

**Table 8. Summary of the p-values from the Simples Effects Test partitioned by temperature for the Hunter Color CIE b* values**

| | 50°C | 70°C | 110°C |
|---|---|---|---|
| **Method Drying Comparisons** | **Pr>F** | **Pr>F** | **Pr>F** |
| Vacuum versus Cabinet | 0.0684 | 0.0238 | 0.0404 |
| Vacuum versus Infrared | 0.1598 | 0.0029 | 0.0076 |
| Cabinet versus Infrared | 0.0026 | 0.3793 | 0.4633 |

**Table 9 Summary of the p-values from the Simple Effects Test partitioned by drying method for the Hunter Color CIE b* values**

| | Vacuum Drying | Infrared Drying |
|---|---|---|
| **Air Temperature Comparisons (°C)** | **Pr>F** | **Pr>F** |
| 50 versus 70 | 0.2819 | <0.0001 |
| 50 versus 90 | 0.0016 | <0.0001 |
| 50 versus 110 | 0.0013 | 0.0384 |
| 70 versus 90 | 0.0219 | 0.9343 |
| 70 versus 110 | 0.0175 | 0.0012 |
| 90 versus 110 | 0.9203 | 0.0010 |

### 3.1.2 pH

The average pH value of the raw tart cherry pomace was 3.41 ± 0.01 which is within the acceptable range of pH (3.2-4.7) for cherries (Woroboo and Splittstoesser 2005). The average pH values for the tart cherry powder dried using the four drying methods are shown in Table 10. The differences of the means of the pH values were analyzed using the Fisher's LSD test at a significance level of 5% and were found to be not significantly different from each other (p=0.2198) as hypothesized.

**Table 10. The average pH values of tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average pH** |
| Freeze Dried | 23* | 3.61 ± 0.03 |
| Vacuum Dried | 50 | 3.59 ± 0.05 |
| | 70 | 3.62 ± 0.04 |
| | 90 | 3.63 ± 0.01 |
| | 110 | 3.66 ± 0.06 |
| Cabinet Dried | 50 | 3.61 ± 0.04 |
| | 70 | 3.65 ± 0.03 |
| | 90 | 3.61 ±0.07 |
| | 110 | 3.63 ± 0.03 |
| Infrared Dried | 50 | 3.60 ± 0.03 |
| | 70 | 3.62 ± 0.05 |
| | 90 | 3.63 ± 0.01 |
| | 110 | 3.64 ± 0.05 |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time

### 3.1.3 Titratable Acidity

The average titratable acidity value for the raw tart cherry pomace was 1.24 ± 0.03% malic acid. The average titratable acidity values for the tart cherry powder dried using the four drying methods are shown in Table 11. The pH values in Table 11 were analyzed using the Fisher's LSD test and found to be significantly different ($p<0.0001$). The sample dried at 70°C in the vacuum dryer contained the highest titratable acidity and the samples dried at 110°C in the vacuum dryer and 90°C in the infrared dryer contained the lowest levels of titratable acidity.

**Table 11. The average titratable acidity values and the Fisher's LSD comparison results of tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Titratable Acidity (Percent Malic Acid)** |
| Freeze Dried | 23* | 5.00 ± 0.03 [a,b,c,d] |
| Vacuum Dried | 50 | 4.99 ± 0.05 [a,b,c,d] |
| | 70 | 5.07 ± 0.04 [a] |
| | 90 | 4.94 ± 0.01 [b,c,d,e] |
| | 110 | 4.87 ± 0.06 [e] |
| Cabinet Dried | 50 | 5.02 ± 0.04 [a,b,c] |
| | 70 | 4.94 ± 0.03 [b,c,d,e] |
| | 90 | 5.05 ± 0.07 [a,b] |
| | 110 | 5.00 ± 0.03 [a,b,c,d] |
| Infrared Dried | 50 | 4.89 ± 0.00 [d,e] |
| | 70 | 4.94 ± 0.05 [b,c,d,e] |
| | 90 | 4.86 ± 0.01 [e] |
| | 110 | 4.91 ± 0.05 [c,d,e] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

The titratable acidity data was analyzed using a two-way ANOVA to examine the main effects and the interaction of the type of drying method and the temperature at which the samples were dried. The main effect of the drying method was found to be significant ($p<0.0001$), the main effect of temperature was found to be significant ($p=0.0495$), and the overall interaction between the two variables was found to be significant ($p=0.0001$). The interaction was further analyzed by applying the Simple Effects Test to determine which temperature and drying method comparisons affect the interaction of these two variables on the titratable acidity values (Table 12). Through partitioning by temperature it

may be seen that the null hypothesis is rejected; at all temperature levels the type of drying method will affect the water solubility values. When the data is partitioned by the type of dryer the null hypothesis is rejected for all drying methods except for infrared drying meaning there is an effect of temperature for the vacuum and cabinet drying method.

**Table 12 Summary of the p-values from the Simple Effects Test the titratable acidity values**

| Interaction Effect | Type of Drying | Air Temperature (°C) | Pr>F |
|---|---|---|---|
| Type*Temp | | 50 | 0.0023 |
| Type*Temp | | 70 | 0.0005 |
| Type*Temp | | 90 | <0.0001 |
| Type*Temp | | 110 | 0.0027 |
| Type*Temp | Vacuum | | <0.0001 |
| Type*Temp | Cabinet | | 0.0339 |
| Type*Temp | Infrared | | 0.1457 |

These interactions were further analyzed through comparisons of individual slopes to determine which drying methods significantly affect the titratable acidity values at 50°C, 70°C, 90°C and 110°C (Table 13); as well as which temperatures within the vacuum, cabinet, and infrared drying methods significantly affect the values (Table 14). All of the drying method comparisons showed a significant difference in titratable acidity values except for vacuum versus cabinet drying at 50°C (p=0.5010), cabinet versus infrared drying at 70 °C (p=0.8428), and vacuum versus infrared drying at 110 °C (p=0.1744). In Table 14 it is seen that within the vacuum drying method all of the temperature levels

produced significantly different titratable acidity values except for 70°C versus 90°C (p=0.1546). There were two temperature comparisons in the cabinet drying method that produced significantly different titratable acidity values are those were was 50°C versus 70°C (p=0.0414) and 50°C versus 90°C (p=0.0047). In the infrared drying method there was only temperature comparison that produced a significant effect was 70°C versus 90°C (p=0.5152).

**Table 13 Summary of the p-values from the Simple Effects Test partitioned by temperature for the titratable acidity values**

| | 50°C | 70°C | 90°C | 110°C |
|---|---|---|---|---|
| **Method Drying Comparisons** | **Pr>F** | **Pr>F** | **Pr>F** | **Pr>F** |
| Vacuum versus Cabinet | 0.5010 | 0.0007 | 0.0047 | 0.0007 |
| Vacuum versus Infrared | 0.0054 | 0.0004 | 0.0201 | 0.1744 |
| Cabinet versus Infrared | 0.0010 | 0.8428 | <0.0001 | 0.0213 |

**Table 14 Summary of the p-values from the Simple Effects Test partitioned by type of drying method for the titratable acidity values**

| | Vacuum Drying | Cabinet Drying | Infrared Drying |
|---|---|---|---|
| **Temperature Comparisons (°C)** | **Pr>F** | **Pr>F** | **Pr>F** |
| 50 versus 70 | 0.0232 | 0.0414 | 0.1787 |
| 50 versus 90 | 0.0007 | 0.0047 | 0.3764 |
| 50 versus 110 | 0.0380 | 0.1603 | 0.4361 |
| 70 versus 90 | 0.1546 | 0.3448 | 0.0313 |
| 70 versus 110 | 0.0012 | 0.6319 | 0.5585 |
| 90 versus 110 | <0.0001 | 0.1079 | 0.1033 |

It was expected that the freeze dried sample would contain the highest levels of titratable acidity. With the addition of heat to the fruit, the rate of

respiration will increase. During respiration the organic acids are converted to sugar thus decreasing the titratable acidity of the sample (Ramaswamy 2005). The freeze drying process does not apply as much heat as compared to the other three drying methods which therefore might limit fruit respiration. Differences in titratable acidity may also be attributed to differences in fruit cultivar, fruit maturity, climate, and soil makeup (Woroboo and Splittstoesser 2005).

### 3.1.4 Water Solubility

Water solubility is an important characteristic for powdered ingredients that will be incorporated into dry mixes that must be reconstituted. To satisfy the normality assumption during the statistical analysis, a log transformation was applied to the water solubility data. The average water solubility values for the tart cherry powder is in Table 15. The differences of the means of the water solubility values were analyzed using the Fisher's LSD test at a 5% significance level and found to be significantly different ($p<0.0001$). The samples dried at 110°C in the vacuum dryer had the highest average percent of water solubility. The samples dried at 70°C in the infrared drying had the lowest average percent of water solubility.

**Table 15. The average water solubility values and the Fisher's LSD comparisons for tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Percent Water Solubility** |
| Freeze Dried | 23* | 30.40 ± 0.09 [b] |
| Vacuum Dried | 50 | 28.23 ± 0.61 [e] |
| | 70 | 28.60 ± 0.44 [d,e] |
| | 90 | 30.53 ± 0.39 [b] |
| | 110 | 31.44 ± 0.19 [a] |
| Cabinet Dried | 50 | 26.19 ± 0.27 [g] |
| | 70 | 29.30 ± 0.31 [c] |
| | 90 | 25.68 ± 0.35 [g] |
| | 110 | 27.56 ± 0.50 [f] |
| Infrared Dried | 50 | 27.55 ± 0.327 [f] |
| | 70 | 23.47 ± 0.32 [h] |
| | 90 | 30.57 ± 0.29 [b] |
| | 110 | 29.19 ± 0.30 [c,d] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time

The water solubility data was analyzed using a two-way ANOVA to examine the main effects and the interaction of the type of drying method and the temperature at which the samples were dried. The main effect of the drying method was found to be significant ($p<0.0001$), the main effect of temperature was found to be significant ($p<0.0001$), and the overall interaction between the two variables was found to be significant ($p<0.0001$). The interaction was further analyzed by applying the Simple Effects Test to determine which temperature and drying method comparisons affect the interaction of these two variables on the water solubility values Table 16. Through partitioning by temperature it may be seen that the null hypothesis is rejected; at all temperature levels the type of

drying method will affect the water solubility values. When the data were partitioned by the type of dryer it may be seen that the null hypothesis was rejected for all drying methods Table 15 meaning there is an effect of temperature for each drying method.

**Table 16. Summary of p-values from the Simple Effects Test for the water solubility values**

| Interaction Effect | Type of Dryer | Air Temperature (°C) | Pr>F |
|---|---|---|---|
| Type*Temp | | 50 | <0.0001 |
| Type*Temp | | 70 | <0.0001 |
| Type*Temp | | 90 | <0.0001 |
| Type*Temp | | 110 | <0.0001 |
| Type*Temp | Vacuum | | <0.0001 |
| Type*Temp | Cabinet | | <0.0001 |
| Type*Temp | Infrared | | <0.0001 |

These interactions were further analyzed through comparisons of individual slopes to determine which drying methods significantly affect the water solubility values at 50°C, 70°C, 90°C and 110°C (Table 17) as well as which temperatures within the vacuum, cabinet, and infrared drying methods significantly affect the water solubility values (Table 18). At 50°C, 90°C and 110°C all of the drying method comparisons produced significantly different water solubility values (Table 17). Through comparison of the drying methods at 70°C it is concluded that all of the drying method comparisons produced significantly different water solubility values except for the vacuum versus the infrared drying method (p=0.9111). In Table 18 it is seen that within the vacuum drying method all of the temperature levels produced significantly different water solubility values. In the cabinet drying method the only temperature comparison that

produced non-significant water solubility values was 90°C versus 110°C (p=0.9951). In the infrared drying method the only temperature comparison that produced non-significant water solubility values was 70°C versus 110°C (p=0.5152).

**Table 17. Summary of the p-values from the Simple Effects Test partitioned by temperature for the water solubility values**

| | 50°C | 70°C | 90°C | 110°C |
|---|---|---|---|---|
| **Method Drying Comparisons** | **Pr>F** | **Pr>F** | **Pr>F** | **Pr>F** |
| Vacuum versus Cabinet | 0.0220 | <0.0001 | <0.0001 | <0.0001 |
| Vacuum versus Infrared | <0.0001 | 0.9111 | <0.0001 | <0.0001 |
| Cabinet versus Infrared | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

**Table 18. Summary of the p-values from the Simple Effects Test partitioned by drying method for the water solubility values**

| | Vacuum Drying | Cabinet Drying | Infrared Drying |
|---|---|---|---|
| **Air Temperature Comparisons (°C)** | **Pr>F** | **Pr>F** | **Pr>F** |
| 50 versus 70 | <0.0001 | <0.0001 | <0.0001 |
| 50 versus 90 | <0.0001 | <0.0001 | <0.0001 |
| 50 versus 110 | <0.0001 | <0.0001 | <0.0001 |
| 70 versus 90 | 0.0071 | <0.0001 | <0.0001 |
| 70 versus 110 | <0.0001 | <0.0001 | 0.5152 |
| 90 versus 110 | <0.0001 | 0.9951 | 0.0004 |

### 3.1.5 Water Absorption Index

Water absorption index is another important characteristic in terms of being able to reconstitute the powder into a liquid system. In order to satisfy the normality assumption during the statistical analysis, a log transformation was applied to the water absorption index data. The average water absorption index

values for the tart cherry powder may be found in Table 19. The differences of the means of the water absorption index values were analyzed using the Fisher's LSD test at a 5% significance level and found to be significantly different ($p<0.001$). The samples dried at 50°C in the cabinet dryer had the highest average water absorption index value. The samples dried at 90°C in the vacuum dryer and at 110°C in the infrared dryer had the lowest average water absorption index values.

