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Bioactive Compounds, Antioxidant Activities, and Health Beneficial Effects of Selected Commercial Berry Fruits: A Review

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Abstract

Epidemiological studies have provided the evidence that regular consumption of fruits and vegetables reduce the risk of pathological condition such as cardiovascular disease, cancer, inflammation, and aging. Among fruits, berries are considered as superfruits due to their highly packed phytochemicals comprising phenolic acids, flavonoids viz. flavonols, flavanols, and anthocyanins. These bioactive compounds are associated with significant antioxidant, antidiabetic, antiinflammation, and anticancer properties. This review highlights the basic information and interesting findings of some selected commercial berries with their phytochemical composition, antioxidant properties, and potential health benefits to human.

Keywords: berries, polyphenols, antioxidant activity, antidiabetic and anticancer properties, nutrition

1. Introduction

Free radicals are reactive oxygen or nitrogen molecule that damage cellular biomolecules viz. protein, nucleic acid, lipids membranes and results in various pathological condition such as cardiovascular disease, cancer, inflammation, and aging (Sun, 1990; Valko, Leibfritz, Jan, Cronin, Mazur, & Telser, 2007; Phaniendra, Jestadi, & Periyasamy, 2015). Antioxidants are molecule that scavenge or inhibit the actions of reactions of free radical to protect the cells and tissues (Uttara, Singh, Zamboni, & Mahajan, 2009). Several epidemiologic studies demonstrated that consumption of fruits and vegetables could lower these chronic pathologies including obesity, inflammation, cardiovascular diseases, and cancer due to their strong antioxidant activities (Kristo, Klimis-Zacas, & Sikalidis, 2016; Kalemba-Drożdż, Cierniak, & Cichoń, 2020). Among fruits, berries are important part of the human diet for many centuries and are receiving considerable attention continuously all over the world due to their beneficial effects to the human health and nutrition (Bravo, 1998; Nile& Park, 2014, Cianciosi, Simal-Gándara, & Forbes-Hernández, 2019).

Berries are considered as superfruits due to their high packed phytochemicals, dietary fibers, vitamins, and minerals. Berries polyphenolic compounds composed of diverse group of compounds which include phenolic acids, flavonoids viz., flavonols, flavanols, and anthocyanins. Phenolic acids are the derivatives of benzoic acid and cinnamic acid and consist of an aromatic ring structure with hydroxyl group. However, hydroxy derivatives of cinnamic acid are much more abundant than hydroxybenzoic acid among berries. Among flavonoids berries phenolic compounds include anthocyanins, flavanols, flavonols, and proanthocyanidins. These groups differ each other in the spatial positions and numbers of hydroxyl and alkyl groups on the basic chemical structure. Anthocyanins are the most abundant among flavonoids and are responsible for the color of the fruits. In their structure anthocyanins are glycosylated with glucose, galactose, rhamnose, xylose, or arabinose are attached to the aglycone called anthocyanidins mainly cyanidin, pelarogonidin, malvidin, petunidin, delphinidin, and peonidin. Usually the sugar components of anthocyanins are connected to the anthocyanidin skeleton via the C3 hydroxyl group in ring C of the anthocyanin.

Due to the presence of these polyphenolic compounds berries and their extracts exhibit several health benefits such as retarding inflammation, lowering cardiovascular diseases, or protect to lower the risk of various cancers, and antioxidant activities (Heinonen, Meyer, & Frankel, 1998; Seeram, Adams, Zhang, Lee, Sand, Scheuller, & Heber, 2006; Pan, Skaer, Yu, Hui, Zhao, Ren, Oshima & Wang, 2017; Reboredo-Rodr´ıguez, 2018; Pan et al., 2018). However, the contents of polyphenols and nutrients of berries are highly dependent on genotypes, environments, and the cultivation techniques. In addition to these, various agronomic factors such as pre and postharvest practices, maturity at harvest, storage, and processing operations plays crucial role in the quality and levels of phytochemicals in berries. Interestingly among these factors the genotype plays most significant role which regulates the content of nutrients and phytochemicals and influence health beneficial activities. In an important study Halvorsen et al., (2006) evaluated 1120 food samples listed in USDA for antioxidant content and found that blueberries, strawberries, cranberries and their juice product occupied top position in the first 50 antioxidant rich foods (Halvorsen et al., 2006). Large body of literature is available with studies of berries' health benefits to humans. Recently Yeung, et al., (2019) concluded that berries which were mentioned at the 100 top cited research articles dealing with anticancer and antioxidant activities were strawberry, blueberry, cranberry, raspberry, blackberry, billberry, and grape berry. However, at the current time in addition to these commonly cultivated berries some other native berry fruits viz, sea buckthorn, acai, maqui, viburnum, and elder berries are gaining remarkable attention worldwide due to their rich source of antioxidants. Due to the increasing demand of antioxidant rich berries, continuous research on the identification of phytochemicals and their health benefits of these berries have been carried out. However, a very few review and research articles are seen covering most of the top commercial berries. In this review article we provide an overview of polyphenolic composition of selected top commercial berries and their health beneficial properties.

2. Commercial Berries

Berries are available with distinctive skin and flesh colors such as red, blue, or purple. They are highly perishable fruits. Some of the top commercial varieties of berries include members of *genera*: *Fragaria* (strawberry), *Vaccinium* (blueberry, cranberry, bilberry), *Prunus* (cherries), *Hippophae* (sea buckthorn), *Rubus* (raspberries), *Euterepe* (açaíberry), *Aristotelia* (Maqui berry), and *Sambucus* (elderberry, red elderberry).

2.1 Strawberries

2.1.1 Source

Strawberry fruits belong to the family of *Rosaceae* and genus *Fragaria* are globally cultivated for their popularity due to distinctive aroma, bright red color, and juicy texture. The plant is widely cultivated worldwide, intensively in Europe, USA, and China. The USA is the world leading producer of strawberries after Turkey and Spain. The US strawberry industry has significantly rising as per person consumption increasing because of the high consumer acceptance for its sensory attributes.

