Converting Apple, Blueberry, and Cranberry Waste Biomass into a Powder Food Ingredient

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Abstract

Tonnes of fruit processing by-products (FPB) are generated from the manufacture of fruit juice and other fruit products annually. Disposal of this waste product creates a great environmental and economic concern to the industry. The current main methods of disposal include landfilling, use in animal feed, and composting. However, they each have their own limitations. Other methods have been applied for re-utilizing this waste product since it is rich in nutrients, dietary fiber, and other bioactive compounds. Fruits, specifically apples, blueberries, and cranberries, are considered a rich source of antioxidant compounds such as phenolics. They contain high amounts of flavonoids, which are the most abundant bioactive phenolic compounds. Their consumption was proven to reduce the risk of cardiovascular diseases, cancers, and diabetes. Most of these compounds are found in the skin and seeds, which remain in the processing by-product, making it a valuable biomass. As a result, FPB has been considered in the production of fermentable products (such as sugars), for use in biofuel, extraction of nutraceuticals, enzymes, and biopolymers. The production of a powder from FPB for use as a food ingredient is very promising since the process results in zero waste. This study focused on the production of a powder from apple, blueberry, and cranberry pomaces by convective drying and grinding. Three conditions were varied: the drying temperature (50°C and 60°C), the duration of drying (24h and 48h), and homogenization of the pomace prior to drying. The powder was then characterized for moisture, protein, fat, ash, total dietary fiber content (TDF), hydration and oil absorption properties, colour, antioxidant activity (AA), total phenolic content (TPC), and total flavonoid content (TFC).

It was observed that the higher drying temperature resulted in a better-quality powder for all fruits. Homogenization of the pomace prior to drying affected the powder's AA, TPC, TFC, and TDF. Homogenized blueberry and cranberry powders were found to have higher AA, TPC, TFC, and TDF compared to unhomogenized samples due to the release of bound phenolics and dietary fiber. The best apple pomace powder was obtained by drying unhomogenized pomace at 60°C for 24h. This resulted in a TPC, TFC, and TDF of 1.91 mg GAE/ g dm, 3.38 mg CE/ g dm, 31 g/ 100g dm, respectively. Blueberry pomace powder had the highest TPC, TFC, and TDF at 60°C and 24 hours with homogenization and resulted in 22.4 mg GAE/ g dm, 21.2 CE/ g dm, and 24.12 g/ 100

g dm, respectively. The best cranberry pomace powder was also produced at 60°C and 24 hours with homogenization, resulting in aTPC, TFC, and TDF of 20.2 mg GAE/ g dm, 19.5 g CE/ g dm, and 40.77 g /100 g, respectively.

It can be concluded that producing a powder from FPB is an environmentally friendly alternative for using this otherwise wasted resource. The resulting powder was high in dietary fiber and phenolics, especially flavonoids. This powder can be used in the formulation of cookies, muffins, cakes, in meat products, dairy products, and many other food applications.

Résumé

Chaque année, des tonnes de sous-produits de la transformation des fruits (PBF) sont générées par la fabrication de jus de fruits et d'autres produits fruitiers. L'élimination de ces déchets crée une grande préoccupation environnementale et économique pour l'industrie. Les principales méthodes actuelles d'élimination comprennent l'enfouissement, l'utilisation dans l'alimentation animale et le compostage. Cependant, ces méthodes ont chacune leurs propres limites. D'autres méthodes doivent être considérées pour réutiliser ce déchet, car il est riche en nutriments, en fibres alimentaires et en autres composés bioactifs. Les fruits, en particulier les pommes, les bleuets et les canneberges, sont considérés comme une riche source de molécules antioxydantes comme les composés phénoliques. Ils contiennent de grandes quantités de flavonoïdes, qui sont les composés phénoliques bioactifs les plus abondants. Leur consommation s'est avérée apte à réduire le risque de maladies cardiovasculaires, de cancers et de diabète. La plupart de ces composés se trouvent dans la peau et les graines, qui restent dans le sous-produit de transformation, ce qui en fait une biomasse précieuse. Par conséquent, le PBF a été pris en considération dans la production de produits fermentescibles (comme les sucres), l'utilisation dans les biocarburants, l'extraction de nutraceutiques, les enzymes et les biopolymères. La production d'une poudre à partir de ce sous-produit pour une utilisation comme ingrédient alimentaire est très prometteuse, car le processus aboutit à zéro déchet. Cette étude a porté sur la production d'une poudre de marcs de pomme, de bleuet et de canneberge par séchage par convection et broyage. Trois conditions ont été variées : la température de séchage (50°C et 60°C), la durée de séchage (24h et 48h) et l'homogénéisation du marc avant séchage (oui ou non). La poudre a ensuite été caractérisée en ce qui concerne son taux d'humidité, les protéines, les matières grasses, les cendres, la teneur en fibre alimentaire totale (TDF), les propriétés d'hydratation et d'absorption d'huile, la couleur, l'activité antioxydante (AA), la teneur en composés phénoliques (TPC) et la teneur en flavonoïdes (TFC).

Il a été observé que la température de séchage plus élevée résultait en une poudre de meilleure qualité pour tous les fruits. De plus, l'homogénéisation de la poudre a affecté les AA, les TPC, les TFC et les TDF. Ces propriétés ont augmenté avec l'homogénéisation du marc de bleuet et de canneberge, mais ont diminué avec l'homogénéisation du marc de pomme. La poudre de marc

de pomme la plus optimale a été obtenue par séchage de marc non homogénéisé à 60°C et 24h. Il en est résulté une PTC, une TFC et une TDF de 1,91 mg d'EAG/g p.s., de 3,38 mg d'EC/g p.s., de 31 g/100 g p.s., respectivement. La poudre de marc de bleuet a présenté les concentrations les plus élevées de TPC, TFC et TDF à 60 °C et 24 heures après homogénéisation, ce qui a donné 22,4 mg d'EAG/g p.s., 21,2 CE/g p.s. et 24,12 g/100 g p.s., respectivement. La poudre de marc de canneberge la plus optimale a également été produite dans les mêmes conditions avec un TPC, TFC et TDF de 20,2 mg EAG/g p.s., 19,5 g EC/g p.s. et 40,77 g/100 g, respectivement.

On peut conclure que la production d'une poudre à partir de FPB est une alternative écologique au rejet de ce produit comme déchets. La poudre résultante était riche en fibres alimentaires et en composés phénoliques, en particulier en flavonoïdes. Cette poudre peut être utilisée dans la formulation de biscuits, de muffins, de gâteaux, dans des produits à base de viande, des produits laitiers et dans de nombreuses autres applications alimentaires.

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List of Abbreviations

AA	Antioxidant activity
ABTS	2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonate)
APP	Apple pomace powder
BOD	Biological oxygen demand
BPP	Blueberry pomace powder
CE	Catechin equivalent
COD	Chemical oxygen demand
CPP	Cranberry pomace powder
dm	Dry mass
DPPH	2,2-diphenyl-1-picrylhydrazyl
fm	Fresh mass
FAO	Food and Agriculture Organization
FPB	Fruit processing by-product
FRAP	Ferric reducing antioxidant power
GAE	Gallic acid equivalent
GAPP	Ground apple powder
GBPP	Ground blueberry powder

GCPP	Ground cranberry powder
GHG	Greenhouse gas
MC	Moisture content
OBC	Oil binding capacity
ORAC	Oxygen radical absorbance capacity
SMP	Specific methane potential
TDF	Total dietary fiber
TE	Trolox equivalent
TFC	Total flavonoid content
TPC	Total phenolic compound
v/v	Volume per volume
w/v	Weight per volume
WBC	Water binding capacity
WHC	Water holding capacity

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1. Introduction & objectives

1.1 Introduction

Canada produces more than 800,000 tonnes of fruit annually (Statistics Canada, 2021). Fruits are typically processed into juice, jams, dried fruit, and other food products which increase its shelf-life (Iqbal, Schulz, & Rizvi, 2021). These processes can produce a considerable amount of by-products, exceeding 0.5 billion tonnes globally, which causes disposal issues (Banerjee et al., 2017). The fruit processing by-products (FPB) include the pomace, which is the solid materials consisting of pulp, seeds, and stems that remain after processing. It can vary in composition depending on the fruit and method of processing. For example apple pomace, the main by-product of apple juice or cider processing, is typically 20-30% of the dry mass of apples and can have a moisture content of 70-80% (Struck & Rohm, 2020).

Fruits and their processing by-products are a very rich source of bioactive compounds, which are secondary metabolites found in plants. The main class of these phytochemicals are phenolic compounds which contain at least one aromatic ring and hydroxyl group (Laura et al., 2019). Flavonoids are the biggest class of phenolic compounds and are the most bioactive (Laura et al., 2019). They include anthocyanins, which are responsible for the red and blue colour of berries (Ignat, Volf, & Popa, 2011). There are over 8,000 phenolic compounds, and over 6,000 of those are known flavonoids (Vuolo, 2019). Bioactive compounds are associated with many potential health benefits resulting from the following properties: antioxidant, antimicrobial, antiviral, anti-inflammatory antidiabetic, antihypertensive, neuroprotective, cell detoxification, cholesterol synthesis, anticonvulsant, and their ability to lower blood pressure (Karasawa & Mohan, 2018).

Apples, blueberries, and cranberries are the most important fruits produced in Canada, making up about 44%, 18%, and 17%, respectively (Statistics Canada, 2021). When compared to many other fruits, blueberries were found to contain the highest total phenolic content (Prior et al., 1998). Blueberries are known to be high in many antioxidant compounds that can prevent or reduce the effects of diabetes, obesity, inflammation, microbial infections, tumours, cognitive decline, and bone loss (Patel, 2014). A higher concentration of these phytochemicals is present in the skin rather than the flesh (Wolfe & Liu, 2003). Due to the loss of moisture during fruit

processing and the higher concentration of skin, pomace has a higher concentration of bioactive compounds. Consumption of cranberries is associated with the prevention of many diseases and infections including urinary tract infections, various cancers, cardiovascular diseases, dental health, and certain stomach ulcers (Côté, Caillet, Doyon, Sylvain, & Lacroix, 2010).

Fruits are known to be a rich source of dietary fiber (Sagar, Pareek, Sharma, Yahia, & Lobo, 2018). The recommended daily intake of dietary fiber for women and men in the United States are 28 g/day and 36 g/day, respectively, however, most people consume less than half the recommended amount (Anderson et al., 2009).

Fruit processing by-products are typically disposed of in landfills (Lyu et al., 2020). Its high moisture content causes it to be bulky and susceptible to microbial decomposition (Iqbal et al., 2021). The deterioration of pomace produces greenhouse gases, foul smells, and public health issues (Dhillon, Kaur, & Brar, 2013). In addition to being harmful to the environment, disposal of FPB is an economic concern to industries. Other methods of disposal have been implemented; however, they have their own limitations. Fruit pomace has been used as animal feed, soil fertilizer, or as a substrate for bioenergy generation. Some of the drawbacks in these applications are the typically high acidity of the pomace, low amount of digestible energy, low protein, and high content of phytochemicals (Struck & Rohm, 2020).

One approach of by-product handling is through value-added processing, which is any method that takes an otherwise waste material and turns it into a useful commodity. Value-added processing results in significantly less waste while generating an economic return. Applying this approach with FPB and converting it into a food ingredient is very promising. The FPB can be dried to extend its shelf life. Drying reduces the moisture content and water activity, resulting in a slower rate of deterioration. It is typically used due to its simplicity and ability to reduce the bulk volume (Larrauri, 1999). Grinding the dried fruit processing by-products results in an ingredient that can easily be incorporated into foods, such as muffins or cookies.

1.2 Research hypothesis

- Convective oven drying and knife mill grinding of apple, blueberry, and cranberry pomace can produce a powder that is rich in bioactive compounds, dietary fiber, and colour
- The powder exhibits acceptable hydration and oil absorption properties for use in food formulations
- Homogenizing the pomace prior to drying can affect its nutritional, hydration, and oil absorption properties.

1.3 Research objectives

The main objective of this thesis was to produce a fruit powder ingredient that could provide nutritional value to other food products. The specific objectives were:

1. Study a process to produce a powder ingredient from apple, blueberry, and cranberry pomaces
2. Evaluate the antioxidant capacity, dietary fiber content, total phenolic content, total flavonoid content, hydration and oil absorption capacities, proximate analysis, and colour of the produced fruit pomace powders
3. Investigate the effect of grinding the pomace prior to drying on the powder characteristics

2. Literature Review

2.1 Bioactive compounds

2.1.1 Antioxidants

Antioxidants are substances that when present in small amounts relative to an oxidizable substrate, will significantly delay or prevent oxidation of the substrate (Benzie and Strain (1996). Thus, they prevent the damage of cells from the action of free radicals, which are atoms or molecules that have unpaired electrons. Natural antioxidants are mainly derived from foods such as fruits, vegetables, cereals, and flowers (Xu et al., 2017). They include vitamins (such as vitamin A, C, and E), polyphenols (phenolic acids, flavonoids, anthocyanins, lignans and stilbenes) and carotenoids (Xu et al., 2017). Studies have shown that frequent consumption of natural antioxidants is associated with lower risk of cardiovascular disease and cancers as well as having anti-inflammatory, antibacterial, antiviral and anti-aging effects (Thaipong, Boonprakob, Crosby, Cisneros-Zevallos, & Byrne, 2006; Xu et al., 2017). Natural antioxidants have higher efficiencies and lower manufacturing costs than synthetic antioxidants, additionally the latter may exhibit toxicity (C. Li, Feng, Huang, & An, 2013).

The human body generates two types of free radicals from biological processes: reactive oxygen species (ROS) and reactive nitrogen species (RNS). These molecules can harm cells by oxidizing lipids, proteins, and other cell membranes and tissues, which can cause injury (Li et al., 2015). The antioxidant systems in the human body naturally keep the balance between oxidation and anti-oxidation by scavenging the ROS and RNS. While these species, at certain levels, are vital for physiological functions, large levels can disrupt the balance of the oxidation and antioxidation system and cause cell death and tissue injury (Li et al., 2015). This can result in some chronic and degenerative diseases such as cancer and cardiovascular diseases (Xu et al., 2017). Exposure to cigarette smoke, alcohol, radiation, or environmental toxins can induce the production of excessive radicals (Xu et al., 2017). The intake of exogenous antioxidants can prevent the oxidation reactions by acting as free radical scavengers, quenchers of singlet oxygen (oxygen in an excited state which is highly reactive and can be found in biological systems), and reducing agents.(Baiano & Del Nobile, 2016). A redox reaction will still generally occur in the presence of

antioxidants unless they completely prevent the generation of oxidizing species. Antioxidants will react with the oxidizing species instead of an oxidizable substrate such as tissues, i.e., antioxidants reduce the oxidant and result in a redox reaction.

In this context, antioxidant power may be referred to as a reducing ability (Benzie & Strain, 1996). There are multiple methods to determine antioxidant activity. The most common assays are the ferric reducing antioxidant power (FRAP) assay (Benzie & Strain, 1996), 2,2-diphenyil-picrylhydrazyl (DPPH) radical-scavenging capacity assay (Brand-Williams, Cuvelier, & Berset, 1995), trolox equivalent antioxidant capacity (TEAC or ABTS (2,2'-azinobis-(3-ethylbenzothiazoline-6-sulfonate)) assay (Miller, Rice-Evans, Davies, Gopinathan, & Milner, 1993), and oxygen radical absorbance capacity (ORAC) assay (Prior et al., 1998). The FRAP, which directly measures the reducing capacity of antioxidants, is based on the reduction of ferric-tripridyltriazine (Fe^{3+}-TPTZ) complex to the ferric form (Fe^{2+}) at a low pH. This produces an intense blue colour with an absorption maximum at 593nm. The higher the antioxidant content, the more intense the colour. Another method that can be used to evaluate the antiradical activities of antioxidants is to react them with a stable radical, DPPH° in methanol solution, which forms a deep purple colour and absorbs at 515nm (Brand-Williams et al., 1995). The antioxidant reduces the DPPH radical to DPPH-H and the colour disappears. Reducing ability is determined by measuring the decrease of its absorbance. Contrary to the FRAP assay, the lighter the colour of the reacted solution, the higher the antioxidant activity. DPPH assay is widely used for determining antioxidant capacity of fruit and vegetable juices or extracts due to its simplicity (Thaipong et al., 2006).

2.1.2 Phenolic Compounds

There are over 200,000 chemicals found in plants which are divided into two groups: primary and secondary metabolites. Primary metabolites are essential to cell maintenance and include fatty acids, proteins, and carbohydrates. Secondary metabolites, which include phenolic compounds, are necessary for plant survival (Chikezie, Ibegbulem, & Mbagwu, 2015). Phenolic compounds are a class of compounds that consist of an aromatic ring bonded to one or more hydroxyl groups. They are the most abundant secondary metabolites in plants) and can be found in most plant tissues, including fruits (Ayad & Akkal, 2019). Their role includes structural support, protection

against ultraviolet (UV) solar radiation, oxidation, pathogens, and predators. They also provide colour and sensory characteristics (Chikezie et al., 2015). The levels of phytochemicals present in a plant or fruit are determined largely by the environment. For example, berries grown in cold northern climates with short vegetation season and no fertilizers or pesticides have a higher phenolic content than the same variety grown in milder climates (Szajdek & Borowska, 2008).

Phenolic compounds are considered as antioxidants since they can scavenge reactive oxygen species. They provide protection against non-transmissible chronic diseases such as cardiovascular diseases, cancers, obesity, and diabetes. This is due to their capacity to regulate cellular processes at different levels including, but not limited to, enzyme inhibition, modification of gene expression and protein phosphorylation (Laura et al., 2019).

There are over 8000 types of phenolic compounds which are classified into five main groups: flavonoids, phenolic acids, tannins (hydrolysable and condensed), stilbenes and lignans (D Archivio et al., 2007). Figure 2.1 shows a classification of phenolic compounds, some examples, and their generic structures. Phenolic acids contain at least one aromatic ring with a carboxylic group and are classified into two major types depending on their structure: benzoic acid derivatives (C6-C1) and cinnamic acid derivatives (C6-C3) (Karasawa & Mohan, 2018). Some examples of phenolic acids are ellagic acid, which can be found in blackberries and strawberries; gallic acid, found in teas; and caffeic acid, found in coffee.

Tannins contain a large number of hydroxyl or other functional groups and can form an insoluble complex with water (Ferrer, Austin, Stewart, & Noel, 2008). They can be classified into hydrolysable and condensed tannins, with the latter being more complex and uniform. The most common condensed tannins are procyanidins and prodelphinidins, which are found in fruits, vegetables, red wine, cocoa, legumes, and some grains (Tsao, 2010).

Lignans contain two phenylpropanoid units (C6-C3-C3-C6) and are distributed in low concentrations in fruits, vegetables, nuts, and cereals (Laura et al., 2019). Stilbenes have a C6-C2-C6 structure and are also found in low quantities, mostly in grapes, berries, and peanuts.

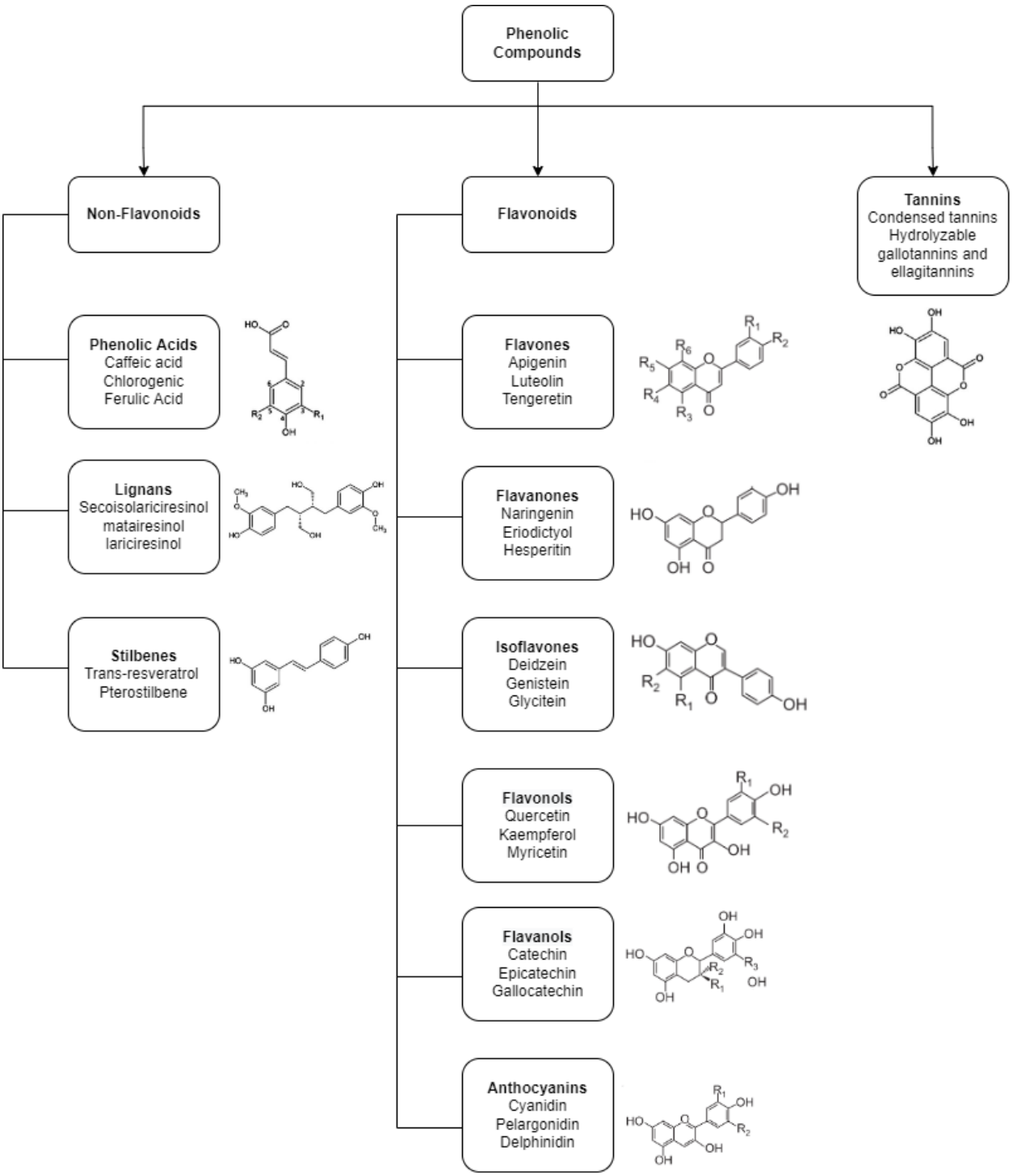

Figure 2.1: *Classification of phenolic compounds, examples, and their structures. Adapted from (Laura, Moreno-Escamilla, Rodrigo-García, & Alvarez-Parrilla, 2019).*

2.1.1 Flavonoids

Flavonoids are the most abundant phenolic compounds, the most bioactive, and account for two thirds of total dietary phenolic compounds (Laura et al., 2019). They contain a phenyl benzopyran skeleton, which is made up of two phenyl rings joined through a heterocyclic pyran ring (Figure 2.1). Flavonoids are low molecular weight compounds that consist of fifteen carbon atoms arranged in a C6–C3–C6 configuration (Laura et al., 2019). They are divided into six groups: anthocyanins, flavones, isoflavones, flavanones, flavonols and flavanals (Tsao & Yang, 2003).

Flavonoids are typically bound to sugars in the plant, called glycosides. This form of flavonoids is more stable than the free form however, they have relatively low bioavailability (ability to be absorbed and used by the body) when ingested (Vuolo, Lima, & Maróstica Junior, 2019).

Flavones, such as apigenin and luteonin, can be found in spices and herbs, fats and oils, fruits (especially cantaloupe and watermelon), vegetables, and cereal grains. Flavonols, like kaempherol, myricetin, quercetin, and rutin are found in dairy products, spices and herbs, fruits (like berries and apples), vegetables, seeds, and beverages. Flavanones, such as naringenin, eriodictyol, and hesperidin are found in fruits (citrus fruits), vegetables, spices and herbs, nuts and seeds, and cereal grains. Flavanols are the most abundant flavonoids found in nature. Compounds such as catechins, epicatechins and gallocatechin are found in dairy products, fruits (apples, peaches, strawberries), vegetables, legumes, nuts, and seeds (Faggio et al., 2017). Anthocyanins are water-soluble pigments that are responsible for the red, blue, and purple colour in fruits and vegetables. The colour and stability of the pigments depend on pH, light, temperature and structure (Khoo, Azlan, Tang, & Lim, 2017). Some examples include cyanidin, delphinidin, and pelargonidin, are found in fruits (especially berries), vegetables, nuts and seeds, legumes, and cereal grains (Faggio et al., 2017).

Flavonoids have a high redox potential which characterizes them as antioxidants. This allows them to act as reducing agents, hydrogen donors, and singlet oxygen quenchers (Tsao & Yang, 2003). They are known to have, anti-inflammatory, antiallergic, antiulcer, antibiotic, and anticarcinogenic properties (Cho, Howard, Prior, & Clark, 2004). Flavonoids play a major role in protecting against oxidative stress promoted by free radicals in both humans and plants. Thus, it

is believed that increased consumption of flavonoid rich foods may reduce incidence and mortality from chronic diseases (Cho et al., 2004; Karasawa & Mohan, 2018). It was proven that long-term intake of foods rich in flavonoids lower the risks of Alzheimer disease and related dementias (Shishtar, Rogers, Blumberg, Au, & Jacques, 2020).

2.1.2 Dietary Fiber

Dietary fibers are composed of a mixture of nondigestible carbohydrates, lignin and other associated substances of plant origin (Institute of Medicine, 2001). It has the ability to reduce cholesterol, diabetes, coronary heart disease and ease constipation (O'Shea, Arendt, & Gallagher, 2012). Increased intake is linked to a reduced risk of obesity and colon cancer (Mann & Cummings, 2009). Dietary fiber has the ability to increase the fecal bulk, stimulate colonic fermentation, reduce postprandial blood glucose (reduce insulin responses), and reduce pre-prandial cholesterol levels (Elleuch et al., 2011). Supplementing foods with dietary fibers results in lower cholesterol, calories, and fat, which is fitness-promoting.