**Table 19. The average water absorption index values and the Fisher's LSD comparisons of tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Water Absorption Index** |
| Freeze Dried | 23* | 4.59 ± 0.11 [b] |
| Vacuum Dried | 50 | 4.24 ± 0.05 [c] |
| | 70 | 4.09 ± 0.05 [d] |
| | 90 | 3.78 ± 0.08 [f] |
| | 110 | 3.94 ± 0.07 [d,e] |
| Cabinet Dried | 50 | 4.77 ± 0.09 [a] |
| | 70 | 4.63 ± 0.03 [b] |
| | 90 | 4.65 ± 0.05 [a,b] |
| | 110 | 4.35 ± 0.07 [c] |
| Infrared Dried | 50 | 4.27 ± 0.03 [c] |
| | 70 | 3.87 ± 0.05 [e,f] |
| | 90 | 3.88 ± 0.07 [e,f] |
| | 110 | 3.74 ± 0.04 [f] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time

A two-way ANOVA model was used to analyze the results in Table 19. The main effect of the drying method was found to be significant ($p<0.0001$), the

main effect of temperature was found to be significant ($p<0.0001$), and the overall interaction between the two variables was found to be significant ($p<0.0001$). In the Simple Effects Test through the partitioning of drying method it is shown in Table 20 that the null hypothesis is rejected for all drying methods meaning there was an effect of temperature for each drying method. In Table 20 it may be seen for temperatures 50°C, 90°C, and 110°C that there was a signicant difference in water absorption index values among drying methods. At 70 °C the only drying method comparison that produced significantly different water absorption index values is the vacuum versus the infrared dryer. Table 21 displays the results of the Simple Effects Test partitioned by drying method. In the vacuum drying method the only temperature comparison that produced non-significant water absorption index values were 50°C versus 90°C ($p=0.0682$). In the cabinet drying method the only temperatures that produced non-significant water absorption index values were 50°C versus 70°C ($p=0.5876$) and well as 90°C versus 110°C ($p=0.2461$). In the infrared drying method there were also two temperature comparisons that produced non-significant water absorption index values and those were 50°C versus 70°C ($p=1.000$) and 70°C versus 90°C ($p=0.0559$).

**Table 20. Summary of the p-values from the Simple Effects Test for the water absorption index values**

| Interaction Effect | Type of Dryer | Air Temperature (°C) | Pr>F |
|---|---|---|---|
| Type*Temp | | 50 | <0.0001 |
| Type*Temp | | 70 | <0.0001 |
| Type*Temp | | 90 | <0.0001 |
| Type*Temp | | 110 | <0.0001 |
| Type*Temp | Vacuum | | <0.0001 |
| Type*Temp | Cabinet | | <0.0001 |
| Type*Temp | Infrared | | <0.0001 |

**Table 21. Summary of the p-values from the Simple Effects Test partitioned by temperature for the water absorption index values**

| | 50°C | 70°C | 90°C | 110°C |
|---|---|---|---|---|
| Method Drying Comparisons | Pr>F | Pr>F | Pr>F | Pr>F |
| Vacuum versus Cabinet | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Vacuum versus Infrared | 0.0007 | 0.0559 | 0.0006 | 0.0118 |
| Cabinet versus Infrared | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

**Table 22. Summary of the p-values from the Simple Effects Test partitioned by drying method for the water absorption index values**

| | Vacuum Drying | Cabinet Drying | Infrared Drying |
|---|---|---|---|
| Air Temperature Comparisons (°C) | Pr>F | Pr>F | Pr>F |
| 50 versus 70 | <0.0001 | 0.5876 | 1.0000 |
| 50 versus 90 | 0.0682 | <0.0001 | <0.0001 |
| 50 versus 110 | <0.0001 | <0.0001 | <0.0001 |
| 70 versus 90 | 0.0006 | <0.0001 | 0.0559 |
| 70 versus 110 | <0.0001 | <0.0001 | 0.5152 |
| 90 versus 110 | <0.0001 | 0.2461 | 0.0004 |

## 3.2 Effects of Drying on the Antioxidant Levels in Tart Cherry Pomace

### 3.2.1 Total Antioxidants

In order to satisfy the normality assumption during the statistical analysis, a log transformation was applied to the total antioxidant data. All of the total antioxidant values are expressed in ORAC units of micromoles of Trolox equivalents (TE) per gram of tart cherry powder or pomace. The average total antioxidants value of the raw tart cherry pomace was 771 ± 217 umol TE/ g cherry pomace db. The average total antioxidant values for the tart cherry powder are listed in Table 23 and plotted in Figure 9. The differences of the means of the total antioxidant values were analyzed using the Fisher's LSD test at a 5% significance level and found to be significantly different (p=0.0036). The highest average of total antioxidant level was detected in the freeze dried tart cherry powder and was only significantly different from the sample dried at 110°C in the infrared dryer, which contained lowest average total antioxidants..

**Table 23. The average total antioxidant values and the Fisher's LSD comparison results of tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average ORAC (umol TE/g cherry powder db)** |
| Freeze Dried | 23* | 477 ± 236 [a] |
| Vacuum Dried | 50 | 429 ± 181 [a,b] |
| | 70 | 473 ± 172 [a] |
| | 90 | 368 ± 152 [a,b] |
| | 110 | 356 ± 111 [a,b] |
| Cabinet Dried | 50 | 348 ± 122 [a,b] |
| | 70 | 351 ± 138 [a,b] |
| | 90 | 463 ± 213 [a] |
| | 110 | 449 ± 204 [a] |
| Infrared Dried | 50 | 391 ± 195 [a,b] |
| | 70 | 415 ± 154 [a,b] |
| | 90 | 425 ± 137 [a] |
| | 110 | 307 ± 72 [b] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

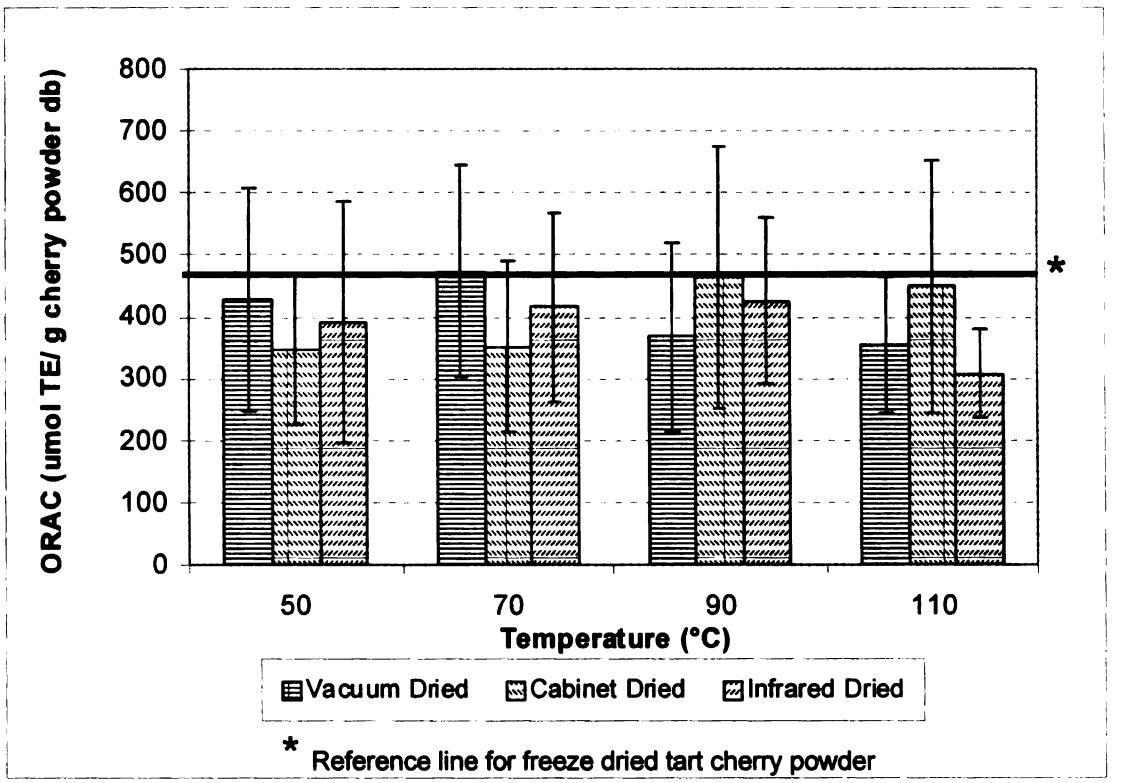


**Figure 9. The average total antioxidant values of the freeze dried, vacuum dried, cabinet dried, and infrared dried tart cherry powder**

A two-way ANOVA was applied to the data set located in Table 23. The main effect of the type of drying method was found to be non-significant ($p=0.9179$), the main effect of temperature was found to be non-significant ($p=0.5748$), and the interaction effect was also found to be non-significant (0.1128). To be certain of the absence of an interaction effect, a Simple Effects Test was applied to the data set. Table 24 confirms that the null hypothesis is accepted; there was no interaction between the type of drying method and the temperature used to dry the tart cherry pomace. Therefore, the antioxidant activity was not decreased by any condition except the more severe condition of infrared heating at 110°C.

**Table 24. Summary of p-values from the Simple Effects Test for the total antioxidant values**

| Interaction Effect | Type of Drying | Air Temperature (°C) | Pr>F |
|---|---|---|---|
| Type*Temp | | 50 | 0.5920 |
| Type*Temp | | 70 | 0.1713 |
| Type*Temp | | 90 | 0.3367 |
| Type*Temp | | 110 | 0.1409 |
| Type*Temp | Vacuum | | 0.2294 |
| Type*Temp | Cabinet | | 0.2150 |
| Type*Temp | Infrared | | 0.2972 |

### 3.2.2 Total Phenolics

To satisfy the normality assumption during the statistical analysis, a log transformation was applied to the total phenolics data. All of the total phenolic values are expressed in milligrams of gallic acid equivalents (GAE) per gram of tart cherry powder or pomace. The average total phenolics value of the raw tart cherry pomace was 34.56 ± 3.75 mg GAE/ g cherry pomace db. The average total phenolic values for the tart cherry powder is listed in Table 25 and plotted in Table 25 may be found in Figure 10. The differences of the means of the total antioxidant values were analyzed using the Fisher's LSD test at a 5% significance level and found to be significantly different ($p=<0.0001$). The highest average of total phenolics level was detected in the freeze dried tart cherry powder and the lowest average total phenolics level was detected in the sample dried at 110°C in the infrared dryer.

**Table 25. The average total phenolic values and the Fisher's LSD comparison results of tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Total Phenolics (GAE/g cherry powder db)** |
| Freeze Dried | 23* | 28.02 ± 0.29 [a] |
| Vacuum Dried | 50 | 20.88 ± 3.45 [b] |
| | 70 | 17.98 ± 1.58 [e,f] |
| | 90 | 18.82 ± 1.53 [c,d,e] |
| | 110 | 20.50 ± 1.29 [b,c] |
| Cabinet Dried | 50 | 20.55 ± 0.43 [b,c] |
| | 70 | 20.93 ± 0.55 [b] |
| | 90 | 20.28 ± 1.12 [b,c,d] |
| | 110 | 18.49 ± 1.82 [d,e] |
| Infrared Dried | 50 | 17.83 ± 0.79 [e,f] |
| | 70 | 17.47 ± 1.18 [e,f,g] |
| | 90 | 16.58 ± 0.84 [f,g] |
| | 110 | 15.92 ± 0.39 [g] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

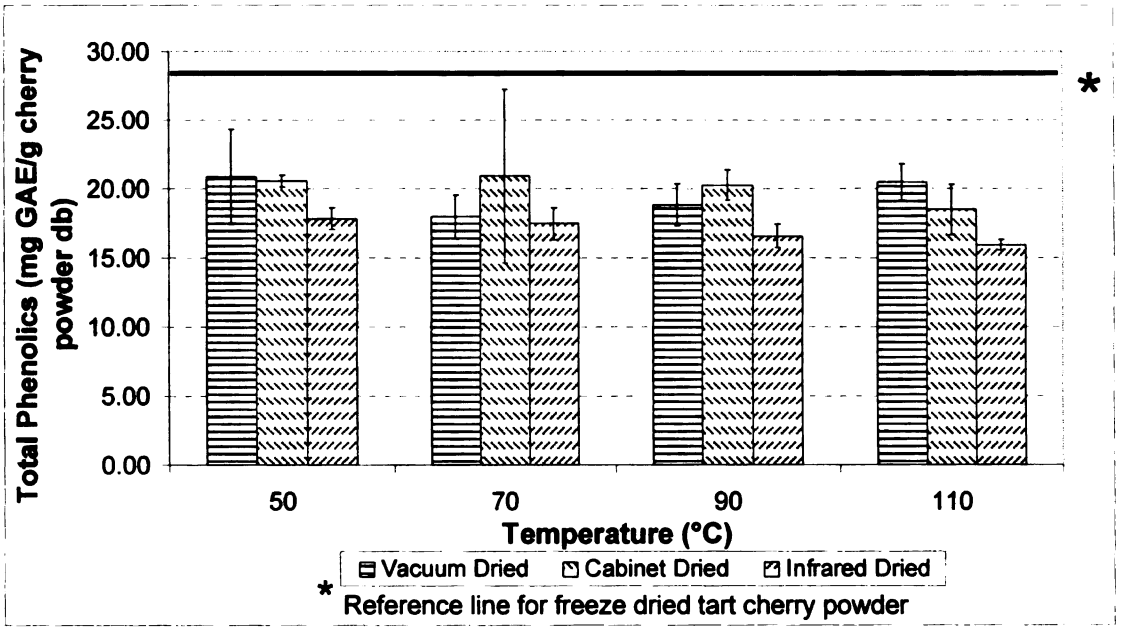


**Figure 10. The average total phenolic values of the freeze dried, vacuum dried, cabinet dried, and infrared dried tart cherry powder**

A two-way ANOVA was applied to the data set in Table 25. The main effect of the type of drying method was found to be significant ($p<0.0001$), the main effect of temperature was found to be significant ($p=0.0487$), and the interaction effect was also found to be significant (0.0046). The Simple Effects Test was applied to the data set and the results are found in Table 26. The results reveal that the type of drying method significantly affected the total phenolic values of the tart cherry powder when dried at all temperature levels. The temperature levels within the vacuum drying method produced significantly different total phenolics values but not within the cabinet or infrared drying methods.