2.1.2 Composition

Vitamin C is one of the major nutrients available in strawberries. Other vitamins such as thiamine, riboflavin, niacin, and vitamins A, E, K, and B6 including carotenoids are also available in strawberries (Rothwell et al., 2013, Fierascu, Temocico, Fierascu, Ortan, & Babeanu, 2020). However, depending on the varieties, geographic, and agronomic condition these levels vary among them (Aaby, Mazur, Nes, & Skrede, 2012; Nowicka, Kucharska, Sokół-Łętowska, & Fecka, 2019, Akimov, et al., 2019). The major polyphenolic compounds in strawberries are flavonol, flavanol, anthocyanins, and phenolic acids (Kähkönen, Hopia, & Heinonen, 2001; Aaby, Skrede, & Wrolstad, 2005; Giampieri, et al., 2020), (Table 1). Moreover, the major polyphenolic compounds in strawberries are anthocyanins and they are responsible for the color of the fruits. The major anthocyanins in strawberries are derivatives of pelargonidin and cyanidin with glycosides or acylated forms such as pelargonidin 3-glucoside, cyanidin 3-glucoside, cyanidin 3-rutinoside, pelargonidin 3-galactoside, pelargonidin 3-rutinoside, pelargonidin 3-arabinoside, pelargonidin 3 malylglucoside etc (Lopes-da-Silva, de Pascual-Teresa, Rivas-Gonzalo, & Santuos-Buelga, 2002; Giampieri, et al., 2020). Quercetin, kaempferol, fisetin, and their glycoside were found to be as major flavonols in strawberries. Among flavanols catechin, proanthocyanidin B1, proanthocyanidin trimer, proanthocyanidin B3 were reported to be major ones. Phenolic acids such as 4-coumaric acid, p-hydroxybenzoic acid, ferulic acid, vanillic acid, sinapic acid were found to be in significant level in strawberries. Storage and processing greatly influence the quality and levels of phenolic and anthocyanin compounds of strawberries. In the processed products such as jams, jellies, puree, and juices the levels of phenolic compounds decrease relative to the fresh strawberries (Álvarez-Fernández, Hornedo-Ortega, Cerezo, Troncoso, García-Parrilla, 2014; Méndez-Lagunas, Rodríguez-Ramírez, Cruz-Gracida, Sandoval-Torres, & Barriada-Bernal, 2017). The color and composition of anthocyanins are affected by pH. During storage lower pH (2.5) were found to be better to preserve its polyphenols.

Table 1. Major phenolic compounds in selected commercial berries

Berries	Flavonol	Phenolic acid	Anthocyanin	Flavanol
Strawberries	Kaempferol 3-O-glucoside	4-Hydroxybenzoic acid 4-O-glucoside	Cyanidin	(+)-Catechin
	Kaempferol 3-O-glucuronide	5-O-Galloylquinic acid	Cyanidin 3-O-(6"-succinyl-glucoside)	(+)-Gallocatechin
	Quercetin 3-O-glucuronide	Ellagic acid glucoside	Pelargonidin	(-)-Epicatechin 3-O-gallate
	Kaempferol	5-Caffeoylquinic acid	Pelargonidin 3-O-(6"-malonyl-glucoside)	(-)-Epigallocatechin
	Myricetin	Caffeoyl glucose	Pelargonidin 3-O-arabinoside	Procyanidin dimer B1
	Quercetin	Cinnamic acid	Pelargonidin 3-O-glucoside	Procyanidin dimer B2
		Feruloyl glucose	Pelargonidin 3-O-rutinoside	Procyanidin dimer B3
		p-Coumaric acid	pelargonidin 3 malylglucoside	Procyanidin dimer B4
		p-Coumaric acid 4-O-glucoside		Procyanidin trimer
		p-Coumaroyl glucose		
		Vanillic acid		
		Protocatechuic acid		
		Sinapic acid		
Blueberries	Kaempferol	4-Hydroxybenzoic acid	Cyanidin 3-O-(6"-acetyl-galactoside)	
	Myricetin	Ellagic acid	Cyanidin 3-O-(6"-acetyl-glucoside)	
	Quercetin	Gallic acid	Cyanidin 3-O-arabinoside	
	Kaempferol 3-O-glucoside	Caffeic acid	Cyanidin 3-O-galactoside	
	Myricetin 3-O-arabinoside	Ferulic acid	Cyanidin 3-O-glucoside	
	Myricetin 3-O-rhamnoside	p-Coumaric acid	Delphinidin 3-O-(6"-acetyl-galactoside)	
	Quercetin 3-O-acetyl-rhamnoside	5-Caffeoylquinic acid	Delphinidin 3-O-(6"-acetyl-glucoside)	
	Quercetin 3-O-arabinoside		Delphinidin 3-O-arabinoside	
	Quercetin 3-O-galactoside	Syringic acid	Delphinidin 3-O-galactoside	
	Quercetin 3-O-glucoside	Vanillic acid	Delphinidin 3-O-glucoside	
	Quercetin 3-O-xyloside	4-Hydroxybenzoic acid 4-O-glucoside	Malvidin 3-O-(6"-acetyl-galactoside)	
		Gallic acid 4-O-glucoside	Malvidin 3-O-(6"-acetyl-glucoside)	
		Protocatechuic acid 4-O-glucoside	Malvidin 3-O-arabinoside	
		3-Caffeoylquinic acid	Malvidin 3-O-galactoside	
		4-Caffeoylquinic acid	Malvidin 3-O-glucoside	
		5-Caffeoylquinic acid	Peonidin 3-O-(6"-acetyl-galactoside)	
		5-Feruloylquinic acid	Peonidin 3-O-(6"-acetyl-glucoside)	
		5-p-Coumaroylquinic acid	Peonidin 3-O-galactoside	
		Caffeic acid 4-O-glucoside	Peonidin 3-O-glucoside	
		Ferulic acid 4-O-glucoside	Petunidin 3-O-(6"-acetyl-galactoside)	
		p-Coumaric acid 4-O-glucoside	Petunidin 3-O-(6"-acetyl-glucoside)	
			Petunidin 3-O-arabinoside	
			Petunidin 3-O-galactoside	
			Petunidin 3-O-glucoside	
			Cyanidin 3-O-(6"-acetyl-galactoside)	
			Cyanidin 3-O-(6"-acetyl-glucoside)	
			Cyanidin 3-O-arabinoside	
			Cyanidin 3-O-galactoside	
			Cyanidin 3-O-glucoside	
			Delphinidin 3-O-(6"-acetyl-galactoside)	
			Delphinidin	(-)-Epicatechin