Fibers are classified as soluble if they form a solution when mixed with water, usually viscous gels. They are considered insoluble if they do not form a solution. The soluble fraction includes pectic substances, gums, mucilage, and some hemicellulose, which are resistant to digestion in the small intestine but fermented by the microbiota in the large intestine. Whereas the insoluble fraction includes cellulose, types of hemicellulose, and lignin, which do not ferment easily in the human gastrointestinal track (Quiles, Campbell, Struck, Rohm, & Hernando, 2018). Soluble dietary fiber positively affects serum lipids while insoluble dietary fiber is linked to laxation benefits (Quiles et al., 2018).

Due to its nature of having both soluble and insoluble properties, dietary fibers have a range of technological attributes such as water binding, gelling, and structure building. The soluble fibers, in comparison with the insoluble fraction, demonstrate a greater potential to increase viscosity, ability to form gels, act as an emulsifier, having neither a bad taste or texture, and easier to incorporate into processed foods and drinks (Elleuch et al., 2011).. Moreover, soluble fiber can be used as a fat replacer. Soluble fibers can reduce glycemic response and plasma cholesterol (Abdul-Hamid & Luan, 2000). Insoluble fibers are characterized by their porosity, low density, and

by their ability to increase fecal bulk and decrease intestinal transit. Food products that contain mostly soluble fiber, such as oat bran, barley, and psyllium, are known to lower blood lipid levels. Products with more insoluble fibers, such as wheat bran, are usually linked to laxative properties (Elleuch et al., 2011).

2.1.3 Hydration and oil absorption capacities

Hydration and oil absorption properties are parameters often used to describe the quality of powders, such as flours, related to their suitability for the production of food products such as cakes and cookies, since it is directly related to the rheology of the dough and its expansion during the baking process (Elleuch et al., 2011). Water holding capacity is the amount of water retained by a sample in the absence of stress. Water binding capacity is the amount of water retained by a sample after it has been subjected to low-speed centrifugation. Technological treatments, such as grinding and heating affect the physico-chemical properties of the fiber, including its hydration and oil absorption capacities (Guillon & Champ, 2000). Their ability to hold water is directly related to the source of the fiber. For example, fibers from algae have a greater affinity to water and oil than those from fruit juice by-products (Elleuch et al., 2011). Hydration properties are related to the chemical structure of the composing polysaccharides, and other factors such as particle size, ionic form, porosity, pH, ionic strength, type of ions in solution, and stresses upon fiber (Elleuch et al., 2011). These terms are important in food processing applications. For example, materials that have a low water binding capacity may not hold water effectively and may be brittle and dry, especially during storage, while material that have a high water-binding capacity may result in food products that shrink or deteriorate due to their high water activity (Farooq & Boye, 2011).

Dietary fibers have the ability to hold oils. The oil binding capacity (OBC) is the amount of oil retained by the sample after mixing, incubation with oil, and low-speed centrifugation. Dietary fibers with high oil binding capacity stabilize high-fat food products and emulsions (Elleuch et al., 2011), improve palatability, extend shelf life, and improve flavour retention (Awuchi, Igwe, & Echeta, 2019). Meanwhile, dietary fibers with high oil or water holding capacity can modify the viscosity and texture of food products as well as be used as a functional ingredient to avoid syneresis (Grigelmo-Miguel & MartíN-Belloso, 1999). The oil absorption mechanism depends on

the entrapment of oil within the food structure, thus factors that affect OBC are particle size, composition, moisture content, and microstructure (Farooq & Boye, 2011).

2.1.4 Fruit production in Canada

Canada grows a wide range of fruits, despite its northern latitude and short growing seasons. In 2020, almost 900,000 tonnes of fruit were produced, which was down from 945,112 in 2019 due to labour shortages caused by the COVID-19 pandemic. The top 5 fruits, by production volume in Canada are apples, blueberries, cranberries, grapes, and strawberries (Figure 2.2). In 2020, apples, blueberries, and cranberries, accounted for 78.4% of all fruits produced by volume in Canada (Statistics Canada, 2021).

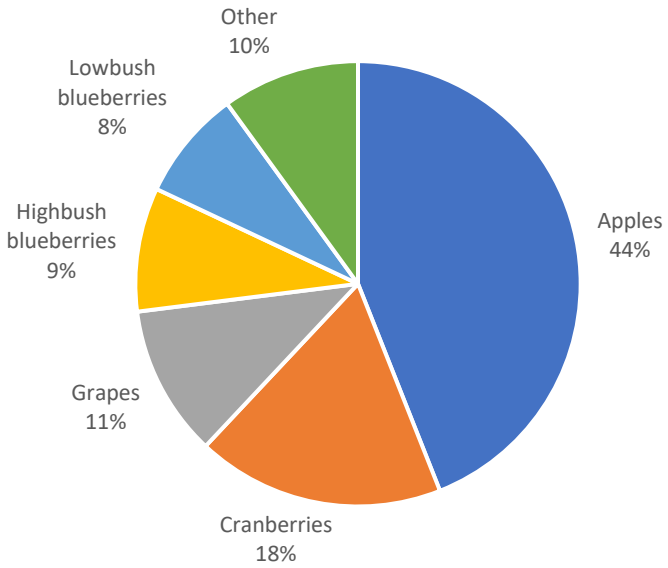

Figure 2.2: *Fruit production volume in Canada (Statistics Canada, 2021)*

2.2 Apples

2.2.1 Production and market status

Apples (*Malus domestica*) are one of the most consumed fruits globally. In 2019, about 87 million tonnes were produced worldwide (FAO, 2020a). Of that, 368,422 tonnes were produced in Canada, the highest fruit produced by volume. Apples are one of two fruits in which production

increased in 2020, to 390,995 tonnes, or 43.7% of total fruits produced in Canada, despite the COVID-19 pandemic (Statistics Canada, 2021).

2.2.2 Structure, classification, and proximate analysis

Apple is best grown in regions where the average winter temperature is near freezing for at least 2 months (Girard Kristen, 2012). There are over 7,500 apple varieties worldwide (Bohn & Bouayed, 2020). Table 2.1 shows the proximate composition analysis of a typical apple fruit.

Table 2.1: *Proximate composition analysis of apple fruit (USDA, 2020).*

Parameter	Value (%)
Water	84.6
Protein	0.13
Total fat	0.15
Ash	0.3
Fiber	2.1
Carbohydrate by difference	14.8

2.2.3 Uses (Food products, juices, other)

About 70-75% of apples produced are for fresh consumption (Figure 2.3). The remaining 25-30% is processed to juice, cider, jams, wine and dried apple products (Bhushan, Kalia, Sharma, Singh, & Ahuja, 2008). Each product may utilize a different cultivar due to its properties. For example, cider production uses apples with high phenolic content while cloudy juices need apples with a low phenolic content (Wu et al., 2007).

Apple juice is the most demanded apple product, accounting for 65% of processed apples, or about 20% of apples produced (Bhushan et al., 2008). The process begins with washing and sorting apples and subsequently grinding them to a pulp by a disintegrator, hammer mill or grating mill. A commercial macerating enzyme is usually added to lower the viscosity, reduce pulp slipperiness and achieve higher yields by breaking down cell walls. Apple juice is extracted by pressing milled apples continuously or in batches. It is extremely cloudy at this point, so any larger

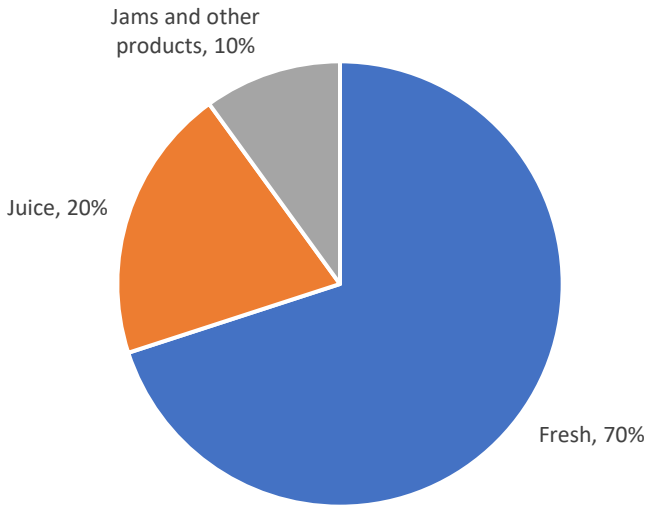

Figure 2.3: *Utilization of apples (Bhushan et al., 2008)*

particles are removed by screening. To obtain a lighter-coloured juice, the ground apple pulp is treated with ascorbic acid, prior to pressing, to minimize browning. If the final product is meant to be clear, the raw apple juice is treated with enzymes to remove the suspended solids by hydrolyzing pectin, hemicellulose, and other polymers and colloids that increase viscosity of the juice. If the juice is meant to be cloudy, this step is skipped. The enzyme treatment is either performed by the cold method (at 20°C for six to eight hours) or the hot method (at 54°C for one to two hours). The resulting juice then undergoes heat clarification to allow coagulation of particles, which can be easily filtered. Fining, another clarification process, introduces bentonite clay particles to absorb tannins and protein-tannin complexes. Finally, the juice is ready to be filtered from the large particles, certain proteins, and microorganisms. The last step, which is very important for the preservation of the juice, is pasteurization. This involves heating the juice to a temperature near the boiling point (above 88°C) to destroy all organisms that can develop (Vukušić et al., 2021). The process produces about 25% pomace (Sudha et al., 2016). Using this information, we can estimate that Canada produces about 17,960 tonnes of apple pomace annually. Quebec alone produces about 33, 819 tonnes of apples for processing, resulting in 5,895 tonnes of apple pomace (Institut de la statistique du Québec, 2020).

2.2.4 Bioactive compounds and nutritional qualities of apples

Apples are a rich source of monosaccharides, minerals, dietary fiber, and various biologically active compounds such as vitamin C, phenolic compounds, and antioxidants (Wu et al., 2007). They contain a variety of phytochemicals, particularly a large concentration of flavonoids which varies between cultivars and other growing factors (Boyer & Liu, 2004). The bioactive compounds most commonly found in apples are quercetin, catechin, phloridzin, and chlorogenic acid (Boyer & Liu, 2004). Generally, apple peels are rich in dietary fibers while seeds are rich in bioactive lipids and polyphenols (Iqbal et al., 2021). Apples have a higher soluble fiber fraction than cereal, which gives rise to the availability of pectin, a natural polymer that occurs as a structural material in all land-growing plants (Rolin & De Vries, 1990). Apples were found to have a soluble and insoluble dietary fiber contents of about 5.8 and 7.5 g/100 g dm (Englyst & Hudson, 1996). Pectin can act as a stabilizer, gelling and thickening agent, health-enhancing polymer, in addition to having health benefits such as the ability to lower cholesterol and delay gastric emptying (O'Shea et al., 2012).

Studies have shown that consumption of apple is associated with reduced lung cancer incidence, coronary and total mortality, symptoms of chronic obstructive pulmonary disease, and risk of thrombotic stroke (Wolfe & Liu, 2003). The majority of phenolic acids and fiber are present in the skin, more so than in the flesh (O'Shea et al., 2012).

2.2.5 Pomace

Pomace is the main byproduct of cider and juice processing and represents about 25% of the mass of fresh apples. It is generally comprised of 93-97% skin and flesh, 2-4% seeds and 1% stems (Lyu et al., 2020). It is composed mainly of carbohydrates, dietary fibers, small amounts of protein, fat, and ash (Sudha, Baskaran, & Leelavathi, 2007). Composition of apple pomace is highly dependent on many factors such as cultivar, geographic location, harvesting, time, manufacturing process, and extraction parameters (Lyu et al., 2020). It is a rich source of phytochemicals such as phenolic compounds and flavonoids (Soler, Soriano, & Mañes, 2009). Apple pomace consists of a well-balanced content of soluble and insoluble fibers, as well as a significant amount of starch and sugar that make it a perfect substrate for fermentation products

(L. Liu, You, Deng, Guo, & Meng, 2019). Almost 90% of total oil in apple pomace is composed of unsaturated fatty acids, mainly linoleic and oleic acids (Iqbal et al., 2021). The main phenolic compounds present in apple pomace are phenolic acids and flavonoids, with the latter being the majority (Reis, Rai, & Abu-Ghannam, 2012).

Phenolic compounds from apple pomace proved to have anti-inflammatory effects resulting from the inhibition of the expression of cyclooxygenase (COX)-2, an inflammatory enzyme (Iqbal et al., 2021). Alvarez et al. (2012) observed that acetone and methanol extracts from apple pomace inhibited Herpes simplex 1 and 2 (HSV-1, HSV-2) infection in Vero cells, when used at the start of the infection. The extract did not have any effects against virus replications; however, it inhibited the virus adsorption and entry to host cells. Consumption of apple pomace was found to counteract several glucose metabolism disorders and can aid in diabetes management (Kacey et al., 2014). Quercetin proved to have anti-diabetic properties at an early stage of type-2 diabetes by preventing damage of pancreatic β-cells (Iqbal et al., 2021).

2.3 Blueberries

2.3.1 Production and market status

Worldwide, 823,328 tonnes of blueberries were produced in 2019 (FAO, 2020a). In Canada, blueberries are the third most important crop in terms of production. About 148,444 tonnes were produced in 2020, down 10% from 2019. They are, however, the most important crop in terms of value, with a farm gate value of $274 million. Two types of blueberries are produced and processed in Canada: highbush (cultivated blueberries) and lowbush (wild blueberries). Quebec is the largest producer of lowbush blueberries (48%) followed by New Brunswick (18%). British Columbia accounts for 96% of highbush blueberries grown in Canada (Statistics Canada, 2021).

2.3.2 Structure, classification and proximate analysis

Commercial blueberries include highbush (*Vaccinium corymbosum* L., lowbush (*Vaccinium angustifolium Aiton*) and rabbiteye (*Vaccinium virgaturn Aiton,* (Girard Kristen, 2012). blueberries. Highbush blueberries are woody shrubs that may grow to over 10 ft high. They are sensitive to severe winter temperatures (-20°C or below). Lowbush blueberriesgrow about 1 ft high and can tolerate severe winter conditions. The latter has smaller fruits than highbush

blueberries. Rabbit eye blueberries grow in relatively warmer climates and can tolerate droughts (Girard Kristen, 2012). The fruit is soft on the inside and is covered by a hydrophobic cuticle and epicuticular wax (Michalska & Łysiak, 2015). Anthocyanins, which are present in high concentrations in the skin, are responsible for the blue-violet colour. Table 2.2 presents the proximate composition of the blueberry fruit.

Table 2.2: *Proximate composition of blueberry fruit (USDA,2020)*

Parameter	Value
Water	84.2
Protein	0.74
Total fat	0.33
Ash	0.24
Fiber	2.4
Carbohydrate by difference	14.5

2.3.3 Uses (food products, juices, other)

Due its short harvest period and poor postharvest storability, the majority of blueberries are processed into other food products such as juice, canned blueberries, dried, baked goods, and in sorbet (Kalt et al., 2003).

2.3.4 Bioactive compounds in blueberries

Blueberries are rich in fiber, minerals, vitamins, and antioxidants. They have a high content of polyphenols, anthocyanins, phenolic acids, flavanols, and tannins (Szajdek & Borowska, 2008). Blueberries were found to have a higher antioxidant activity than 34 common fruits and vegetables, with lowbush blueberries having the highest values (Cao, Sofic, & Prior, 1996; Prior et al., 1998; H. Wang, Cao, & Prior, 1996). Their exceptionally high antioxidant activity ranges between 13.9-45.9 mM TE/g of dry powder (C. Li et al., 2013). They contain a range of phenolic compounds including anthocyanins, quercetin, kaempferol, myricetin, chlorogenic acid and procyanidins (Hancock & Retamales, 2012). Anthocyanins are responsible for the blue colour of blueberries (Routray & Orsat, 2011). In highbush blueberries, up to 60% of the total phenolic

content is accounted for by anthocyanins (Kalt et al., 2003). Neto (2007) reported that wild (lowbush) blueberries have a higher flavonoid content than other species.

A blueberry-enriched diet had positive effect on chronic heart failure in rats (Ahmet et al., 2009). Studies have shown that consumption of blueberries has a positive effect on minimizing oxidative stress (Khanal, Howard, & Prior, 2009). Intake of its extract improved short term memory, balance, and coordination in aging rats (Joseph et al., 1999). Krikorian et al. (2010) investigated the effects of blueberry consumption in older adults with early memory loss. The results showed that after 12 weeks, their memory improved and there were trends suggesting reduced depressive symptoms and lower glucose levels. Consumption of blueberries was found to prevent excess gestational weight gain and reduce gestational diabetes in women with obesity (Basu et al., 2021). Consumption of blueberries was proved to have ophthalmo-protective, anti-cancer, antimicrobial, and osteoprotective properties (Patel, 2014).

2.3.5 Pomace

Blueberry pomace is the by-product of blueberry juice production. It is about 20% of the fresh fruit mass, is a rich source of phenolic compounds, and has a high antioxidant capacity (Šarić et al., 2016). The most valuable part of the fruit is the skin, which contains nearly all of the anthocyanins. The outer layer contains almost all of the polyphenolics present in the fruit, with a small amount found in the flesh and seeds (Michalska & Łysiak, 2015). The pomace is about 19% skin (Lee, Durst, & Wrolstad, 2002).

2.6 Cranberries

2.6.1 Production and market status

In 2019, 687,534 tonnes of cranberry were produced worldwide, with Canada being the second largest producer after the United States. About 162,234 tonnes were produced in Canada in 2020, making it the second most important fruit crop in terms of production volume. Over 90% of cranberries in Canada are produced in two provinces: Quebec (64.5%) and British Columbia (29%). Cranberries are considered the 4th most important fruit crop in terms of value, with a farm gate value of $154.9 million (Statistics Canada, 2021).

2.6.2 Structure, classification, and proximate analysis

Cranberry (*Vaccinium macrocarpon)*, also known as the American cranberry*,* is an evergreen plant with slender horizontal stems that produce pink flowers borne on upright shoots 5-15cm high (Small, 2013). The ripe fruit has an acidic and tart taste, deep red skin and a white flesh (Terry, 2011). The proximate composition of cranberry fruit is shown in Table 2.3.

Table 2.3: *Proximate composition of cranberry fruit (USDA, 2020)*

Parameter	**Amount (%)**
Water	87.3
Protein	0.46
Total fat	0.13
Ash	0.12
Fiber	3.6
Carbohydrate by difference	12

2.6.3 Uses

Cranberries are mainly used for three major purposes as shown in Figure 2.4. These include fresh, juice and beverages, and processed products such as sauce, concentrate, and sweetened dried cranberries (Tokusoglu & Hall III, 2011). Due to their tartness, about 95% of cranberries harvested are processed into sweetened juice cocktails, sauces, and other processed products while only 5% are sold fresh (Terry, 2011).

Cranberry juice, the major product obtained from cranberries, is extracted through several methods including pressing, mash depectinization, and counter current extraction (Girard Kristen (2012). The first method uses a mechanical press to extract the juice. This process produces high-quality juice with a yield of 75%, and a stable colour, since no heat is used to degrade the anthocyanins that are responsible for the bright red colour. The second method is through mash depectinization, a process which involves the addition of enzymes to the crushed cranberries which produces a mash that can be further extracted for juice production. This process has a high

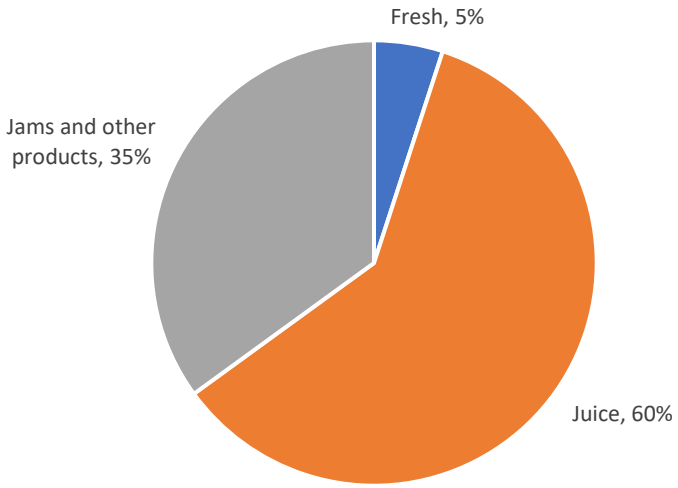

Figure 2.4: *Utilization of cranberries (Terry, 2011)*

yield of 100%, however heat degradation can affect the colour, flavour, and shelf life of the product. The last method is through counter current extraction using water and sliced fruit fed in a large screw press into opposite ends. This method produces a high-quality juice, with a yield of over 90%. Additionally, the remaining fruit pieces can be sweetened and dried to produce dried cranberries (Girard Kristen, 2012).

2.6.4 Bioactive compounds in cranberries

Cranberries are known to be rich in polyphenols (Vinson, 2008). The main bioactive compounds found in cranberries are anthocyanins, tannins (proanthocyanidins and ellagitannins), flavanols, flavonols, and phenolic acid derivatives (Côté et al., 2010). Wang and Stretch (2001) reported a total phenolic content of 141.2 mg GAE/ 100 g of fresh mass and an antioxidant capacity of 10.4 µmol TE/ g of fresh mass.

Administering cranberry extract to rats was found to reduce weight gain and visceral obesity, decreased triglyceride accumulation, and improved insulin sensitivity (Anhê et al., 2015). Consumption of cranberry extract in humans resulted in the reduction of bacterial adhesion to the cell walls in the urinary tract, preventing urinary tract infections (Liu, Black, Caron, & Camesano, 2006). Cranberry and cranberry juice consumption was also found to inhibit the

development of esophagus, stomach, colon, bladder, prostate, glioblastoma, and lymphoma cancers in humans (Weh, Clarke, & Kresty, 2016), to inhibit the growth of *Helicobacter pylori*, a type of bacteria that causes most ulcers (Zhang et al., 2005), with inflammatory effects similar to aspirin (Duthie et al., 2005).

2.6.5 Pomace

Cranberry pomace is the main by-product of the cranberry processing industry. It is mainly comprised of the pulp, skin, seeds, and stems after processing. It is rich in fibers but contains relatively small amounts of protein and carbohydrates (White, Howard, & Prior, 2010).

2.7 Environmental concerns with disposal

2.7.1 Canada's food loss and waste

According to the Food and Agriculture Organization (FAO, 2020b), food loss is defined as the discarded food from harvest up to, but not including the retail level. Food waste is the discarded food from retail and consumption levels. Food loss or waste does not include food that has been diverted to other applications, such as animal feed, or food that is unfit to eat. The total food loss and waste in Canada is estimated to be 35.54 million tonnes, or 58.1% of commodities entering the food system (Second Harvest, 2019). About 16.7 million tonnes of this waste, or 47%, is due to processing and manufacturing. This accounts for 56.5 million tonnes of CO_2 equivalent, or 56.6% of total CO_2 equivalent footprint (GHG emissions). The total waste accounts for 4.5 billion tonnes of surface and ground water use, or 57.6% of total water footprint associated with food production, manufacturing, and distribution (Second Harvest, 2019). It is important to note that 92% of the food industry's water footprint occurs on farm during primary production (Hoekstra & Mekonnen, 2012). If food wastage was represented as a country, it would be the third largest emitter of greenhouse gases, after China and the United States. Around 198 million hectares of cropland, 173 billion cubic meters of water and 28 million tonnes of fertilizer are exhausted annually to grow this lost and wasted food. Additionally, the amount of food wasted every year is enough to feed more than four times the 800 million people who suffer from hunger (Rajeh, Saoud, Kharroubi, Naalbandian, & Abiad, 2021).

The Sustainable Development Goal 12.3 aims at halving the per capita global food waste at the retail and consumer levels and reducing food loss along the production and supply chains by 2030 (UN, 2021). This goal, however, does not specify a reduction target specific for food loss.

2.7.2 Fruit waste

About 14% of food is lost globally after the post-harvest stage up to, but excluding, the retail stage (FAO, 2020b). This number varies across regions. For instance, North America and Europe have a Food Loss Index of 15.7%, which is second to Central and Southern Asia (FAO, 2020b). While a variety of fruits are produced in Canada, they can also be processed to juices and other fruit products in the country. Apple juice production alone produces about 18,000 tonnes of pomace annually in Canada (Bhushan et al., 2008; Statistics Canada, 2021; Sudha et al., 2007). Fruit processing waste is produced in large volumes with high water content and tends to quickly deteriorate.

2.7.3 Disposal

Fruit processing by-products are currently disposed of, at a cost to the producer, and usually discarded in landfills, used as animal feed or incinerated, which all have negative effects on the environment (O'Shea et al., 2012). Every tonne of food waste results in 4.5 tonnes of CO_2 emissions (Monspart-Sényi, 2012). This presents a major issue for disposal.

2.7.3.1 Direct Landfill

The most common method of disposal of fruit processing by-products is through direct disposal into landfills, which is discarding a material to a site and usually burying it with soil (Lyu et al., 2020). About 80% of pomace is discarded in a landfill or sent for composting (Gassara et al., 2011). This method of disposal results in harmful impacts by: 1) production of greenhouse gases; 2) being a secondary source of pollution, such as foul odors and contaminating underground water; 3) negative impact on human health from diseases being borne from that environment; and 4) losses incurred by industries regarding waste treatment and transportation to landfills (Dhillon et al., 2013). Fruit processing by-products are also typically low in pH (White et al., 2010). Their disposal would lower the pH of the landfill, which contributes to stronger odours (Sundberg et al., 2013).

Direct landfilling causes a great environmental concern, mainly due to its level of emissions (Matthews & Themelis, 2007). Fruit processing by-products have a high biological oxygen demand (BOD, amount of oxygen needed by microbes to break down organic matter) and chemical oxygen demand (COD, amount of oxygen needed to break down organic matter by oxidation). The high contents of organic matter, moisture, BOD and COD cause unwanted fermentation, microbial decomposition, ecological pollution, and severe health issues to human and aquatic life (Lyu et al., 2020). Apples, in particular, have a COD of 250 to 300 g O_2/kg (Shalini & Gupta, 2010). Organic matter's decomposition in landfills results in 38% of Canada's methane emission (Gassara et al., 2011). To reduce environmental problems, researchers suggest that waste disposal should be applied on the site of processing, which may require additional economic investments (Lyu et al., 2020).