**Table 26. Summary of p-values from the Simple Effects Test for the total phenolic values**

| Interaction Effect | Type of Drying | Air Temperature (°C) | Pr>F |
|---|---|---|---|
| Type*Temp | | 50 | 0.0073 |
| Type*Temp | | 70 | 0.0015 |
| Type*Temp | | 90 | 0.0019 |
| Type*Temp | | 110 | <0.0001 |
| Type*Temp | Vacuum | | 0.0029 |
| Type*Temp | Cabinet | | 0.0855 |
| Type*Temp | Infrared | | 0.1406 |

Table 27 demonstrates that when samples were dried at 50°C the only drying method comparison that yielded non-significantly different total phenolic values was the vacuum drying method versus the cabinet drying method (p=0.9499). At 70°C the only drying method comparison that yielded non-significantly different total phenolic values is the vacuum drying method versus the infrared drying method (p=0.5799). At 90°C the only drying method comparison that yielded non-significantly different total phenolic values is the vacuum drying method versus the cabinet drying method (p=0.1739). At 110°C all of the drying method comparisons produced significantly different total phenolics values. Table 28 It may be concluded that there were two temperature comparisons that produced non-significantly different total phenolics values, they were 50°C versus 110°C (p=0.8555) and 70°C versus 110°C (p=0.3000) (Table 28). In summary, total phenolics tended to decrease from 19-54% after drying (compared to the raw pomace), depending on the drying method.

**Table 27. Summary of the p-values from the Simple Effects Test partitioned by temperature for the total phenolic values**

| | 50°C | 70°C | 90°C | 110°C |
|---|---|---|---|---|
| **Method Drying Comparisons** | **Pr>F** | **Pr>F** | **Pr>F** | **Pr>F** |
| Vacuum versus Cabinet | 0.9499 | 0.0023 | 0.1739 | 0.0220 |
| Vacuum versus Infrared | 0.0039 | 0.5799 | 0.0123 | <0.0001 |
| Cabinet versus Infrared | 0.0085 | 0.0010 | 0.0005 | 0.0071 |

**Table 28. Summary of the p-values from the Simple Effects Test partitioned by drying method for the total phenolic values**

| | Vacuum Drying |
|---|---|
| **Air Temperature Comparisons (°C)** | **Pr>F** |
| 50 versus 70 | 0.0024 |
| 50 versus 90 | 0.0382 |
| 50 versus 110 | 0.8555 |
| 70 versus 90 | 0.3000 |
| 70 versus 110 | 0.0016 |
| 90 versus 110 | 0.0347 |

### 3.2.3 Total Anthocyanins

To satisfy the normality assumption during the statistical analysis, a log transformation was applied to the total anthocyanin data. All of the total anthocyanin values are expressed in milligrams of cyaniding-3-glucoside per 100 grams of tart cherry powder or pomace. The average total anthocyanins value of the raw tart cherry pomace was 23.83 ± 2.97 mg cyn-3-glu/100 g cherry pomace db. The average total anthocyanin values for the tart cherry powder may be found in Table 29. A visual representation of the data in may be found in Figure

11. The differences of the means of the total anthocyanin values were analyzed using the Fisher's LSD test at a 5% significance level and found to be significantly different (p=<0.0001). The highest average of total anthocyanins was detected in the freeze dried tart cherry powder and the lowest average total anthocyanins was detected in the sample dried at 110°C in the infrared dryer. This is the same trend found in the total antioxidant results.

**Table 29. The average total anthocyanin values of tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Total Anthocyanins (mg cyn-3-glu /100g cherry powder db)** |
| Freeze Dried | 23* | 25.02 ± 5.12 [a] |
| Vacuum Dried | 50 | 13.60 ± 1.32 [c,d,e] |
| | 70 | 13.93 ± 1.91 [c,d] |
| | 90 | 13.46 ± 1.53 [c,d,e] |
| | 110 | 13.20 ± 0.93 [d,e,f] |
| Cabinet Dried | 50 | 14.86 ± 0.74 [b,c] |
| | 70 | 15.73 ± 1.69 [b] |
| | 90 | 14.21 ± 2.55 [c,d] |
| | 110 | 13.85 ± 2.09 [c,d] |
| Infrared Dried | 50 | 11.98 ± 0.58 [f,g] |
| | 70 | 12.35 ± 1.55 [e,f,g] |
| | 90 | 11.11 ± 0.54 [g,h] |
| | 110 | 10.00 ± 0.86 [h] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

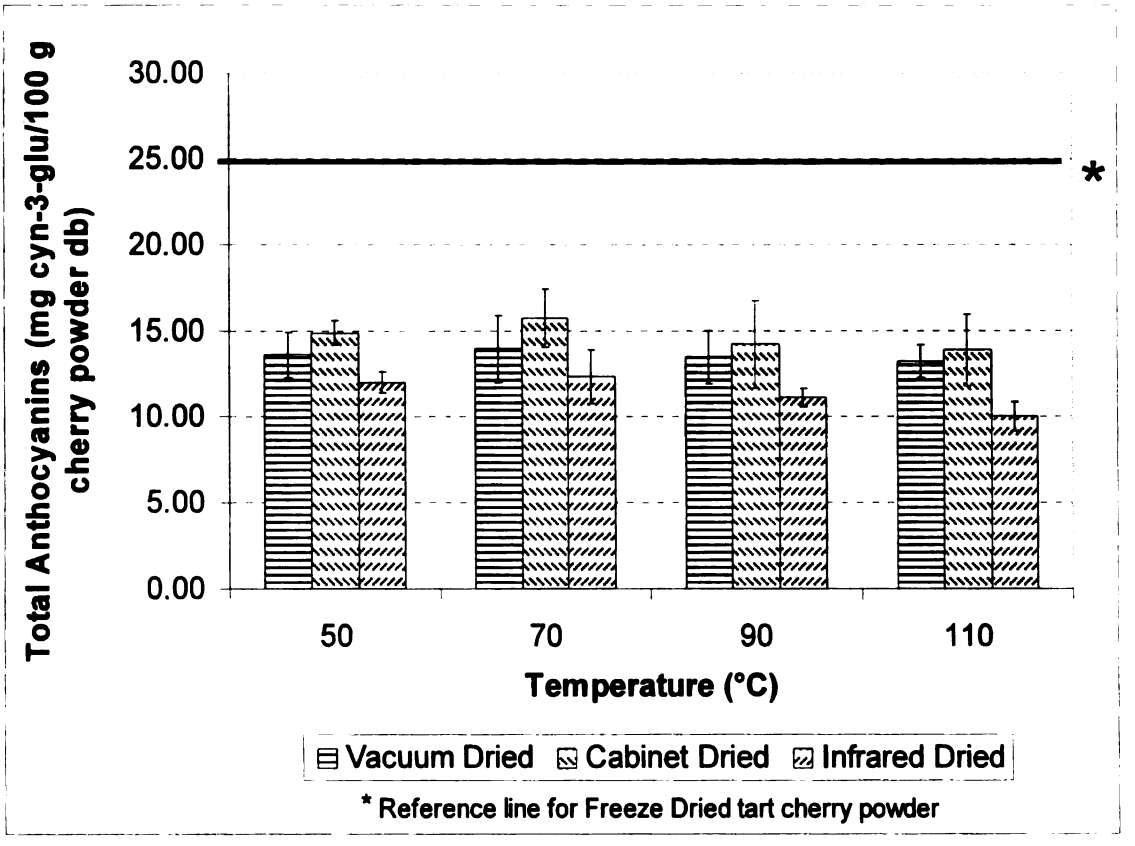


**Figure 11. The average total anthocyanin values of the freeze dried, vacuum dried, cabinet dried, and infrared dried tart cherry powder**

A two-way ANOVA was applied to the data set from Table 29. The main effect of the type of drying method was found to be significant ($p<0.0001$), the main effect of temperature was found to be significant ($p=0.0042$), and the interaction effect was found to be non-significant ($p=0.5335$). To be certain of the absence of an interaction effect, a Simple Effects Test was applied to the data set (Table 30). The results revealed that the temperature levels within the infrared drying method produced significantly different total anthocyanin values but not within the vacuum or cabinet drying methods.

**Table 30. Summary of p-values from the Simple Effect Test for the total anthocyanin values**

| Interaction Effect | Type of Drying | Air Temperature (°C) | Pr>F |
|---|---|---|---|
| Type*Temp | | 50 | 0.0084 |
| Type*Temp | | 70 | 0.0027 |
| Type*Temp | | 90 | 0.0019 |
| Type*Temp | | 110 | <0.0001 |
| Type*Temp | Vacuum | | 0.8197 |
| Type*Temp | Cabinet | | 0.2128 |
| Type*Temp | Infrared | | 0.0138 |

Table 31 demonstrates that when samples were dried at 50°C and 70°C the only drying method comparison that yielded significantly different total anthocyanin values were the cabinet drying method versus the infrared drying method (p=0.0022 and p=0.0620). At 90°C the only drying method comparison that yielded significantly different total anthocyanin values was the vacuum drying method versus the cabinet drying method (p=0.4551). At 110°C the only drying method comparison that yielded significantly different total anthocyanin values was the vacuum drying method versus the cabinet drying method (p=0.4578). Temperature comparisons within the vacuum drying method were performed and the results are found in Table 32. There were only two temperature comparisons that demonstrated significantly different total anthocyanins values; they included 50°C versus 110°C (p=0.0087) and 70°C versus 110°C (p=0.0031). These results, that temperature was not significant until above 100°C, were similar to other studies on anthocyanins in grape pomace (Mishra and others 2008; Lai 2003) that showed that rate of degradation increased rapidly at temperatures

above 90°C. In summary, total anthocyanins decreased 38-60% after drying (compared to freeze-drying), depending on the drying method.

**Table 31. Summary of the p-values from the Simple Effects Test partitioned by temperature for the total anthocyanin values**

| | 50°C | 70°C | 90°C | 110°C |
|---|---|---|---|---|
| **Method Drying Comparisons** | **Pr>F** | **Pr>F** | **Pr>F** | **Pr>F** |
| Vacuum versus Cabinet | 0.1429 | 0.0491 | 0.4551 | 0.4678 |
| Vacuum versus Infrared | 0.0525 | 0.0620 | 0.0037 | <0.0001 |
| Cabinet versus Infrared | 0.0022 | 0.0006 | 0.0009 | <0.0001 |

**Table 32. Summary of the p-values from the Simple Effects Test partitioned by drying method for the total anthocyanin values**

| | Infrared Drying |
|---|---|
| **Air Temperature Comparisons (°C)** | **Pr>F** |
| 50 versus 70 | 0.7101 |
| 50 versus 90 | 0.2642 |
| 50 versus 110 | 0.0087 |
| 70 versus 90 | 0.1387 |
| 70 versus 110 | 0.0031 |
| 90 versus 110 | 0.1178 |

## 3.3 Comparison of Experiment Tart Cherry Powder to Commercial Tart Cherry Powder

### 3.3.1 Physical Characteristics

The Hunter Color CIE variables of the commercial samples were compared to the experimentally produced powders (Table 33). The L* values for

the drum dried sample from Van Drunen Farms and the freeze dried sample from Shoreline Fruit samples were comparable to the L* values of the experimental powders. The freeze dried sample from Van Drunen Farms contained significantly the lowest L* values ($p<0.0001$). All of the commercial samples contained significantly higher a* values ($p<0.0001$) and significantly lower b* values ($p<0.0001$) compared to the experimental powders.

**Table 33 The average Hunter Color CIE values and the Fisher's LSD comparison results for the comparison of the experimental versus commercial tart cherry powders**

| Tart Cherry Powder Sample | | | | | |
|---|---|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average L*** | **Average a*** | **Average b*** | **Average dE*** |
| Freeze Dried | 23* | 56.96 ± 0.68 $^{a}$ | 12.26 ± 0.39 $^{d}$ | 22.30 ± 0.51 $^{a}$ | 62.39 ± 0.44 $^{a}$ |
| Vacuum Dried | 50 | 49.00 ± 2.25 $^{d,e,f}$ | 11.63 ± 0.68 $^{d,e,f,g}$ | 20.01 ± 0.05 $^{b,c}$ | 54.21 ± 1.88 $^{c,d}$ |
| | 70 | 48.66 ± 1.18 $^{e,f}$ | 11.50 ± 0.20 $^{d,e,d,g}$ | 19.73 ± 0.17 $^{b,c,d}$ | 53.76 ± 1.08 $^{c,d,e,f}$ |
| | 90 | 49.69 ± 1.31 $^{c,d,e}$ | 10.52 ± 0.24 $^{h,i}$ | 19.12 ± 0.19 $^{d,e}$ | 54.27 ± 1.22 $^{c,d}$ |
| | 110 | 47.09 ± 1.47 $^{f}$ | 11.44 ± 0.57 $^{e,f,g}$ | 19.10 ± 0.34 $^{d,e}$ | 52.10 ± 1.15 $^{e,f}$ |
| Cabinet Dried | 50 | 48.82 ± 2.80 $^{e,f}$ | 11.82 ± 0.73 $^{d,e,f}$ | 19.53 ± 0.12 $^{c,d,e}$ | 53.91 ± 2.36 $^{c,d,e}$ |
| | 70 | 46.66 ± 1.96 $^{f}$ | 12.12 ± 0.83 $^{d,e}$ | 19.13 ± 0.30 $^{d,e}$ | 51.88 ± 1.45 $^{f}$ |
| | 90 | 48.59 ± 0.48 $^{e,f}$ | 11.20 ± 0.37 $^{f,g,h}$ | 19.19 ± 0.40 $^{d,e}$ | 53.43 ± 0.46 $^{d,e,f}$ |
| | 110 | 47.25 ± 0.83 $^{c,d}$ | 11.80 ± 0.51 $^{d,e,f}$ | 19.64 ± 0.23 b, $^{c,d,e}$ | 52.51 ± 0.55 $^{d,e,f}$ |
| Infrared Dried | 50 | 48.35 ± 2.10 $^{e,f}$ | 12.03 ± 0.62 $^{d,e}$ | 20.39 ± 0.25 $^{b}$ | 53.85 ± 1.65 $^{c,d,e,f}$ |
| | 70 | 48.16 ± 0.80 $^{e,f}$ | 11.02 ± 0.33 $^{g,h}$ | 18.92 ± 0.44 $^{e}$ | 52.90 ± 0.52 $^{d,e,f}$ |
| | 90 | 51.38 ± 0.56 $^{b,c,d}$ | 9.88 ± 0.15 $^{i}$ | 18.89 ± 0.11 $^{e}$ | 55.63 ± 0.53 $^{c}$ |
| | 110 | 48.55 ± 1.96 $^{e,f}$ | 10.56 ± 0.42 $^{h}$ | 19.83 ± 0.58 $^{b,c,d}$ | 53.50 ± 1.79 $^{d,e,f}$ |
| Drum Dried (Van Drunen Farms) | | 52.92 ± 1.27 $^{b}$ | 26.44 ± 0.38 $^{a}$ | 2.87 ± 0.22 $^{h}$ | 59.23 ± 1.20 $^{b}$ |
| Freeze Dried (Van Drunen Farms) | | 42.22 ± 0.32 $^{g}$ | 21.85 ± 0.22 $^{b}$ | 9.39 ± 0.14 $^{g}$ | 48.46 ± 0.26 $^{g}$ |
| Freeze Dried (Shoreline Fruit) | | 51.55 ± 0.33 $^{b,c}$ | 15.83 ± 0.35 $^{c}$ | 14.08 ± 0.22 $^{f}$ | 55.73 ± 0.19 $^{c}$ |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

The average values of the pH for the two groups of cherry powders were very similar (Table 34). The exception was the drum dried powder which contained a significantly higher ($p<0.0001$) average pH value than the pomace dried at 50°C in the vacuum dryer. The titratable acidity results are shown in Table 35. The two commercial freeze dried samples contained significantly the highest ($p<0.0001$) values compared to the experimental powders. The drum dried sample contained significantly the lowest ($p<0.0001$) values compared to the other powders.