			3-O-(6"-acetyl-glucoside)	
			Delphinidin 3-O-arabinoside	
			Delphinidin 3-O-galactoside	
			Delphinidin 3-O-glucoside	
			Malvidin 3-O-(6"-acetyl-galactoside)	
			Malvidin 3-O-(6"-acetyl-glucoside)	
			Malvidin 3-O-arabinoside	
			Malvidin 3-O-galactoside	
			Malvidin 3-O-glucoside	
			Peonidin 3-O-(6"-acetyl-galactoside)	
			Peonidin 3-O-(6"-acetyl-glucoside)	
			Peonidin 3-O-arabinoside	
			Peonidin 3-O-galactoside	
			Peonidin 3-O-glucoside	
			Petunidin 3-O-(6"-acetyl-galactoside)	
			Petunidin 3-O-(6"-acetyl-glucoside)	
			Petunidin 3-O-arabinoside	
			Petunidin 3-O-galactoside	
			Petunidin 3-O-glucoside	
			Peonidin 3-O-glucoside	
			Petunidin 3-O-(6"-acetyl-galactoside)	
			Petunidin 3-O-(6"-acetyl-glucoside)	
			Petunidin 3-O-arabinoside	
			Petunidin 3-O-galactoside	
			Petunidin 3-O-glucoside	
Bilberries	Myricetin	Caffeic acid	Cyanidin 3-O-glucosides	
	Quercetin	p-Coumaric acid	Delphinidin-3-O-glucosides	
		Chlorogenic acid	Peonidin 3-O-glucosides	
		Chlorogenic acid	Petunidin3-O-glucosides	
		Gallic acid 4-O-glucoside	Malvidin 3-O-glucosides	
		Cinanamic acid	Cyanidin 3-O-galactosides	
			Cyanidin 3-O-arabinoside	
			Delphinidin 3-O-arabinoside	
			Peonidin 3-O-arabinoside	
			Petunidin3-O-arabinoside	
			Malvidin s3-O-arabinoside	
Cranberries	Kaempferol 3-O-glucoside	2,4-Dihydroxybenzoic acid	Cyanidin 3-O-arabinoside	
	Myricetin 3-O-arabinoside	3-Hydroxybenzoic acid	Cyanidin 3-O-galactoside	
	Quercetin 3-O-arabinoside	4-Hydroxybenzoic acid	Cyanidin 3-O-glucoside	
	Quercetin 3-O-galactoside	Benzoic acid	Peonidin 3-O-arabinoside	
	Quercetin 3-O-rhamnoside	Vanillic acid	Peonidin 3-O-galactoside	
	Myrecetin	Caffeic acid	Peonidin 3-O-glucoside	
	Quercetin	Cinnamic acid	Cyanidin 3-sophoroside	
		Ferulic acid	Pelargonidin 3-glucoside	
		p-Coumaric acid	pelargonidin 3-rutinoside	
		Sinapic acid		
		4-Hydroxybenzoic acid		
		5-Caffeoylquinic acid		
		Caffeic acid		
		Ferulic acid		
		p-Coumaric acid		
Cherries	Quercetin	3-Caffeoylquinic acid	Cyanidin 3-O-glucoside	(+)-Catechin
	Quercetin 3-glucoside	3-Feruloylquinic acid	Cyanidin 3-O-rutinoside	(-)-Epicatechin
	Quercetin 3-rutinoside	3-p-Coumaroylquinic acid	Pelargonidin 3-O-rutinoside	(-)-Epicatechin 3-O-gallate
	Kaempferol 3-rutinoside	4-Caffeoylquinic acid	Peonidin 3-O-glucoside	(-)-Epigallocatechin
		4-p-Coumaroylquinic acid	Peonidin 3-O-rutinoside	Procyanidin dimer B1

		5-Caffeoylquinic acid	Cyanidin 3-sophoroside	Procyanidin dimer B2
		p-Coumaroylquinic acid	Pelargonidin 3-glucoside	Procyanidin dimer B3
		4-p-Coumaroylquinic acid	Cyanidin 3-O-glucosyl-rutinoside	Procyanidin dimer B4
		5-Caffeoylquinic acid		Procyanidin dimer B5
		5-Feruloylquinic acid		Procyanidin dimer B7
		5-p-Coumaroylquinic acid		Procyanidin trimer C1
Sea Buckthorn	Isorhamnetin	Gallic acid		(epi)gallocatechin
	Kaempferol	p-Coumaric acid		Catechin
	Quercetin	Ferulic acid;		Proanthocyanidin(dimer, trimer, tetramers)
		Ellagic acid		
Viburnum berries	Quercetin	Chlorogenic acid	Cyanidin-3-glucoside	Epicatechin
	Isorhamnetin		Cyanidin-3-rutinoside	Catechin
			Cyanidin 3-sambubioside	
Raspberries	Quercetin-3-glucuronide	Gallic acid	Cyanidin 3-sophoroside	(+)-Catechin)
	Kaempferol-3-glucuronide,	Salicylic acid	Cyanidin 3-glucosylrutinoside	
	Quercetin-3- rutinoside	Caffeic acid	Cyanidin 3-glucoside	
	Quercetin-3-rhamnoside	p-Hydroxybenzoic	Cyanidin 3-rutinoside	
	Apigenin	ferulic acid	Cyanidin 3-sambubioside	
	Naringenin	p-Coumaric acid	Cyanidin 3-rutinoside	
		Cinnamic acid	Cyanidin 3-xylosylrutinoside	
		Vanillic acids acid		
Acai berries	Quercetin	Gallic acid	Cyanidin-3-glucoside	
	Kaempferol	3,4-Dihydroxybenzoic acid	Delphinidin-glucoside	
	Dihydrokaempferol	Chlorogenic acid	Malvidin-glucoside	
		Caffeic acid	Pelargonidin-3-glucoside	
		Syringic acid	Peonidin glucoside	
		Ferulic acid	Cyanidin-3-sambubioside	
		Trans-cinnamic acid	Peonidin 3-rutinoside	
		Vanillic acid		
Maqui berries	Quercetin	Caffeic acid	Cyanidin and delphinidin	
	Dimethoxy-quercetin	Ferulic acid	Cyanidin 3-glucosides	
	Quercetin-3-rutinoside	Gallic acid	Cyanidin 3,5-diglucosides	
	Quercetin-3-galactoside	p-Coumeric acid	Cyanidin 3-sambubiosides	
	Myrecetin	Chlorogenic acid	Cyanidin 3-sambubioside-5-glucosides	
			Delphinidin 3-sambubioside-5-glucosides	
	Kaempferol			
Elderberries	Kaempferol	Chlorogenic	Cyanidin-3-glucoside	+)-Catechin
	Quercetin	neo-chlorogenic acid	Cyanidin 3-sambubioside-5-glucoside	(-)-Epicatechin
	Isorhamnetin	crypto-chlorogenic acid	Cyanidin 3-rutinoside	Proanthocyanidin monomer
	Quercetin 3-O-rutinoside	Caffeic acid	Pelargonidin 3-glucoside	Proanthocyanidin dimer
	Quercetin 3-O-glucoside	p-Coumaric acid	Delfinidine-3-rutinoside	Proanthocyanidin trimer
	Kaempferol 3-O-rutinoside		Cyanidin-3-sambubioside	Proanthocyanidin tetramer
	Isorhamnetin 3-O-glucoside		Cyanidin 3,5-diglucoside	
	Myricetin 3-O-rutinoside		Cyanidin 3-rutinoside	
			Pelargonidin 3-sambubioside	
			Delfinidine-3-rutinoside	
			Petunidin 3-rutinoside	

2.1.3 Health Benefits

Strawberries shows anti-inflammatory, anti-oxidative, anticancer properties, and other health benefits because of the presence of high levels of flavonoids, anthocyanins, and vitamin C. Large number of studies have been investigated to screen their antioxidant activities adopting DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS

(2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid), peroxyl, and superoxide free radical scavenging assays (Wang & Lin, 2000; Kähkönen, Hopia, & Heinonen, 2001, Giampieri, et al., 2012). It has been observed that total phenolic compounds were highly correlated with the radical scavenging activities. Prymont Przyminska et al., (2014) found that daily consumption of strawberries increased the plasma antioxidant activity measured by DPPH assay in healthy subjects (Prymont Przyminska et al., 2014). Strawberries containing anthocyanin crude extracts have been reported to show i*n vitro* antioxidant and anti-proliferative activities in human tumor cell. Ellagic acid and quercetin from strawberries have been shown to promote anti-cancer activity by suppressing the growth of human oral, colon, breast, and prostate cancer cells (Zhang, Seeram, Lee, Feng, & Heber, 2008; Casto, Knobloch, Galioto,Yu, Accurso, & Warner, 2013). *In vivo* and *in vitro* studies demonstrated that strawberries bioactive compounds reduces intracellular reactive oxygen species concentration, increases the activity of antioxidant enzymes, reduces DNA (Deoxyribonucleic Acid) damage; reduces inflammation, reduces oxidative stress, slows down the aging process, treats stomach ulcers, improves plasma lipid profile, and reduces oxidation of low-density lipoproteins (Giampieri, et al., 2012, Basu, Morris, Nguyen, Betts, Fu, & Lyons, 2016)). Agarawal et al., (2019) has reported that consumption of strawberries reduces the risk of Alzheimer’s dementia (Agarwal, Holland, Wang, Bennett, & Morris, 2019). Schell et al. (2017) reported that dietary strawberries supplemented to obese adults suffering from osteoarthrities have resulted analgesic and anti-inflammatory effects (Schell et al., 2017). Basu et al., (2016) reported that dietary strawberry selectively increased plasma antioxidant biomarkers in obese adults with elevated lipids (Basu, Morris, Nguyen, Betts, Fu, & Lyons, 2016).