Fruit based agro-industrial waste has a higher specific methane potential (SMP, amount of methane biogas released during anaerobic degradation) than that of agricultural crop residues (such as rice straw, maize straw and coffee husk) but not higher than vegetable. Apple peels had an SMP of 0.407 m^3 CH_4 kg^{-1} volatile solid (VS_{added}), which is second to vegetable waste 0.420 m^3 CH_4 kg^{-1} volatile solid (Suhartini, Nurika, Paul, & Melville, 2020). Gassara et al. (2011) evaluated the impact of greenhouse gas emissions of apple pomace waste management in Quebec using five methods: landfill, composting, incineration, enzyme production by fermentation, and use as animal feed. When considering the life cycle analysis, disposal of apple pomace in landfills results in GHG releases greater than all other methods. Higher emissions during landfilling are due to the anaerobic digestion of apple pomace. Organic wastes are decomposed by microorganisms in the absence of oxygen, causing the production of a gas which is primarily composed of methane, as well as carbon dioxide. Methane has a warming potential 21 times that of carbon dioxide (Gassara, 2011). Biowastes are the main contributors for odor emission in landfills. Food wastes generally release NH_3 and H_2S, while fruit waste mainly contributes NH_3 (Lou, Wang, Zhao, & Huang, 2015).

2.7.3.2Composting

Composting is another method used for the disposal of organic waste. This process includes the decomposition of complex organic material in the presence of microorganisms and oxygen under

appropriate environmental conditions, producing stable organic compounds, inorganic mineral substances and heat (Stanley & Turner, 2010). Temperatures can reach 50-70°C, depending on the technological factors applied. As a result, pathogenic microorganisms present in the waste are destroyed. A soil-like material with 40-50% moisture content is formed from this process, which can be used as fertilizer and soil conditioner in agriculture (Monspart-Sényi, 2012). Although the process is meant to occur under aerobic conditions, uneven oxygen supply between particles can result in anaerobic conditions, resulting in the release of volatile, harmful gases and adverse odors. To ensure that microorganisms have access to enough oxygen, permanent or periodic aeration is necessary. Moisture distribution also plays an important factor in composting; thus, homogenization of waste is recommended. Aeration, and consequently speed of composting, is influenced by particle size of waste materials. The ideal particle size is 25-40mm, as too small a particle size results in anaerobic conditions due to solidification. Thus, the waste material may need to be ground and chopped to achieve the optimal particle size along with mixing for proper aeration.

2.7.3.3 Animal feed

Converting the fruit pomace to animal feed may require little to no further processing. Compared to disposal in landfill, composting and incineration, utilizing fruit pomace as animal feed produces the least GHG (Gassara et al., 2011). In Quebec, 20% of solid waste from fruits is used as animal feed (Gassara et al., 2011).

There are three major methods to treat food waste as animal feed: wet-based, dry-based, and fermenting/ensiling (Rajeh et al., 2021). The wet-based method involves heating the feed with high moisture content (70-80%). Its major advantage is that it requires minimum processing; however, the feed ends up having a limited shelf life if not refrigerated and it is expensive to transport. Dry-based methods involve the drying of the food wastes to a moisture content of less than 20%. Dry feeds have a longer shelf life and a smaller bulk volume compared to wet feeds due to their lower moisture content. This makes them easier to transport and store, as well as making it less costly. Finally, treatment through ensiling, involves the addition of microbial or yeast agents (after heating/ sterilizing) to stabilize the feed and prolong shelf life. Apple, pomegranate, and carrot pomaces met the nutrition's growth and lactation requirements for

ruminants and could potentially substitute barley grain in their diets. Yeganehpour et al. (2021) reported that due to ruminal microorganisms, ruminants are able to utilize biomass that is unusable to humans and convert it to energy and amino acids by converting non-protein nitrogen into microbial protein.

Using fruit pomace as animal feed reduces food wastage and provides means to meet growing food demands. For example, it is estimated that the increasing demand for meat and milk is expected to reach 465 million tons and 1,043 million tons, respectively (Rajeh et al., 2021). Use of fruit pomace as feed for livestock would cut the cost of crop production and reduce the large accumulation of waste that poses a risk to the environment (Yeganehpour et al., 2021).

However, there are limitations to using fruit pomace as animal feed. The pomace must be characterized by batch to determine nutrient availability and to make any necessary modifications to ensure it meets the dietary requirements of the livestock. For example, apple pomace is not considered a high-quality feed due to its poor protein content (Kammerer, 2014). Collection and transportation of pomace to farms is another issue due to its high moisture content, which makes it bulky and highly susceptible to microbial decomposition (Rajeh et al., 2021).

2.7.3.4 Incineration

Incineration involves burning to release energy, which results in pomace being transformed to ash and gas. According to (Gassara et al., 2011), total GHG emissions of incinerating 16,209 tonnes of apples pomace (in Quebec) results in a net value of 1,122.1 tonnes of CO_2 per year, which takes into consideration the CO_2 that was recycled during energy recovery as well as CO_2 released during transportation. Incineration of pomace may not be efficient due to its high moisture content (Banerjee et al., 2017).

2.8 Applications

Due to the excessive volumes of fruit waste biomass produced, its high affinity for microbial decomposition, and contribution to GHG emissions, the need for alternative ways to recover this by-product is apparent. It is recommended to deal with the by-product at the processing plant itself in a closed cycle design preventing contamination, with the use of waste-free or low waste

technologies, which are designed to use low amounts of water and air (Monspart-Sényi, 2012). Some methods involved in the utilization of fruit processing by-product include pectin production (Adetunji, Adekunle, Orsat, & Raghavan, 2017; Grassino et al., 2018), extraction of nutraceuticals, enzymes and biopolymers (Alexandri et al., 2021; Babbar, Oberoi, & Sandhu, 2015), use in edible films or coating (Dilucia, Lacivita, Conte, & Del Nobile, 2020), biofuel (Shehu, Akanbi, Wyatt, & Aryee, 2019), and production of fermentable products (Koutinas et al., 2014).

2.8.1 Food Ingredient

A promising alternative to discarding fruit processing by-product is to utilize it as a food ingredient. Fruit pomace can be considered as a functional food, which is a food or ingredient that can provide health benefits beyond their nutrition (Reis, Rai, & Abu-Ghannam, 2014). Due to the presence of bioactive compounds and dietary fiber, fruit pomace can enhance the nutritional value, flavour, and colour of the processed food it is added to. It is preferable to promote direct reuse practices instead of recovery using new processes and materials that may result in more harm to the environment. For instance, using solvents in extraction processes may be harmful to the environment (Mirabella, Castellani, & Sala, 2014). Inclusion of fruit processing by-products as a food ingredient in food products could dramatically increase their nutrition and perhaps the health of the consumer, while adding value to the biomass residue and reducing GHG emissions.

The conversion of fruit processing by-product into a powder is advantageous because the drying process prolongs its shelf-life by reducing its water content and activity, which prevents its degradation (Jiang, Zhang, & Adhikari, 2013). It presents other advantages such as reduced volume and weight, convenience for packaging, handling and transportation, versatility of applications, improved bioaccessibility, and greater nutritional value (Barbosa-Cánovas, Ortega-Rivas, Juliano, & Yan, 2005).

The incorporation of dietary fiber-rich fruit processing by-products in foods such as bakery items, dairy, jams, meats, and soups can improve viscosity, texture, sensory characteristics, and shelf life (Elleuch et al., 2011). Dietary fibers have a range of technological characteristics that allow to modify textural properties, avoid syneresis (separation of a liquid from a gel due to contraction),

stabilize high fat foods and emulsions, and improve shelf life. They can serve as non-caloric bulking agents (by partially replacing flour, fat and/or sugar), enhance water and oil retention, and improve emulsion and oxidative stability. However, in high amounts, fruit processing by-products may cause undesirable colour or texture changes in food (Elleuch et al., 2011).

Studies have shown that use of dietary fibers in dairy products produces positive results. The incorporation of inulin, a fiber found in plants, was found to improve the body and mouthfeel of cheese analogues or ice cream and reduce syneresis in yoghurt and other fermented milk products (Blecker et al., 2001). The use of fibers in ice cream improved its texture by providing a uniformly smooth bulk with a desirable resistance to melting. It improved handling properties by hindering crystal growth due to temperature fluctuations during storage (Regand & Goff, 2003). Another study showed that the use of dietary fibers, particularly from oat, wheat, apple, and inulin, controlled crystallization and recrystallization in frozen dairy products (Soukoulis, Lebesi, & Tzia, 2009).

Fruit fibers have been used as a substitute for pectin in jams. The use of peach dietary fiber as a replacement for pectin in strawberry jam resulted in satisfactory sensory evaluations. The study proved that the higher the dietary fiber content, the higher the viscosity (Grigelmo-Miguel & MartíN-Belloso, 1999). Using apple pomace powder to replace up to 40% of pectin in jams did not change their rheological properties, increased the nutritional value due to the high antioxidant content, and showed good storage stability. In addition, it increased the marketing value of the jam due to less additives being used while decreasing the apple pomace waste that is usually discarded in landfills (Szabó-Nótin, Juhász, Barta, & Stéger-Máté, 2014).

The addition of apple pomace powder can improve the quality of the food it is incorporated in. Cookies that had 15-20% apple pomace powder were about 44-59% softer, 30% chewier, and 14% more moist than those of the control (Jung, Cavender, & Zhao, 2015). Meat products that contained apple pomace powder had a significantly higher dietary fiber content and radical scavenging activity than that of the control (Jung et al., 2015). The addition of apple pomace powder in extruded snacks and baked scones was found to increase the fiber content, phenolic content, antioxidant capacity via DPPH radical scavenging activity and ferric reducing antioxidant

power (FRAP), compared to products without apple pomace(Reis et al., 2014). The study found that there was a loss in phenolic compounds during heat treatment, however the DPPH radical scavenging activity was not affected. Sudha et al. (2016) incorporated apple pomace powder into buns and cookies to identify the phytochemicals present and evaluate their bioactivity such as free radical scavenging and cyto/DNA protectivity. The results showed that the addition of apple pomace powder decreased the volume and enhanced the firmness of the buns and muffins.The products exhibited better free radical scavenging and cyto/DNA protective properties which suggested that the bioactivity of apple pomace powder was retained after baking. Rocha Parra, Sahagún, Ribotta, Ferrero, and Gómez (2019) found that incorporating apple pomace powder (APP) in sugar-snap cookies resulted in higher global acceptability scores than the control, mainly better taste. The study also found that use of a larger particle size APP rendered cookies that were less hard with a higher spread ratio than cookies with a smaller particle size APP, which are desirable attributes. Blueberry and raspberry pomace powders used in the formulation of gluten-free cookies improved their nutritional quality. The cookies had a higher phenolic content, dietary fibers and minerals, reduction in fat and improved fatty acid composition. This was of particular importance as gluten free products tend to be higher in fats and calories to ensure sensory and textural properties (Šarić et al., 2016).

It is quite apparent that the incorporation of apple, blueberry, and cranberry pomace powders in food products results in better nutritional quality and sensory evaluations. The closed cycle design also ensures that the entire fruit processing by-product is being valorized.

2.9 Fruit Powder Preparation

Fruit processing by-product has a high moisture content, on average up to 50%, which makes it susceptible to microbial spoilage. To obtain a fruit powder pomace with a high quantity of bioactive compounds, appropriate processing such as optimum drying, milling, and conditioning is necessary (Iqbal et al., 2021).

2.9.1 Grinding

Grinding is an energy intensive process in which a hard material is broken down. There are many methods of reducing the particle size of foods. These include grinding, milling, crushing,

granulation, pulverization, and mixing (Gao, Chen, Wang, & Meng, 2020). These processes can involve one or more compressive, impact, attrition, or cutting forces. Selection of the suitable method depends on the size distribution of the feed and products, hardness and mechanical structure of the feed, moisture content, and temperature sensitivity of the feed (Barbosa-Cánovas et al., 2005). Fruits and their pomace have fibrous structures that present great plasticity, and can deform before reaching a breaking point when subject to impact or compression forces (Baudelaire, 2013). Additionally, the pomace is not homogenous and may have larger pieces of flesh, seeds, or stems present. Thus, cutting or shearing would be more suitable.

It is also important to control the temperature during the grinding process since fruit materials are heat sensitive and are susceptible to thermal degradation (Jiang et al., 2013). Djantou, Mbofung, Scher, Phambu, and Morael (2011) reported that dried mangoes that were ground for more than 35s exhibited a change of structure. The temperature of the grinder used in that study was found to reach 110°C after 35s of grinding, which resulted in increased molecular mobility, superficial plasticization of mango granules, creation of liquid bonds between granules and their aggregation due to contact forces generated by the grinder. The study showed that alternate drying and grinding improved the grinding behaviour due to the change in the structure of the mango. The initial amorphous structure of the granules was changed to a crystalline structure, which resulted in a crispy material with better grinding behaviour.

Moisture content of the feed material plays an important role in influencing powder and process properties such as particle size distribution, shapes of particles, flowability, energy, product yield and grinding loss (H. Jung, Lee, & Yoon, 2018). Materials with a higher moisture content resulted in powders with larger average particle sizes and higher energy consumption compared to materials with lower moisture content. This is due to the water acting as a plasticizer, making it more difficult to grind the material (Moon & Yoon, 2018). Djantou, Mbofung, Scher, and Desobry (2007) reported that mangoes which had a lower moisture content resulted in lower energy consumption during the grinding process and volume surface mean diameter, and therefore, improved the grinding behaviour. The same was reported for wheat (Doblado-Maldonado,

Flores, & Rose, 2013), maize (Velu, Nagender, Prabhakara Rao, & Rao, 2006), and balloon flower (Moon & Yoon, 2018).

Wet grinding is a method that requires the material to have a high moisture content. Generally, this method results in higher quality powders. Several studies reported highest whiteness and lowest damaged starch content in rice powder prepared using wet grinding (Asmeda, Noorlaila, & Norziah, 2015; Leewatchararongjaroen & Anuntagool, 2016; Tong et al., 2015). The efficiency of dry grinding depends on the mechanical strength of the material, with harder (or dryer) materials being more efficient. Moisture content has a different effect on wet grinding. In the case of soybean grinding, soaking the grains in water resulted in softer tissue with decreased resistance to rupture forces (Pan & Tangratanavalee, 2003). This results in increased grinding efficiency. However, this process can be very costly and may result in chemical and physical property changes (Ngamnikom & Songsermpong, 2011).

Micronization of fruit processing by-product enhances phenolic compound extraction, improves antioxidant activity and modifies the fiber content by increasing the soluble dietary fiber fraction (Bender et al., 2020). Mechanical damage induced by grinding reduces the total fiber content of fruit pomace powder, while increasing the soluble dietary fiber. This is the result of the breakdown of long polysaccharide chains into shorter molecules, which in turn affects water and oil interaction properties. Studies showed that a finer powder had a lower wettability, swelling capacity, water holding and water retention capacity (Bender et al., 2020; Calabuig Jiménez, Barrera Puigdollers, Seguí Gil, & Betoret Valls, 2018).

Micronization of fruit pomace was also found to produce emulsifying properties (Iqbal et al., 2021). Wet-milled apple pomace of 550nm particle size demonstrated a 99.19% emulsifying capacity in a rapeseed water-in-oil pickering emulsion at a concentration of 3.2% (m/v). Boudria, Hammoui, Adjeroud, Djerrada, and Madani (2018) reported the use of high-shear wet milling and high-energy ball milling to produce an emulsifier from olive pomace. It was reported that the high-shear wet milling system increases antioxidant activity by shearing bound polyphenols.

Thus, the efficiency of the grinding process is higher for materials with a low moisture content due to their brittle nature at that state. Materials with a higher moisture content have increased

plasticity or ductility, which increases the energy consumption during grinding (H. Jung et al., 2018). Additionally, knife mills are considered a low-energy equipment ideal for fruit and vegetable processing due to their fibrous nature (Kaur, Orsat, & Singh, 2021).

2.9.2 Drying

Drying is the main and most expensive step in producing powders and dried dietary fibers. Drying improves shelf life without addition of preservatives, while reducing the weight and volume of package, as well as transport costs (Larrauri, 1999). However, it can affect the quality and cause physical and biochemical changes in the food (Ratti, 2001). Generally, a severe heat treatment breaks down the cell membrane and releases cell contents. However, studies have shown that thermal processing of foods, especially fruits and vegetables, increases their biological activity due to the chemical changes occurring during heat treatment (Henríquez et al., 2010). One of the main causes of degradation of fruit powders' quality during drying and storage is browning (Jiang et al., 2013). Enzymes in the fruit must be adequately inactivated during pretreatments to prevent oxidation reactions. During storage, the browning reaction depends on moisture and product temperature. To sustain its quality and storage ability, the fruit processing by-product must be dried to a moisture content less than 20% and preferably close to 10% (Jung et al., 2015). The cohesiveness of the powder is an important property since it determines its ability to flow, which is vital for handling. It is associated with the moisture content because of the inter-particle liquid bridges that cause agglomeration (Jung et al., 2015).

Optimal temperatures for drying fruits are reported to be between 40°C – 80°C, since antioxidant activity and phenolic content are less temperature sensitive in that range (Sablani et al., 2011). Sablani et al. (2011) also reported that temperatures above 70°C changed the colour of blueberries and raspberries. Regardless of drying method, Diez-Sánchez, Quiles, and Hernando (2021) reported that temperatures above 60°C negatively impact the phenolic content of berries. Drying temperature can affect the bioactive and hydration properties of foods. Vega-Gálvez et al. (2009) reported that a higher drying temperature reduced the water holding capacity of red pepper. Their antioxidant activity was also found to increase with increased drying temperatures. Colour deterioration, which is linked to antioxidant and vitamin content, is also affected by drying

temperatures. Higher temperatures were found to cause greater degradation of colour in strawberries compared to freeze-drying, which slightly increased their colour (Ratti, 2001).

There are many methods of drying and the selection of a particular method can depend on the cost, characteristics of the material to be dried, and quality of the final product (Tuyen, Nguyen, & Roach, 2011). Hot air drying is one of the most common drying methods due to its simplicity and low cost (Ratti, 2001). The process includes exposing the material to hot air. The heat is then transferred from the surface to the inside of the material which causes the moisture to evaporate. There are many methods of hot air drying such as tray/ cabinet drying, fluidized bed, and impingement drying (Michalska & Łysiak, 2015). To obtain products of optimal quality and cost, drying must occur fairly rapidly. Holdsworth (2007) listed four main factors that affect the rate and total time of drying: physical properties of the food (particle size and geometry); air flow in relation to its arrangement (crossflow, through-flow, tray load etc.); physical properties of air (velocity, temperature, humidity); and design characteristics of the drying equipment (co-current, countercurrent, crossflow, through-flow, pneumatic, etc. (Jayaraman, Das, & Contents, 2006).

Freeze drying involves sublimating water at low temperature and pressure. The main advantages are it retains the shape, colour, and chemical properties of the material (Barbosa-Cánovas et al., 2005). Freeze-dried foods generally have a higher rehydration ratio, typically 4-6 times higher than air-dried foods, which indicates good quality due to the ability of water to reenter the cells (Ratti, 2001). This makes them excellent for soups and ready-to-eat meals. Freeze-drying is known to retain the highest quality of foods however, it may not be suitable for low value-added materials, such as FPB, due to its high production cost, high energy consumption, and time-consuming procedure (Ma et al., 2021).

Spray drying involves the transformation of atomized liquid feed into a powder by passing it through a hot drying medium(Ramaswamy & Marcotte, 2005). The feed can be a suspension, solution, or paste. This drying method is typically used in the production of dairy products, coffee and tea extracts, and baby foods (Barbosa-Cánovas et al., 2005). Advantages of spray drying include producing a powder with constant specifications, a continuous operation, and can be

controlled automatically. However, spray dryers have high installation costs, low thermal efficiency, and solid materials cannot be dried (Barbosa-Cánovas et al., 2005). Spray drying of fruit juices, pulps, and pastes with the addition of additives is possible however special consideration must be taken in the design of the equipment and post-drying operations due to the hygroscopic and thermoplastic nature of the product (Jayaraman et al., 2006).

Microwave drying is where heat is generated inside the food material due to the interaction of its chemical constituents and radio frequency energy. . The use of microwave energy in drying can reduce drying times as a result of enhanced penetrating quality, selective absorption of radiation by liquid water, and capacity for easy control (Jayaraman et al., 2006). However, the high initial equipment cost and cost per unit energy limit its use for drying.

Drum drying is a technique used for a wide range of products such as liquid, slurry and puree. The material is applied as a thin, uniform layer to the outer surface of a slowly revolving hollow drum that is heated internally by steam (Jayaraman et al., 2006). It is one of the cheapest drying methods, has high drying rates and thermal efficiency, and is suitable for small and medium production runs (Barbosa-Cánovas et al., 2005). The main limitation is the use of high temperatures (Jayaraman et al., 2006). Due to the hygroscopic nature of certain materials, such as dry fruit sheets, it is necessary to over-dry under severe heating conditions to ease its removal. This results in a product with a lower quality. Additionally, the material to be dried must contain a relatively high fiber content, otherwise an additive (fiber) must be added to aid in sheet formation (Jayaraman et al., 2006).

Connecting Statement

Chapter 2 discussed some of the bioactive compounds found in fruit, specifically apples, blueberries, and cranberries. The chapter also mentioned their market status and main products produced in industry. Chapter 2 emphasized the amount of fruit processing by-products (FPB) in the industry as well as the main disposal techniques. The environmental impact associated with disposal was discussed. Direct disposal was found to be the main method of disposal, which contributes to a range of environmental issues. The conversion of FPB into a powder ingredient was suggested and discussed. Chapter 3 investigates a method of producing fruit powders by drying homogenized and un-homogenized pomace and subsequent grinding. The proximate composition, hydration and absorption properties were evaluated and compared.

3 Effect of Drying Temperature, Duration, and Homogenization of Pomace on the Physicochemical Properties of Apple, Blueberry, and Cranberry Powders

Abstract

The disposal of fruit processing by-product (FPB) is a great environmental concern. Alternative large-scale handling methods, such as valorization of FPB, must be applied. This study focused on the production of a powder ingredient from apple, blueberry, and cranberry pomaces by hot air convective drying and grinding. The influences of temperature (50 and 60°C), duration (24h and 48h), and homogenization (yes or no) prior to drying the pomace, on the proximate composition (including total dietary fiber, (TDF), hydration and oil absorption properties, and colour were established. The results showed that drying temperature and duration had no effect on protein, fat, ash, and oil absorption, however they affected the moisture content, TDF, and hydration properties of all three fruits. The optimum conditions were 60°C and 24h. Homogenization increased the TDF in blueberry and cranberry powders, while decreased it in apple powders. Homogenization generally reduced the hydration and oil absorption properties. Under these optimum conditions, apple, blueberry, and cranberry pomace powders had a TDF of 31.05, 24.12, and 40.77 g/ 100g dm, respectively.

3.1 Introduction

Fruit processing by-products (FPB) are a major disposal concern for the food industry. Annually, more than 0.5 billion tonnes are generated and typically disposed of in landfills (Banerjee et al., 2017). This method of disposal creates a considerable amount of greenhouse gases, harmful odors, and causes other adverse environmental effects (Dhillon et al., 2013).

Fruits are known to be a poor source of protein and fat (Kammerer, Kammerer, Valet, & Carle, 2014). However, they are rich in dietary fiber (Sagar et al., 2018). Dietary fiber is made up of carbohydrate polymers such as cellulose, hemicellulose, lignin and pectin, that provide structural integrity to the plant cell wall (Hussain, Jõudu, & Bhat, 2020). Dietary fibers are categorized into soluble (SDF) and insoluble (IDF) dietary fibers, depending on their water solubility (Quiles et al., 2018). Types of SDF include pectin (sugars from whole grains, fruits, etc.), gums (sugar monomers from beans, legumes, etc.), and mucilage (aquatic plants, flax, okra, aloe vera). Whereas IDF includes cellulose (long polymeric chain of glucose monomers obtained from fruits, vegetables, etc.), hemicellulose (complex sugars from cereal brans and grains), and lignin (aromatic alcohols from vegetables) (Hussain et al., 2020). Food products that contain mostly soluble fiber are known to lower blood lipid levels, whereas products with more insoluble fibers are usually linked to laxative properties (Elleuch et al., 2011). As such, having a balanced proportion is very beneficial. Apples contain a well-balanced proportion of soluble and insoluble dietary fiber fractions (Iqbal et al., 2021). The recommended intake of DF is 28 g/day and 36 g/day for women and men in the United States, however, less than half is consumed (Anderson et al., 2009).

FPB's are a valuable resource that can be valorized into a useful food ingredient. Depending on the fruit and processing method, fruit processing by-products can contain up to 80% moisture, making it highly susceptible to microbial degradation. It must be dried to extend its shelf life and reduce its bulk size (Larrauri, 1999). The selection of the drying method depends on the energy cost, change in nutritional profile, and intended purpose. Studies have shown that the optimal range for drying fruits is between 40 and 80°C because antioxidants and phenolic content are less heat sensitive in that region (Sablani et al., 2011). Drying temperature has effects on the chromatic parameters, non-enzymatic browning compounds (such as Maillard reaction products), and extractable color which contribute to discolouration during the process (Vega-

Gálvez et al., 2009). Hot air drying is one of the most common drying methods due to its simplicity and low cost (Ratti, 2001). It will be used to investigate the effect of temperature on pomace powder properties.

Grinding is an important step in creating fruit powders. There are many methods of reducing particle size in food. These processes can involve one or more compressive, impact, attrition, or cutting forces. Selection of the suitable method depends on the size distribution of the feed and products, hardness and mechanical structure of the feed, moisture content, and temperature sensitivity of the feed (Barbosa-Cánovas et al., 2005). Fruits, and their pomace, have fibrous structures, present great plasticity, and can deform before reaching a breaking point when subject to impact or compression forces (Baudelaire, 2013). FPB's are typically unhomogenized, containing seeds, skin, stems, as well as chunks of flesh. Since fruits are typically fibrous, a knife mill is optimal for an effective grinding process (Kaur et al., 2021).

Due to its nature of having both soluble and insoluble properties, dietary fibers have a range of technological attributes such as water binding, gelling, and structure building (Elleuch et al., 2011). This contributes to their hydration and oil absorption properties, which are important to consider since they provide information on how the powder would act in food formulations. The grinding method affects the hydration and oil absorption properties (Bender et al., 2020; Calabuig Jiménez et al., 2018). Materials that have a low water binding capacity may not hold water effectively, however materials that have a high water-binding capacity may result in food products that are brittle and dry, especially during storage (Farooq & Boye, 2011). Dietary fibers with high oil binding capacity stabilize high-fat food products and emulsions, improve palatability, extend shelf life, and improve flavor retention (Awuchi et al., 2019).