**Table 34 The average pH values and the Fisher's LSD comparison results for the comparison of the experimental versus commercial tart cherry powders**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average pH** |
| Freeze Dried | 23* | 3.61 ± 0.03 **a,b** |
| Vacuum Dried | 50 | 3.59 ± 0.05 **b** |
| | 70 | 3.62 ± 0.04 **a,b** |
| | 90 | 3.63 ± 0.01 **a,b** |
| | 110 | 3.66 ± 0.06 **a,b** |
| Cabinet Dried | 50 | 3.61 ± 0.04 **a,b** |
| | 70 | 3.65 ± 0.03 **a,b** |
| | 90 | 3.61 ±0.07 **a,b** |
| | 110 | 3.63 ± 0.03 **a,b** |
| Infrared Dried | 50 | 3.60 ± 0.03 **a,b** |
| | 70 | 3.62 ± 0.05 **a,b** |
| | 90 | 3.63 ± 0.01 **a,b** |
| | 110 | 3.64 ± 0.05 **a,b** |
| Drum Dried (Van Drunen Farms) | | 3.68 ± 0.02 **a** |
| Freeze Dried (Van Drunen Farms) | | 3.61 ± 0.01 **a,b** |
| Freeze Dried (Shoreline Fruit) | | 3.60 ±0.01 **a,b** |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

**Table 35 The average titratable acidity values and the Fisher's LSD comparison results for the comparison of the experimental versus commercial tart cherry powders**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Titratable Acidity (Percent Malic Acid)** |
| Freeze Dried | 23* | 5.00 ± 0.03 [d,e] |
| Vacuum Dried | 50 | 4.99 ± 0.05 [d,e] |
| | 70 | 5.07 ± 0.04 [c] |
| | 90 | 4.94 ± 0.01 [e,f] |
| | 110 | 4.87 ± 0.06 [g,h] |
| Cabinet Dried | 50 | 5.02 ± 0.04 [c,d] |
| | 70 | 4.94 ± 0.03 [e,f] |
| | 90 | 5.05 ± 0.07 [c,d] |
| | 110 | 5.00 ± 0.03 [d,e] |
| Infrared Dried | 50 | 4.89 ± 0.00 [f,g,h] |
| | 70 | 4.94 ± 0.05 [e,f,g] |
| | 90 | 4.86 ± 0.01 [h] |
| | 110 | 4.91 ± 0.05 [f,g,h] |
| Drum Dried (Van Drunen Farms) | | 4.68 ± 0.01 [i] |
| Freeze Dried (Van Drunen Farms) | | 8.46 ± 0.11 [a] |
| Freeze Dried (Shoreline Fruit) | | 7.15 ± 0.03 [b] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

The average water solubility values are shown in Table 36. The drum dried and freeze dried samples from Van Drunen Farms contained significantly the highest ($p<0.0001$) average water solubility values. The drum dried sample contained a low water solubility values and it was statistically the same as the sample dried at 70°C in the infrared dryer.

**Table 36 The average water solubility values and the Fisher's LSD comparison results for the comparison of the experimental versus commercial tart cherry powders**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Percent Water Solubility** |
| Freeze Dried | 23* | 30.40 ± 0.09 [b] |
| Vacuum Dried | 50 | 28.23 ± 0.61 [e] |
| | 70 | 28.60 ± 0.44 [d,e] |
| | 90 | 30.53 ± 0.39 [b] |
| | 110 | 31.44 ± 0.19 [a] |
| Cabinet Dried | 50 | 26.19 ± 0.27 [g] |
| | 70 | 29.30 ± 0.31 [c] |
| | 90 | 25.68 ± 0.35 [g] |
| | 110 | 27.56 ± 0.50 [f] |
| Infrared Dried | 50 | 27.55 ± 0.327 [f] |
| | 70 | 23.47 ± 0.32 [h] |
| | 90 | 30.57 ± 0.29 [b] |
| | 110 | 29.19 ± 0.30 [c,d] |
| Drum Dried (Van Drunen Farms) | | 44.16 ± 0.94 [b] |
| Freeze Dried (Van Drunen Farms) | | 66.25 ± 2.01 [a] |
| Freeze Dried (Shoreline Fruit) | | 25.49 ± 0.80 [h] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

The average water absorption index values are shown in Table 37. The freeze dried sample from Shoreline Fruit contained the significantly highest ($p<0.0001$) water absorption index values while the freeze dried sample from Van Drunen Farms contained the significantly lowest ($p<0.0001$) values.

**Table 37 The average water absorption index values and the Fisher's LSD comparison results for the comparison of the experimental versus commercial tart cherry powders**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Water Absorption Index** |
| Freeze Dried | 23* | 4.6 ± 0.11 [d] |
| Vacuum Dried | 50 | 4.2 ± 0.05 [e] |
| | 70 | 4.1 ± 0.05 [g,h] |
| | 90 | 3.8 ± 0.08 [e,f] |
| | 110 | 3.9 ± 0.07 [b] |
| Cabinet Dried | 50 | 4.8 ± 0.09 [b,c] |
| | 70 | 4.6 ± 0.03 [b,c] |
| | 90 | 4.7 ± 0.05 [d] |
| | 110 | 4.4 ± 0.07 [d] |
| Infrared Dried | 50 | 4.3 ± 0.03 [f,g] |
| | 70 | 3.9 ± 0.05 [f,g] |
| | 90 | 3.9 ± 0.07 [g,h] |
| | 110 | 3.7 ± 0.04 [c] |
| Drum Dried (Van Drunen Farms) | | 3.73 ± 0.12 [h] |
| Freeze Dried (Van Drunen Farms) | | 1.73 ± 0.04 [i] |
| Freeze Dried (Shoreline Fruit) | | 5.49 ± 0.06 [a] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

### 3.3.2 Total Antioxidants

The average total antioxidant values for the three commercially available tart cherry powders are found in Figure 12. The average total antioxidant values of the commercial cherry powders were compared to the tart cherry powders produced in the laboratory experiments (Figure 13).

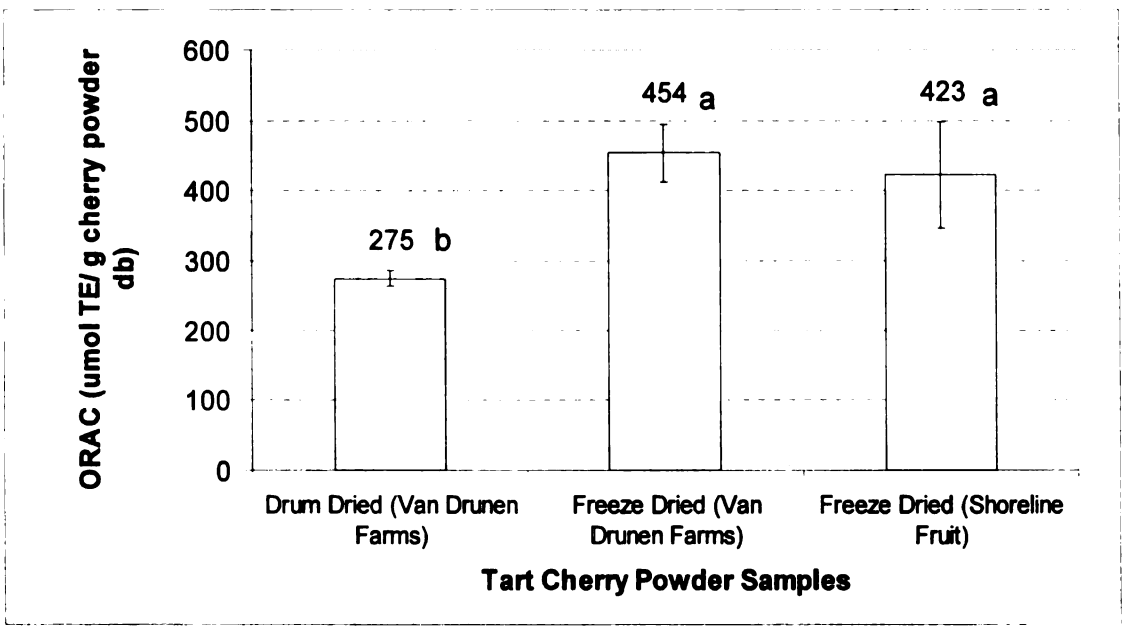


**Figure 12. The average total antioxidant values and the Fisher's LSD comparison results for three commercially available tart cherry powders**

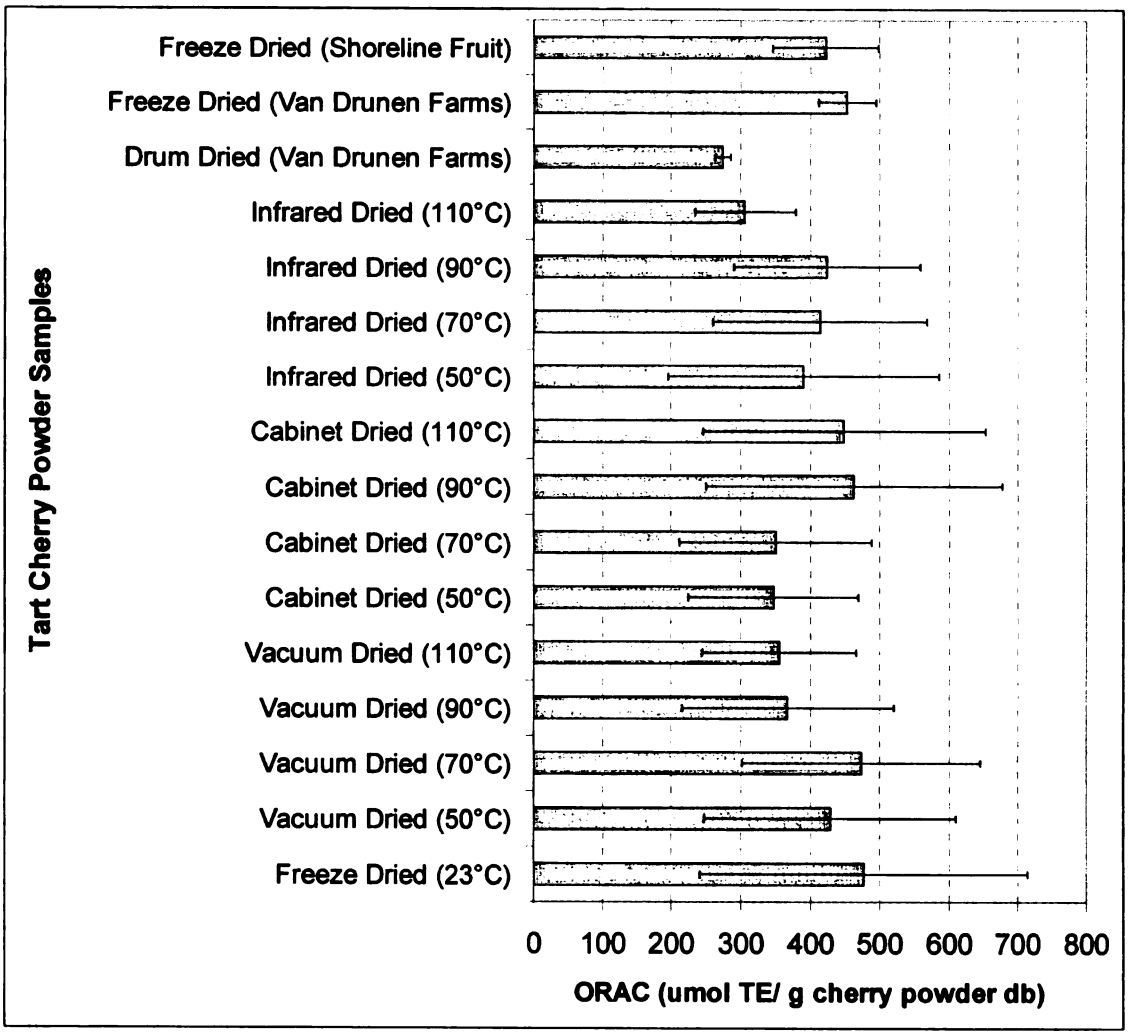


**Figure 13. The average total antioxidant values of the commercial tart cherry powders as compared to the experimentally produced tart cherry powders**

**Table 38. The average total antioxidant values and the Fisher's LSD comparison results of the commercial tart cherry powder as compared to the experimentally produced tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average ORAC (umol TE/g cherry powder db)** |
| Freeze Dried | 23* | 477 ± 236 $^{a,b}$ |
| Vacuum Dried | 50 | 429 ± 181 $^{a,b,c}$ |
| | 70 | 445 ± 172 $^{a,b}$ |
| | 90 | 368 ± 152 $^{a,b,c,d}$ |
| | 110 | 356 ± 111 $^{a,b,c,d}$ |
| Cabinet Dried | 50 | 348 ± 122 $^{b,c,d}$ |
| | 70 | 351 ± 138 $^{b,c,d}$ |
| | 90 | 463 ± 213 $^{a,b}$ |
| | 110 | 449 ± 204 $^{a,b}$ |
| Infrared Dried | 50 | 391 ± 195 $^{a,b,c,d}$ |
| | 70 | 415 ± 154 $^{a,b,c}$ |
| | 90 | 425 ± 137 $^{a,b,c}$ |
| | 110 | 307 ± 72 $^{c,d}$ |
| Drum Dried Van Drunen Farms | | 275 ± 12 $^{d}$ |
| Freeze Dried Van Drunen Farms | | 454 ± 41 $^{a}$ |
| Freeze Dried Shoreline Fruit | | 423 ± 76 $^{a,b}$ |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

The differences of the means of the total antioxidant values were analyzed using the Fisher's LSD test at a 5% significance level and found to be significantly different (p=0.0015) Table 38. As shown in Table 38 the freeze dried

cherry powder from Van Drunen Farms and freeze dried cherry powder from the laboratory experiments contained the highest total antioxidants values and were not significantly different from each other. It was expected that the freeze dried samples from Van Drunen Farms would contain the highest level of total antioxidants, since this tart cherry powder is produced from the whole cherry fruit and not just the pomace. The drum dried cherry powder from Van Drunen Farms contained the lowest total antioxidants value; this is consistent with our expectation that the higher drum-drying temperatures would cause greater decrease in antioxidant values. However the freeze dried powders are not significantly different from the vacuum dried powders, the cabinet dried powders dried at 90°C and 110°C, or the infrared dried powders dried at 50°C, 70°C, or 90°C. Overall, the dried cherry pomace produced in this studied compared favorably to the commercial powders, in terms of total antioxidant values.