2.2 Blueberries

2.2.1 Source

Historically, blueberries have been a popular fruit due to their well-known health and nutritional benefits. Blueberries belongs to family *Ericacea* and genus *Vaccinum*. Numerous species (approx. 450) of blueberries are grown wildly or cultivated worldwide. Major commercially available blue berries that are grown across the worldwide are rabbit eye blueberries (*Vaccinium ashei*), lowbush blueberry (*Vaccinium angustifolium* A.) and highbush blueberry (*Vaccinium corymbosum* L.). USA is the largest producer of blue berries in world after Australia and Canada. However various part of the Europe and other countries produce blueberries commercially. Blueberries are highly perishable and therefore blueberries are processed after harvesting. Various postharvest techniques for storage and processing are applied to prolong their shelf lives and preserve quality properties of blueberry.

2.2.2 Composition

Blueberries are packed with various nutrients and bioactive active compounds. They are listed top of the superfoods. Blueberries are the richest source of polyphenolic compounds. It also contains several vitamins including vitamin C. Numerous studies have been carried out to screen the level polyphenolic compounds including analysis by chromatographic and mass spectrophotometric analysis. Analysis in the content of total phenolic compounds and total anthocyanins demonstrated that it has several folds differences among the different varieties depending on the geographic location and agricultural practices. Major polyphenolic compounds of blueberries are flavonols (mainly quercetin derivatives), anthocyanins, flavan-3-ols, proanthocyanidins, and phenolic acids (Table 1). Among the phenolic acids of blueberries hydroxycinnamic and hydroxybenzoic acids and their derivatives such as chlorogenic, caffeic, gallic, p-coumaric, ferulic, ellagic, syringic, vanillic acids are common (Kalt & McDonald, 1996;Kalt, Forney, Martin, & Prior, 1999, Gu et al., 2004; Rodriguez-Mateos, Cifuentes-Gomez, Tabatabaee, Lecras, Spencer, 2012,;). Anthocyanins are the major polyphenolic compounds comprising 60% of total phenolic compounds in blue berries. In a study of 215 phenotypes of blueberries cyanidin-3-glucoside was reported to be the major again among the anthocyanin compounds (Kalt, et al., 2001). In some other studies it was found that malvidin, delphinidin, petunidin, and peonidin are the major components comprising 75% of all identified anthocyanins (Scibisz & Mitek, 2007; Routray & Orsat, 2011).The composition and levels of anthocyanins in blueberries vary with cultivars and varieties. The color of blueberries also varies with the composition of anthocyanins (Routray & Orsat, 2011). The level of polyphenolic compounds differs with maturity stages of blueberries where ripening stages showed higher level of anthocyanins than the other phenolic compounds. Postharvest condition such as oxygen level, temperature, and light of blueberries impacts the nutritional quality and phenolic contents (Kalt, Forney, Martin, & Prior, 1999).

2.2.3 Health Benefits

Blueberries have tremendous pharmacological properties. Consumption of blueberries help in controlling diabetes and its complication such as lowering blood pressure and blood cholesterol (Martineau, et al., 2006; Basu, et al.,2010; Stull, Cash, Johnson, Champagne, & Cefalu, 2010, McAnulty, Collier, Pike, Thompson, & McAnulty, 2019). It possesses anti-diabetic properties and help to protect pancreatic β-cells from glucose-induced oxidative stress (Al-Awwadi, et al., 2005; Martineau, et al., 2006). It has been reported that consumption of blueberry significantly reduced H_2O_2-induced DNA damage (Del Bo′, et al., 2013). Phytochemicals present in blueberry could inhibit the growth and metastatic potential of breast and colon cancer cells (Adams, Phung, Yee, Seeram, Li, & Chen, 2010; Schantz, 2010). It was found that pure anthocyanins, such as cyanidin, delphinidin, as well as peonidin 3-glucoside, suppressed growth of human tumor cells and apoptosis of colon and breast cell line. In a recent clinical study comprising 52 US adult veterans reported that consumption of 22 g freeze-dried blueberries for 8 weeks could beneficially affect cardiometabolic health parameters in men with type 2 diabetes (Stote, et al., 2020). Recently Rodriguez-Daza et al., (2020) revealed the key role of blueberry extract with proanthocynaidins in modulating the gut microbiota and restoring colonic epithelial mucus layer triggering health effects of blueberry polyphenols (Rodriguez-Daza et al., 2020). Moreover Türck, et al., (2020) evaluated the effect of blueberry extract on functional parameters and oxidative stress levels in rat lungs with pulmonary arterial hypertension (PAH) and reported that intervention with blueberry extract mitigated functional PAH outcomes through improvement of the pulmonary redox state (Türck et al., 2020). Tian et al., (2019) reported that cyanidin-3-arabinoside extracted from blueberry as a selective Protein Tyrosine Phosphatase 1B Inhibitor (PTP1B) which is an important target for type 2 diabetes (Tian et al., 2019). PTP1B inhibitors can reduce blood glucose levels by increasing insulin sensitivity. Jielong et al., (2019) reported that extracts of blueberry reduces obesity complications through the regulation of gut microbiota and bile acids via pathways involving FXR(Farensoid X Receptor) and TGR5 (Jielong, Xue, Hongyu, Weidong, Yilin, & Jicheng, 2019).

2.3 Bilberries

2.3.1 Source

Bilberry (*Vaccinium myrtillus* L.) a small dark blue berry belongs to *Ericacea* family and is native to Europe and North America. Bilberry is also known as European blueberry differs from blueberry relative to *Vaccinium corymbosum* and *Vaccinium angustifolium* with their morphology and flesh color. The blue coloration is due to its high content in anthocyanin (Prior et al., 1998). Cultivation of bilberries have been increasing continuously during several years.

2.3.2 Composition

Bilberry contains several polyphenolic compounds such as lignin, flavonoids, tannins, and phenolic acids (Bravo, 1998) (Table1). Among flavonoids of bilberries anthocyanins are the major compounds while simple phenolics constitute phenolic acids such as cinnamic acid, gallic acid, caffeic acid, and chlorogenic acid (Puupponen-Pimiä et al., 2001; Taiz & Zeiger, 2006). The bilberries contain five different anthocyanidins comprising cyanidin, delphinidin, peonidin, petunidin, and malvidin with three sugar moieties viz., 3-O-arabinoside, 3-O-glucosides and 3-O-galactosides (Martinelli, Baj, Bombardelli, 1986).