There are studies that reported some of the physicochemical properties of fruit powders and their use in certain processed foods (Bas-Bellver et al., 2020; Calabuig Jiménez et al., 2018; Carson, Collins, & Penfield, 1994; Ćetković et al., 2008; Gouw, Jung, & Zhao, 2017; Irigoytia, Irigoytia, Sosa, De Escalada Pla, & Genevois, 2022; Jurevičiūtė, Keršienė, Bašinskienė, Leskauskaitė, & Jasutienė, 2022; Reis et al., 2014; Ross, Delury, Fukumoto, & Diarra, 2020; Sudha et al., 2016; Tagliani, Perez, Curutchet, Arcia, & Cozzano, 2019; White et al., 2010). Table 3.1

Table 3.1: Literature values of proximate composition of apple, blueberry, and cranberry pomace (P), pomace powders (PP), and skin powder (SP)

Fruit	State	Moisture (%)	Protein (%)	Fat (%)	Ash (%)	TDF (%)	Carbo hydrate (%)	Water Holding Capacity (g/g)	Water Binding Capacity (g/g)	Oil Binding Capacity (g/g)	Reference
Apple	P	74.9 – 80.1	-	-			-	-	-	-	(Ćetković et al., 2008)
Apple	PP	1.2 – 1.5	1.9 – 2.5	1.0 – 1.1	5.5 – 6.2	35.5 – 41.4	-	-	-	-	(Carson et al., 1994)
Apple	PP	1.2 ± 0.1	2.5 ± 0.1	1.1 ± 0.1	6.2 ± 0.1	38.4	-	-	-	-	(Carson et al., 1994)
Apple	PP	1.3 ± 0.1	2.2 ± 0.1	1.1 ± 0.1	4.8 ± 0.1	30.3	-	-	-	-	(Carson et al., 1994)
Apple	PP	-	-	-	-	31.63	-	9.27	6.51	1.48	(Gouw et al., 2017)
Apple	PP	-	-	-	-	26.8	-	-	-	-	Sudha, 2016
Apple	SP	8 ± 0.4	3 ± 0.1	2 ± 0.1	1 ±0.2	42 ± 1.4	-	-	-	-	Reis, 2014
Blueberry	P	53.62	12.03	2.99	-	55.6	83.55	-	-	-	(Ross et al., 2020)
Blueberry	P	57.91	8.34	2.21	-	62	87.05	-	-	-	(Ross et al., 2020)
Blueberry	PP	3.67 ± 0.03	-	-	-	29.28	-	-	-	-	Bas-Bellever, 2020
Blueberry	PP	-	-	-	-	33.69 – 38.5	-	4.63-5.1	3.08-3.4	2.7-2.9	Calabuig Jiménez,2018
Blueberry	PP	-	-	-	-	49.92	-	8.29	3.71	1.96	Gouw, 2017
Blueberry	PP	-	5.3	0. 5	0.99	27.3	62	8.4	3.3	1.93	(Irigoytia et al., 2022)
Blueberry	PP	13	6.64	4.05	2.06	26.15	60.94	-	-	-	(Tagliani et al., 2019)
Cranberry	P	71.53	4.55	2.5	0.7	61.2	91.25	-	-	-	(Ross et al., 2020)
Cranberry	PP	4.25	2.2	12	1.1	71.2	8.4	-	-	-	(White et al., 2010)
Cranberry	PP	-	-	-	-	58.65	-	8.7	5.87	1.97	(Gouw et al., 2017)
Cranberry	PP	5.51	7.4	9.83	0.96	72.67	9.14	3.87	7.99	1.57	(Jurevičiūtė et al., 2022)

shows a summary of the proximate composition and oil and hydration properties of apple, blueberry, and cranberry pomace powders found in these studies. The powders were prepared under different conditions and cultivars which accounts for their variability. Most notably, the total dietary fiber of the three fruits varied from 26.15 to 72.67%, with cranberries generally having the highest values while blueberries had the lowest. The water holding capacity and water binding capacity of these powders ranged from 4.63 to 9.27 g/ g dm and 3.08 to 7.99 g/ g dm, respectively. The oil binding capacity ranged from 1.48 to 2.9 g/ g dm. The objective of this study was to produce powders from apple, blueberry, and cranberry pomace using hot air convective drying. The influences of temperature and duration in the drying oven on proximate composition (including TDF), hydration and oil absorption properties, and colour were studied. The effect of homogenization of the pulp prior to drying was also investigated.

3.1 Materials and Methods

3.1.1 Materials

All pomace samples were obtained by juice extraction of apples, blueberries, and cranberries. Mcintosh apples grown in Quebec were obtained from a local grocery store (Provigo, Montreal, QC, Canada). Frozen wild blueberries and cranberries (Compliment's brand, Stellarton, Nova Scotia) were obtained from a local grocery store (Super C, Montreal, QC, Canada). The apples were stored at 4°C until use. The cranberries and blueberries were stored at -18°C until use, at which point it was defrosted.

3.1.2 Preparation of dried pomace powder

Apples, blueberries, and cranberries were juiced using a juicer (Breville BJE430SIL, Australia). The pomace was collected and used for the study. Half of the pomace was homogenized using a knife mill (Retsch Grindomix GM 200, Germany) and the other half was used in the study as-is. The homogenized samples were ground for two 30 s intervals at 7,000 rpm and 10 s at 10,000 rpm. Both samples were dried in a forced convection oven (Blue M Stabil-Therm Oven OV-520C-2, USA) at two temperatures (50°C and 60°C) and for two different durations (24h and 48h). All dried samples were ground using the same knife mill for two 30s intervals at 7,000 rpm and 10 s

at 10,000 rpm. Unhomogenized pomace (also referred to as pomace), homogenized pomace (also referred to as ground pomace), and all powders were used for analysis.

3.1.3 Preparation of samples for protein analysis

The sample extracts were prepared using the method outlined in (Rupasinghe, Wang, Huber, & Pitts, 2007), with a slight modification. About 15 mL of methanol was added to 0.3 g of apple, blueberry, and cranberry pomace powders, respectively. The mixture was subjected to sonication in an ultrasonic bath (FS30 Fisher Scientific, USA) for 15 min x 3 times. An interval of 10 min between sonication cycles was done to ensure the temperature remains below 30°C during the extraction. The mixture was centrifuged (Sorval Legend X1R, Thermo Scientific, USA) at 3,000 g for 15 min and filtered through a 0.2µm chromafil filter. The extract was used for protein analysis.

3.1.4 Proximate Compositional Analysis

3.1.4.1 Moisture content

The moisture content was determined according to the AOAC method 925.10. About 2 g of powder was placed in an aluminum dish that was previously heated to 130°C, cooled and weighed. The dish with sample was placed in a convection oven at 130°C for 1 h. The dried samples were quickly placed in a desiccator, allowed to cool to room temperature and weighed again. The moisture content was found by the loss in mass and was done in duplicates.

$$Moisture\ Content\ (\%) = 100 - \left(\frac{Dried\ Sample\ Mass}{Initial\ Sample\ Mass} \times 100\right)$$

3.1.4.2 Protein

The protein content was found using the bicinchoninic acid (BCA) method (Casal, Vermaat, & Wiegman, 2000). All solutions were obtained from the Thermo-Fisher BCA assay kit. The working reagent was prepared by mixing 50 parts of BCA reagent A (a solution of sodium bicinchoninate, sodium bicarbonate, sodium tartrate, and sodium hydroxide in distilled water) and 1 part BCA reagent B (a solution of cupric sulfate pentahydrate in distilled water) until a clear green solution was formed. The reaction mixture, which consisted of 2 mL of working solution and 0.1 mL of sample extract, was allowed to incubate at 37°C for 30 min. After allowing the tubes to cool down to room temperature, the absorbance was measured at 562 nm using a UV spectrophotometer.

All extracts were analyzed in duplicate. The standard curve was prepared using bovine serum albumin (BSA, 25-2000 µg/mL).

3.1.4.3 Total dietary fiber

The total dietary fiber was measured using the AOAC method 991.43. Duplicate samples of 1.000 ± 0.005 g were weighed into 250 mL glass jars with lids. Two blank samples were performed in parallel with each run. MES-TRIS buffer solution (40mL, pH 8.2) was added to the jars, along with a magnetic stirrer bar. The contents of the jar were mixed with the magnetic stirrer to allow complete dispersal of the sample. While stirring at low speed, 50 µL of heat-stable α-amylase solution was added and the mixture was incubated in a shaking water bath (WS17 Shel Lab, USA) at 98-100°C for 30 min. The jars were then allowed to cool to 60°C, and 10 mL of distilled water was used to rinse the sides. The mixture was subsequently incubated with 100 µL protease solution at 60°C for 30 min. After removing the jars from the shaking water bath, 5 mL of 0.561 N HCl solution was dispensed in the sample and the pH was adjusted to 4.1-4.8 using 5% NaOH. While stirring on a magnetic stirrer, 200 µL amyloglucosidase solution was added and the mixture was incubated at 60°C for 30 min. The jars were then removed from the water bath and 225 mL of 95% EtOH, pre-heated to 60°C, was added. Samples were allowed to precipitate at room temperature for 60 min. The fritted crucibles were ashed, soaked in a 2% cleaning solution, rinsed with water, distilled water, and acetone, and allowed to air dry. Approximately 1.0 g of celite was added and both were dried at 130°C to constant weight. The crucible and celite were cooled in a desiccator, then weighed. To prepare the celite bed for filtration, 15 mL of 78% ethanol was passed through the crucible with suction. The precipitated enzyme digest was filtered through the crucible and the residue was washed successively with two 15 mL portions each of 78% ethanol, 95% ethanol, and acetone. The crucible containing the residue was dried overnight at 103°C in a forced convection oven, cooled in desiccator, then weighed. The residue weight was obtained by subtracting the weight of the dried crucible and celite. One residue was analyzed for protein using the BCA method (Casal et al., 2000). The second residue was analyzed for ash by incineration in a muffle furnace for 5 h at 525°C. The crucible was cooled in a desiccator and weighed. The TDF was calculated using equation 3.1:

$$TDF\ (\%) = \left(\frac{\left(\frac{R_1+R_2}{2}\right)-P-A-B}{\left(\frac{M_1+M_2}{2}\right)}\right) \times 100 \qquad (3.1)$$

Where R_1 and R_2 are residue weights for duplicates and test portions, P is protein weight, A is ash weight, M_1 and M are sample weights, and B is the blank weight (equation 3.2):

$$B = \frac{BR_1+BR_2}{2} - P_B - A_B \qquad (3.2)$$

3.1.4.4 Ash

Ash content was determined using the AOAC method 923.03. About 3-5g of dried sample was placed in a ceramic ashing dish that was ignited, cooled in a desiccator, and weighed. The dish was placed in a furnace (48000 Furnace, Barnstead Thermolyne, USA) at 550°C for 7h, cooled in a desiccator, and weighed again. Ash content was calculated by the difference of both measurements and was analyzed in duplicates (Equation 3.3).

$$Ash\ (\%) = \left(\frac{Incinerated\ Sample\ Mass}{Initial\ Dried\ Sample\ Mass}\right) \times 100 \qquad (3.3)$$

3.1.4.5 Fat

Fat content was evaluated using the method outlined in (Folch, Lees, & Sloane Stanley, 1957). A solution of 2:1 (v/v) of chloroform: methanol solution was prepared. A sample of 0.2 g of powder was added to 10 mL of this solution. The tubes were placed in a shaker for 20 min and vacuum filtered using a 125 mm Whatman filter paper. The filtered solution was placed in a clean tube and 2 mL of 0.3% NaCl aqueous solution was added. The tubes were vortexed for 1 min and subsequently centrifuged for 5 min at 2,000 rpm. The upper layer (methanol and NaCl) was removed, and the lower layer (chloroform and lipids) was transferred to a weighed aluminum dish. The dish was placed on a heating tray inside a fume hood to evaporate the solvent and subsequently placed in an oven at 100°C for 15 min. The aluminum dish was then weighed, and the fat content was calculated using difference between the empty dish and the dish with the residue. Fat content was analyzed in duplicates.

3.1.4.6 Carbohydrate

Total carbohydrates were calculated using equation 3.4:

$$Total\ Carbohydrate\ (\%) = 100 - (Protein + Fat + Moisture + Ash + Fiber) \quad (3.4)$$

3.1.5 Colour

The colour parameters were measured using a CR300 Chroma Meter (Minolta, Osaka, Japan). The device was initially calibrated on a standard white plate and three parameters were reported: L*, a* and b*. The parameter L* indicates brightness (0 = black, 100 = white)), a* is the chromacity on a green (-) to red (+) axis, and b* represents the chromacity on a yellow (+) to blue (-) axis. The hue angle (H°) and chroma (C) were calculated using the values of a* and b* in equations 3.5 and 3.6. The hue is an angle on a colour wheel of 360° where 0°, 90°, 180°, and 270° represent red-purple, yellow, bluish-green, and blue, respectively, and chroma is the intensity or purity of the hue (McGuire, 1992)

$$H° = tan^{-1}\left(\frac{b^*}{a^*}\right) \quad (3.5)$$

$$C = (a^{*2} + b^{*2})^{1/2} \quad (3.6)$$

3.1.6 Hydration and Oil Absorption Properties

Water holding capacity, represented as the grams of water retained per gram of sample when not subjected to stress, was determined by dispersing 3.25 g of powder in 65 mL of distilled water in a test tube and allowed to rest for 24h. The excess water was removed, and the swelled solid was weighed (AACC method 88-04, 2012). The retained water was calculated by the difference. Water binding capacity, consisting of the grams of water that remain bound to the sample after employing low-speed centrifugation, was determined by mixing 5 g of powder with 25 mL distilled water and centrifuged at 2,000g for 10 min (AACC method 56-30.01, 2012).

Oil absorption capacity OAC, representing the grams of oil bound per gram of sample on a dry basis, was evaluated using the method described by (Lin, Humbert, & Sosulski, 1974). A powder sample of 0.5 g and 3 mL of vegetable oil were mixed with a wire rod to ensure dispersal of powder and allowed to rest for 30 min. The samples were centrifuged at 3,200 g for 25 min. the supernatant was removed, and tubes were upturned on paper towel to drain the remaining oil. The residue was weighed (w_r) and the OAC was calculated using equation 3.7:

$$OAC\ (g/g) = \frac{w_r}{w_i} \qquad (3.7)$$

where w_i was the sample mass (g). Hydration properties and OAC were analyzed in duplicates.

3.1.7 Experimental Design and Statistical Analysis

A factorial experimental design was used with three independent variables (temperature, time, and homogenization) and two levels each. The WHC, WBC, OBC, and proximate analysis were performed in duplicate. All data was reported as mean and standard deviation of the replicates. The results were compared by analysis of variance (ANOVA) using SAS software. Significant differences ($p \leq 0.05$) between means were determined by Tukey's method.

3.2 Results & Discussion

3.2.1 Fresh fruit and pomace proximate composition

Figure 3.1 shows the apple, blueberry, and cranberry pomace, homogenized pomace, and powder. Proximate composition analysis of the fresh fruit, pomace, and ground pomace of apple, blueberry and cranberry are shown in Table 3.2. Moisture content of apple pomace was 84.60 ± 0.03% and fresh apple was 87.53 ± 0.05%. Blueberry pomace had a moisture content (MC) of 82.83 ± 0.24%, while the whole fruit had 83.97 ± 0.28%. Cranberry pomace had a moisture content of 86.74 ± 1.74% while the whole fruit had 88.37 ± 0.31% of moisture. No press was applied after juice extraction so little moisture reduction was observed. The values indicate that the juicer only removed about 3%, 1%, and 2% of moisture from the apples, blueberries, and cranberries, respectively.

The proximate analysis results showed that blueberries have the highest protein content of the three fruits, with values of the fresh fruit, pomace, and ground pomace ranging from 4.06 – 5.79%, while cranberries had the lowest protein content, ranging from 1.41 – 2.88%. However, cranberries had the highest TDF, which was 5.89%, while blueberries and apples had a TDF of 2.93% and 2.28%, respectively. Protein and fat values were different from those reported by the USDA (2020) which could be due to difference in cultivars.

The fat content of the whole apple, pomace and ground pomace was determined to be 0.50, 0.86, and 0.52%, respectively. The difference between all samples is likely due to non-

homogeneous sampling where some pomace samples may have contained more high fat components such as seeds or skin. Blueberry fruit had a significantly lower fat content (0.22%) than the pomace, and ground pomace, which were 0.94%, and 1.09%, respectively. The same was observed with the cranberry fruit, pomace, and ground pomace, which were 0.39%, 0.64%, and 0.95%, respectively. The higher fat in the processed pomace is likely caused by the effective cellular rupture which liberated more fat from the samples during their preparation and analysis (when compared to the fresh samples).

Figure 3.1 *Apple (top row), blueberry (middle row), and cranberry (bottom row) pomace (left column), homogenized pomace (middle column), and powder (right column).*

Table 3.2: *Proximate analysis of fresh, pomace, and ground pomace of apples, blueberries, cranberries*

Fruit	State	Moisture Content (%)	Protein (%)	Fat (%)	TDF (%)
Apple	Fresh	87.5 ± 0.1	2.38 ± 0.05	0.50 ± 0.07	2.28 ± 0.27
	Pomace	84.6 ± 0.0	2.19 ± 0.02	0.86 ± 0.10	-
	Ground Pomace	84.2 ± 0.5	2.23 ± 0.05	0.52 ± 0.10	-
Blueberry	Fresh	84.0 ± 0.3	5.79 ± 0.08	0.22 ± 0.10	2.93 ± 0.54
	Pomace	82.8 ± 0.2	3.73 ± 0.06	0.94 ± 0.08	-
	Ground Pomace	80.7 ± 0.1	4.76 ± 0.12	1.09 ± 0.01	-
Cranberry	Fresh	88.4 ± 0.3	1.37 ± 0.06	0.39 ± 0.07	5.89 ± 0.10
	Pomace	86.7 ± 1.7	2.36 ± 0.22	0.64 ± 0.07	-
	Ground Pomace	84.5 ± 1.9	2.66 ± 0.07	0.95 ± 0.002	-

3.2.2 Proximate analysis of processed pomace

Figure 3.2 illustrates the proximate composition analysis of the apple, blueberry, and cranberry pomace dried powders produced at temperatures of 50°C and 60°C for drying durations of 24h and 48h. The powders with the lowest moisture content were produced at 60°C and 48h for all fruits. At those conditions, apple pomace powders (APP), blueberry pomace powders (BPP), and cranberry pomace powders (CPP) had moisture contents of 4.97 ± 0.08%, 9.69 ± 0.12% and 6.65 ± 0.06%, respectively. The ground apple pomace powders (GAPP), ground blueberry pomace powders (GBPP), and ground cranberry pomace powders (GCPP) had moisture contents of 6.61 to 7.94%, 7.31 to 9.69%, and 6.16 to 7.44 %, respectively.

As expected, higher temperatures and longer durations reduced the moisture since the energy of water molecules increases with increase in temperature, causing evaporation to occur more quickly (Ross et al., 2020). Blueberry and cranberry pomace powders generally had a higher moisture content than the apple powders. Generally, grinding resulted in a slightly lower moisture. However, the decrease in moisture content was not very high and all non-homogenized samples had moisture contents below 10%, which was the target for microbiologically safe fruit powders (Jung et al., 2015). Therefore, homogenization is not a justified process for reducing the

moisture content since it consumes additional energy. Alternatively, it may affect the drying time- the time it takes to reach a constant dry mass. The APP, BPP, and CPP had protein contents that ranged from 3.17 – 3.81%, 4.72 – 5.71% and 2.11 – 2.47%, respectively. Blueberries have the highest protein content out of the three fruits, followed by apples and cranberries, respectively. Homogenization resulted in GAPP, GBPP, and GCPP having values that are not significantly different from the unhomogenized fruit samples. The results showed temperature, duration, and homogenization had no effect on the protein content in all powders.

The fat content of the APP, BPP and CPP ranged from 2.28 – 5.01%, 1.0 – 1.67% and 4.14 – 5.84%, respectively. Results showed that the CPP had the highest fat content of all three fruits, followed by APP and BPP, respectively. The values for all pomace powders were significantly higher than those of their respective fresh fruits. This is due to the relative higher concentration of seeds, stems, and skin in the pomace, which all have higher fat components (Morais et al., 2016). Generally, homogenization of the pomace prior to drying did not have any significant effect on fat content in GCPP, which ranged from 4.60 to 5.59%. However, a significant increase was observed in GBPP, which had values that varied from 3.25 to 3.70%. There was a slight decrease of fat content in GAPP, which ranged from 2.02 to 2.39%. Drying temperature and duration had no significant effect on the crude fat content in all powders.

The ash content in APP, BPP, and CPP ranged from 1.08 – 1.68%, 1.22 – 1.30% and 1.46 – 1.58%, respectively. Whereas the ash content for GAPP, GBPP, and GCPP varied from 1.49 to 1.56%, 0.98 to 1.28%, and 1.41 to 1.52%, respectively. Neither drying temperature, duration, nor homogenization had a significant effect on the ash content of the powders. The protein, fat, and ash content of the powders are all in agreement with literature values, which are summarized in table 3.1.

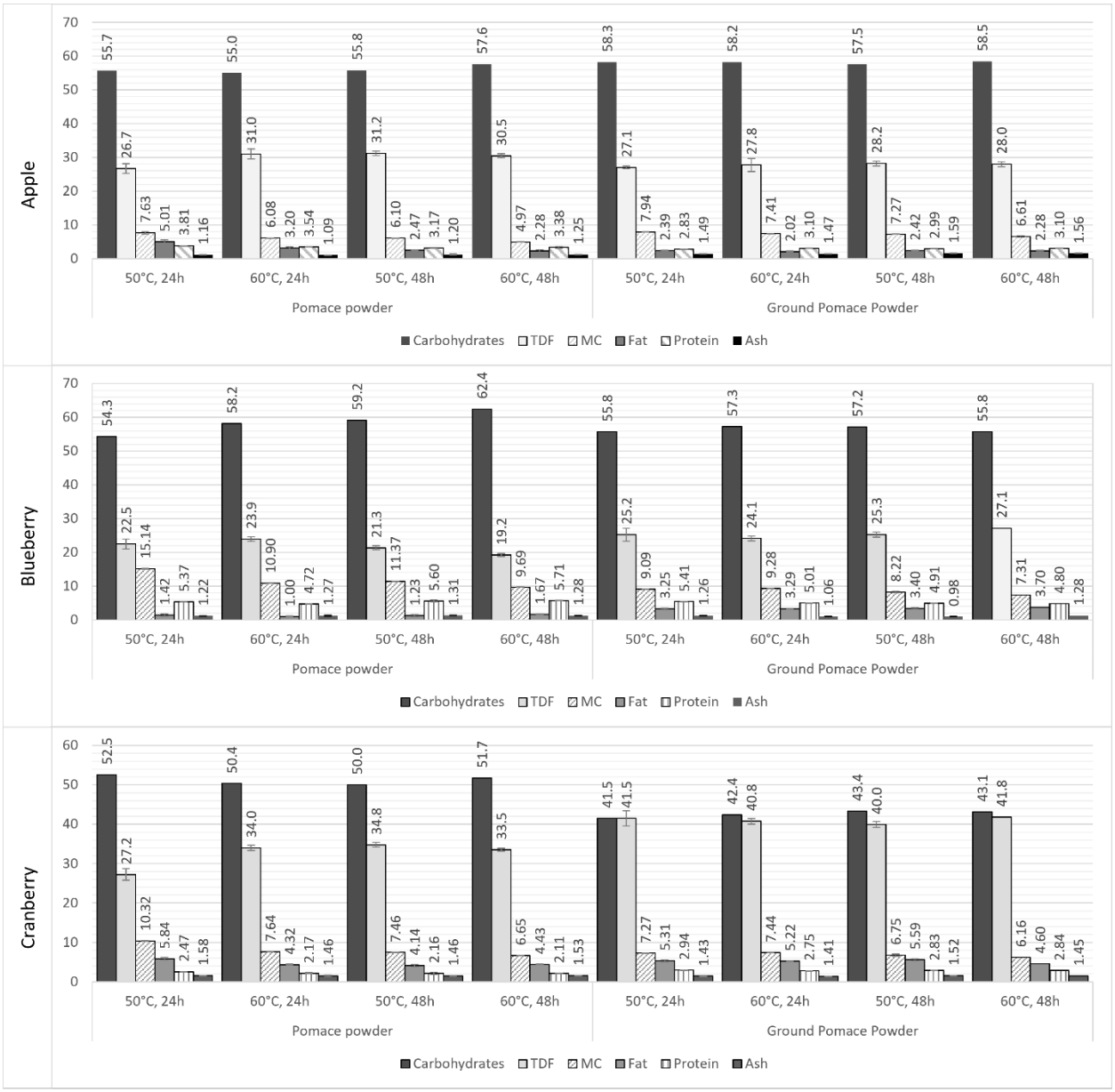

Figure 3.2: *Proximate analysis of apple, blueberry, and cranberry pomace powders produced under different conditions. Values are on a dry mass basis.*

3.2.3 Total Dietary Fiber

The TDF of APP, BPP, and CPP varied from 26.71% to 31.23%, 19.22% to 22.51%, and 27.25% to 34.78%, respectively. The results showed that there was an interaction effect ($p < 0.05$) between drying temperature and duration on all three powders. The TDF of GAPP, GBPP, and GCPP ranged from 27.75 to 28.21%, 25.23 to 27.13%, and 39.95 to 41.83%, respectively. Generally, homogenization of the pomace prior to drying showed a significant increase in TDF for GBPP and GCPP values compared to BPP and CPP, respectively. There was a significant decrease in TDF of GAPP compared to APP. There were no significant differences between the means of ground pomace powders produced at the respective conditions.

The blueberry and apple powder properties fall within the range reported in the literature. Cranberry powders, however, had significantly lower TDF than those reported in the literature. The difference may be attributed to variation in cultivar, maturity, or analytical procedures being used (Bas-Bellver et al., 2020). Several studies have found that homogenization, or reduction of particle size in general, can affect the TDF, including IDF and SDF components. Mullin and Wolynetz (1995) found that finer powders produced from sweet potato, hard red spring wheat, soft white winter wheat, and soft wheat bran had a lower TDF compared to coarser powders. Finer potato powderhad a greater TDF than the coarser powder. The wet homogenization of carrot using different methods (mechanical and enzymatic) was found to vary the TDF, as well as IDF and SDF (Pickardt, Dongowski, & Kunzek, 2004). Ahmed, Thomas, and Arfat (2019) also found that finer quinoa flour resulted in significantly higher TDF compared to coarser powders. The study looked at the influence of particle size on properties of the flour such as composition, physicochemical, functional, and rheological.