### 3.3.3 Total Phenolics

The average total phenolic values for the three commercially available tart cherry powders are found in Figure 14. The average total phenolic values of the commercial cherry powders were compared to the tart cherry powders produced in the laboratory experiments (Figure 15).

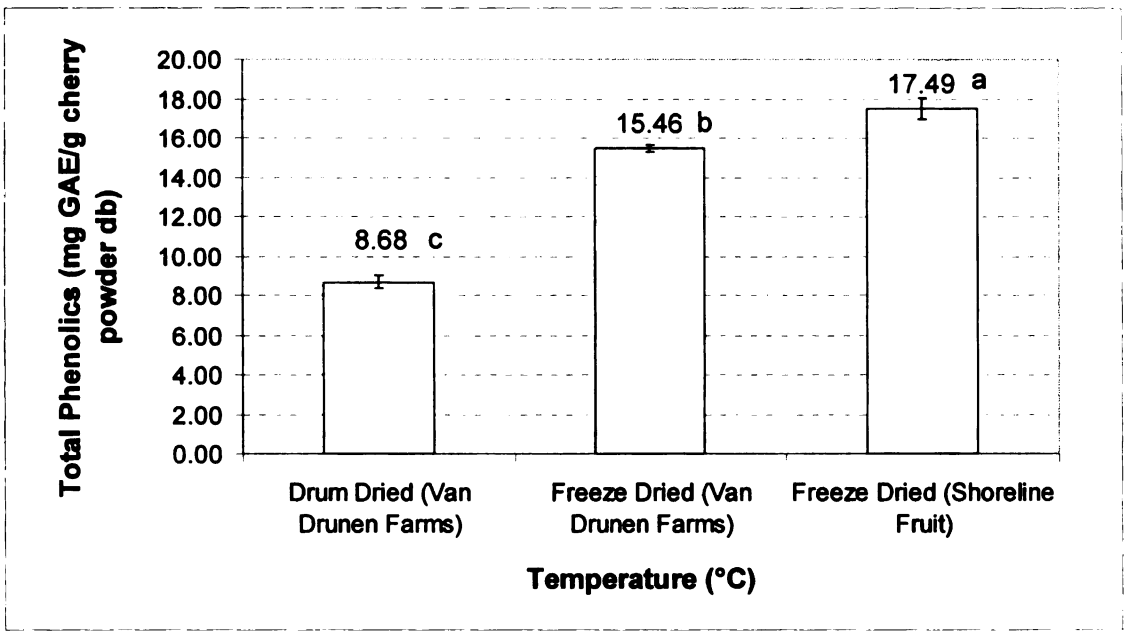


**Figure 14. The total phenolic values of commercially available tart cherry powders**

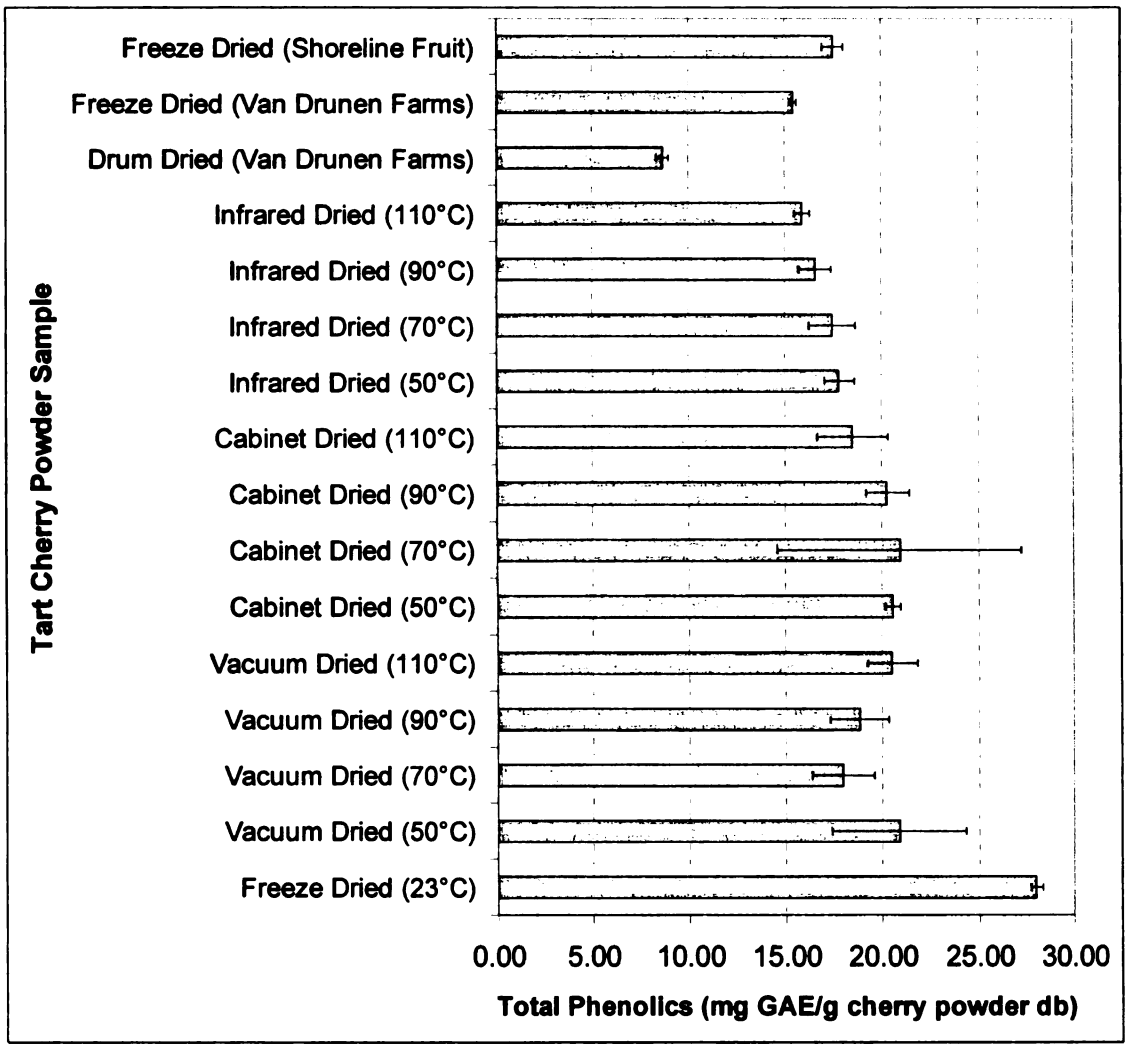


**Figure 15 The average total phenolic values of the commercial tart cherry powder as compared to the experimentally produced tart cherry powder**

**Table 39. The average total phenolic values and the Fisher's LSD comparison results of the commercial tart cherry powder as compared to the experimentally produced tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Total Phenolics (GAE/g cherry powder db)** |
| Freeze Dried | 23* | 28.02 ± 0.29 [a] |
| Vacuum Dried | 50 | 20.88 ± 3.45 [a,b,c] |
| | 70 | 17.98 ± 1.58 [b,c,d,e] |
| | 90 | 18.82 ± 1.53 [b,c,d,e] |
| | 110 | 20.50 ± 1.29 [a,b,c,d] |
| Cabinet Dried | 50 | 20.55 ± 0.43 [a,b,c,d] |
| | 70 | 20.93 ± 0.55 [a,b] |
| | 90 | 20.28 ± 1.12 [a,b,c,d] |
| | 110 | 18.49 ± 1.82 [b,c,d,e] |
| Infrared Dried | 50 | 17.83 ± 0.79 [b,c,d,e,f] |
| | 70 | 17.47 ± 1.18 [d,e,f] |
| | 90 | 16.58 ± 0.84 [e,f] |
| | 110 | 15.92 ± 0.39 [e,f] |
| Drum Dried Van Drunen Farms | | 8.68 ± 0.33 [g] |
| Freeze Dried Van Drunen Farms | | 15.46 ± 0.17 [f] |
| Freeze Dried Shoreline Fruit | | 17.49 ± 0.52 [c,d,e,f] |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

The differences of the means of the total phenolics values were analyzed using the Fisher's LSD test at a 5% significance level and found to be significantly different ($p<0.0001$) (Table 39). The freeze dried cherry powder

from the laboratory experiments contained the highest total phenolic values, 58% higher than the commercial freeze-dried sample. The drum dried cherry powder from Van Drunen Farms contained the lowest total phenolic value, similar to the total antioxidants trend. However the freeze dried powders were not significantly different from the samples dried at 70°C and 110°C in the vacuum dryer or the samples dried at 50°C, 70°C and 90°C in the infrared dryer. Overall, the dried cherry pomace produced in the present study compared very well to the commercial samples in terms of total phenolics.

### 3.3.4 Total Anthocyanins

The average total anthocyanin values for the three commercially available tart cherry powders are found in Figure 16. The average total anthocyanin values of the commercial cherry powders were compared to the tart cherry powders produced in the laboratory experiments (Figure 17). The differences of the means of the total anthocyanin values were analyzed using the Fisher's LSD test at a 5% significance level and found to be significantly different ($p=0.0015$) (Table 40).

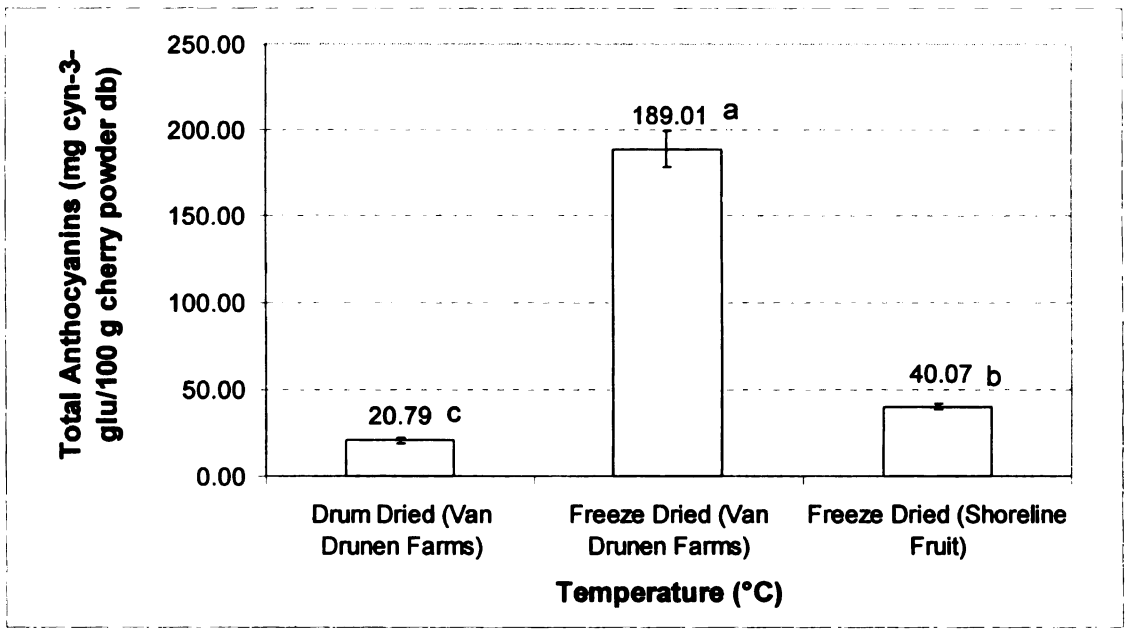


**Figure 16. The average total anthocyanin values for three commercially available tart cherry powders**

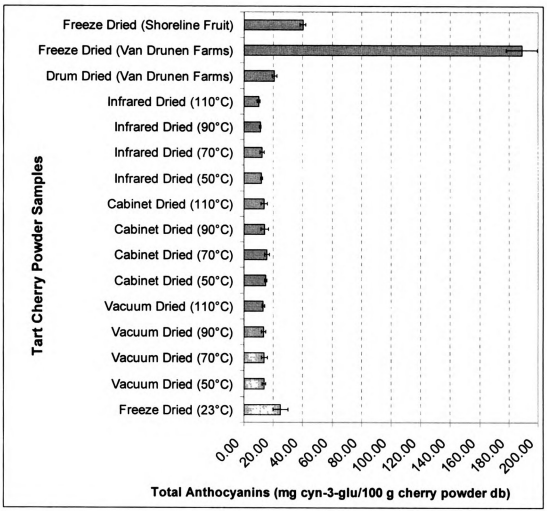


**Figure 17. The average total anthocyanin values of the commercial tart cherry powder as compared to the experimentally produced tart cherry powder**