2.3.3 Health Benefits

Due to the presence of anthocyanins as major bioactive compounds in bilberry fruit it exhibits several health-promoting properties (Park, Shin, Seo, Kim, 2007; Schantz, Mohn, Baum, & Richling, 2010, Pieberger et al., 2011; Kolehmainen et al., 2012). Recently, Arevstrom et al., (2019) in a study involving 50 patients found that bilberry powder supplementation (40 g/day) over eight weeks significantly reduced both total and LDL (low-density lipoprotein) cholesterol compared to baseline (Arevstrom et al., 2019). Karlsen et al., (2010) investigated the effect of bilberry juice on serum and plasma biomarkers of inflammation and antioxidant status in subjects with elevated levels risk factor for cardiovascular disease (CVD) and found that supplementation with bilberry polyphenols modulated the inflammation processes (Karlsen et al., 2010)). Triebel et al., (2012) investigated the influence of bilberry (*Vaccinium myrtillus* L.) extract containing anthocyanins on pro-inflammatory genes in IFN-γ/IL-1β/TNF-α stimulated human colon epithelial cells (T84) and demonstrated that anti-inflammatory activity mostly depends on the aglycon structure and the sugar moiety of the billberry anthocyanin (Triebel, Trieu, & Richling, 2012). Roth et al., (2014) reported that bilberry-derived anthocyanins reduced IFN-γ-induced pro-inflammatory gene expression and cytokine secretion in human THP-1 monocytic cells (Roth, Spalinger, Müller, Lang, Rogler, & Scharl, 2014). These findings suggested a crucial role for anthocyanins in modulating inflammatory responses. Billberry extract showed antihypoglycemic effect by inhibition the action of intestinal α-glucosidase activity (Martineau et al., 2006). Takkikawa et al., (2010) investigated antidiabetic activities of billberry extract and found that dietary anthocyanin-rich bilberry extracts ameliorated hyperglycemia and insulin sensitivity in diabetic mice (Takikawa, Inoue, Horio, & Tsuda, 2010). In another study Cignarella, et al., (1996) found that bilberry extract decreased levels of plasma glucose and triglycerides in streptozotocin (STZ)-induced diabetic mice (Cignarella, Nastasi, Cavalli, & Puglisi, 1996).

2.4 Cranberries

2.4.1 Source

Cranberries (*Vaccinium macrocarpon* Ait.) also known as lowbush cranberries are native to USA belongs to *Ericaceae* family. USA is the world leader of cranberry producer with 90% of world production. Cranberries are consumed as fresh fruits, dried, jams, and juices. The US per capita consumption of cranberries is raising continuously mostly in the form of juices and remains at the top of healthy drinks.

2.4.2 Composition

Cranberries are rich source of various phytochemical compounds viz., flavan-3-ols, A type procyanidins (PACs), anthocyanins, benzoic acid, ursolic acid, and vitamin C (Table1). Among the PAC's comprising catechin, epicatchin, epigallocatechin cranberries have been known to have epicatechin as the major one. Although many fruits have proanthocyanidins but only cranberry have significant level of A type PAC. Recently Wang et al., (2020) investigated the analysis of cranberry proanthocyanidins using UPLC (Ultra Performance-ion mobility-high-resolution mass spectrometry and identified total of 304 individual A-type and B-type proanthocyanidins, including 40 trimers, 68 tetramers, 53 pentamers, 54 hexamers, 49 heptamers, 28 octamers, and 12 nonamers (Wang, Harrington, Chang, Wu, & Chen, 2020). Anthocyanins in cranberries are composed of glycosides of the 6 aglycones with cyanidin, peonidin, malvidin, pelargonidin, delphinidin, and petunidin (Wu, & Prior, 2005). The major phenolic acid including hydroxycinnamic acids in cranberry are p-coumaric, sinapic, caffeic, and ferulic acids. Quercetin is the major flavonol compound present in cranberries. Ellagic acid with and without glucosides represent more than 50% of total phenolic compounds. However, level of phenolics and anthocyanins depends on the maturation stage of the cranberries.

2.4.3 Health Benefits

Cranberries have been used for several decades to prevent urinary tract infection. This health benefit is attributed to cranberries because proanthocyanidin can prevent adhering of *Escherichia coli* to uroepithelial cells in the urinary tract (Ermel, Georgeault, Inisan, Besnard, 2012). After consumption juice and various products of cranberries it was also believed to enhance the plasma antioxidant activities (Pedersen et al., 2000). In vitro study confirmed that cranberry extracts inhibited activities of angiotensin converting enzyme and thus it showed the potential in lowering blood pressure (Apostolidis, Kwon, & Shetty, 2006). Cranberry also helped to reduce the cardiovascular disease risks and to protect against lipoprotein oxidation. Several studies confirmed that cranberries bioactive compounds have anti-cancer and antimutagenic activities (Prasain, Grubbs, & Barnes, 2020; Howell, 2020). Recently Hsia et al., (2020) investigated that whether consumption of cranberry beverage would improve insulin sensitivity and other cardiovascular complications and reported that daily consumption for 8 weeks may not impact insulin sensitivity but could be helpful in lowering triglycerides and alters some oxidative stress biomarkers in obese individuals with a proinflammatory state (Hsia, Zhang, Beyl, Greenway, & Khoo, 2020). Chew et al., (2019) reported the health benefits of cranberry beverage consumption on gluco regulation, oxidative damage, inflammation, and lipid metabolism in healthy overweight humans (Chew et al., 2019). Consumption of significant amount of cranberry beverage improved antioxidant status and reduced cardiovascular disease risk factors by improving glucoregulation, downregulating inflammatory biomarkers, and increasing HDL cholesterol.

2.5 Viburnum Berries

2.5.1 Source

Viburnum opulus L. (Adoxaceae), commonly known as European guelder, is also called as European cranberry bush, guelder rose, cherry-wood, and snowball bush. It grows in Europe, North and Central Asia, and North Africa. Viburnum is commonly used both in conventional and folk medicine in Russia. The State Pharmacopoeia of the Russian Federation (XI edition, issue 2) contains a monograph on the preparation of Viburnum fruits, and two medicinal drugs with Viburnum fruits are entered in the State Register of Medicinal Remedies of the Russian Federation. While parts of viburnum such as bark, flowers, and fruits are widely used in traditional medicine some fruits are used as cooking ingredients. In Russia, Ukraine, and among many Siberian nations the *viburnum opulus* (VO) fruits are used in traditional cuisine such as marmalades, jams, and "Kalinnikov" pies, and herbal teas.