The change in total dietary fiber after homogenization may be the result of the redistribution of fiber components. Grinding causes damage to the matrix fiber, which in turn breaks the intermolecular bonds between the insoluble components, such as lignin and hemicellulose. This causes them to breakdown into a form of lower molecular-weight and fragments, resulting in more soluble forms of complex carbohydrates. Additionally, the degradation of components such as cellulose and lignin exposes phenolics which have been embedded in the fibrous plant matrix and may become more soluble (Bender et al., 2020; Nunes, Pimentel, Costa, Alves, & Oliveira,

2016). This is of importance since SDF is considered more significant than IDF in many health aspects such as regulating blood glucose level and lowering blood cholesterol levels (Galisteo, Duarte, & Zarzuelo, 2008). It is also considered challenging to convert IDF to SDF, thus grinding presents a useful modification method to produce high quality dietary fiber compared to conventional methods such as high-pressure homogenization, fermentation, enzymatic and extrusion cooking (Zhu, Huang, Peng, Qian, & Zhou, 2010).

The main sources of dietary fiber in western countries were reported to be cereals (50%), vegetables (30-40%), and fruits (16%) with the remaining 3% from other minor sources (Dhingra, Michael, Rajput, & Patil, 2012). The fruit powders produced in this study, which have a TDF ranging from 19.22 to 41.8%, all have a TDF higher than most grains, legumes and pulses, vegetables, fruits, nuts and seeds as reported by Dhingra et al. (2012). These include foods high in TDF such as barley, corn, wheat germ. soy, almonds, and flaxseed. The gluten-free nature of fruit pomace powders increases their potential as a fiber-rich food ingredient (Garcia, Milani, & Ries, 2020).

3.2.4 Colour

Table 3.3 presents the measured colour parameters for the apple, blueberry, and cranberry pomace powders. There was no significant difference in the hue amongst powders dried at 50°C and 60°C. Hue angles for APP ranged from 73.91 – 76.64°, indicative of a red-to-yellow (brownish) colour. Chroma ranged from 30.65 – 32.81°, which indicated a low intensity. Hue angles for BPP and CPP varied from 9.83 – 19.45, and 22.21 – 24.43°, respectively, which indicates a more red-purple colour. Chroma of BPP and CPP ranged from 11.95 - 15.77° and 43.15 – 46.44°, respectively, indicating a relatively high intensity for the CPP There were no observed differences in colour among apple and cranberry powders, however, there was a slight variation for the blueberry powders. Powders prepared at 60°C and 24h had a light purple colour while the powder prepared at 50°C and 24h was dark purple. The brown colour of the APP can be linked to the partial caramelization of apple sugars during drying as well as Maillard reactions occurring between proteins and sugars (Caparino et al., 2012). Typically, higher temperatures cause a degradation of colour, however our study showed that there was no effect of the higher

temperature on the colour. This can be attributed to the small difference between the temperatures in this study, which is only 10°C for a maximum temperature of only 60°C.

Table 3.1: *Colour parameters for apple, blueberry, and cranberry pomace powders*

Fruit	Conditions		L	a*	b*	H°	C
	Temperature (°C)	Time (h)					
Apple	50	24	63.23	8.64	29.95	73.91	31.17
	50	48	65.53	8.24	30.16	74.72	31.27
	60	24	63.3	8.13	31.79	75.65	32.81
	60	48	64.63	7.29	29.77	76.24	30.65
Blueberry	50	24	13.59	12.93	2.24	9.83	13.12
	50	48	17.62	11.27	3.98	19.45	11.95
	60	24	19.88	11.58	3.42	16.45	12.07
	60	48	18.54	15.26	3.96	14.55	15.77
Cranberry	50	24	35.95	42.28	19.21	24.43	46.44
	50	48	37.95	41.52	17.56	22.92	45.08
	60	24	33.85	40.43	16.73	22.48	43.75
	60	48	36.95	39.95	16.31	22.21	43.15

3.2.5 Hydration and oil absorption properties

Figure 3.4 presents the results obtained for water holding capacity (WHC), water binding capacity (WBC), and oil binding capacity (OBC) of apple, blueberry, and cranberry pomace powders. The WHC of the APP, BPP, and CPP ranged from 5.65- 6.11 g/g, 2.55- 3.83 g/g, and 6.87- 12.11 g/g, respectively. The WBC of the APP, BPP, and CPP ranged from 2.39-2.67%, 1.08-1.27%, and 3.62 to 5.49 g/g, respectively. The OBC of the APP, BPP, and CPP ranged from 0.95-1.12 g/g, 0.65 – 0.85 g/g, and 0.98 – 1.17 g/g, respectively. The results showed that neither temperature nor time had a significant effect on WHC or OBC, however, there was a combined effect of temperature and time on the WBC. Additionally, the CPP had the highest WHC and WBC, meanwhile BPP had the lowest.

Homogenizing the pomace prior to drying significantly reduced the WHC and OBC for all fruits but had no effect on the WBC of APP and CPP. There was a significant effect ($p < 0.05$) of homogenization on the WBC of BPP, which resulted in an increase. This trend suggests that overall, homogenization reduced the hydration and oil absorption properties of all the pomace

powders. When comparing all three fruits, cranberry powders generally had higher hydration and oil absorption properties, followed by apple and blueberry powders, respectively.

Hydration properties of dietary fiber mainly depend on the particle size, IDF/SDF ratio, extraction condition, and source (Cadden, 1987). The ability of dietary fiber to hold water is related to the porous matrix structures of the polysaccharide chains. Thus, the reduced hydration properties reported here can be explained by the reduction in particle size or alteration in the fiber matrix structure by damaging regions of potential water holding capacity. Having a large particle size results in larger intra-molecular spaces available for the holding of interstitial water, which is also beneficial to the health of colonic functions (Calabuig Jiménez et al., 2018; Kirwan, Smith, McConnell, Mitchell, & Eastwood, 1974). These results are consistent with other studies that reported lower hydration properties when particle size is decreased. Raghavendra, Rastogi, Raghavarao, and Tharanathan (2004) reported that a decrease of the particle size of coconut dietary fibers from 550 to 390 μm resulted in decreasing hydration properties due to the breakdown of the fiber matrix. This reduces the pores available for trapping water molecules. There are cases however where the hydration properties can also increase as a result of grinding, as was observed with the WBC of GBPP.

A possible explanation is that grinding can increase the surface area of particles to bond with water molecules (Elleuch et al., 2011). Raghavendra et al. (2004) also reported that decreasing the particle size of coconut dietary fibers from 1,127 μm to 550 μm had improved hydration properties. That was explained by oil being stuck within the fiber matrix of the larger molecules which restricted the entry of water molecules. Ultimately, hydration and oil absorption properties are dependent on both the particles' composition and structure (Raghavendra et al., 2004).

These results show that all powders have significantly greater hydration properties than wheat flour, which has a WHC of 1.53 g/g, a WBC of 1.94 g/g, and an OBC of 2.02 g/g (Rocha Parra et al., 2019). The same observation was noted with rice and cassava flour due to the greater fiber content in the fruit powders, which are rich in cellulose, hemicellulose, and pectin in the case of the apple powders (Rocha Parra, Ribotta, & Ferrero, 2015). Un-homogenized cranberry pomace

powder was found to have a higher WHC than oat bran, pea hull, citrus, and coconut residue powder, which all have a WHC less than 7 g/g (Raghavendra et al., 2004). These water and oil holding properties are of importance to the food industry since they provide information regarding the potential use of fruit powders as a food ingredient and thickening agent, with their associated health benefits (Irigoytia et al., 2022).

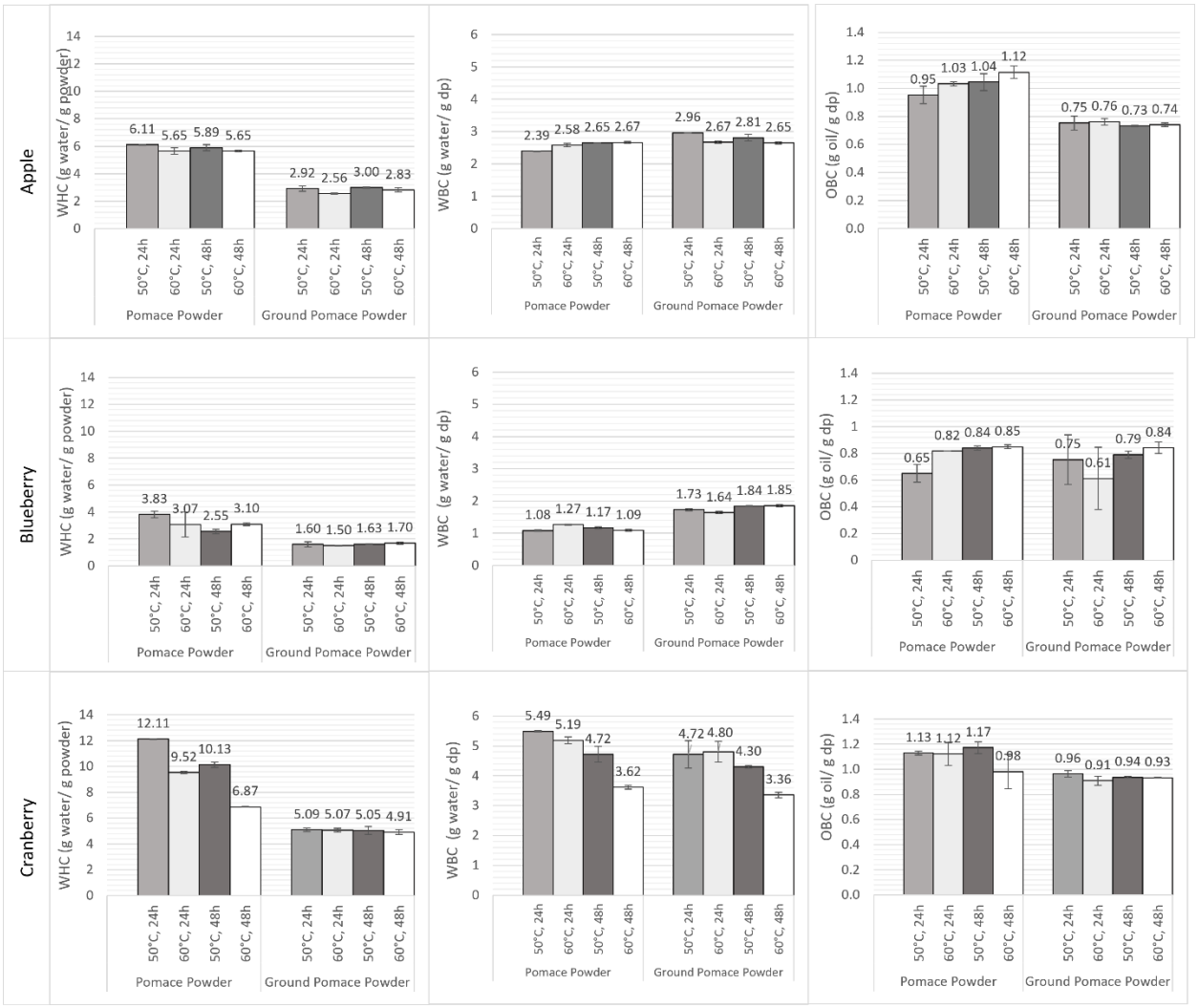

Figure 3.2: *Hydration and oil absorption properties of apple, blueberry, and cranberry pomace powders as a function of produced conditions*

3.3 Conclusion

Pomace powders produced from apples, blueberries, and cranberries had higher TDF, protein, and fat contents than their respective fresh fruits. This was due to the relative higher concentration of seeds, skin, and stems found in the powders. The temperature, duration, and homogenization of the pomace prior to drying had no effect on the protein, ash, and fat contents of the pomace powders. Temperature and duration had an effect on the moisture content and WBC. Homogenization increased the TDF in blueberry and cranberry powders, however, decreased it in apple powders. The increase in TDF was much higher in cranberry powders. Homogenization reduced the hydration and oil absorption properties in all powders, with the exception of the WBC of blueberry powders. Generally, powders produced at 60°C and 24h resulted in higher TDF.

Connecting Text

Chapter 3 discussed the physicochemical properties (proximate composition and hydration and oil absorption) of apple, blueberry, and cranberry pomace powders. The powders were found to have a high proportion of dietary fiber, good hydration and oil absorption properties, as well as vibrant colours.

To better understand the benefits of apple, blueberry, and cranberry pomace powders, their bioactive compound contents were investigated in Chapter 4. The same powders produced in Chapter 3 were used for the analysis of antioxidant activity (DPPH and FRAP), total phenolic content, and total flavonoid content.

4 Effect of Drying Temperature, Duration, and Homogenization on the Bioactive Properties of Apple, Blueberry, and Cranberry Pomace Powders

Abstract

Fruit processing by-products create a great concern for disposal due to their volume, negative environmental impact, and cost. However, fruit biomass is an excellent source of bioactive compounds and presents a great potential for valorization. This study focused on the production of fruit pomace powders, made from apples, blueberries, and cranberries, by hot air convective drying and grinding. The influence of drying temperature (50°C and 60°C), duration (24h and 48h), and homogenization (with or without) of the pomace prior to drying on antioxidant activity (AA; ferric reducing antioxidant power, FRAP, and 2,2-diphenyl-1-picrylhydrazyl, DPPH), total phenolic content (TPC), and total flavonoid content (TFC) was investigated. The results showed that a temperature of 60°C, duration of 24h and homogenization of the blueberry and cranberry pomace resulted in the highest AA, TPC, and TFC. Blueberries had an AA (FRAP), TPC and TFC value of 177 µM TE/g dm, 22.39 mg GAE/ g dm, and 22.4 mg CE/ g dm, respectively. While cranberries had an AA (FRAP), TPC and TFC value of 142.5 µM TE/g dm, 20.19 mg GAE/ g dm, and 20.2 mg CE/ g dm, respectively. Homogenized samples had significantly higher AA, TPC, and TFC than un-homogenized samples, thus suggesting that homogenization caused bound phenolics to be released. Contrary to blueberry and cranberry samples, un-homogenized apple pomace powders had a slightly higher AA (FRAP) and TPC than homogenized samples. Un-homogenized apple powders produced at 60°C and drying time of 24h had AA (FRAP), TPC and TFC values of 19.1 µM TE/g dm, 1.91 mg GAE/ g dm, and 3.38 mg CE/ g dm, respectively.

4.1 Introduction

Apples, blueberries, and cranberries are the most important and valuable fruits produced in Canada. In 2020, 44%. 18%, and 17% of the total fruit production (more than 800,000 tonnes) was attributed to the three fruits, respectively (Statistics Canada, 2021). Generally, fruits can be consumed fresh or processed into juices, jams and dried fruits which can increase their shelf-life. These processes can generate large amounts of by-products which create a disposal concern for the industry.

Fruit processing by-products are high in moisture and enzymes, making them highly susceptible to microbial and enzymatic deterioration (Iqbal et al., 2021). However, this biomass is rich in bioactive compounds making it a valuable material. Fruit pomace typically contains more bioactive compounds, per gram, than its whole fruit before juicing. For example, the press-cake residue of blueberries typically contains about 184 mg/ 100g of anthocyanins, while the whole fruit and pressed juice have respectively about 99.9 mg/ 100g and 33.6 mg/100g (Skrede, Wrolstad, & Durst, 2000). They contain other phenolic compounds such as quercetin, kaempferol, myricetin, chlorogenic acid and procyanidins (Hancock & Retamales, 2012). Apples are rich in flavonoids such as procyanidins, catechin, epicatechin, chlorogenic acid, phloridzin, and the quercetin conjugates (Bhushan et al., 2008). Cranberries are rich anthocyanins, tannins (proanthocyanidins and ellagitannins), flavanols, flavon-3-ols, and phenolic acid derivatives (Côté et al., 2010).

Consumption of these fruits have been linked to lower cardiovascular disease, obesity, diabetes, and reduced risk of some cancers (Xu et al., 2017). These benefits are linked to the presence of phenolic compounds which are widely distributed in fruits and vegetables and contribute to colour and flavour (Laura et al., 2019). Depending on the phenolic compounds present, they can have the following properties which contribute to their health benefits: antioxidant, antimicrobial, antiviral, anti-inflammatory, antidiabetic, antihypertensive, neuroprotective, cell detoxification, cholesterol synthesis, anticonvulsant, and the ability to lower blood pressure (Karasawa & Mohan, 2018).

While landfilling is the current main method of disposal (Lyu et al., 2020), other alternatives have been applied and/or considered. This includes the extraction of useful components such as pectin, dietary fiber, biopolymers, and pigments (Adetunji et al., 2017; Babbar et al., 2015; Koutinas et al., 2014; Shehu et al., 2019). Additionally, FPB has been used as biofuel, in the production of organic acids, enzymes, and ethanol (Bhushan et al., 2008). However, each method will still generate some waste. Converting the FPB into a powder ensures all the material is used (resulting in virtually no waste) and that the nutritional benefits are maximized.

The fruit powder can be produced by two major steps: drying and grinding. Drying is typically the most energy intensive step in fruit processing since fruits contain a high moisture content. It is a way to extend the shelf life of the FPB without preservatives and can reduce both the size of the package and transport costs (Larrauri, 1999). To ensure the fruit powder is microbially safe, the moisture content must be less than 10% (Jung et al., 2015). This means that high temperatures and/ or long drying times may be needed. Both temperature and duration can affect the antioxidant activity, phenolic content, and flavonoid content (Diez-Sánchez et al., 2021). There are many drying techniques used to produce food powders such as hot air drying, freeze drying, spray drying, and vacuum drying. The selection of a drying method depends on the energy cost, characteristics of the material to be dried, and quality of the final product. Hot air drying, which includes exposing the material to hot air, is known to be the simplest and cheapest option (Tyun, 2011). Studies have proved that antioxidant content, total phenolic content, and vitamin C content were shown to increase with drying temperature up to a point (Vega-Gálvez, 2009). Indeed, elevated temperatures, especially over 100°C, adversely affect these properties (Larrauri, 1999). The grinding step is important in formulating a powder which can be incorporated in food products. Due to the fibrous nature and plasticity of FPB, it has been reported that knife mills are suitable for size reduction (Baudelaire, 2013). Grinding can have an effect on the bioactive content in fruits since it can break down and re-distribute components such as dietary fibers into smaller molecules, including phenolic compounds (Bender et al., 2020).

Previous studies have reported the content of some bioactive compounds in fruit powders and their use in certain processed foods. Table 4.1 highlights the antioxidant activity (DPPH and FRAP), total phenolic content and total flavonoid content of apple, blueberry, and cranberry

powders. These values showed that blueberry powders generally had the highest antioxidant activity and total phenolic content, followed by cranberry and apple powders, respectively. The objective of this study was to produce powders from apple, blueberry, and cranberry pomaces using hot air convective drying. The influence of temperature and duration in the drying oven on antioxidant activity, total phenolic content, and total flavonoid content was observed. The effect of homogenization of the pulp prior to drying was also investigated.

4.2 Materials and Methods

4.2.1 Materials

All pomace samples were obtained by juice extraction of apples, blueberries, and cranberries. Mcintosh apples grown in Quebec were obtained from a local grocery store (Provigo, Montreal, QC, Canada). Frozen wild blueberries and cranberries (Compliment's brand, Stellarton, Nova Scotia) were obtained from a local grocery store (Super C, Montreal, QC, Canada). The apples were stored at 4°C until use. Frozen cranberries and blueberries were stored at -18°C until use, at which point it was defrosted.

4.2.2 Preparation of dried pomace powder

Apples, blueberries, and cranberries were juiced using a juicer (Breville BJE430SIL, Australia). The pomace was collected and used for the study. Half of the pomace was homogenized using a knife mill (Retsch Grindomix GM 200, Germany). The other half was used in the study as-is and referred to as the unhomogenized pomace. The homogenized samples were ground for two 30 s intervals at 7,000 rpm and 10 s at 10,000 rpm. Both samples were dried in a forced convection oven (Blue M Stabil-Therm Oven OV-520C-2, USA) at two temperatures (50°C and 60°C) and for two different durations (24h and 48h). All samples were ground using the same knife mill for two 30s intervals at 7,000 rpm and 10 s at 10,000 rpm. Unhomogenized pomace (also referred to as pomace), homogenized pomace (also referred to as ground pomace), and all powders were used for analysis.

Table 4.1: Literature values of DPPH, FRAP, TPC, and TFC of apple, blueberry, and cranberry pomace (P), pomace powders (PP), skin powder (SP), and fruit (F)

Fruit	State	DPPH (µM TE/ g)	FRAP (µM TE/ g)	TPC (mg GAE/ g dm)	TFC	Ref
Apple	PP	-	-	1.5 ± 0.14	3.92 ± 0.26 mg CE/g	(Sudha et al., 2016)
Apple	P	-	-	4.22 - 8.67 mg Clorogenic acid/g	0.45 - 1.19 mg rutin/g	(Ćetković et al., 2008)
Apple	SP	-	28.59 - 32.28	4.63 - 5.59	-	(Rupasinghe et al., 2007)
Blueberry	PP	270 ± 3.2	-	35 ± 2	18.3 ± 0.8 mg QE/g dm	Bas-Bellever, 2020
Blueberry	PP	-	-	285.15 ± 4.48	-	(Tagliani et al., 2019)
Blueberry	P	145.7 ± 0.6	-	0.44	-	(Calabuig Jiménez et al., 2018)
Blueberry	PP	100.8 - 101.1	-	3.02 - 3.36	-	(Calabuig Jiménez et al., 2018)
Blueberry	F	-	-	-	-	(Tobar-Bolaños, Casas-Forero, Orellana-Palma, & Petzold, 2021)
Blueberry	PP	-	117.74 - 126.10	18.35-19.97	-	(Ross et al., 2020)
Blueberry	PP	-	100.78 - 120.51	17.76 - 20.27	-	(Ross et al., 2020)
Blueberry	PP	-	-	1.62 ± 0.01	-	(Irigoytia et al., 2022)
Cranberry	PP	149.58 - 156.94	64.92 - 71.47	-	-	(Oszmiański, Kolniak-Ostek, Lachowicz, Gorzelany, & Matłok, 2015)
Cranberry	F	144.84 ± 3.64	63.68 ± 0.59	-	-	(Oszmiański et al., 2015)
Cranberry	PP	-	67.13 - 70.80	13.55 - 14.97	-	(Ross et al., 2020)
Cranberry	PP	-	-	3.89 ± 0.29	-	(Jurevičiūtė et al., 2022)

4.2.3 Preparation of samples for analysis

The sample extracts were prepared using the method outlined in (Rupasinghe et al., 2007), with a slight modification. About 15 mL of methanol was added to 0.3 g of apple, blueberry, and cranberry pomace powders, respectively. The mixture was subjected to sonication in an ultrasonic bath (FS30 Fisher Scientific, USA) for 15 min x 3 times. An interval of 10 min between sonication cycles was respected to ensure the temperature remains below 30°C during the extraction. The mixture was centrifuged (Sorval Legend X1R, Thermo Scientific, USA) at 3,000 g for 15 min and filtered through a 0.2µm chromafil filter. These samples were used for the determination of antioxidant activity (FRAP and DPPH), total phenolic content, and total flavonoid content.

4.2.4 Total antioxidant content

The ferric reducing antioxidant power (FRAP) was analyzed using the method outlined by (Benzie & Strain, 1996) and (Thaipong et al., 2006), with some slight modifications. Acetate buffer solution (330 mMol/L) with a pH of 3.6 was prepared by mixing 3.1 g of sodium acetate, 16 mL of acetic acid and making up the volume to 1 L with distilled water. The pH was adjusted with acetic acid, when necessary. The TPTZ solution (10 mMol/L) was made by adding 0.31 g of TPTZ to 100 mL of 40 mMol/L HCl. A third stock solution was prepared by adding 0.135 g of $FeCl_3 \bullet 6H_20$ to 25 mL distilled water to form a 20 mMol/L solution. The fresh working solution was prepared by mixing 150 mL acetate buffer, 15mL TPTZ solution and 15mL $FeCl_3 \bullet 6H_20$ solution (or a ratio of 10:1:1). The reagent was warmed to 37°C before use. Fruit extract (0.15 mL) was reacted with 2.85 mL of FRAP reagent for 30 minutes in the dark. The absorbance was measured at 593 nm using a spectrophotometer. Results were expressed in trolox equivalent (µMol TE/g dm) using a trolox standard curve (25-600 µMol/L). All extracts were diluted using methanol, since preliminary runs showed that the absorbance measurements were over the linear limit in the standard curve. Samples were analyzed in triplicates.

The DPPH assay was performed using the method outlined by Brand-Williams et al. (1995) and Thaipong et al. (2006), with some slight modifications. The stock solution was prepared by adding 24 mg of DPPH to 100 mL methanol. To prepare the working solution, 30 mL of stock solution

was added to 135 mL of methanol (or a ratio of 2:9). Fruit extract (0.15 mL) was reacted with 2.85 mL of DPPH working solution in a 15 mL centrifuge tube for 24 hours in the dark. The absorbance was measured at 515 nm using a spectrophotometer. All extracts were analyzed in triplicates. Results were expressed in trolox equivalent (µMol TE/g dry powder) using a trolox standard curve (25-600 µmol/L).

4.2.5 Total phenolic content

Total phenolic content (TPC) was analyzed using the method outlined by (Singleton & Rossi, 1965) and (Kähkönen et al., 1999), with minor modifications. Fruit extract (0.5 mL) was mixed with 2.5 mL of 1:10 diluted Folin–Ciocalteu's phenol reagent. To that, 2mL of 7.5% (w/v) aqueous sodium carbonate solution was added and mixed in a vortex mixer for 10 s to ensure proper mixing. The solution was left to stand in a water bath at 45°C in the dark for 15 min. The absorbance was measured at 765nm using a UV spectrophotometer. All extracts were analyzed in triplicates. Results were expressed in gallic acid equivalents (GAE, mg GA/ g dry powder) using a gallic acid standard curve (0-200mg/L).

4.2.6 Total flavonoid content

Total Flavonoid content (TFC) was determined using the method described by (Zhishen, Mengcheng, & Jianming, 1999), with some slight modifications. Fruit extract (250 µL) was mixed with 1.25 mL of distilled water and 75 µL of 5% $NaNO_2$. After 6 min, 150 µL of 10% $AlCl_3$ was added, allowed to react for 5 min and 0.5 mL of 1M NaOH was added. The total volume was made to 2.5 mL with distilled water, mixed thoroughly using a vortex mixer and the absorbance was determined at 510 nm using a spectrophotometer. All extracts were analyzed in triplicates. Results were expressed in catechin equivalent (mg CE/g dry powder) using a catechin standard curve (0.05-0.5 mg/mL).