**Table 40. The average total anthocyanin values and the Fisher's LSD comparison results of the commercial tart cherry powder as compared to the experimentally produced tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Average Total Anthocyanins (mg cyn-3-glu /100g cherry powder db)** |
| Freeze Dried | 23* | 25.02 ± 5.12 $^{c}$ |
| Vacuum Dried | 50 | 13.60 ± 1.32 $^{f,g,h}$ |
| | 70 | 13.93 ± 1.91 $^{f,g}$ |
| | 90 | 13.46 ± 1.53 $^{f,g,h}$ |
| | 110 | 13.20 ± 0.93 $^{g,h,i}$ |
| Cabinet Dried | 50 | 14.86 ± 0.74 $^{e,f}$ |
| | 70 | 15.73 ± 1.69 $^{e}$ |
| | 90 | 14.21 ± 2.55 $^{f,g}$ |
| | 110 | 13.85 ± 2.09 $^{f,g}$ |
| Infrared Dried | 50 | 11.98 ± 0.58 $^{i,j}$ |
| | 70 | 12.35 ± 1.55 $^{h,i,j}$ |
| | 90 | 11.11 ± 0.54 $^{j}$ |
| | 110 | 10.00 ± 0.86 $^{k}$ |
| Drum Dried Van Drunen Farms | | 20.79 ± 1.75 $^{d}$ |
| Freeze Dried Van Drunen Farms | | 189.01 ± 10.61 $^{a}$ |
| Freeze Dried Shoreline Fruit | | 40.07 ± 1.94 $^{b}$ |

* The air temperature of the pre-chilled sample chamber came to ambient temperatures within a few hours of the start time of the experiment

As shown in Table 40 the freeze dried cherry powder from Van Drunen Farms contained the highest total anthocyanin values and was significantly different from all of the other tart cherry powder samples. The total anthocyanins

in this sample were exceptionally high, almost eight times higher than that in our freeze dried sample, and almost five times higher than that found in Shoreline Fruit's freeze dried sample. These results were expected since the starting material of the freeze dried powder from Van Drunen Farms is whole cherry fruit and not just the cherry pomace. The freeze dried sample from Shoreline Fruit and the experimentally produced freeze dried sample contained the second and third highest levels of total anthocyanins respectively. The cherry powder dried at 110°C in the infrared dryer contained the lowest total anthocyanin value. Overall, the total anthocyanins in the freeze-dried cherry pomace in the present study was much lower than Van Drunen Farm's (about 13% of Van Drunen Farm's freeze dried), and ~60% that of Shoreline Fruit's freeze dried sample. The other dried cherry pomace samples in the present study also had lower levels of anthocyanins than the commercial drum-dried sample, ranging from 15-50% lower.

# 4 CONCLUSIONS

## 4.1 Summary and Conclusions

The physical characteristics of the tart cherry powder are affected by the type of drying method and the temperature at which the sample is dried. The pH was the only characteristic that was not significantly different among the different samples. Drying temperatures within the vacuum and cabinet drying methods significantly affected the titratable acidity values. The different drying temperatures used within the infrared drying method did not significantly affect the titratable acidity values. The Hunter Color CIE variables were affected differently by the drying methods and temperatures. The freeze dried samples were significantly higher in L*, a*, and b*values compared to all of the other tart cherry powder samples. Only the a* and b* variables contained interactions between the type of drying method and temperature. Drying temperatures affected the a* and b* values within the vacuum and infrared drying methods. The water solubility and the water absorption index values were both affected by the type of drying method and the temperature at which the samples were dried.

In the total antioxidant analysis of the tart cherry powders, the four different methods of drying tested in these laboratory experiments (freeze drying, vacuum drying, cabinet drying, and infrared drying) did not significantly affect the levels found in the final product. The four temperature levels (50°C, 70°C, 90°C, and 110°C) tested within each drying method also did not significantly affect the total antioxidant levels of the tart cherry powder. Upon the analysis of total phenolics and total anthocyanins, similar trends were observed. The freeze dried powder contained the highest levels of total phenolics and total anthocyanins.

The powder dried at 110 °C in the infrared dryer contained the lowest levels of the total phenolics and total anthocyanins. Interaction effects between the type of drying method and the temperature were observed when measuring the levels of total phenolics and total anthocyanins. For each assay, no matter what temperature was chosen, the drying method selected significantly affected the levels of total phenolics and total anthocyanins. Temperature did affect the level of total phenolics when the tart cherry pomace was dried using the vacuum dryer. However the only drying method where the temperature affected the level of total anthocyanins was the infrared dryer. In terms on nutraceutical retention the vacuum dried (50 or 70°C) or cabinet dried (70°C) powders may be suitable alternatives to freeze drying however drying pomace at these low temperatures is impractical due to long processing times. Infrared drying is not a suitable alternative to freeze drying in terms of nutraceutical retention yet the processing time is considerably shorter and would appeal to manufacturers. Even though harsh temperatures were used to dry the pomace in the infrared dryer, there still were antioxidants that survived the process.

The levels of total antioxidants in the three commercially available tart cherry powders were comparable to the tart cherry powders produced experimentally. The two commercial freeze dried powders were not significantly different from some of the other powders that contained higher levels of total antioxidants. The commercial drum dried powder were not significantly different from some of the other powders that contained lower levels of total antioxidants. The total phenolic values of the commercial tart cherry powders were somewhat

comparable to the cherry powders produced experimentally. The two commercial freeze dried powders were not significantly different than some of the experimentally produced cherry powders that contained lower levels of total phenolics. However the drum dried sample contained significantly the lowest level total phenolics. The total anthocyanin values of the commercially available tart cherry powders were not comparable to the tart cherry powders produced experimentally. The two commercial freeze dried samples had significantly higher levels of total anthocyanins compared to all of the other samples. The sample that contained the next significantly highest level of total anthocyanins was the commercial drum dried powder. It is interesting to note that the freeze dried sample from Van Drunen Farms processed from the whole cherry fruit did not contain significantly higher levels of total antioxidants or total phenolics than the freeze dried sample from Shoreline Fruit which is manufactured from cherry pomace. However the freeze dried sample from Van Drunen farms did contain significantly higher levels of total anthocyanins as compared to the freeze dried sample from Shoreline Fruit.

## 4.2 Future Research Recommendations

There are numerous studies that would complement the research completed in Chapter 3. The following topics are recommended for future research:

1. An analysis of the nutraceutical retention in infrared dried pomace using more mild temperature conditions.

2. An analysis of additional drying methods such as fluidized bed drying.
3. A shelf life study of tart cherry powder manufactured from tart cherry pomace that would explore the nutraceutical retention over time influence by various packaging options as well as include a microbial and sensory analysis.
4. Further tart cherry powder analysis, which would include analysis of key vitamins and minerals as well as the soluble and insoluble fiber.

# APPENDICES

## APPENDIX 1 RAW DATA FOR THE PHYSICAL CHARACTERISTICS OF TART CHERRY POMACE AND POWDER

**Table A 1 Raw data for the percent moisture of the raw tart cherry pomace**

| Raw Pomace Sample | Percent Moisture (wb) | Average Percent Moisture (wb) |
|---|---|---|
| Sample 1 | 79.13 | 78.43 ± 0.72 |
| Sample 2 | 77.60 | |
| Sample 3 | 78.06 | |
| Sample 4 | 78.94 | |

**Table A 2 Raw data for the pH values of the raw tart cherry pomace**

| Raw Tart Cherry Pomace Sample | pH | Average pH |
|---|---|---|
| Sample 1.1 | 3.42 | 3.41 ± 0.01 |
| 1.2 | 3.40 | |
| 1.3 | 3.41 | |
| Sample 2.1 | 3.41 | 3.41 ± 0.00 |
| 2.2 | 3.41 | |
| 2.3 | 3.41 | |

**Table A 3. Raw data for the pH values of tart cherry powder**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **pH** | **Average pH** |
| Freeze Dried | | 3.60 | 3.61 ± 0.03 |
| | | 3.59 | |
| | | 3.65 | |
| Vacuum Dried | 50 | 3.53 | 3.59 ± 0.05 |
| | | 3.62 | |
| | | 3.63 | |
| | 70 | 3.62 | 3.62 ± 0.04 |
| | | 3.60 | |
| | | 3.63 | |
| | 90 | 3.60 | 3.63 ± 0.01 |
| | | 3.64 | |
| | | 3.65 | |
| | 110 | 3.65 | 3.66 ± 0.06 |
| | | 3.69 | |
| | | 3.65 | |
| Cabinet Dried | 50 | 3.59 | 3.61 ± 0.04 |
| | | 3.62 | |
| | | 3.62 | |
| | 70 | 3.64 | 3.65 ± 0.03 |
| | | 3.67 | |
| | | 3.63 | |
| | 90 | 3.58 | 3.61 ± 0.07 |
| | | 3.60 | |
| | | 3.65 | |
| | 110 | 3.64 | 3.63 ± 0.03 |
| | | 3.61 | |
| | | 3.65 | |
| Infrared Dried | 50 | 3.57 | 3.6 ± 0.03 |
| | | 3.62 | |
| | | 3.61 | |
| | 70 | 3.60 | 3.62 ± 0.05 |
| | | 3.61 | |
| | | 3.64 | |
| | 90 | 3.60 | 3.63 ± 0.01 |
| | | 3.65 | |
| | | 3.65 | |
| | 110 | 3.66 | 3.64 ± 0.05 |
| | | 3.61 | |
| | | 3.65 | |

**Table A 4. Raw data for the pH values of commercially available tart cherry powders**

| Tart Cherry Powder Sample | pH | Average pH |
|---|---|---|
| Drum Dried (Van Drunen Farms) | 3.67 | 3.68 ± 0.02 |
| | 3.70 | |
| | 3.66 | |
| Freeze Dried (Van Drunen Farms) | 3.62 | 3.61 ± 0.01 |
| | 3.60 | |
| | 3.62 | |
| Freeze Dried (Shoreline Fruit) | 3.60 | 3.6 ± 0.01 |
| | 3.59 | |
| | 3.61 | |

**Table A 5 Raw data for the titratable acidity values of raw tart cherry pomace**

| Raw Tart Cherry Pomace Sample | Titratable Acidity (Percent Malic Acid) | Average Titratable Acidity (Percent Malic Acid) |
|---|---|---|
| Sample 1.1 | 1.25 | 1.24 ± 0.03 |
| 1.2 | 1.21 | |
| 1.3 | 1.27 | |
| Sample 2.1 | 1.26 | 1.24 ± 0.02 |
| 2.2 | 1.24 | |
| 2.3 | 1.22 | |

**Table A 6 Raw data for the titratable acidity values of tart cherry powder**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Titratable Acidity (Percent Malic Acid)** | **Average Titratable Acidity (Percent Malic Acid)** |
| Freeze Dried | | 5.03 | 5.00 ± 0.03 |
| | | 4.97 | |
| | | 5.00 | |
| Vacuum Dried | 50 | 4.99 | 4.99 ± 0.05 |
| | | 5.04 | |
| | | 4.95 | |
| | 70 | 5.12 | 5.07 ± 0.04 |
| | | 5.05 | |
| | | 5.06 | |
| | 90 | 4.95 | 4.94 ± 0.01 |
| | | 4.93 | |
| | | 4.95 | |
| | 110 | 4.80 | 4.87 ± 0.06 |
| | | 4.90 | |
| | | 4.91 | |
| Cabinet Dried | 50 | 5.03 | 5.02 ± 0.04 |
| | | 5.05 | |
| | | 4.97 | |
| | 70 | 4.94 | 4.94 ± 0.03 |
| | | 4.91 | |
| | | 4.98 | |
| | 90 | 5.12 | 5.05 ± 0.07 |
| | | 5.05 | |
| | | 4.98 | |
| | 110 | 4.98 | 5.00 ± 4.89 |
| | | 5.03 | |
| | | 4.99 | |
| Infrared Dried | 50 | 4.89 | 4.89 ± 0.00 |
| | | 4.89 | |
| | | 4.89 | |
| | 70 | 4.95 | 4.94 ± 0.05 |
| | | 4.98 | |
| | | 4.88 | |
| | 90 | 4.87 | 4.86 ± 0.01 |
| | | 4.86 | |
| | | 4.85 | |
| | 110 | 4.97 | 4.91 ± 0.05 |
| | | 4.89 | |
| | | 4.89 | |

**Table A 7 Raw data for the titratable acidity of commercially available tart cherry powders**

| Tart Cherry Powder Sample | Titratable Acidity (Percent Malic Acid) | Average Titratable Acidity (Percent Malic Acid) |
|---|---|---|
| Drum Dried (Van Drunen Farms) | 4.67 | 4.68 ± 0.01 |
| | 4.66 | |
| | 4.69 | |
| Freeze Dried (Van Drunen Farms) | 8.34 | 8.46 ± 0.11 |
| | 8.56 | |
| | 8.48 | |
| Freeze Dried (Shoreline Fruit) | 7.23 | 7.15 ± 0.03 |
| | 7.10 | |
| | 7.12 | |

**Table A 8 Raw data for the Hunter Color CIE variables of the raw tart cherry pomace**

| | L* | Average L* | a* | Average a* | b* | Average b* | ΔE* | Average ΔE* |
|---|---|---|---|---|---|---|---|---|
| Sample 1.1 | 27.68 | | 15.89 | | 17.52 | | 70.32 | |
| 1.2 | 26.95 | 27.35 ± 0.37 | 16.43 | 15.95 ± 0.45 | 17.38 | 17.01 ± 0.76 | 71.11 | 70.53 ± 0.51 |
| 1.3 | 27.42 | | 15.53 | | 16.14 | | 70.17 | |

**Table A 9 Raw data for the Hunter Color CIE variables of the freeze dried tart cherry powder**

| Tart Cherry Powder Sample | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Drying Method | L* | Average L* | a* | Average a* | b* | Average b* | dE* | Average dE* |
| Freeze | 56.45 | | 12.38 | | 22.34 | | 61.96 | |
| Dried | 57.74 | 56.96 ± 0.68 | 11.82 | 12.26 ± 0.39 | 21.77 | 22.30 ± 0.51 | 62.83 | 62.39 ± 0.44 |
| | 56.70 | | 12.58 | | 22.78 | | 62.38 | |