2.5.2 Composition

Viburnum opulus contain high level phenolic compounds such as hydroxybenzoic acids, tannins, flavonoids, anthocyanins, chlorogenic acid, catechin, epicatechin, cyanidin-3-glucoside, cyanidin-3-rutinoside and quercetin (Velioglu, Ekici, & Poyrazoglu, 2006; Perova, I. B., Zhogova,Cherkashin,Éller, &Ramenskaya, 2014).) (Table 1). In an investigation to profile phenolic compounds in viburnum berries using high-performance liquid chromatography Velioglu et al., (2006) identified chlorogenic acid (upto 2037 mg/kg), catechin, epicatechin, cyanidin-3-glucoside, cyanidin-3-rutinoside and different glucosides of quercetin and cyanidin derivatives (Velioglu, Ekici, & Poyrazoglu, 2006). Zakłos-Szyda (2019) has identified and quantified the major phenolic compounds where they reported chlorogenic acid as main component. Catechin was found to second most abundant phenolic compounds and Cyanidin 3-sambubioside was found to be major anthocyanin (Zakłos-Szyda, Majewska, Redzynia, & Koziołkiewicz, 2019). In addition to these flavonol compounds quercetin-pentose, quercetin-hexose, quercetin-deoxyhexose and isorhamnetin glycosides, rutin and isorhamnetin were obtained. Çam et al. (2007) have showed that *Viburnum Opulus* seeds are also good source of total phenolics and flavonoids (Çam, Hisil, & Kuscu, 2007).

2.5.3 Health Benefits

Viburnum opulum phenolic compounds impart various health beneficial properties. Number of in vitro studies reported high antioxidant activities by viburnum berries. Zakłos-Szyda et al, (2019) investigated the antioxidant activities of *viburnum opulus* and reported the strong correlation between total phenolics and radical scavenging activities such as ABTS and ORAC with high Pearson's correlation coefficients, r = 0.993 and 0.991 respectively(Zakłos-Szyda, Majewska, Redzynia, & Koziołkiewicz, 2019). Similar linear relationships between phenolics and antioxidants activities were observed by Karaçelik et al., (2015) in their study of identification of bioactive compounds of *Viburnum opulus L.* using on-line HPLC-UV-ABTS (High Performance Liquid Chromatography-Ultra violet- 2,2′-azinobis-(3-ethylbenzothiazoline-6-sulfonic acid) radical scavenging assay and LC-UV-ESI-MS (Liquid Chromatogrpahy-Ultra Violet Electro Spray Ionization Mass Spectrometry) (Karaçelik et al., 2015). *Viburnum opulus* extract also showed anticancer activities. *In vitro* studies using Caco-2 cell culture indicated that *Viburnum opulus* phenolic rich fraction prompted to decrease the uptake of free fatty acids and lower the accumulation of glucose and lipids by Caco-2 cells without affecting their viabilities (Zakłos-Szyda, Majewska, Redzynia, & Koziołkiewicz, 2019). Moreover i*n vivo* antitumoral activity of *Viburnum opulus* were confirmed by Ceylan et al., (2018) in Ehrlich ascites tumor model. Phenolic extract of *Viburnum. opulus* fruit also reported to be strong inhibitor of α-amylase, α-glucosidase, and/or PTP-1B phosphatase enzymes involved in lipid and carbohydrate metabolism (Zakłos-Szyda, Majewska, Redzynia, & Koziołkiewicz, 2015).

2.6 Cherries

2.6.1 Source

Cherry is one of the major small fruits with bigger benefits belongs to family: *Rosaceae* and genus: *Prunus.* It is one of the major berries native to United States and is the second-largest producer in the world. The two major types of cherries are sweet cherries (*Prunus avium*) and tart or sour cherries (*Prunus cerasus*).

2.6.2 Composition

Sweet and sour cherries are distinguished from each other by their ratios of sugars (e.g., glucose, fructose, and others) to organic acids (mainly maleic acid). Cherries are rich source vitamins A, B, C, E, K, carotenoids, minerals, and phenolic compounds. Sour cherries have higher contents of vitamin A and betacarotene. Tart cherries contain significant levels of melatonin (13.46 ± 1.10 ng/g and 2.06 ± 0.17 ng/g in Balaton and Montmorency, respectively) (Burkhardt, Tan, Manchester, Hardeland, & Reiter, 2001). Chemical profiling of tart cherries indicated presence of cyanidin 3-glucoside, cyanidin 3-rutinoside, cyanidin 3-sophoroside, pelargonidin 3-glucoside, pelargonidin 3-rutinoside, peonidin 3-glucoside, and peonidin 3-rutinoside as important flavonoids (Kirakosyan, Seymour, Llanes, Daniel, Kaufman, & Bolling, 2008) (Table 1). Among phenolic acids, hydroxycinnamates (neochlorogenic acid and p-coumaroylquinic acid) are reported to present in significant levels. Cherries also contain flavonols and flavan-3-ols such as catechin, epicatechin, quercetin 3-glucoside, quercetin 3-rutinoside, and kaempferol 3-rutinoside. Different cultivars of sweet and sour cherries have different levels of phenolics and flavonoids. For example, in a study Kim et al., (2005) studied different cultivars it was found that total anthocyanins of sweet cherries were 30 - 79 mg cyanidin-3-glucoside equivalents (CGE)/100 g, whereas in sour cherries these were 45 - 109 mg CGE/100g (Kim, Heo, Kim, Yang, & Lee, 2005).

2.6.3 Health Benefits

Various studies demonstrated that tart cherries extract, and its compounds showed strong antioxidant activities

(Blando, Gerardi, & Nicoletti, 2004). Kirakosyan et al., (2008) reported the high TEAC (trolox equivalent antioxidant capacity) of two tart cherries viz Balaton and Montmorency and cyanidin and its derivatives were found to be the important antioxidants in the assays (Kirakosyan, Seymour, Llanes, Daniel, Kaufman, & Bolling, 2008). Numerous studies indicated that cherry consumption inhibited inflammatory pathways. Consumption of cherries also helped to lower blood pressure, control blood glucose, protect against oxidative stress, and reduce inflammation (Martin, Burrel, & Bopp, 2018; Martin, & Coles, 2019). Kelley *et al.* (2006) showed that intake of sweet cherries decreased levels of C-reactive protein (CRP), a biomarker for inflammation and cardiovascular disease in healthy subjects (Kelley, Rasooly, Jacob, Kader, Mackey, 2006). *In vitro* and *in vivo* studies suggested that anti-inflammatory properties of polyphenolic compounds of cherries evidenced by the inhibition of activity of the cyclooxygenase II (COX II), another biomarkers for inflammation, carcinogenesis, cell proliferation, and angiogenesis (Wang, Nair, & Strasburg,1999). Consumption of Cherry also showed to lower serum urate levels and inflammation (Martin, & Coles, 2019). Zhang et al., (2012). reported that cherry consumption affected the risk of recurrent gout attacks (Zhang, Neogi, Chen, Chaisson, Hunter, & Choi, 2012). Recently Lamb et al., (2020) also demonstrated the effect of tart cherry juice to reduce risk of recurrent gout flare (Lamb, Lynn, Russell, & Barker, 2020). Di Bonaventura et al., (2020) indicated that tract cherry has potential role to prevent obesity-related risk factors, especially neuroinflammation based on a rat model study (Di Bonaventura et al., 2020). In a mice model study Smith et al., (2019) found that cherry supplementation (5% and 10%) improved bone mineral density (BMD) and some indices of trabecular and cortical bone microarchitecture and they proposed that these effects were likely attributed to increased bone mineralization (Smith et al., 2019).

2.7 Sea Buckthorn Berries

2.7.1 Source

Sea buckthorn, known as seaberry, (*Elaeagnus rhamnoides L*.) belongs to the family *Elaeagnaceae*. Even though sebuckthorn is cultivated mostly in Russia and China, now a days it is cultivated around other countries like Finland, Germany, and Estonia.