4.2.7 Experimental design and statistical analysis

A factorial experimental design was used with three independent variables (drying temperature, drying time, and homogenization) at two levels each. The TPC, FRAP, DPPH, TFC, measurements were carried out in three independent extractions and performed in triplicate. All data was reported as mean and standard deviation of the replicates. The results were compared by

analysis of variance (ANOVA) using SAS software. Significant differences ($p \leq 0.05$) between means were determined by Tukey's method.

4.3 Results & Discussion

4.3.1 Antioxidant activity

The responses for the antioxidant activity (AA) obtained using the FRAP and DPPH assays for apple, blueberry, and cranberry in either whole fruit, pomace, and processed pomace powders under different processing conditions are shown in Figure 4.1. The FRAP and DPPH of the whole apple (5.41 and 10.7 µM TE/ g fm was significantly higher than that of the pomace (2.57 and 1.93µM TE/ g fm), respectively. The reverse was observed with cranberries. The FRAP and DPPH of the whole fruit was 15.4 and 17.3 µM TE/ g fm while the pomace had values of 22.4 and 26.6 µM TE/ g fm, respectively. The blueberry whole fruit, pomace and ground pomace had a FRAP and DPPH of 38.0 and 46.24 µM TE/ g dm, 30.7 and 33.3 µM TE/ g dm, and 36.5 and 33.27 µM TE/ g dm, respectively. There were no statistical differences in AA among homogenized and un-homogenized pomace, respectively.

The values for AA measured using the FRAP and DPPH assay for the APP, BPP and CPP ranged from 3.93 to 19.1 µM TE/ g dm, 99.2 to 168.8 µM TE/ g dm, and 99.2 to 168.8 µM TE/ g dm, respectively. Temperature had a significant effect on the FRAP of the APP, with the highest AA being observed at 60°C, regardless of drying time. There was an interaction effect of temperature and time on the BPP and CPP. The FRAP and DPPH values for the GAPP, GBPP, and GCPP varied from 9.49 to 26.6 µM TE/ g dm, 145.6 to 177.0 µM TE/ g dm, and 142.5 to 151.4 µM TE/ g dm, respectively. As shown, grinding the pomace prior to drying generally increased the antioxidant activity in blueberries and cranberries. However, the contrary was true for apples; homogenizing apple pomace prior to drying generally resulted in a lower AA. The results also showed that there was no statistical difference between the means of producing the ground pomace powders. The highest FRAP and DPPH for blueberries and cranberries were observed with pomace dried at 60°C for 24h with homogenization. Meanwhile for APP, 60°C and 24h were the optimum conditions, however without homogenization.

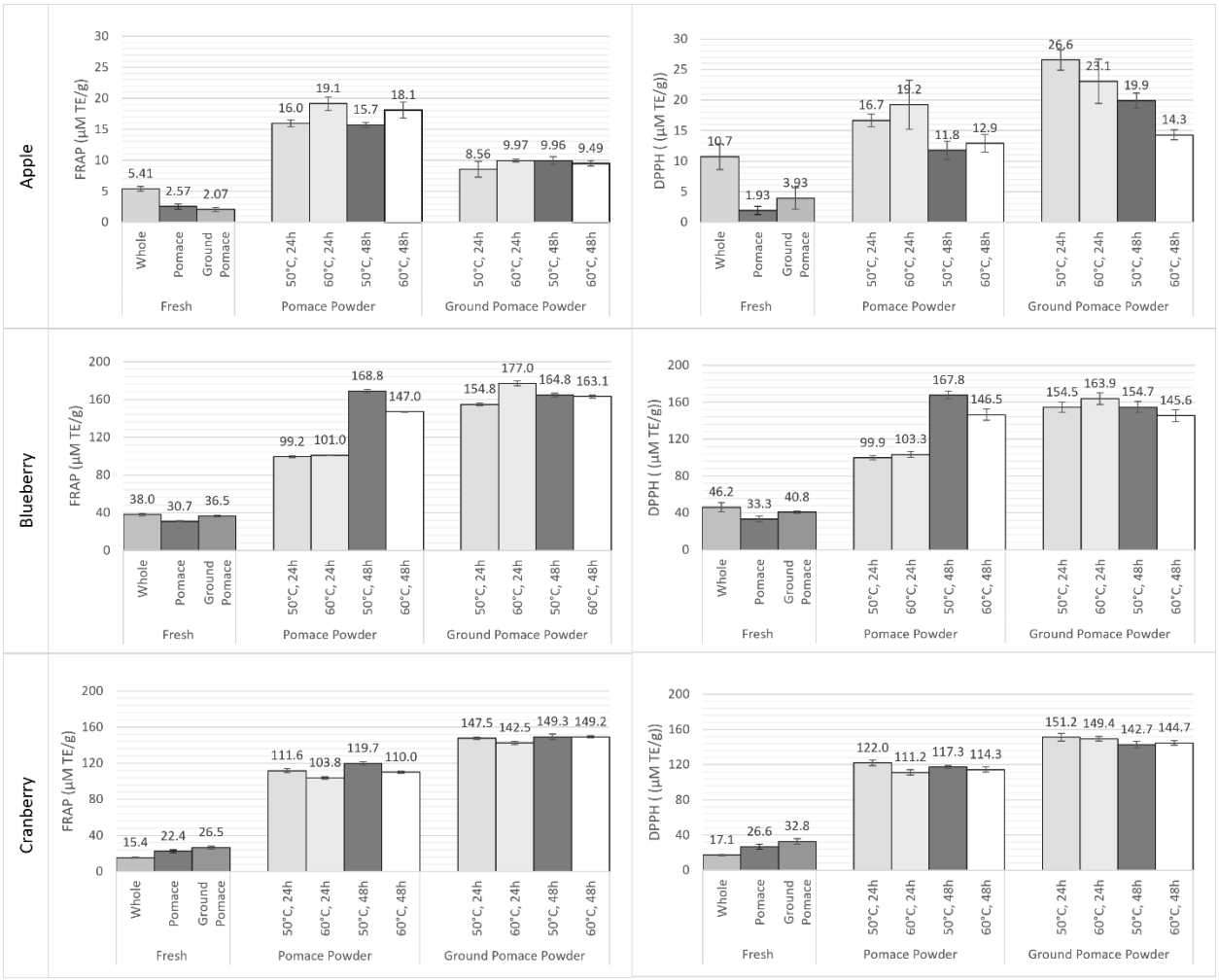

Figure 4.1: *FRAP and DPPH of apple, blueberry, and cranberry fruit, pomace, and pomace powders produced under different drying conditions. Fresh fruit values are on a fresh mass basis, powder values are on a dry mass basis*

Of the three fruits, blueberries had a higher AA, as expected (Prior et al., 1998), followed by cranberries and apples. The higher AA observed in the powders compared to the fresh fruit can be explained by the higher concentration of seeds, peels, and stems which all have a higher content of phenolic compounds than the pulp (Lee et al., 2002; Morais et al., 2016). Phenolic compounds are known to act as antioxidants, thus contributing to the AA in the fruit (Ćetković et al., 2008). While heat processing can be responsible for the degradation of antioxidants, it can also result in its enhancement in certain foods (Nicoli, Anese, & Parpinel, 1999). High

temperatures can cause Maillard reaction products (MRP) to form, which are caused by the non-enzymatic reaction of proteins and sugars. The MRP can cause browning in foods and are reported to have strong antioxidant properties (Atrooz, 2008). This may explain the increased AA in APP dried at 60°C. With regards to the effect of grinding in the blueberries and cranberries, Oszmiański et al. (2015) reported similar results with cranberry pomace powders. They investigated the effect of crushing the fruit prior to juicing and measured the antioxidant activity (DPPH, ABTS, and FRAP) of the resulting powders and juices. Their results showed that crushing increased the antioxidant activity of both the juice and pomace powders. The FRAP and DPPH increased from 64.91 to 71.47 µM TE/ g dm and 149.58 to 156.94 µM TE/ g dm, respectively. They reported that the antioxidant activities in the pomace powders were about 10 (DPPH) and 5 (FRAP) times higher compared to the juices.

Table 4.1 shows the literature values of AA, TPC, and TFC of similar samples. The variation of AA between our study and that of Oszmiański et al. (2015), (as well as other studies cited in Table 4.1), was not unexpected as production area and climates are known to affect AA, TPC and TFC (Xu, Zhang, Zhu, Huang, & Lu, 2011). The cranberry pomace from this study was sourced from Quebec while the pomace analyzed in their study was obtained from Warsaw, Poland. Zhu, Du, Li, and Li (2014) found that micronization of buckwheat hulls resulted in a higher AA. Zhu et al. (2010) also reported that grinding wheat bran dietary fiber resulted in a greater antioxidant activity, more specifically a higher reducing power and lower DPPH radical scavenging activity, as compared to dietary fiber that was not ground. Similar results were observed after grinding wheat bran (Rosa, Barron, Gaiani, Dufour, & Micard, 2013). However, this is not the case for all fibers as was observed with the GAPP in this study. Zhu, Du, and Li (2014) who found that micronization of grape pomace resulted in a lower AA. Further explanation may be linked with the TPC and TFC.

4.3.2 Total Phenolic Content

The total phenolic contents (TPC) observed for apple, blueberry, and cranberry whole fruit, pomace, and pomace powders produced under different processing conditions are shown in Figure 4.2. The TPC of the whole apple (0.94 mg GAE/ g fm) was significantly higher than that of the pomace and ground pomace (0.51 and 0.50 mg GAE/ g fm), respectively. On the contrary,

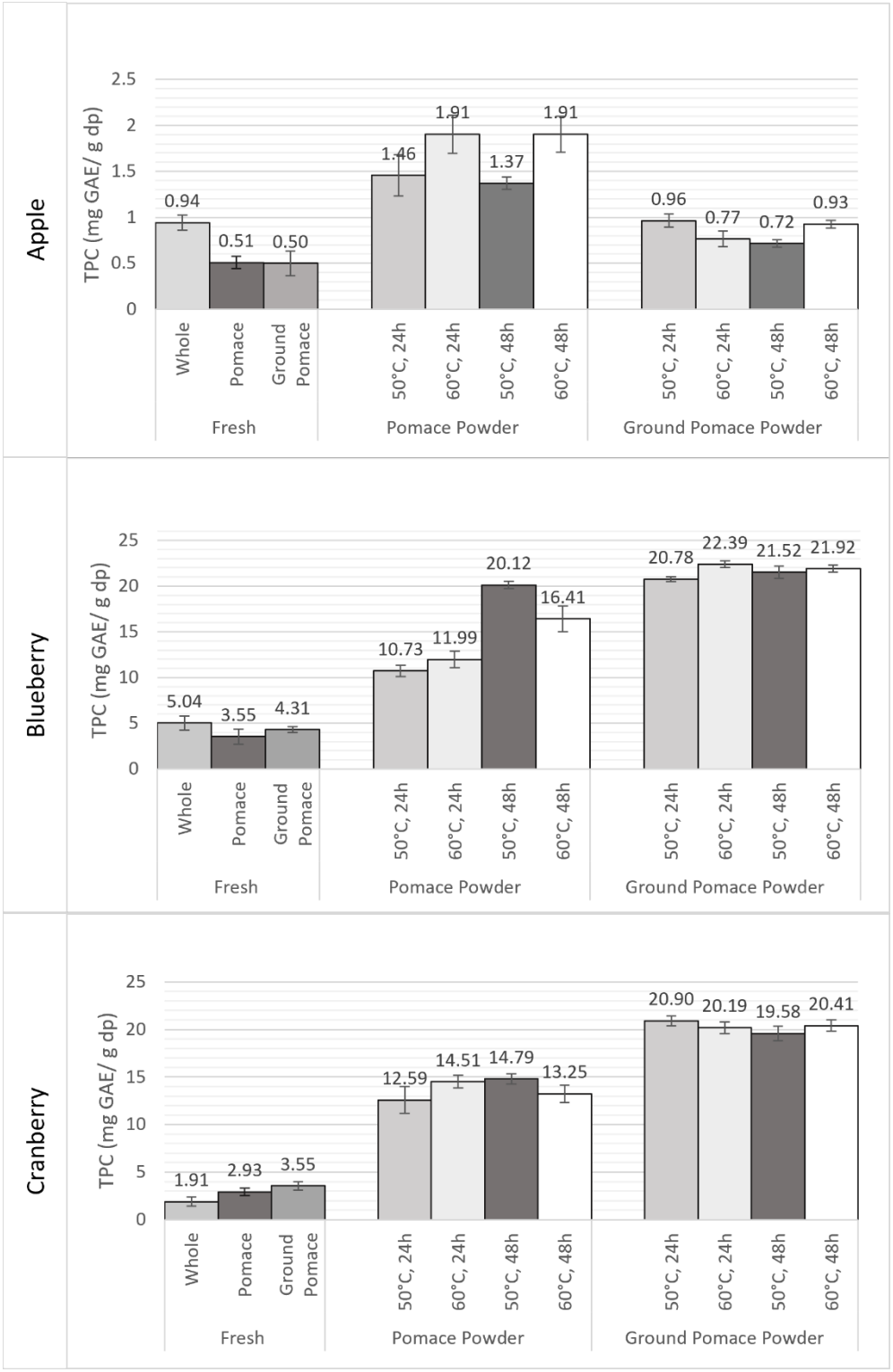

Figure 4.2: *TPC of apple, blueberry, and cranberry fruit, pomace, and pomace powders produced under different conditions. Fresh fruit values are on a fresh weight basis, powder values are on a dry mass basis.*

cranberry whole fruit had a significantly lower TPC (1.91 mg GAE/ g fm) than the pomace (2.93 mg GAE/ g fm) and ground pomace (3.55 mg GAE/ g dm). There was no significant difference between the TPC of the whole blueberry, its pomace, and ground pomace (5.04, 3.55, and 4.31 mg GAE/ g dm, respectively).

The TPC of the APP varied from 1.37 to 1.91 mg GAE/ g dm. The BPP and CPP had a TPC ranging from 10.73 to 20.12 mg GAE/ g dm and 12.59 to 14.79 mg GAE/ g dm, respectively. All fruit powders had a TPC significantly higher ($p < 0.05$) than their respective whole fruit and pomace. Fresh fruits consist of pulp, skin, and seeds. As explained earlier with the AA, the powders contain a greater concentration of skin, seeds, and stems which contributes to the increase in TPC (Lee et al., 2002; Morais et al., 2016). There was a significant interaction effect of temperature and duration on the TPC of BPP and CPP. However, in the case of APP, temperature was the only observed effect. On average, blueberries had the highest TPC of the three fruits tested, which is in agreement with the AA results.

When comparing the effect of homogenizing the pomace prior to drying on the TPC, the results generally show improved values for blueberries and cranberries, apart from BPP dried at 50°C and 48h which was higher than GBPP. The values for GBPP and GCPP varied from 20.78 to 22.39 mg GAE/ g dm and 19.58 to 20.90 mg GAE/ g dm, respectively. However, the TPC of GAPP was significantly lower than that of APP, with values ranging from 0.72 to 0.96 mg GAE/ g dm. This suggests that grinding decreases the TPC in apple pomace powders but increases TPC in blueberry and cranberry pomace powders. The highest TPC of APP was observed at 60°C and 24h with no homogenization. On the other hand, the optimum conditions for blueberry and cranberry powders were also observed at 60°C and 24h, however with homogenization.

Fruits contain phenolics in soluble free and insoluble bound forms, with the latter existing in the form of β-glycosides. The majority of these phenolic compounds exist in soluble free form. Those that exist in insoluble bound forms are covalently bonded to cell wall structural components such as cellulose, hemicellulose, lignin, pectin, and structural proteins (Acosta-Estrada, Gutiérrez-Uribe, & Serna-Saldívar, 2014). Of their TPC, apples contain about 8.2% bound phenolics while cranberries contain only 3.2% (Sun, Chu, Wu, & Liu, 2002). Processing methods, such as drying or

grinding, can have different effects on phenolic compounds in fruits (Nayak, Liu, & Tang, 2015). They can degrade the free form phenolic compounds in the fruits resulting in a lower TPC, which was observed with GAPP. Conversely, these same processing methods can release phenolic compounds that were bound to lignin or hemicellulose (Maillard & Berset, 1995). Additionally, the degradation of insoluble dietary fiber components such as lignin, which is a complex polyphenolic macromolecule, can occur and result in phenolic compounds with a lower molecular weight (Nunes et al., 2016). López et al. (2010) reported a decrease in TPC of blueberries with increasing air-drying temperatures up to a point, however where at higher temperatures (80°C and 90°C), the TPC increased. Ma et al. (2021) observed that increasing air-drying temperatures (from 55°C to 75°C) resulted in lower TPC in apple peels. However, the opposite was true for heat pumped-dried peels, where 65°C resulted in the highest TPC. Prolonged heat treatment has also shown to increase TPC (Jiratanan & Liu, 2004), as was observed with the BPP in this study. The results are within the range of TPC of similar samples found in the literature, as shown in Table 4.1. Any differences, as discussed earlier, may be attributed to the difference in cultivar, growing conditions, and maturity, which all influence the TPC (Michalska & Łysiak, 2015). Additionally, the total phenolic compounds estimation can vary with the analytical procedure used.

4.3.3 Total Flavonoid Content

The TFC of the whole apple (2.88 mg CE/ g fm) was significantly higher than that of the pomace and ground pomace (0.45 and 0.84 mg CE/ g fm, respectively). As for blueberry, there were no significant differences between the TFC of the whole fruit, its pomace and ground pomace, with the observed values being 5.04, 3.55, and 4.31 mg CE/ g fm, respectively. The whole cranberry, pomace, and ground pomace had a mean TFC of 1.91, 2.93 and 3.55 mg CE/g fm, respectively (Figure 4.3).

The TFC of APP, BPP, and CPP ranged from 2.49 to 3.38 mg CE/ g dm, 10.73 to 20.12 mg CE/ g dm, and 12.59 to 14.79 mg CE/ g dm respectively. Similar to the TPC and AA, the results showed that drying temperature had a significant effect ($p < 0.05$) on the TFC of APP, with the highest values for APP observed at a temperature of 60°C, regardless of time. There was an interaction effect of temperature and time on the TFC values of BPP and CPP. All fruit powders,

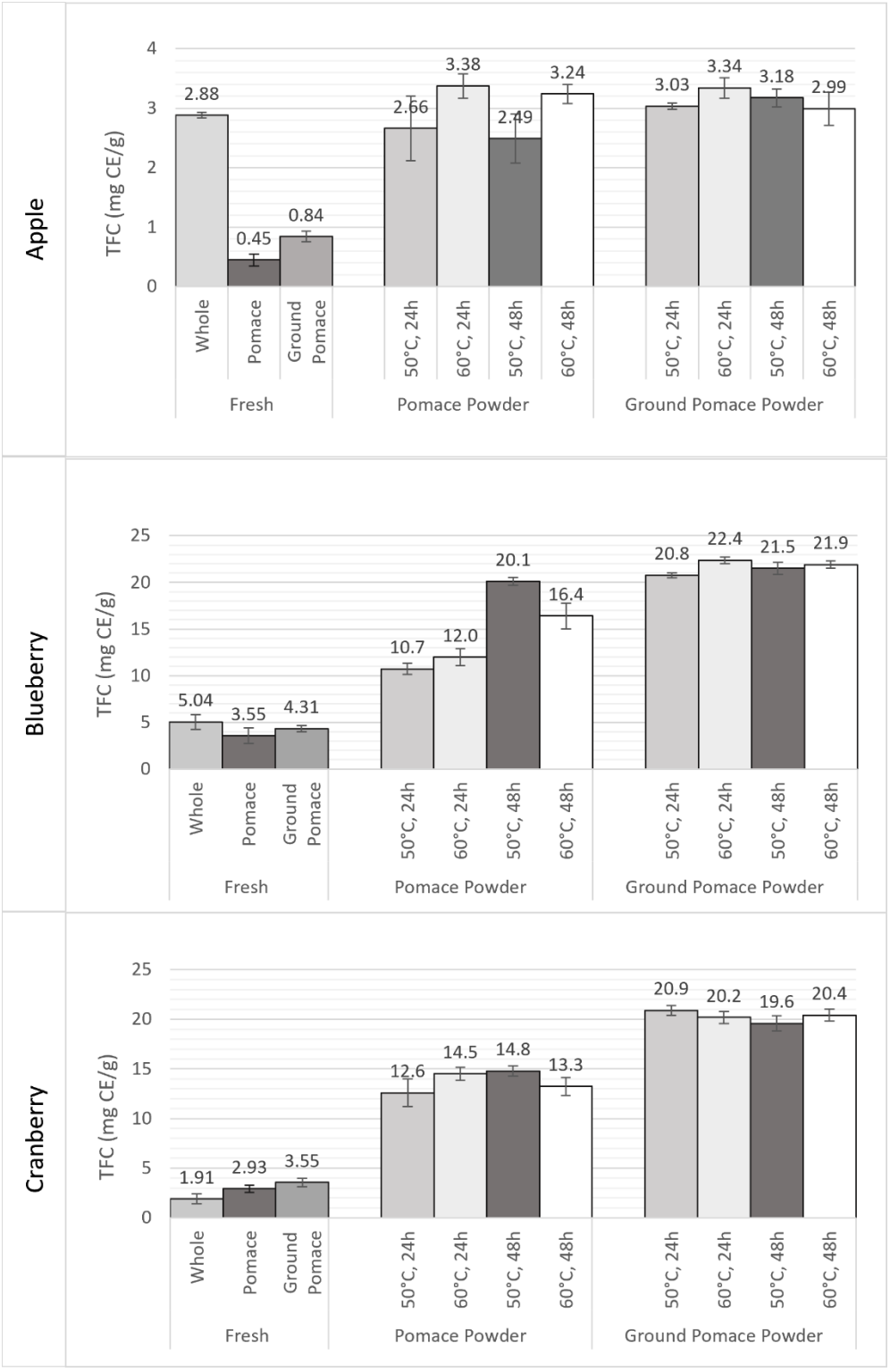

Figure 4.3: *TFC of apple, blueberry, and cranberry fruit, pomace, and pomace powders produced under different conditions. Fresh fruit values are on a fresh weight basis, powder values are on a dry mass basis*

except for GAPP, had a TFC significantly higher than their respective whole fruits, pomace, and ground pomace. Similar to TPC and AA, grinding the pomace prior to drying generally resulted in significantly higher TFC in blueberry and cranberry. The TFC of GBPP and GCPP varied from 20.78 to 21.92 mg CE/ g dm, and 19.58 mg CE/ g dm, respectively. Generally, both powders had significantly higher TFC than the BPP and CPP, respectively, and their respective whole fruit and pomaces. On the other hand, APP and GAPP had TFC values similar to the whole fruit but not the pomaces. Temperature and time had an interaction effect on the TFC of all the powders, except the APP where only temperature had an effect, and GCPP which was not affected by temperature nor time.

4.3.4 Correlations

To compare their relationship, a regression was plotted between the FRAP, TPC, TFC, and DPPH shown in Figure 4.4. Table 4.2 shows Pearson's coefficients of AA, TPC and TFC. Across all fruits, correlations were positively high ($0.7683 < r < 0.9937$) except for TPC vs DPPH ($r = 0.1780$). All fruit powders demonstrated particularly high correlations between TPC and FRAP. Ćetković et al. (2008) reported that there is a high correlation between antiradical activities, TPC, TFC, and some individual phenolic compounds in apple pomace. The results confirm that phenolic compounds, as well as flavonoids, are significant contributors to AA, particularly when measured with the FRAP technique. TPC may also be used as measure of the AA, as suggested by Thaipong (2006). It can be concluded that due to the high correlations, any effect of temperature, duration, and homogenization of pomace are linked to reported results for AA, TPC and TFC.

Table 4.2: *Pearson's correlation coefficients of antioxidant activity, total phenolic content, and total flavonoid content.*

Fruit	TPC vs FRAP	TFC vs FRAP	TPC vs DPPH	TFC vs DPPH
Apple	0.9263	0.7369	0.1780	0.7683
Blueberry	0.9976	0.9893	0.9929	0.9864
Cranberry	0.9937	0.8989	0.9915	0.9157

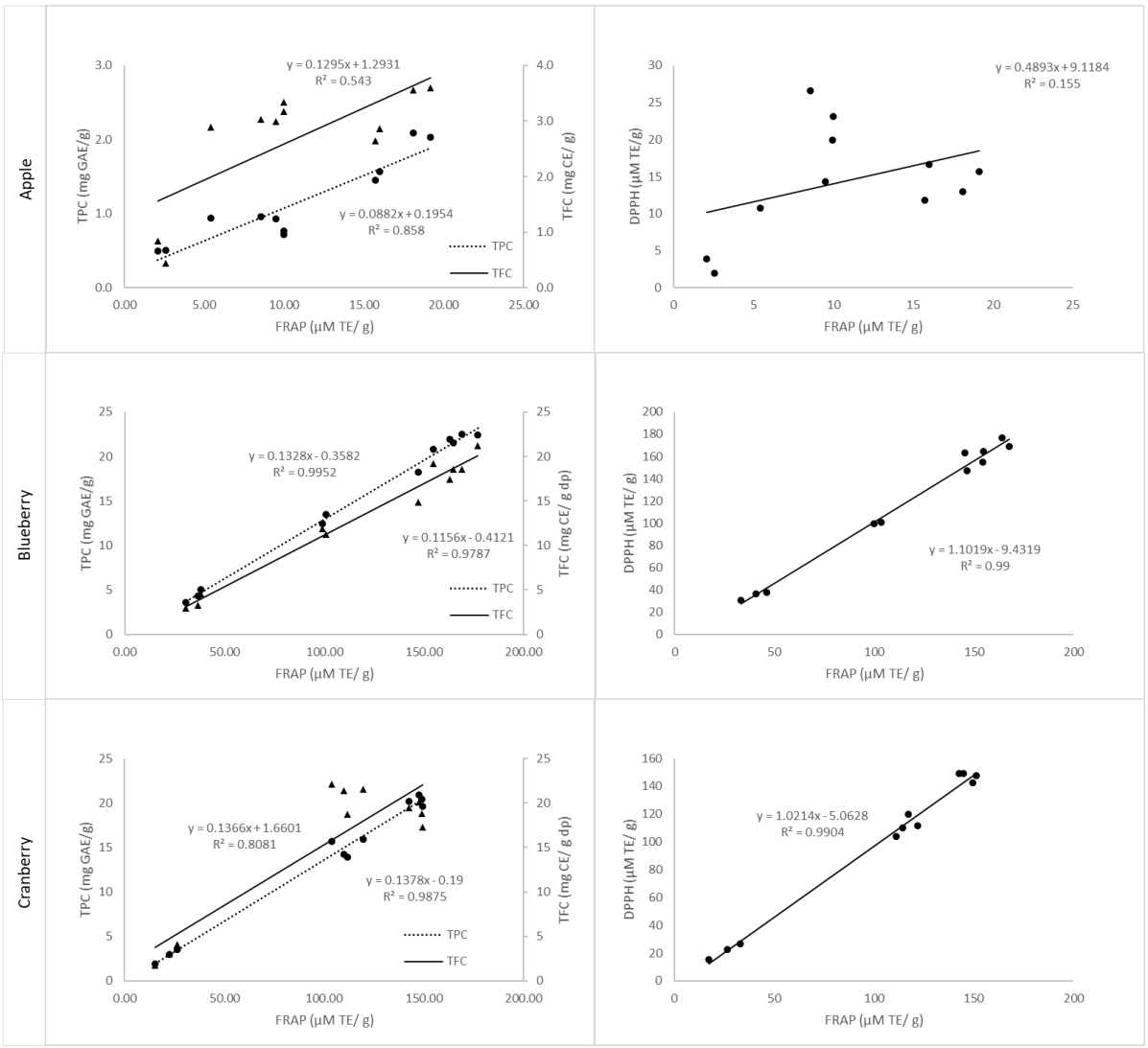

Figure 4.4: *Regression between FRAP vs. total phenolic content and total flavonoid content*

4.4 Conclusion

Pomace powders produced from apples, blueberries, and cranberries were abundant in total phenolic compounds and total flavonoids that contributed to their high antioxidant activity. Homogenization resulted in powders that were higher in AA, TPC and TFC due to the release of bound phenolics. High correlations between the three properties suggest that TPC can be used to indirectly estimate AA. Blueberry powders had the highest AA, TPC, and TFC.