**Table A 10 Raw data for the Hunter Color CIE variables of the vacuum dried tart cherry powder**

| Tart Cherry Powder Sample | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Drying Method** | **Temp-erature (°C)** | **L*** | **Average L*** | **a*** | **Average a*** | **b*** | **Average b*** | **dE*** | **Average dE*** |
| Vacuum Dried | 50 | 46.70 | 49.00 ± 2.25 | 12.33 | 11.63 ± 0.68 | 20.07 | 20.01 ± 0.05 | 52.30 | 54.21 ± 1.88 |
| | | 49.10 | | 11.58 | | 19.99 | | 54.27 | |
| | | 51.20 | | 10.97 | | 19.98 | | 56.05 | |
| | 70 | 47.37 | 48.66 ± 1.18 | 11.72 | 11.50 ± 0.20 | 19.54 | 19.73 ± 0.17 | 52.57 | 53.76 ± 1.08 |
| | | 48.94 | | 11.47 | | 19.84 | | 54.03 | |
| | | 49.67 | | 11.32 | | 19.82 | | 54.67 | |
| | 90 | 48.24 | 49.69 ± 1.31 | 10.79 | 10.52 ± 0.24 | 18.92 | 19.12 ± 0.19 | 52.93 | 54.27 ± 1.22 |
| | | 50.02 | | 10.43 | | 19.15 | | 54.57 | |
| | | 50.80 | | 10.33 | | 19.30 | | 55.31 | |
| | 110 | 45.59 | 47.09 ± 1.47 | 11.88 | 11.44 ± 0.57 | 19.16 | 19.10 ± 0.34 | 50.86 | 52.10 ± 1.15 |
| | | 47.17 | | 11.65 | | 19.41 | | 52.32 | |
| | | 48.52 | | 10.80 | | 18.73 | | 53.12 | |

**Table A 11 Raw data for the Hunter Color CIE variables of the cabinet dried tart cherry powder**

| Tart Cherry Powder Sample | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Drying Method** | **Temp-erature (°C)** | **L*** | **Average L*** | **a*** | **Average a*** | **b*** | **Average b*** | **dE*** | **Average dE*** |
| Cabinet Dried | 50 | 45.61 | | 12.64 | | 19.51 | | 51.19 | |
| | | 50.09 | 48.82 ± 2.80 | 11.57 | 11.82 ± 0.73 | 19.66 | 19.53 ± 0.12 | 55.04 | 53.91 ± 2.36 |
| | | 50.75 | | 11.24 | | 19.42 | | 55.49 | |
| | 70 | 44.42 | | 13.07 | | 19.48 | | 50.24 | |
| | | 47.50 | 46.66 ± 1.96 | 11.60 | 12.12 ± 0.83 | 18.92 | 19.13 ± 0.30 | 52.43 | 51.88 ± 1.45 |
| | | 48.06 | | 11.68 | | 19.00 | | 52.98 | |
| | 90 | 48.62 | | 10.80 | | 18.73 | | 53.21 | |
| | | 48.10 | 48.59 ± 0.48 | 11.54 | 11.20 ± 0.37 | 19.38 | 19.19 ± 0.40 | 53.12 | 53.43 ± 0.46 |
| | | 49.06 | | 11.26 | | 19.46 | | 53.96 | |
| | 110 | 48.09 | | 11.32 | | 19.43 | | 53.09 | |
| | | 47.22 | 47.25 ± 0.83 | 11.76 | 11.80 ± 0.51 | 19.59 | 19.64 ± 0.23 | 52.46 | 52.51 ± 0.55 |
| | | 46.43 | | 12.33 | | 19.89 | | 51.99 | |

**Table A 12 Raw data for the Hunter Color CIE variables of the infrared dried tart cherry powder**

| Tart Cherry Powder Sample | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Drying Method** | **Temp-erature (°C)** | **L*** | **Average L*** | **a*** | **Average a*** | **b*** | **Average b*** | **dE*** | **Average dE*** |
| Infrared Dried | 50 | 46.16 | | 12.65 | | 20.62 | | 52.12 | |
| | | 48.53 | 48.35 ± 2.10 | 12.03 | 12.03 ± 0.62 | 20.42 | 20.39 ± 0.25 | 54.01 | 53.85 ± 1.65 |
| | | 50.35 | | 11.41 | | 20.13 | | 55.41 | |
| | 70 | 47.34 | | 11.38 | | 19.42 | | 52.42 | |
| | | 48.19 | 48.16 ± 0.80 | 10.96 | 11.02 ± 0.33 | 18.71 | 18.92 ± 0.44 | 52.84 | 52.90 ± 0.52 |
| | | 48.94 | | 10.72 | | 18.62 | | 53.45 | |
| | 90 | 51.31 | | 9.79 | | 18.84 | | 55.53 | |
| | | 50.86 | 51.38 ± 0.56 | 10.05 | 9.88 ± 0.15 | 18.82 | 18.89 ± 0.11 | 55.16 | 55.63 ± 0.53 |
| | | 51.97 | | 9.80 | | 19.02 | | 56.20 | |
| | 110 | 46.71 | | 11.04 | | 20.05 | | 52.01 | |
| | | 48.32 | 48.55 ± 1.96 | 10.28 | 10.56 ± 0.42 | 19.17 | 19.83 ± 0.58 | 52.99 | 53.50 ± 1.79 |
| | | 50.61 | | 10.36 | | 20.27 | | 55.49 | |

**Table A 13 Raw data for the Hunter Color CIE variables of commercial tart cherry powders**

| Tart Cherry Powder Sample | L* | Average L* | a* | Average a* | b* | Average b* | dE* | Average dE* |
|---|---|---|---|---|---|---|---|---|
| Drum Dried (Van Drunen Farms) | 51.60 | 52.92 ± 1.27 | 26.13 | 26.44 ± 0.38 | 2.93 | 2.87 ± 0.22 | 57.91 | 59.23 ± 1.20 |
| | 54.14 | | 26.33 | | 2.62 | | 60.26 | |
| | 53.01 | | 26.87 | | 3.05 | | 59.51 | |
| Freeze Dried (Van Drunen Farms) | 41.86 | 42.22 ± 0.32 | 22.00 | 21.85 ± 0.22 | 9.40 | 9.39 ± 0.14 | 48.22 | 48.46 ± 0.26 |
| | 42.35 | | 21.59 | | 9.25 | | 48.43 | |
| | 42.45 | | 21.95 | | 9.53 | | 48.73 | |
| Freeze Dried (Shoreline Fruit) | 51.19 | 51.55 ± 0.33 | 16.06 | 15.83 ± 0.35 | 14.23 | 14.08 ± 0.22 | 55.51 | 55.73 ± 0.19 |
| | 51.85 | | 15.43 | | 13.82 | | 55.83 | |
| | 51.60 | | 16.00 | | 14.18 | | 55.85 | |

**Table A 14 Raw data for the water solubility values of tart cherry powder**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Percent Water Solubility** | **Average Percent Water Solubility** |
| Freeze Dried | | 30.34 | 30.40 ± 0.09 |
| | | 30.35 | |
| | | 30.50 | |
| Vacuum Dried | 50 | 27.53 | 28.23 ± 0.61 |
| | | 28.65 | |
| | | 28.50 | |
| | 70 | 28.22 | 28.60 ± 0.44 |
| | | 29.08 | |
| | | 28.50 | |
| | 90 | 30.88 | 30.50 ± 0.39 |
| | | 30.11 | |
| | | 30.60 | |
| | 110 | 31.28 | 31.44 ± 0.19 |
| | | 31.65 | |
| | | 31.40 | |
| Cabinet Dried | 50 | 26.05 | 26.19 ± 0.27 |
| | | 26.01 | |
| | | 26.50 | |
| | 70 | 29.00 | 29.30 ± 0.31 |
| | | 29.61 | |
| | | 29.30 | |
| | 90 | 26.00 | 25.68 ± 0.35 |
| | | 25.75 | |
| | | 25.30 | |
| | 110 | 27.97 | 27.56 ± 0.50 |
| | | 27.00 | |
| | | 27.70 | |
| Infrared Dried | 50 | 27.16 | 27.55 ± 0.37 |
| | | 27.61 | |
| | | 27.90 | |
| | 70 | 23.82 | 23.47 ± 0.32 |
| | | 23.20 | |
| | | 23.40 | |
| | 90 | 30.88 | 30.57 ± 0.29 |
| | | 30.53 | |
| | | 30.30 | |
| | 110 | 29.52 | 29.19 ± 0.30 |
| | | 28.94 | |
| | | 29.10 | |

**Table A 15 Raw data for the water solubility values of commercial tart cherry powders**

| Tart Cherry Powder Sample | Percent Water Solubility | Average Percent Water Solubility |
|---|---|---|
| Drum Dried (Van Drunen Farms) | 44.22 | 44.16 ± 0.94 |
| | 45.07 | |
| | 43.18 | |
| Freeze Dried (Van Drunen Farms) | 68.54 | 66.25 ± 2.01 |
| | 65.41 | |
| | 64.78 | |
| Freeze Dried (Shoreline Fruit) | 26.09 | 25.49 ± 0.80 |
| | 25.79 | |
| | 24.59 | |

**Table A 16 Raw data for the water absorption index values of tart cherry powders**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Water Absorption Index** | **Average Water Absorption Index** |
| Freeze Dried | | 4.47 | 4.59 ± 0.11 |
| | | 4.69 | |
| | | 4.60 | |
| Vacuum Dried | 50 | 4.29 | 4.24 ± 0.05 |
| | | 4.24 | |
| | | 4.20 | |
| | 70 | 4.13 | 4.09 ± 0.05 |
| | | 4.04 | |
| | | 4.10 | |
| | 90 | 3.85 | 3.78 ± 0.08 |
| | | 3.79 | |
| | | 3.70 | |
| | 110 | 3.96 | 3.94 ± 0.07 |
| | | 3.87 | |
| | | 4.00 | |
| Cabinet Dried | 50 | 4.74 | 4.77 ± 0.09 |
| | | 4.87 | |
| | | 4.70 | |
| | 70 | 4.67 | 4.63 ± 0.03 |
| | | 4.63 | |
| | | 4.60 | |
| | 90 | 4.69 | 4.65 ± 0.05 |
| | | 4.67 | |
| | | 4.60 | |
| | 110 | 4.33 | 4.35 ± 0.07 |
| | | 4.43 | |
| | | 4.30 | |
| Infrared Dried | 50 | 4.25 | 4.27 ± 0.03 |
| | | 4.26 | |
| | | 4.30 | |
| | 70 | 3.81 | 3.87 ± 0.05 |
| | | 3.90 | |
| | | 3.90 | |
| | 90 | 3.94 | 3.88 ± 0.07 |
| | | 3.89 | |
| | | 3.80 | |
| | 110 | 3.76 | 3.74 ± 0.04 |
| | | 3.77 | |
| | | 3.70 | |

**Table A 17 Raw data for the water absorption index values of the commercial tart cherry powders**

| Tart Cherry Powder Sample | Water Absorption Index | Average Water Absorption Index |
|---|---|---|
| Drum Dried (Van Drunen Farms) | 3.68 | 3.73 ± 0.12 |
| | 3.63 | |
| | 3.87 | |
| Freeze Dried (Van Drunen Farms) | 1.70 | 1.73 ± 0.04 |
| | 1.72 | |
| | 1.78 | |
| Freeze Dried (Shoreline Fruit) | 5.55 | 5.49 ± 0.06 |
| | 5.46 | |
| | 5.45 | |

## APPENDIX 2 RAW DATA FOR THE EFFECTS OF DRYING ON THE ANTIOXIDANT LEVELS IN TART CHERRY POMACE

**Table A 18 Raw data for the total antioxidant values of the tart cherry pomace**

| ORAC (umol TE/g cherry pomace db) | Average ORAC (umol TE/g cherry pomace db) |
|---|---|
| 930 | |
| 1237 | |
| 1156 | |
| 1204 | |
| 584 | |
| 882 | |
| 889 | |
| 662 | |
| 878 | |
| 733 | |
| 770 | |
| 482 | 771 ± 217 |
| 554 | |
| 738 | |
| 429 | |
| 516 | |
| 728 | |
| 663 | |
| 785 | |
| 773 | |
| 674 | |
| 610 | |
| 853 | |

**Table A 19 Raw data for the total antioxidant values of the freeze dried tart cherry powders**

| Tart Cherry Powder Sample | | |
|---|---|---|
| **Drying Method** | **ORAC (umol TE/g cherry pomace db)** | **Average ORAC (umol TE/g cherry pomace db)** |
| Freeze Dried | 845 | 477 ± 236 |
| | 1069 | |
| | 631 | |
| | 746 | |
| | 223 | |
| | 293 | |
| | 403 | |
| | 238 | |
| | 312 | |
| | 390 | |
| | 298 | |
| | 412 | |
| | 514 | |
| | 353 | |
| | 436 | |
| | 475 | |

**Table A 20 Raw data for the total antioxidant values of the vacuum dried tart cherry powders**

| Drying Method | Air Temperature (°C) | ORAC (umol TE/g cherry powder db) | Average ORAC (umol TE/g cherry powder db) |
|---|---|---|---|
| Vacuum Dried | 50 | 420 | 429 ± 181 |
| | | 510 | |
| | | 646 | |
| | | 654 | |
| | | 227 | |
| | | 236 | |
| | | 310 | |
| | 70 | 446 | 445 ± 152 |
| | | 573 | |
| | | 341 | |
| | | 563 | |
| | | 495 | |
| | | 535 | |
| | | 690 | |
| | | 227 | |
| | | 267 | |
| | | 315 | |
| | 90 | 425 | 368 ± 152 |
| | | 438 | |
| | | 268 | |
| | | 165 | |
| | | 413 | |
| | | 498 | |
| | | 496 | |
| | | 649 | |
| | | 196 | |
| | | 236 | |
| | | 265 | |
| | 110 | 316 | 356 ± 111 |
| | | 403 | |
| | | 565 | |
| | | 589 | |
| | | 324 | |
| | | 333 | |
| | | 324 | |
| | | 353 | |
| | | 294 | |
| | | 335 | |
| | | 312 | |
| | | 167 | |
| | | 371 | |
| | | 505 | |
| | | 439 | |