2.7.2 Composition

Sea buckthorn have been found to have a range of bioactive compounds including vitamin A, C, E, carotenoids, minerals, and polyphenols (Olas, 2016; Gradt, Kuhn, Morsel, & Zvaigzne, 2017). A recent intensive analysis on composition of seabuckthorn berries indicated the presence of 21 phytochemicals such as isorhamnetin, quercetin, kaempferol glycosides and catechin. Phenolic compounds also include primarily proanthocyanidins, gallocatechins and flavonol glycosides (Dienaitė, Pukalskas, Pukalskienė, Pereira, Matias, & Venskutonis, 2020) (Table 1). Criste et al., (2020) also reported that seabuckthorn berries are great source of phenolic compounds such as derivatives of quercetin and hydrocinnamic acid. (Criste et al., 2020).

2.7.3 Health Benefits

Sea buckthorn exhibits a wide spectrum of pharmacological activities such as anti-inflammatory, anticancer, antioxidant, and anti-atherosclerotic activities (Zeb, 2006; Basu, Prasad, Jayamurthy, Pal, Arumughan, & Sawhney, 2007; Olas, 2016). They also induce apoptosis and strengthen the immune system. In a study on the content and antioxidant activities of phenolic compounds of seabucthorn Gao et al., (2000) reported that antioxidant activities were strongly correlated with the content of total phenolic compounds and ascorbic acid (Gao, Ohlander, Jeppsson, Bjork, & Trajkovski, 2000). It was also found that antioxidant activity of the lipophilic extract correlated with the total carotenoids content. A strong correlation existed between flavonoid content in seabuckthorn and their antioxidant activities ($r = 0.96$) (Criste et al., 2020). To investigate other health benefits recently Guo et al., (2020) reported that administration of freeze-dried seabuckthorn powder lowered body weight, Lee's index, adipose tissue weight, liver weight, and serum lipid levels induced by obesity (Guo, Han, Li, & Yu, 2020). Tkacz et al., (2019) reported high *in-vitro* anti-oxidant and anti-enzymatic activities related to digestion system due to the presence of phytochemicals such as phenolic acids, flavonols, xanthophylls, carotenes, tocopherols, and tocotrienols(Tkacz, Wojdyło, Turkiewicz, Bobak, & Nowicka, 2019). Number of studies reported that seabuckthorn oil exhibits anti-tumor properties due to the presence flavonoid compounds kaempferol, quercetin, and isorhamnetin (Christaki, 2012). Hao et al., (2019) found that seabuckthorn seed oil extracts were effective in reducing blood cholesterol in hypercholesterolemia hamsters (Hao et al., 2019).

2.8 Raspberries

2.8.1 Source

Raspberries, a popular soft fruit grown in Eastern Europe belongs to the family *Rosaceae* and genus *Rubus*. It is cultivated all over the world mainly in Europe (European red raspberry), North America (American variety), and

Asia. In the early of 19th century raspberries were grown in the United State of America. Now it is the third highest producer of raspberries. Black raspberries are also grown commercially in America. Purple raspberries are the hybrid of red and black raspberries. There are approximately 250 species of *Rubus* genera fruits however red raspberry (*Rubus idaeus L.*), the North American red raspberry (*R. idaeus*), and the black raspberry (*Rubus occidentalis L.*) are the most important commercial varieties (Wu, et al., 2019).

2.8.2 Composition

Raspberries are considered as healthy superfruits due to their rich source of vitamins C, A, B, B1, B2, E, folic acid, polyphenols, anthocyanins, and minerals. Raspberry as fruits are rich sources of polyphenols such as flavonoids, phenolic acids, ellagitannins, and ellagic acid. Among anthocyanins the major components in red raspberries (*R. idaeus*) are cyanidin 3-sophoroside, cyanidin 3-glucosylrutinoside, cyanidin 3-glucoside and cyanidin 3-rutinoside (Table 1). Black raspberries (*Rubus occidentalis*) have cyanidin 3-sambubioside, cyanidin 3-rutinoside, and cyanidin 3-xylosylrutinoside. Ellagitannins and their derivative ellagic acid are other important hydrolysable tannins bioactive compounds that are available in fruit pulp and seeds of raspberries. Other biologically active phenolic compounds are quercetin-3- glucuronide and kaempferol-3-glucuronide, flavan-3-ols (catechin), and phenolic and hydroxy acids (gallic, salicyl, caffeic, p-hydroxybenoic, ferulic, p-cumaric, cinnamic and vanillic acids (Määttä-Riihinen, Kamal-Eldin, & Törrönen, 2004; Tian, Giusti, Stoner, & Schwartz, 2006; Mazur, Nes, Wold, Remberg,& Aaby, 2014)).

2.8.3 Health Benefits

Raspberries confers significant antioxidant activities because of their polyphenolic compounds. (Lee, Dossett, & Finn, 2012; Chen, Xin, Zhang, & Yuan, 2013). Raspberries have been known to use traditional drug such as antipyretic and diaphoretic drug. It has been used in managing diabetes and hypertension, and inflammation (Liu,Schwimer, Liu, Greenway,Anthony, & Woltering, 2005; Cheplick, Kwon, Bhowmik, & Shetty, 2007; Medda et al., 2015). Polyphenol compounds of raspberries exerted antiproliferative activities against cervical and colon cancer cells (McDougall, Ross, Ikeji, & Stewart, 2008). The raspberries extract also showed anti-proliferative activities against colon, prostate, breast, and oral cancer cells. (Wedge et al., 2001; Seeram et al., 2006; Ross, McDougall, & Steward, 2007; Peiffer, 2018). Raspberry phenolics exhibited antimicrobial and antiviral activities. A growing evidence was found that berries could modify the composition of the gut microbiota (May, McDermott, Marchesi & Perry, 2020). Recently Tu et al., (2020) investigated that administration of a diet rich in black raspberry changed the composition and diverse functional pathways in the mouse gut microbiome which suggested important role of the gut microbiome in the health effects of black raspberry extract (Tu et al., 2020).

2.9 Acai Berries

2.9.1 Source

Açaí palm fruit, belongs to family *Arecaceae* and genus *Euterpe.* They are native to South America and grows significantly in the Amazon River delta in Brazil. Two primary species of açaí fruit that are popular are *Euterpe precatoria* (EP) and *Euterpe oleracea* (EO).They are highly consumed by the native people in that region but it has gained international reputation because of their potential nutrition and health benefits. The use of açaí berries by native people to treat malaria related symptoms such as fever, pain, inflammation, and anemia has been seen long time. In the US marketplace commercial products containing açai fruit have been increasing rapidly during recent years (Lee, 2019).