5 Conclusions and recommendations

5.1 Conclusions

It is clear that there must be a large-scale intervention to manage fruit processing by-products to reduce their environmental footprint and to make use of the resource. This valuable biomass resource is full of nutrients and bioactive compounds that have many potential nutritional health benefits. In a world where food insecurity is a problem, discarding FPB is wasteful. This precious material can be transformed into a food ingredient to enhance the flavour, texture, colour, and nutritional value of foods such as baked goods, dairy and meat products, or as nutritional supplements. Pomace powders produced from apples, blueberries, and cranberries have a high concentration of dietary fibers, phenolic compounds, and flavonoids which contribute to their health benefits. Their vibrant colours and strong aromas can add a new dimension to the foods they are added to. The fruit powders had hydration and oil absorption properties much greater than wheat flour giving them particular functionality. Drying the powder at 60°C resulted in powders with high AA, TDF, TPC, and TFC. Homogenization of the pomace prior to drying released bound phenolics which increased the AA, TPC, and TFC. However, homogenization reduced the hydration and oil absorption properties. Blueberry powders had the highest AA, TPC, and TFC while blueberry powders also had the highest TDF and hydration properties.

5.2 Recommendation

The following are recommendations from this research for further studies:

- Assess powder physical properties such as flowability, hygroscopicity, glass transition temperatures, moisture isotherms
- Optimize drying time and method for continuous industrial use
- Investigate fiber components (soluble and insoluble) to better understand their redistribution and functionality upon homogenizing
- Assess the effects of pre-treatments of pomace on drying mechanisms and bioactive compounds
- Evaluate the storage stability and shelf-life of powders.

6. References

Abdul-Hamid, A., & Luan, Y. S. (2000). Functional properties of dietary fibre prepared from defatted rice bran. *Food Chemistry, 68*(1), 15-19. doi:10.1016/s0308-8146(99)00145-4

Acosta-Estrada, B. A., Gutiérrez-Uribe, J. A., & Serna-Saldívar, S. O. (2014). Bound phenolics in foods, a review. *Food Chemistry, 152*, 46-55. doi:10.1016/j.foodchem.2013.11.093

Adetunji, L. R., Adekunle, A., Orsat, V., & Raghavan, V. (2017). Advances in the pectin production process using novel extraction techniques: A review. *Food Hydrocolloids, 62*, 239-250. doi:10.1016/j.foodhyd.2016.08.015

Ahmed, J., Thomas, L., & Arfat, Y. A. (2019). Functional, rheological, microstructural and antioxidant properties of quinoa flour in dispersions as influenced by particle size. *Food Research International, 116*, 302-311. doi:

Ahmet, I., Spangler, E., Shukitt-Hale, B., Juhaszova, M., Sollott, S. J., Joseph, J. A., Talan, M. (2009). Blueberry-Enriched Diet Protects Rat Heart from Ischemic Damage. *PLoS ONE, 4*(6), e5954. doi:10.1371/journal.pone.0005954

Alexandri, M., Maina, S., Tsouko, E., Papapostolou, H., Koutinas, A., & Kourmentza, K. (2021). Chapter 46 - Valorization of fruit processing by-product streams into integrated biorefinery concepts: extraction of value-added compounds and bioconversion to chemicals. In R. Bhat (Ed.), *Valorization of Agri-Food Wastes and By-Products* (pp. 927-945): Academic Press.

Alvarez, A. L., Melón, S., Dalton, K. P., Nicieza, I., Roque, A., Suárez, B., & Parra, F. (2012). Apple pomace, a by-product from the asturian cider industry, inhibits herpes simplex virus types 1 and 2 in vitro replication: study of its mechanisms of action. *Journal of medicinal food, 15*(6), 581-587. doi:10.1089/jmf.2011.0308

Anderson, J. W., Baird, P., Davis Jr, R. H., Ferreri, S., Knudtson, M., Koraym, A., Williams, C. L. (2009). Health benefits of dietary fiber. *Nutrition Reviews, 67*(4), 188-205. doi:10.1111/j.1753-4887.2009.00189.x

Anhê, F. F., Roy, D., Pilon, G., Dudonné, S., Matamoros, S., Varin, T. V., Marette, A. (2015). A polyphenol-rich cranberry extract protects from diet-induced obesity, insulin resistance and intestinal inflammation in association with increasedAkkermansiaspp. population in the gut microbiota of mice. *Gut, 64*(6), 872-883. doi:10.1136/gutjnl-2014-307142

Asmeda, R., Noorlaila, A., & Norziah, M. (2015). Effects of different grinding methods on chemical and functional properties of MR211 rice flour. *Int. J. Food Eng, 1*(2), 111-114.

Atrooz, O. M. (2008). The effects of Maillard reaction products on apple and potato polyphenoloxidase and their antioxidant activity. *International Journal of Food Science & Technology, 43*(3), 490-494. doi:10.1111/j.1365-2621.2006.01478.x

Awuchi, C. G., Igwe, V. S., & Echeta, C. K. (2019). The functional properties of foods and flours. *International Journal of Advanced Academic Research, 5*(11), 139-160.

Ayad, R., & Akkal, S. (2019). Chapter 12 - Phytochemistry and biological activities of algerian Centaurea and related genera. In R. Atta ur (Ed.), *Studies in Natural Products Chemistry* (Vol. 63, pp. 357-414): Elsevier.

Babbar, N., Oberoi, H. S., & Sandhu, S. K. (2015). Therapeutic and nutraceutical potential of bioactive compounds extracted from fruit residues. *Critical Reviews in Food Science and Nutrition, 55*(3), 319-337.

Baiano, A., & Del Nobile, M. A. (2016). Antioxidant Compounds from Vegetable Matrices: Biosynthesis, Occurrence, and Extraction Systems. *Critical Reviews in Food Science and Nutrition, 56*(12), 2053-2068. doi:10.1080/10408398.2013.812059

Banerjee, J., Singh, R., Vijayaraghavan, R., MacFarlane, D., Patti, A. F., & Arora, A. (2017). Bioactives from fruit processing wastes: Green approaches to valuable chemicals. *Food Chemistry, 225*, 10-22.

Barbosa-Cánovas, G. V., Ortega-Rivas, E., Juliano, P., & Yan, H. (2005). *Food powders: physical properties, processing, and functionality* (Vol. 86): Springer.

Bas-Bellver, C., Andrés, C., Seguí, L., Barrera, C., Jiménez-Hernández, N., Artacho, A., Gosalbes, M. J. (2020). Valorization of Persimmon and Blueberry Byproducts to Obtain Functional Powders: In Vitro Digestion and Fermentation by Gut Microbiota. *Journal of Agricultural and Food Chemistry, 68*(30), 8080-8090. doi:10.1021/acs.jafc.0c02088

Basu, A., Feng, D., Planinic, P., Ebersole, J. L., Lyons, T. J., & Alexander, J. M. (2021). Dietary Blueberry and Soluble Fiber Supplementation Reduces Risk of Gestational Diabetes in Women with Obesity in a Randomized Controlled Trial. *The Journal of Nutrition, 151*(5), 1128-1138. doi:10.1093/jn/nxaa435

Baudelaire, E. D. (2013). 6 - Grinding for food powder production. In B. Bhandari, N. Bansal, M. Zhang, & P. Schuck (Eds.), *Handbook of Food Powders* (pp. 132-149): Woodhead Publishing.

Bender, A. B. B., Speroni, C. S., Moro, K. I. B., Morisso, F. D. P., Dos Santos, D. R., Da Silva, L. P., & Penna, N. G. (2020). Effects of micronization on dietary fiber composition, physicochemical properties, phenolic compounds, and antioxidant capacity of grape pomace and its dietary fiber concentrate. *LWT, 117*, 108652. doi:10.1016/j.lwt.2019.108652

Benzie, I. F. F., & Strain, J. J. (1996). The Ferric Reducing Ability of Plasma (FRAP) as a Measure of "Antioxidant Power": The FRAP Assay. *Analytical Biochemistry, 239*(1), 70-76. doi:10.1006/abio.1996.0292

Bhushan, S., Kalia, K., Sharma, M., Singh, B., & Ahuja, P. S. (2008). Processing of Apple Pomace for Bioactive Molecules. *Critical Reviews in Biotechnology, 28*(4), 285-296. doi:10.1080/07388550802368895

Blecker, C., Chevalier, J. P., Herck, J. C. v., Fougnies, C., Deroanne, C., & Paquot, M. (2001). Inulin: its physicochemical properties and technological functionality. *Recent Research Developments in Agricultural & Food Chemistry, 5*, 125.

Bohn, T., & Bouayed, J. (2020). Chapter 37 - Apples: an apple a day, still keeping the doctor away?'. In A. K. Jaiswal (Ed.), *Nutritional Composition and Antioxidant Properties of Fruits and Vegetables* (pp. 595-612): Academic Press.

Boudria, A., Hammoui, Y., Adjeroud, N., Djerrada, N., & Madani, K. (2018). Effect of filler load and high-energy ball milling process on properties of plasticized wheat gluten/olive pomace biocomposite. *Advanced Powder Technology, 29*(5), 1230-1238.

Boyer, J., & Liu, R. H. (2004). Apple phytochemicals and their health benefits. *Nutrition Journal, 3*(1). doi:10.1186/1475-2891-3-5

Brand-Williams, W., Cuvelier, M.-E., & Berset, C. (1995). Use of a free radical method to evaluate antioxidant activity. *LWT-Food Science and Technology, 28*(1), 25-30.

Cadden, A.-M. (1987). Comparative Effects of Particle Size Reduction on Physical Structure and Water Binding Properties of Several Plant Fibers. *Journal of Food Science, 52*(6), 1595-1599. doi:10.1111/j.1365-2621.1987.tb05886.x

Calabuig Jiménez, L., Barrera Puigdollers, M. C., Seguí Gil, L., & Betoret Valls, N. (2018). *Effect of particle size of blueberry pomace powder on its properties.* Paper presented at the IDS 2018. 21st International Drying Symposium Proceedings.

Cao, G., Sofic, E., & Prior, R. L. (1996). Antioxidant Capacity of Tea and Common Vegetables. *Journal of Agricultural and Food Chemistry, 44*(11), 3426-3431. doi:10.1021/jf9602535

Caparino, O. A., Tang, J., Nindo, C. I., Sablani, S. S., Powers, J. R., & Fellman, J. K. (2012). Effect of drying methods on the physical properties and microstructures of mango (Philippine 'Carabao' var.) powder. *Journal of Food Engineering, 111*(1), 135-148. doi:10.1016/j.jfoodeng.2012.01.010

Carson, K. J., Collins, J. L., & Penfield, M. P. (1994). Unrefined, Dried Apple Pomace as a Potential Food Ingredient. *Journal of Food Science, 59*(6), 1213-1215. doi:10.1111/j.1365-2621.1994.tb14679.x

Casal, J. A., Vermaat, J. E., & Wiegman, F. (2000). A test of two methods for plant protein determination using duckweed. *Aquatic Botany, 67*(1), 61-67. doi:10.1016/s0304-3770(99)00093-5

Ćetković, G., Čanadanović-Brunet, J., Djilas, S., Savatović, S., Mandić, A., & Tumbas, V. (2008). Assessment of polyphenolic content and in vitro antiradical characteristics of apple pomace. *Food Chemistry, 109*(2), 340-347. doi:10.1016/j.foodchem.2007.12.046

Chikezie, P. C., Ibegbulem, C. O., & Mbagwu, F. N. (2015). Medicinal Potentials and Toxicity Concerns of Bioactive Principles. *Medicinal and Aromatic plants, 2015*, 1-15.

Cho, M. J., Howard, L. R., Prior, R. L., & Clark, J. R. (2004). Flavonoid glycosides and antioxidant capacity of various blackberry, blueberry and red grape genotypes determined by high-performance liquid chromatography/mass spectrometry. *Journal of the Science of Food and Agriculture, 84*(13), 1771-1782. doi:10.1002/jsfa.1885

Côté, J., Caillet, S., Doyon, G., Sylvain, J. F., & Lacroix, M. (2010). Bioactive Compounds in Cranberries and their Biological Properties. *Critical Reviews in Food Science and Nutrition, 50*(7), 666-679. doi:10.1080/10408390903044107

D Archivio, M., Filesi, C., Di Benedetto, R., Gargiulo, R., Giovannini, C., & Masella, R. (2007). Polyphenols, dietary sources and bioavailability. *Annali-Istituto Superiore di Sanita, 43*(4), 348.

Dhillon, G. S., Kaur, S., & Brar, S. K. (2013). Perspective of apple processing wastes as low-cost substrates for bioproduction of high value products: A review. *Renewable and Sustainable Energy Reviews, 27*, 789-805. doi:10.1016/j.rser.2013.06.046

Dhingra, D., Michael, M., Rajput, H., & Patil, R. T. (2012). Dietary fibre in foods: a review. *Journal of Food Science and Technology, 49*(3), 255-266. doi:10.1007/s13197-011-0365-5

Diez-Sánchez, E., Quiles, A., & Hernando, I. (2021). Use of Berry Pomace to Design Functional Foods. *Food Reviews International*, 1-21. doi:10.1080/87559129.2021.2010217

Dilucia, F., Lacivita, V., Conte, A., & Del Nobile, M. A. (2020). Sustainable Use of Fruit and Vegetable By-Products to Enhance Food Packaging Performance. *Foods, 9*(7), 857. doi:10.3390/foods9070857

Djantou, E. B., Mbofung, C. M., Scher, J., & Desobry, S. (2007). A modelling approach to determine the effect of pre-treatment on the grinding ability of dried mangoes for powder production (Mangifera indica var Kent). *Journal of Food Engineering, 80*(2), 668-677. doi:10.1016/j.jfoodeng.2006.07.003

Djantou, E. B., Mbofung, C. M. F., Scher, J., Phambu, N., & Morael, J. D. (2011). Alternation drying and grinding (ADG) technique: A novel approach for producing ripe mango powder. *LWT - Food Science and Technology, 44*(7), 1585-1590. doi:10.1016/j.lwt.2011.01.022

Doblado-Maldonado, A. F., Flores, R. A., & Rose, D. J. (2013). Low moisture milling of wheat for quality testing of wholegrain flour. *Journal of Cereal Science, 58*(3), 420-423. doi:10.1016/j.jcs.2013.08.006

Duthie, G. G., Kyle, J. A. M., Jenkinson, A. M., Duthie, S. J., Baxter, G. J., & Paterson, J. R. (2005). Increased Salicylate Concentrations in Urine of Human Volunteers after Consumption of Cranberry Juice. *Journal of Agricultural and Food Chemistry, 53*(8), 2897-2900. doi:10.1021/jf040393b

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry, 124*(2), 411-421. doi:10.1016/j.foodchem.2010.06.077

Englyst, H. N., & Hudson, G. J. (1996). The classification and measurement of dietary carbohydrates. *Food Chemistry, 57*(1), 15-21. doi:10.1016/0308-8146(96)00056-8

Faggio, C., Sureda, A., Morabito, S., Sanches-Silva, A., Mocan, A., Nabavi, S. F., & Nabavi, S. M. (2017). Flavonoids and platelet aggregation: A brief review. *European Journal of Pharmacology, 807*, 91-101.

FAO. (2020a). FAOSTAT. Retrieved from http://www.fao.org/faostat/en/#data/QC.

FAO. (2020b). State of Food and Agriculture. Retrieved from https://www.fao.org/documents/card/en/c/cb1447en/

Farooq, Z., & Boye, J. I. (2011). Novel food and industrial applications of pulse flours and fractions. In (pp. 283-323): Elsevier.

Ferrer, J. L., Austin, M. B., Stewart, C., & Noel, J. P. (2008). Structure and function of enzymes involved in the biosynthesis of phenylpropanoids. *Plant Physiology and Biochemistry, 46*(3), 356-370. doi:10.1016/j.plaphy.2007.12.009

Folch, J., Lees, M., & Sloane Stanley, G. H. (1957). A simple method for the isolation and purification of total lipids from animal tissues. *J biol Chem, 226*(1), 497-509.

Galisteo, M., Duarte, J., & Zarzuelo, A. (2008). Effects of dietary fibers on disturbances clustered in the metabolic syndrome. *The Journal of Nutritional Biochemistry, 19*(2), 71-84.

Gao, W., Chen, F., Wang, X., & Meng, Q. (2020). Recent advances in processing food powders by using superfine grinding techniques: A review. *Comprehensive Reviews in Food Science and Food Safety, 19*(4), 2222-2255. doi:10.1111/1541-4337.12580

Garcia, M. V., Milani, M. S., & Ries, E. F. (2020). Production optimization of passion fruit peel flour and its incorporation into dietary food. *Food Science and Technology International, 26*(2), 132-139. doi:10.1177/1082013219870011

Gassara, F., Brar, S. K., Pelletier, F., Verma, M., Godbout, S., & Tyagi, R. D. (2011). Pomace waste management scenarios in Québec—Impact on greenhouse gas emissions. *Journal of Hazardous Materials, 192*(3), 1178-1185. doi:10.1016/j.jhazmat.2011.06.026

Girard Kristen, K. (2012). Cranberry, Blueberry, Currant, and Gooseberry. *Handbook of fruits and fruit processing*, 399.

Gouw, V. P., Jung, J., & Zhao, Y. (2017). Functional properties, bioactive compounds, and in vitro gastrointestinal digestion study of dried fruit pomace powders as functional food ingredients. *LWT, 80*, 136-144. doi:10.1016/j.lwt.2017.02.015

Grassino, A. N., Barba, F. J., Brnčić, M., Lorenzo, J. M., Lucini, L., & Brnčić, S. R. (2018). Analytical tools used for the identification and quantification of pectin extracted from plant food matrices, wastes and by-products: A review. *Food Chemistry, 266*, 47-55. doi:10.1016/j.foodchem.2018.05.105

Grigelmo-Miguel, N., & MartíN-Belloso, O. (1999). Influence of fruit dietary fibre addition on physical and sensorial properties of strawberry jams. *Journal of Food Engineering, 41*(1), 13-21. doi:10.1016/s0260-8774(99)00067-9

Guillon, F., & Champ, M. (2000). Structural and physical properties of dietary fibres, and consequences of processing on human physiology. *Food Research International, 33*(3-4), 233-245. doi:10.1016/s0963-9969(00)00038-7

Hancock, J., & Retamales, J. (2012). Pre-and postharvest management of fruit quality. *Blueberries*, 267-307.

Henríquez, C., Speisky, H., Chiffelle, I., Valenzuela, T., Araya, M., Simpson, R., & Almonacid, S. (2010). Development of an Ingredient Containing Apple Peel, as a Source of Polyphenols and Dietary Fiber. *Journal of Food Science, 75*(6), H172-H181. doi:10.1111/j.1750-3841.2010.01700.x

Hoekstra, A. Y., & Mekonnen, M. M. (2012). The water footprint of humanity. *Proceedings of the National Academy of Sciences, 109*(9), 3232-3237. doi:doi:10.1073/pnas.1109936109

Holdsworth, S. D. (2007). Dehydration of food products A review. *International Journal of Food Science & Technology, 6*(4), 331-370. doi:10.1111/j.1365-2621.1971.tb01623.x

Hussain, S., Jõudu, I., & Bhat, R. (2020). Dietary Fiber from Underutilized Plant Resources—A Positive Approach for Valorization of Fruit and Vegetable Wastes. *Sustainability, 12*(13), 5401. doi:10.3390/su12135401

Ignat, I., Volf, I., & Popa, V. I. (2011). A critical review of methods for characterisation of polyphenolic compounds in fruits and vegetables. *Food Chemistry, 126*(4), 1821-1835. doi:10.1016/j.foodchem.2010.12.026

Institut de la statistique du Québec. (2020). Profil sectoriel de l'industrie horticole au Québec. Retrieved from https://statistique.quebec.ca/en/communique/notice-release-profil-sectoriel-industrie-horticole-quebec-edition-2020

Institute of Medicine. (2001). *Dietary Reference Intakes: Proposed Definition of Dietary Fiber*. Washington, DC: The National Academies Press.

Iqbal, A., Schulz, P., & Rizvi, S. S. H. (2021). Valorization of bioactive compounds in fruit pomace from agro-fruit industries: Present Insights and future challenges. *Food Bioscience, 44*, 101384. doi:10.1016/j.fbio.2021.101384

Irigoytia, M. B., Irigoytia, K., Sosa, N., De Escalada Pla, M., & Genevois, C. (2022). Blueberry by-product as a novel food ingredient: physicochemical characterization and study of its

application in a bakery product. *Journal of the Science of Food and Agriculture*. doi:10.1002/jsfa.11812

Jayaraman, K., Das, D., & Contents, G. (2006). 25 Drying of Fruits and Vegetables. doi:10.1201/9781420017618.ch25

Jiang, H., Zhang, M., & Adhikari, B. (2013). Fruit and vegetable powders. In (pp. 532-552): Elsevier.

Jiratanan, T., & Liu, R. H. (2004). Antioxidant Activity of Processed Table Beets (Beta vulgaris var, conditiva) and Green Beans (Phaseolus vulgaris L.). *Journal of Agricultural and Food Chemistry, 52*(9), 2659-2670. doi:10.1021/jf034861d

Joseph, J. A., Shukitt-Hale, B., Denisova, N. A., Bielinski, D., Martin, A., McEwen, J. J., & Bickford, P. C. (1999). Reversals of Age-Related Declines in Neuronal Signal Transduction, Cognitive, and Motor Behavioral Deficits with Blueberry, Spinach, or Strawberry Dietary Supplementation. *The Journal of Neuroscience, 19*(18), 8114-8121. doi:10.1523/jneurosci.19-18-08114.1999

Jung, Cavender, G., & Zhao, Y. (2015). Impingement drying for preparing dried apple pomace flour and its fortification in bakery and meat products. *Journal of food science and technology, 52*(9), 5568-5578. doi:10.1007/s13197-014-1680-4

Jung, H., Lee, Y., & Yoon, W. (2018). Effect of Moisture Content on the Grinding Process and Powder Properties in Food: A Review. *Processes, 6*(6), 69. doi:10.3390/pr6060069

Jurevičiūtė, I., Keršienė, M., Bašinskienė, L., Leskauskaitė, D., & Jasutienė, I. (2022). Characterization of Berry Pomace Powders as Dietary Fiber-Rich Food Ingredients with Functional Properties. *Foods, 11*(5), 716. doi:10.3390/foods11050716

Kacey, Luu, L., Emma, Liu, Y., Lucy, Kyle, . . . Michael. (2014). The Furan Fatty Acid Metabolite CMPF Is Elevated in Diabetes and Induces β Cell Dysfunction. *Cell Metabolism, 19*(4), 653-666. doi:10.1016/j.cmet.2014.03.008

Kähkönen, M. P., Hopia, A. I., Vuorela, H. J., Rauha, J.-P., Pihlaja, K., Kujala, T. S., & Heinonen, M. (1999). Antioxidant Activity of Plant Extracts Containing Phenolic Compounds. *Journal of Agricultural and Food Chemistry, 47*(10), 3954-3962. doi:10.1021/jf990146l

Kalt, W., Lawand, C., Ryan, D. A. J., McDonald, J. E., Donner, H., & Forney, C. F. (2003). Oxygen Radical Absorbing Capacity, Anthocyanin and Phenolic Content of Highbush Blueberries (Vaccinium corymbosum L.) during Ripening and Storage. *Journal of the American Society for Horticultural Science, 128*(6), 917-923. doi:10.21273/jashs.128.6.0917

Kammerer, D. R., Kammerer, J., Valet, R., & Carle, R. (2014). Recovery of polyphenols from the by-products of plant food processing and application as valuable food ingredients. *Food Research International, 65*, 2-12.