**Table A 20 (Continued) Raw data for the total antioxidant values of the vacuum dried tart cherry powders**

| Drying Method | Air Temperature (°C) | ORAC (umol TE/g cherry powder db) | Average ORAC (umol TE/g cherry powder db) |
|---|---|---|---|
| | | 415 | |
| | | 212 | |
| | | 238 | |
| | | 264 | |

**Table A 21 Raw data for the total antioxidant values of the cabinet dried tart cherry powder**

| Drying Method | Air Temperature (°C) | ORAC (umol TE/g cherry powder db) | Average ORAC (umol TE/g cherry powder db) |
|---|---|---|---|
| Cabinet Dried | 50 | 369 | 348 ± 122 |
| | | 477 | |
| | | 555 | |
| | | 501 | |
| | | 185 | |
| | | 224 | |
| | | 243 | |
| | | 337 | |
| | | 263 | |
| | | 292 | |
| | | 377 | |
| | 70 | 353 | 351 ± 138 |
| | | 520 | |
| | | 631 | |
| | | 414 | |
| | | 183 | |
| | | 211 | |
| | | 215 | |
| | | 327 | |
| | | 276 | |
| | | 314 | |
| | | 419 | |
| | 90 | 541 | 463 ± 213 |
| | | 670 | |
| | | 932 | |
| | | 263 | |
| | | 312 | |
| | | 408 | |
| | | 535 | |
| | | 254 | |
| | | 318 | |
| | | 402 | |
| | 110 | 541 | 449 ± 204 |
| | | 617 | |
| | | 759 | |
| | | 810 | |
| | | 244 | |
| | | 296 | |
| | | 325 | |
| | | 453 | |
| | | 257 | |

**Table A 21 Raw data for the total antioxidant values of the cabinet dried tart cherry powder**

| Drying Method | Air Temperature (°C) | ORAC (umol TE/g cherry powder db) | Average ORAC (umol TE/g cherry powder db) |
|---|---|---|---|
| | | 283 | |
| | | 360 | |

**Table A 22 Raw data for the total antioxidant values of the infrared dried tart cherry powder**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **ORAC (umol TE/g cherry powder db)** | **Average ORAC (umol TE/g cherry powder db)** |
| Infrared Dried | 50 | 273 | 391 ± 195 |
| | | 317 | |
| | | 486 | |
| | | 796 | |
| | | 244 | |
| | | 285 | |
| | | 338 | |
| | 70 | 295 | 415 ± 154 |
| | | 390 | |
| | | 484 | |
| | | 714 | |
| | | 264 | |
| | | 317 | |
| | | 441 | |
| | 90 | 287 | 425 ± 137 |
| | | 395 | |
| | | 491 | |
| | | 687 | |
| | | 290 | |
| | | 384 | |
| | | 443 | |
| | 110 | 253 | 307 ± 72 |
| | | 351 | |
| | | 362 | |
| | | 341 | |
| | | 212 | |
| | | 264 | |
| | | 252 | |
| | | 240 | |
| | | 292 | |
| | | 360 | |
| | | 455 | |

**Table A 23 Raw data for the total phenolic values of the tart cherry pomace**

| Total Phenolics (GAE/g cherry pomace db) | Average Total Phenolics (GAE/g cherry pomace db) |
|---|---|
| 37.56 | 34.56 ± 3.75 |
| 36.01 | |
| 39.58 | |
| 40.04 | |
| 36.84 | |
| 37.94 | |
| 31.05 | |
| 31.05 | |
| 30.72 | |
| 31.96 | |
| 31.22 | |
| 30.72 | |

**Table A 24 Raw data for the total phenolic values of the freeze dried tart cherry powder**

| Tart Cherry Powder Sample | | |
|---|---|---|
| Drying Method | Total Phenolics (GAE/g cherry powder db) | Average Total Phenolics (GAE/g cherry powder db) |
| Freeze Dried | 28.35 | 28.02 ± 0.29 |
| | 28.35 | |
| | 27.86 | |
| | 27.53 | |
| | 28.06 | |
| | 27.88 | |
| | 28.10 | |

**Table A 25 Raw data for the total phenolic values of the vacuum dried tart cherry powders**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Total Phenolics (GAE/g cherry powder db)** | **Average Total Phenolics (GAE/g cherry powder db)** |
| Vacuum Dried | 50 | 16.05 | 20.88 ± 3.45 |
| | | 15.92 | |
| | | 23.88 | |
| | | 24.00 | |
| | | 21.60 | |
| | | 22.45 | |
| | | 22.27 | |
| | 70 | 15.40 | 17.89 ± 1.58 |
| | | 16.66 | |
| | | 19.85 | |
| | | 19.67 | |
| | | 17.75 | |
| | | 18.28 | |
| | | 18.24 | |
| | 90 | 17.17 | 18.82 ± 1.53 |
| | | 17.13 | |
| | | 17.52 | |
| | | 18.98 | |
| | | 20.19 | |
| | | 20.41 | |
| | | 20.34 | |
| | 110 | 20.96 | 20.50 ± 1.29 |
| | | 20.69 | |
| | | 22.86 | |
| | | 22.59 | |
| | | 20.10 | |
| | | 19.84 | |
| | | 20.60 | |
| | | 20.51 | |
| | | 19.15 | |
| | | 19.31 | |
| | | 18.88 | |

**Table A 26 Raw data for the total phenolic values of the cabinet dried tart cherry powders**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Total Phenolics (GAE/g cherry powder db)** | **Average Total Phenolics (GAE/g cherry powder db)** |
| Cabinet Dried | 50 | 20.99 | 20.55 ± 0.43 |
| | | 21.04 | |
| | | 20.17 | |
| | | 20.24 | |
| | | 20.33 | |
| | 70 | 21.63 | 20.93 ± 0.55 |
| | | 20.95 | |
| | | 20.05 | |
| | | 20.10 | |
| | | 21.93 | |
| | 90 | 21.22 | 20.28 ± 1.12 |
| | | 21.27 | |
| | | 19.40 | |
| | | 19.22 | |
| | 110 | 20.63 | 18.49 ± 1.82 |
| | | 20.32 | |
| | | 17.40 | |
| | | 16.90 | |
| | | 17.21 | |

**Table A 27 Raw data for the total phenolic values of the infrared dried tart cherry powders**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Total Phenolics (GAE/g cherry p powder db)** | **Average Total Phenolics (GAE/g cherry powder db)** |
| Infrared Dried | 50 | 18.65 | 17.86 ± 0.79 |
| | | 18.74 | |
| | | 17.46 | |
| | | 17.23 | |
| | | 17.10 | |
| | 70 | 18.94 | 17.47 ± 1.18 |
| | | 18.58 | |
| | | 16.73 | |
| | | 16.60 | |
| | | 16.51 | |
| | 90 | 17.49 | 16.58 ± 0.84 |
| | | 17.40 | |
| | | 16.01 | |
| | | 15.61 | |
| | | 16.37 | |
| | 110 | 16.23 | 15.92 ± 0.39 |
| | | 16.45 | |
| | | 15.60 | |
| | | 15.74 | |
| | | 15.60 | |

**Table A 28 Raw data for the total anthocyanin values of tart cherry pomace**

| Total Anthocyanins (mg cyn-3-glu /100g cherry pomace db) | Average Total Anthocyanins (mg cyn-3-glu /100g cherry pomace db) |
|---|---|
| 24.73 | 23.83 ± 2.97 |
| 24.54 | |
| 25.52 | |
| 27.28 | |
| 27.09 | |
| 28.46 | |
| 21.39 | |
| 18.64 | |
| 20.80 | |
| 23.35 | |
| 21.58 | |
| 22.56 | |

**Table A 29 Raw data for the total anthocyanin values of the freeze dried tart cherry powders**

| Tart Cherry Powder Sample | | |
|---|---|---|
| Drying Method | Total Anthocyanins (mg cyn-3-glu /100g cherry powder db) | Average Total Anthocyanins (mg cyn-3-glu /100g cherry powder db) |
| Freeze Dried | 33.82 | 25.02 ± 5.12 |
| | 33.82 | |
| | 21.70 | |
| | 24.52 | |
| | 20.98 | |
| | 21.37 | |
| | 23.92 | |
| | 23.06 | |
| | 22.01 | |

**Table A 30 Raw data for the total anthocyanin values of the vacuum dried tart cherry powders**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Total Anthocyanins (mg cyn-3-glu /100g cherry powder db)** | **Average Total Anthocyanins (mg cyn-3-glu /100g cherry powder db)** |
| Vacuum Dried | 50 | 14.76 | 13.60 ± 1.32 |
| | | 14.47 | |
| | | 14.18 | |
| | | 14.37 | |
| | | 13.79 | |
| | | 12.53 | |
| | | 11.09 | |
| | 70 | 16.11 | 13.93 ± 1.91 |
| | | 16.40 | |
| | | 13.14 | |
| | | 15.12 | |
| | | 12.79 | |
| | | 12.21 | |
| | | 11.73 | |
| | 90 | 15.70 | 13.46 ± 1.53 |
| | | 14.84 | |
| | | 12.79 | |
| | | 12.81 | |
| | | 11.57 | |
| | | 12.14 | |
| | | 14.40 | |
| | 110 | 14.68 | 13.20 ± 0.93 |
| | | 14.49 | |
| | | 11.94 | |
| | | 13.83 | |
| | | 13.19 | |
| | | 12.84 | |
| | | 11.72 | |
| | | 13.38 | |
| | | 12.62 | |
| | | 13.48 | |
| | | 13.01 | |

**Table A 31 Raw data for the total anthocyanin values of the cabinet dried tart cherry powders**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Total Anthocyanins (mg cyn-3-glu /100g cherry powder db)** | **Average Total Anthocyanins (mg cyn-3-glu /100g cherry powder db)** |
| Cabinet Dried | 50 | 15.98 | 14.86 ± 0.74 |
| | | 15.03 | |
| | | 14.73 | |
| | | 13.95 | |
| | | 14.63 | |
| | 70 | 17.65 | 15.73 ± 1.69 |
| | | 17.07 | |
| | | 15.58 | |
| | | 14.90 | |
| | | 13.45 | |
| | 90 | 17.31 | 14.21 ± 2.55 |
| | | 16.64 | |
| | | 12.08 | |
| | | 12.65 | |
| | | 12.36 | |
| | 110 | 16.10 | 13.85 ± 2.09 |
| | | 16.19 | |
| | | 12.36 | |
| | | 12.36 | |
| | | 12.26 | |

**Table A 32 Raw data for the total anthocyanin values of the infrared dried tart cherry powders**

| Tart Cherry Powder Sample | | | |
|---|---|---|---|
| **Drying Method** | **Air Temperature (°C)** | **Total Anthocyanins (mg cyn-3-glu /100g cherry powder db)** | **Average Total Anthocyanins (mg cyn-3-glu /100g cherry powder db)** |
| Infrared Dried | 50 | 11.79 | 11.98 ± 0.58 |
| | | 12.96 | |
| | | 11.88 | |
| | | 11.88 | |
| | | 11.40 | |
| | 70 | 13.23 | 12.35 ± 1.55 |
| | | 14.50 | |
| | | 12.14 | |
| | | 11.28 | |
| | | 10.61 | |
| | 90 | 11.00 | 11.11 ± 0.54 |
| | | 11.87 | |
| | | 11.24 | |
| | | 10.38 | |
| | | 11.05 | |
| | 110 | 9.86 | 10.00± 0.86 |
| | | 11.13 | |
| | | 9.07 | |
| | | 10.60 | |
| | | 9.36 | |

## APPENDIX 3 RAW DATA FOR THE NUTRACEUTICAL COMPOSITION OF THE COMMERCIALLY AVAILABLE TART CHERRY POWDERS

**Table A 33 Raw data for the total antioxidant values of the commercial tart cherry powders**

| Tart Cherry Powder Sample | ORAC (umol TE/g cherry powder db) | Average ORAC (umol TE/g cherry powder db) |
|---|---|---|
| Drum Dried (Van Drunen Farms) | 270 | 275 ± 12 |
| | 260 | |
| | 291 | |
| | 264 | |
| | 279 | |
| | 284 | |
| Freeze Dried (Van Drunen Farms) | 403 | 454 ± 41 |
| | 403 | |
| | 499 | |
| | 481 | |
| | 473 | |
| | 462 | |
| Freeze Dried (Shoreline Fruit) | 388 | 423 ± 76 |
| | 414 | |
| | 531 | |
| | 361 | |
| | 345 | |
| | 498 | |

**Table A 34 Raw data for the total phenolic values of the commercial tart cherry powders**

| Tart Cherry Powder Sample | Total Phenolics (GAE/g cherry powder db) | Average Total Phenolics (GAE/g cherry powder db) |
|---|---|---|
| Drum Dried (Van Drunen Farms) | 8.43 | 8.86 ± 0.33 |
| | 8.35 | |
| | 8.35 | |
| | 9.10 | |
| | 8.94 | |
| | 8.88 | |
| Freeze Dried (Van Drunen Farms) | 15.44 | 15.46 ± 0.17 |
| | 15.57 | |
| | 15.70 | |
| | 15.30 | |
| | 15.52 | |
| | 15.25 | |
| Freeze Dried (Shoreline Fruit) | 17.85 | 17.49 ± 0.52 |
| | 17.90 | |
| | 18.09 | |
| | 17.12 | |
| | 16.78 | |
| | 17.22 | |

**Table A 35 Raw data for the total anthocyanin values of the commercial tart cherry powders**

| Tart Cherry Powder Sample | Total Anthocyanins (mg cyn-3-glu /100g cherry powder db) | Average Total Anthocyanins (mg cyn-3-glu /100g cherry powder db) |
|---|---|---|
| Drum Dried (Van Drunen Farms) | 20.31 | 20.79 ± 1.75 |
| | 23.23 | |
| | 22.30 | |
| | 18.58 | |
| | 19.38 | |
| | 20.97 | |
| Freeze Dried (Van Drunen Farms) | 168.21 | 189.01 ± 10.61 |
| | 196.07 | |
| | 193.49 | |
| | 188.89 | |
| | 196.52 | |
| | 190.90 | |
| Freeze Dried (Shoreline Fruit) | 40.39 | 40.07 ± 1.94 |
| | 39.85 | |
| | 38.51 | |
| | 43.72 | |
| | 39.43 | |
| | 38.49 | |

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