Karasawa, M. M. G., & Mohan, C. (2018). Fruits as Prospective Reserves of bioactive Compounds: A Review. *Natural Products and Bioprospecting, 8*(5), 335-346. doi:10.1007/s13659-018-0186-6

Kaur, G. J., Orsat, V., & Singh, A. (2021). An overview of different homogenizers, their working mechanisms and impact on processing of fruits and vegetables. *Critical Reviews in Food Science and Nutrition*, 1-14. doi:10.1080/10408398.2021.1969890

Khanal, R. C., Howard, L. R., & Prior, R. L. (2009). Procyanidin Composition of Selected Fruits and Fruit Byproducts Is Affected by Extraction Method and Variety. *Journal of Agricultural and Food Chemistry, 57*(19), 8839-8843. doi:10.1021/jf9015398

Khoo, H. E., Azlan, A., Tang, S. T., & Lim, S. M. (2017). Anthocyanidins and anthocyanins: colored pigments as food, pharmaceutical ingredients, and the potential health benefits. *Food & Nutrition Research, 61*(1), 1361779. doi:10.1080/16546628.2017.1361779

Kirwan, W. O., Smith, A. N., McConnell, A. A., Mitchell, W. D., & Eastwood, M. A. (1974). Action of Different Bran Preparations on Colonic Function. *British Medical Journal, 4*(5938), 187-189. doi:10.1136/bmj.4.5938.187

Koutinas, A. A., Vlysidis, A., Pleissner, D., Kopsahelis, N., Lopez Garcia, I., Kookos, I. K., Lin, C. S. K. (2014). Valorization of industrial waste and by-product streams via fermentation for the production of chemicals and biopolymers. *Chemical Society Reviews, 43*(8), 2587. doi:10.1039/c3cs60293a

Krikorian, R., Shidler, M. D., Nash, T. A., Kalt, W., Vinqvist-Tymchuk, M. R., Shukitt-Hale, B., & Joseph, J. A. (2010). Blueberry Supplementation Improves Memory in Older Adults. *Journal of Agricultural and Food Chemistry, 58*(7), 3996-4000. doi:10.1021/jf9029332

Larrauri, J. (1999). New approaches in the preparation of high dietary fibre powders from fruit by-products. *Trends in Food Science & Technology, 10*(1), 3-8.

Laura, A., Moreno-Escamilla, J. O., Rodrigo-García, J., & Alvarez-Parrilla, E. (2019). Phenolic compounds. In *Postharvest physiology and biochemistry of fruits and vegetables* (pp. 253-271): Elsevier.

Lee, J., Durst, R. W., & Wrolstad, R. E. (2002). Impact of Juice Processing on Blueberry Anthocyanins and Polyphenolics: Comparison of Two Pretreatments. *Journal of Food Science, 67*(5), 1660-1667. doi:10.1111/j.1365-2621.2002.tb08701.x

Leewatchararongjaroen, J., & Anuntagool, J. (2016). Effects of Dry-Milling and Wet-Milling on Chemical, Physical and Gelatinization Properties of Rice Flour. *Rice Science, 23*(5), 274-281. doi:10.1016/j.rsci.2016.08.005

Li, Tan, H.-Y., Wang, N., Zhang, Z.-J., Lao, L., Wong, C.-W., & Feng, Y. (2015). The Role of Oxidative Stress and Antioxidants in Liver Diseases. *International Journal of Molecular Sciences, 16*(11), 26087-26124. doi:10.3390/ijms161125942

Li, C., Feng, J., Huang, W.-Y., & An, X.-T. (2013). Composition of Polyphenols and Antioxidant Activity of Rabbiteye Blueberry (Vaccinium ashei) in Nanjing. *Journal of Agricultural and Food Chemistry, 61*(3), 523-531. doi:10.1021/jf3046158

Lin, M. J. Y., Humbert, E. S., & Sosulski, F. W. (1974). Certain Functional Properties of Sunflower Meal Products *Journal of Food Science, 39*(2), 368-370. doi:10.1111/j.1365-2621.1974.tb02896.x

Liu, Black, M. A., Caron, L., & Camesano, T. A. (2006). Role of cranberry juice on molecular-scale surface characteristics and adhesion behavior ofEscherichia coli. *Biotechnology and Bioengineering, 93*(2), 297-305. doi:10.1002/bit.20675

Liu, L., You, Y., Deng, H., Guo, Y., & Meng, Y. (2019). Promoting hydrolysis of apple pomace by pectinase and cellulase to produce microbial oils using engineered Yarrowia lipolytica. *Biomass and Bioenergy, 126*, 62-69. doi:10.1016/j.biombioe.2019.04.025

López, J., Uribe, E., Vega-Gálvez, A., Miranda, M., Vergara, J., Gonzalez, E., & Di Scala, K. (2010). Effect of Air Temperature on Drying Kinetics, Vitamin C, Antioxidant Activity, Total Phenolic Content, Non-enzymatic Browning and Firmness of Blueberries Variety O´Neil. *Food and Bioprocess Technology, 3*(5), 772-777. doi:10.1007/s11947-009-0306-8

Lou, Z., Wang, M., Zhao, Y., & Huang, R. (2015). The contribution of biowaste disposal to odor emission from landfills. *Journal of the Air & Waste Management Association, 65*(4), 479-484. doi:10.1080/10962247.2014.1002870

Lyu, F., Luiz, S. F., Azeredo, D. R. P., Cruz, A. G., Ajlouni, S., & Ranadheera, C. S. (2020). Apple Pomace as a Functional and Healthy Ingredient in Food Products: A Review. *Processes, 8*(3), 319. doi:10.3390/pr8030319

Ma, Q., Bi, J., Yi, J., Wu, X., Li, X., & Zhao, Y. (2021). Stability of phenolic compounds and drying characteristics of apple peel as affected by three drying treatments. *Food Science and Human Wellness, 10*(2), 174-182.

Maillard, M.-N., & Berset, C. (1995). Evolution of antioxidant activity during kilning: role of insoluble bound phenolic acids of barley and malt. *Journal of Agricultural and Food Chemistry, 43*(7), 1789-1793.

Mann, J. I., & Cummings, J. H. (2009). Possible implications for health of the different definitions of dietary fibre. *Nutrition, Metabolism and Cardiovascular Diseases, 19*(3), 226-229. doi:10.1016/j.numecd.2009.02.002

Matthews, E., & Themelis, N. (2007). *Potential for reducing global methane emissions from landfills, 2000-2030.* Paper presented at the Eleventh International Waste Management and Landfill Symposium.

McGuire, R. G. (1992). Reporting of Objective Color Measurements. *HortScience, 27*(12), 1254-1255. doi:10.21273/hortsci.27.12.1254

Michalska, A., & Łysiak, G. (2015). Bioactive Compounds of Blueberries: Post-Harvest Factors Influencing the Nutritional Value of Products. *International Journal of Molecular Sciences, 16*(8), 18642-18663. doi:10.3390/ijms160818642

Miller, N. J., Rice-Evans, C., Davies, M. J., Gopinathan, V., & Milner, A. (1993). A Novel Method for Measuring Antioxidant Capacity and its Application to Monitoring the Antioxidant Status in Premature Neonates. *Clinical Science, 84*(4), 407-412. doi:10.1042/cs0840407

Mirabella, N., Castellani, V., & Sala, S. (2014). Current options for the valorization of food manufacturing waste: a review. *Journal of Cleaner Production, 65*, 28-41. doi:10.1016/j.jclepro.2013.10.051

Monspart-Sényi, J. (2012). Fruit processing waste management. *Handbook of fruits and fruit processing*, 315-331.

Moon, J. H., & Yoon, W. B. (2018). Effect of moisture content and particle size on grinding kinetics and flowability of balloon flower (Platycodon grandiflorum). *Food Science and Biotechnology, 27*(3), 641-650. doi:10.1007/s10068-017-0291-z

Morais, D. R., Rotta, E. M., Sargi, S. C., Bonafe, E. G., Suzuki, R. M., Souza, N. E., . . . Visentainer, J. V. (2016). Proximate Composition, Mineral Contents and Fatty Acid Composition of the Different Parts and Dried Peels of Tropical Fruits Cultivated in Brazil. *Journal of the Brazilian Chemical Society*. doi:10.5935/0103-5053.20160178

Mullin, W. J., & Wolynetz, M. S. (1995). Effect of Milling Procedure on the Measurement of Dietary Fiber by a Gravimetric Method. *Journal of Association of Official Agricultural Chemists (AOAC) International 78*(1), 83-87. doi:10.1093/jaoac/78.1.83

Nayak, B., Liu, R. H., & Tang, J. (2015). Effect of Processing on Phenolic Antioxidants of Fruits, Vegetables, and Grains—A Review. *Critical Reviews in Food Science and Nutrition, 55*(7), 887-918. doi:10.1080/10408398.2011.654142

Neto, C. C. (2007). Cranberry and blueberry: Evidence for protective effects against cancer and vascular diseases. *Molecular Nutrition & Food Research, 51*(6), 652-664. doi:10.1002/mnfr.200600279

Ngamnikom, P., & Songsermpong, S. (2011). The effects of freeze, dry, and wet grinding processes on rice flour properties and their energy consumption. *Journal of Food Engineering, 104*(4), 632-638.

Nicoli, M. C., Anese, M., & Parpinel, M. (1999). Influence of processing on the antioxidant properties of fruit and vegetables. *Trends in Food Science & Technology, 10*(3), 94-100.

Nunes, M. A., Pimentel, F. B., Costa, A. S. G., Alves, R. C., & Oliveira, M. B. P. P. (2016). Olive by-products for functional and food applications: Challenging opportunities to face environmental constraints. *Innovative Food Science & Emerging Technologies, 35*, 139-148

O'Shea, N., Arendt, E. K., & Gallagher, E. (2012). Dietary fibre and phytochemical characteristics of fruit and vegetable by-products and their recent applications as novel ingredients in food products. *Innovative Food Science & Emerging Technologies, 16*, 1-10. doi:10.1016/j.ifset.2012.06.002

Oszmiański, J., Kolniak-Ostek, J., Lachowicz, S., Gorzelany, J., & Matłok, N. (2015). Effect of dried powder preparation process on polyphenolic content and antioxidant capacity of cranberry (Vaccinium macrocarpon L.). *Industrial Crops and Products, 77*, 658-665. doi:10.1016/j.indcrop.2015.09.054

Pan, Z., & Tangratanavalee, W. (2003). Characteristics of soybeans as affected by soaking conditions. *LWT - Food Science and Technology, 36*(1), 143-151. doi:10.1016/s0023-6438(02)00202-5

Patel, S. (2014). Blueberry as functional food and dietary supplement: The natural way to ensure holistic health. *Mediterranean Journal of Nutrition and Metabolism, 7*(2), 133-143.

Pickardt, C., Dongowski, G., & Kunzek, H. (2004). The influence of mechanical and enzymatic disintegration of carrots on the structure and properties of cell wall materials. *European Food Research and Technology, 219*(3). doi:10.1007/s00217-004-0960-z

Prior, R. L., Cao, G., Martin, A., Sofic, E., McEwen, J., O'Brien, C., Mainland, C. M. (1998). Antioxidant Capacity As Influenced by Total Phenolic and Anthocyanin Content, Maturity, and Variety of Vaccinium Species. *Journal of Agricultural and Food Chemistry, 46*(7), 2686-2693. doi:10.1021/jf980145d

Quiles, A., Campbell, G. M., Struck, S., Rohm, H., & Hernando, I. (2018). Fiber from fruit pomace: A review of applications in cereal-based products. *Food Reviews International, 34*(2), 162-181. doi:10.1080/87559129.2016.1261299

Raghavendra, S. N., Rastogi, N. K., Raghavarao, K. S. M. S., & Tharanathan, R. N. (2004). Dietary fiber from coconut residue: effects of different treatments and particle size on the hydration properties. *European Food Research and Technology, 218*(6), 563-567. doi:10.1007/s00217-004-0889-2

Rajeh, C., Saoud, I. P., Kharroubi, S., Naalbandian, S., & Abiad, M. G. (2021). Food loss and food waste recovery as animal feed: a systematic review. *Journal of Material Cycles and Waste Management, 23*(1), 1-17. doi:10.1007/s10163-020-01102-6

Ramaswamy, H. S., & Marcotte, M. (2005). *Food Processing: Principles and Applications*: CRC Press.

Ratti, C. (2001). Hot air and freeze-drying of high-value foods: a review. *Journal of Food Engineering, 49*(4), 311-319. doi:10.1016/s0260-8774(00)00228-4

Regand, A., & Goff, H. D. (2003). Structure and ice recrystallization in frozen stabilized ice cream model systems. *Food Hydrocolloids, 17*(1), 95-102.

Reis, Rai, D. K., & Abu-Ghannam, N. (2012). Water at room temperature as a solvent for the extraction of apple pomace phenolic compounds. *Food Chemistry, 135*(3), 1991-1998.

Reis, Rai, D. K., & Abu-Ghannam, N. (2014). Apple pomace as a potential ingredient for the development of new functional foods. *International Journal of Food Science & Technology, 49*(7), 1743-1750. doi:10.1111/ijfs.12477

Rocha Parra, A. F., Ribotta, P. D., & Ferrero, C. (2015). Starch–Apple Pomace Mixtures: Pasting Properties and Microstructure. *Food and Bioprocess Technology, 8*(9), 1854-1863. doi:10.1007/s11947-015-1541-9

Rocha Parra, A. F., Sahagún, M., Ribotta, P. D., Ferrero, C., & Gómez, M. (2019). Particle size and hydration properties of dried apple pomace: Effect on dough viscoelasticity and quality of sugar-snap cookies. *Food and Bioprocess Technology, 12*(7), 1083-1092.

Rolin, C., & De Vries, J. (1990). Pectin. In (pp. 401-434): Springer Netherlands.

Rosa, N. N., Barron, C., Gaiani, C., Dufour, C., & Micard, V. (2013). Ultra-fine grinding increases the antioxidant capacity of wheat bran. *Journal of Cereal Science, 57*(1), 84-90.

Ross, K. A., Delury, N., Fukumoto, L., & Diarra, M. S. (2020). Dried berry pomace as a source of high value-added bioproduct: drying kinetics and bioactive quality indices. *International Journal of Food Properties, 23*(1), 2123-2143. doi:10.1080/10942912.2020.1847144

Routray, W., & Orsat, V. (2011). Blueberries and Their Anthocyanins: Factors Affecting Biosynthesis and Properties. *Comprehensive Reviews in Food Science and Food Safety, 10*(6), 303-320. doi:10.1111/j.1541-4337.2011.00164.x

Rupasinghe, H., Wang, L., Huber, G., & Pitts, N. (2007). Effect of baking on dietary fibre and phenolics of muffins incorporated with apple skin powder. *Food Chemistry*. doi:10.1016/j.foodchem.2007.09.057

Sablani, S. S., Andrews, P. K., Davies, N. M., Walters, T., Saez, H., & Bastarrachea, L. (2011). Effects of Air and Freeze Drying on Phytochemical Content of Conventional and Organic Berries. *Drying Technology, 29*(2), 205-216. doi:10.1080/07373937.2010.483047

Sagar, N. A., Pareek, S., Sharma, S., Yahia, E. M., & Lobo, M. G. (2018). Fruit and Vegetable Waste: Bioactive Compounds, Their Extraction, and Possible Utilization. *Comprehensive Reviews in Food Science and Food Safety, 17*(3), 512-531. doi:10.1111/1541-4337.12330

Šarić, B., Mišan, A., Mandić, A., Nedeljković, N., Pojić, M., Pestorić, M., & Đilas, S. (2016). Valorisation of raspberry and blueberry pomace through the formulation of value-added gluten-free cookies. *Journal of food science and technology, 53*(2), 1140-1150. doi:10.1007/s13197-015-2128-1

Second Harvest. (2019). The Avoidable Crisis of Food Waste. Retrieved from https://www.secondharvest.ca/resources/research/the-avoidable-crisis-of-food-waste

Shalini, R., & Gupta, D. K. (2010). Utilization of pomace from apple processing industries: a review. *Journal of food science and technology, 47*(4), 365-371. doi:10.1007/s13197-010-0061-x

Shehu, I., Akanbi, T. O., Wyatt, V., & Aryee, A. N. (2019). Fruit, Nut, Cereal, and Vegetable Waste Valorization to Produce Biofuel. *Byproducts from Agriculture and Fisheries: Adding Value for Food, Feed, Pharma, and Fuels*, 665-684.

Shishtar, E., Rogers, G. T., Blumberg, J. B., Au, R., & Jacques, P. F. (2020). Long-term dietary flavonoid intake and risk of Alzheimer disease and related dementias in the Framingham Offspring Cohort. *The American Journal of Clinical Nutrition, 112*(2), 343-353. doi:10.1093/ajcn/nqaa079

Singleton, V. L., & Rossi, J. A. (1965). Colorimetry of total phenolics with phosphomolybdic-phosphotungstic acid reagents. *American journal of Enology and Viticulture, 16*(3), 144-158.

Skrede, G., Wrolstad, R. E., & Durst, R. W. (2000). Changes in Anthocyanins and Polyphenolics During Juice Processing of Highbush Blueberries (Vaccinium corymbosum L.). *Journal of Food Science, 65*(2), 357-364. doi:10.1111/j.1365-2621.2000.tb16007.x

Small, E. (2013). *North American cornucopia: top 100 indigenous food plants*: CRC Press.

Soler, C., Soriano, J. M., & Mañes, J. (2009). Apple-Products Phytochemicals and Processing: A Review. *Natural Product Communications, 4*(5), 1934578X0900400. doi:10.1177/1934578x0900400504

Soukoulis, C., Lebesi, D., & Tzia, C. (2009). Enrichment of ice cream with dietary fibre: Effects on rheological properties, ice crystallisation and glass transition phenomena. *Food Chemistry, 115*(2), 665-671. doi:10.1016/j.foodchem.2008.12.070

Stanley, A., & Turner, G. (2010). Composting. *Teaching Science: The Journal of the Australian Science Teachers Association, 56*(2), 34-39. Retrieved from https://proxy.library.mcgill.ca/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=a9h&AN=52539912&scope=site

Statistics Canada. (2021). Statistical Overview of the Canadian Fruit Industry 2020. Retrieved from https://agriculture.canada.ca/en/canadas-agriculture-sectors/horticulture/horticulture-sector-reports

Struck, S., & Rohm, H. (2020). Fruit processing by-products as food ingredients. In (pp. 1-16): Elsevier.

Sudha, Baskaran, V., & Leelavathi, K. (2007). Apple pomace as a source of dietary fiber and polyphenols and its effect on the rheological characteristics and cake making. *Food Chemistry, 104*(2), 686-692. doi:10.1016/j.foodchem.2006.12.016

Sudha, Dharmesh, S. M., Pynam, H., Bhimangouder, S. V., Eipson, S. W., Somasundaram, R., & Nanjarajurs, S. M. (2016). Antioxidant and cyto/DNA protective properties of apple pomace enriched bakery products. *Journal of food science and technology, 53*(4), 1909-1918.

Suhartini, S., Nurika, I., Paul, R., & Melville, L. (2020). Estimation of Biogas Production and the Emission Savings from Anaerobic Digestion of Fruit-based Agro-industrial Waste and Agricultural crops residues. *BioEnergy Research*. doi:10.1007/s12155-020-10209-5

Sun, J., Chu, Y.-F., Wu, X., & Liu, R. H. (2002). Antioxidant and Antiproliferative Activities of Common Fruits. *Journal of Agricultural and Food Chemistry, 50*(25), 7449-7454. doi:10.1021/jf0207530

Sundberg, C., Yu, D., Franke-Whittle, I., Kauppi, S., Smårs, S., Insam, H., . . . Jönsson, H. (2013). Effects of pH and microbial composition on odour in food waste composting. *Waste Management, 33*(1), 204-211.

Szabó-Nótin, B., Juhász, R., Barta, J., & Stéger-Máté, M. (2014). Apple pomace powder as natural food ingredient in bakery jams. *Acta Alimentaria, 43*(Supplement 1), 140-147. doi:10.1556/aalim.43.2014.suppl.20

Szajdek, A., & Borowska, E. J. (2008). Bioactive Compounds and Health-Promoting Properties of Berry Fruits: A Review. *Plant Foods for Human Nutrition, 63*(4), 147-156. doi:10.1007/s11130-008-0097-5

Tagliani, C., Perez, C., Curutchet, A., Arcia, P., & Cozzano, S. (2019). Blueberry pomace, valorization of an industry by-product source of fibre with antioxidant capacity. *Food Science and Technology, 39*(3), 644-651. doi:10.1590/fst.00318

Terry, L. (2011). *Health-promoting properties of fruits and vegetables*: CABi.

Thaipong, K., Boonprakob, U., Crosby, K., Cisneros-Zevallos, L., & Byrne, D. H. (2006). Comparison of ABTS, DPPH, FRAP, and ORAC assays for estimating antioxidant activity from guava fruit extracts. *Journal of food composition and analysis, 19*(6-7), 669-675.

Tobar-Bolaños, G., Casas-Forero, N., Orellana-Palma, P., & Petzold, G. (2021). Blueberry juice: Bioactive compounds, health impact, and concentration technologies—A review. *Journal of Food Science*. doi:10.1111/1750-3841.15944

Tokusoglu, Ö., & Hall III, C. A. (2011). *Fruit and cereal bioactives: sources, chemistry, and applications*: CRC press.

Tong, L.-T., Gao, X., Lin, L., Liu, Y., Zhong, K., Liu, L., Zhou, S. (2015). Effects of semidry flour milling on the quality attributes of rice flour and rice noodles in China. *Journal of Cereal Science, 62*, 45-49. doi:10.1016/j.jcs.2014.12.007

Tsao, R. (2010). Chemistry and Biochemistry of Dietary Polyphenols. *Nutrients, 2*(12), 1231-1246. doi:10.3390/nu2121231

Tsao, R., & Yang, R. (2003). Optimization of a new mobile phase to know the complex and real polyphenolic composition: towards a total phenolic index using high-performance liquid chromatography. *Journal of Chromatography A, 1018*(1), 29-40. doi:10.1016/j.chroma.2003.08.034

Tuyen, C. K., Nguyen, M. H., & Roach, P. D. (2011). Effects of pre-treatments and air drying temperatures on colour and antioxidant properties of Gac fruit powder. *International Journal of Food Engineering, 7*(3).

UN. (2021). United Nations Sustainable Development Goals. Retrieved from https://sdgs.un.org/goals

Vega-Gálvez, A., Di Scala, K., Rodríguez, K., Lemus-Mondaca, R., Miranda, M., López, J., & Perez-Won, M. (2009). Effect of air-drying temperature on physico-chemical properties, antioxidant capacity, colour and total phenolic content of red pepper (Capsicum annuum, L. var. Hungarian). *Food Chemistry, 117*(4), 647-653. doi:10.1016/j.foodchem.2009.04.066

Velu, V., Nagender, A., Prabhakara Rao, P. G., & Rao, D. G. (2006). Dry milling characteristics of microwave dried maize grains (Zea mays L.). *Journal of Food Engineering, 74*(1), 30-36. doi:10.1016/j.jfoodeng.2005.02.014

Vukušić, J. L., Millenautzki, T., Cieplik, R., Obst, V., Saaid, A. M., Clavijo, L., Barbe, S. (2021). Reshaping Apple Juice Production Into a Zero Discharge Biorefinery Process. *Waste and Biomass Valorization, 12*(7), 3617-3627. doi:10.1007/s12649-020-01245-5

Vuolo, M. M., Lima, V. S., & Maróstica Junior, M. R. (2019). Phenolic Compounds. In (pp. 33-50): Elsevier.

Wang, & Stretch, A. W. (2001). Antioxidant Capacity in Cranberry Is Influenced by Cultivar and Storage Temperature. *Journal of Agricultural and Food Chemistry, 49*(2), 969-974. doi:10.1021/jf001206m

Wang, H., Cao, G., & Prior, R. L. (1996). Total Antioxidant Capacity of Fruits. *Journal of Agricultural and Food Chemistry, 44*(3), 701-705. doi:10.1021/jf950579y

Weh, K., Clarke, J., & Kresty, L. (2016). Cranberries and Cancer: An Update of Preclinical Studies Evaluating the Cancer Inhibitory Potential of Cranberry and Cranberry Derived Constituents. *Antioxidants, 5*(3), 27. doi:10.3390/antiox5030027

White, B. L., Howard, L. R., & Prior, R. L. (2010). Proximate and Polyphenolic Characterization of Cranberry Pomace. *Journal of Agricultural and Food Chemistry, 58*(7), 4030-4036. doi:10.1021/jf902829g

Wolfe, K. L., & Liu, R. H. (2003). Apple Peels as a Value-Added Food Ingredient. *Journal of Agricultural and Food Chemistry, 51*(6), 1676-1683. doi:10.1021/jf025916z

Wu, J., Gao, H., Zhao, L., Liao, X., Chen, F., Wang, Z., & Hu, X. (2007). Chemical compositional characterization of some apple cultivars. *Food Chemistry, 103*(1), 88-93. doi:10.1016/j.foodchem.2006.07.030

Xu, Li, Y., Meng, X., Zhou, T., Zhou, Y., Zheng, J., Li, H. B. (2017). Natural Antioxidants in Foods and Medicinal Plants: Extraction, Assessment and Resources. *Int J Mol Sci, 18*(1), 96. doi:10.3390/ijms18010096

Xu, Zhang, Y., Zhu, L., Huang, Y., & Lu, J. (2011). Influence of Growing Season on Phenolic Compounds and Antioxidant Properties of Grape Berries from Vines Grown in Subtropical Climate. *Journal of Agricultural and Food Chemistry, 59*(4), 1078-1086. doi:10.1021/jf104157z

Yeganehpour, E., Taghizadeh, A., Paya, H., Hossein-Khani, A., Palangi, V., Shirmohammadi, S., & Abachi, S. (2021). Utilization of fruit and vegetable wastes as an alternative renewable energy source in ruminants' diet. *Biomass Conversion and Biorefinery*. doi:10.1007/s13399-021-01665-w

Zhang, L., Ma, J., Pan, K., Go, V. L. W., Chen, J., & You, W.-C. (2005). Efficacy of Cranberry Juice on Helicobacter pylori Infection: a Double-Blind, Randomized Placebo-Controlled Trial. *Helicobacter, 10*(2), 139-145. doi:10.1111/j.1523-5378.2005.00301.x

Zhishen, J., Mengcheng, T., & Jianming, W. (1999). The determination of flavonoid contents in mulberry and their scavenging effects on superoxide radicals. *Food Chemistry, 64*(4), 555-559.

Zhu, Du, B., & Li, J. (2014). Effect of ultrafine grinding on physicochemical and antioxidant properties of dietary fiber from wine grape pomace. *Food Science and Technology International, 20*(1), 55-62. doi:10.1177/1082013212469619

Zhu, Du, B., Li, R., & Li, J. (2014). Effect of micronization technology on physicochemical and antioxidant properties of dietary fiber from buckwheat hulls. *Biocatalysis and Agricultural Biotechnology, 3*(3), 30-34.

Zhu, Huang, S., Peng, W., Qian, H., & Zhou, H. (2010). Effect of ultrafine grinding on hydration and antioxidant properties of wheat bran dietary fiber. *Food Research International, 43*(4), 943-948. doi:10.1016/j.foodres.2010.01.005