2.9.2 Composition

Açaí fruit is a great source of polyphenolic compounds such as anthocyanins and phenolic acids (Yamaguchi, Pereira, Lamarão, Lima, & Da Veiga-Junior, 2015) (Table 1). However, there were significant differences in the levels of these phytochemicals between the species such as *Euterpe precatoria* (EP) and *Euterpe oleracea* (EO). EP reported to have higher level of polyphenolic compounds compared to EO (Xie et al, 012). The major derivatives of anthocyanins in these berries are cyanidin-3-glucoside and cyanidin-3-rutinoside. In a study by Poulose et al., (2014) reported the level of anthocyanin content in the EP and EO extracts were very significant such as 2035 -66 ng/mg; cyanidin 3-glucoside, 18434 - 575 ng/mg ; cyanidin 3-rutinoside, 113 - 220 ng/mg; delphinidin-glucoside, 538 - 27 ng/mg, for malvidin-glucoside, 84 -8 ng/mg; pelargonidin-glucoside, and 371 - 65 ng/mg for peonidin glucoside. Other phenolic compounds such as catechins, ferulic acid, quercetin, resveratrol, and vanillic acid were also greatly varied between the two species.

2.9.3 Health Benefits

Due to the presence of various polyphenolic composition, açaí berries exhibit important health benefits. Various cell and animal model studies indicated that açaí extracts showed antioxidant, anti-inflammatory, anti-atherosclerotic, anti-aging, analgesic, and neuromodulatory properties.

Through antioxidant and anti-inflammatory activities acai berry extracts reduced the risk of atherosclerosis (Mertens-Talcott et al., 2008). Moreover, Xie et al. (2012) proposed that anti-inflammatory activities were attributed to the flavone velutin (Xie, et al., 2012). *In-vivo* and *in-vitro* cell and animal model study confirmed that extracts of acai fruits reduce oxidative stress and neuroinflammation via inhibition of activities and expression of nitrous oxide synthase (iNOS), cyclooxygenase-2 (COX-2), p38 mitogen-activated protein kinase (p38- MAPK), tumor necrosis factor-α (TNF-α), and nuclear factor κB (NF-κB) (Poulose et al., 2012). Extract of açaí fruit pulp specially from EO protected from neurotoxicity induced by lipopolysaccharide in mouse brain (Noratto, Angel-morales, Talcott, & Mertenstalcott, 2011; Poulose et al., 2012). In addition to the *in vivo* and *in vitro* antioxidant and anticancer activities it was reported that Açaí juice from EO exhibited neuroprotective, anticonvulsant, and anti-seizure properties (Souza-Monteiro et al., 2015). Ferriera, et al., (2019) investigated potential use of acąí polyphenols as novel antimalarial compounds *in vitro* and *in vivo* and indicated its potential effects of proteostasis as major molecular target (Ferriera, et al., 2019). Magalhães et al., (2020) demonstrated the protective effect of açaí pulp components on intestinal damage in 5-fluorouracil-induced Mucositis, as well as the ability to control the response to oxidative stress, in order to mobilize defense pathways and promote tissue repair (Magalhães et al., 2020). Recently de Liz et al., (2020) evaluated the effects of moderate-term açaí juice intake on fasting glucose, lipid profile, and oxidative stress biomarkers in healthy subject by assigning 200 mL/day for four weeks and collected blood before and after consumption. They found that there were increased the concentrations of HDLC (high- density lipoprotein cholesterol) by 7.7%, TAC (total antioxidant capacity) by 66.7%, antioxidant enzyme activities catalase by 275.1%, and glutatathone peroxidase activity by 15.3% (de Liz et al., 2020).

2.10 Maqui Berries

2.10.1 Source

Maqui berry (*Aristotelia chilensis*), belongs to the family *Elaeocarpaceae*. This purple berry is native to Chile (Aristotelia chilensis) is one of the emerging Chilean superfruit with high nutraceutical value. It is consumed as fresh and dried fruits or also used to make tea, jam, cakes, drink, juice, alcoholic beverages.

2.10.2 Composition

Maqui berry are one of the richest sources of polyphenol compounds. The total phenol content of maqui berry is reported to be much higher than even superfruits blue berries (97 μmol GAE g^{-1} FW and 17 μmol GAE g^{-1} FW respectively) (Ruiz et al., 2010). Major phenolic compounds in Maqui berries are phenolic acids and flavonoids that includes flavonols, flavanols, and anthocyanins (Table 1). Among polyphenols maqui berries have highest level of anthocyanins. The major anthocyanins are 3-glucosides, 3,5-diglucosides, 3-sambubiosides and 3-sambubioside-5-glucosides of cyanidin and delphinidin (delphinidin 3-sambubioside-5-glucoside). Other flavonoids compounds are quercetin and its derivatives such as dimethoxy-quercetin, quercetin-3-rutinoside, quercetin-3-galactoside, dimethoxy-quercetinand ellagic acid.

2.10.3 Health Benefits

Maqui berry is reported to exhibit high antioxidant activities. The ORAC values of maqui was found to be 37,174 μmol Trolox per 100 g of dry weight which was much higher than in commercial berries such as raspberries, blueberries and blackberries cultivated in Chile (Speisky, López Alarcón, Gómez, Fuentes, & Sandoval Acuña, 2012). Bastías-Montes (2020) et al., also recently showed that seed oil from Maqui berry and their tocols (α, β, γ, δ-tocopherols, tocotrienols, and β-sitosterol) promoted for clinical investigation due to their high antioxidative and antiobesity potential against DPPH, HORAC (Hydroxyl Radical Antioxidant Capacity), ORAC (Oxygen Radical Absorbance Capacity), FRAP (ferric reducing antioxidant power), Lipid-peroxidation (TBARS), α-amylase, α-glucosidase, and pancreatic lipase (Bastías-Montes et al., 2020). The purified delphinidin extract maqui berry helped in the generation of nitrogen oxide (NO) in endothelial cells, decreased platelet adhesion, and possessed anti-inflammatory effects. Miranda-Rottmann, et al., (2002) reported that maqui berry extracts could prevent the oxidation of low-density lipoproteins and protected the cultures of human endothelial cells (Miranda-Rottmann, Aspillaga, Pérez, Vasquez, Martinez, & Leighton, 2002). Maqui berries are used as dietary management in patients with respiratory disorders as anthocyanin maqui extract could normalize H_2O_2 and IL-6 concentrations in exhaled breath condensates (EBC) by asymptomatic smokers (Vergara, Ávila, Escobar, Carrasco-Pozo,, Sánchez, & Gotteland,2015). Recently Zhou et al., (2019) reported that ethyl acetate fraction from maqui berry crude extract was rich in phenols and exhibited strong antioxidant and anti-inflammatory activities. They suggested that there was a possible prevention of cognitive damage due to the antioxidant activity of the maqui berry (Zhou et al., 2019). In a study with male rat brain exposed to ozone and treatment with extract of Maqui berry it was found that maqui berry extracts improved memory and decreased oxidative stress (Bribiesca-Cruz, Moreno, García-Viguera, Gallardo, Segura-Uribe, Pinto-Almazán, & Guerra-Araiza, 2019).

2.11 Elderberries

2.11.1 Source

Elderberry (*Sambucus nigra)* is one of the richest sources of anthocyanins and are used as great source for production of antioxidants, colorants, and bioactive compounds industrially. Traditionally they have been used as medicinal components and food ingredients in fruits, jams, and juices. They are also more frequently used in the manufacture of various types of liqueurs.

2.11.2 Composition

Nutritional composition analysis reported that elderberry is a good source of nutrients like protein, amino acids, dietary fibres, vitamin B, A, and C phytochemicals. Some elderberries have higher level of organic acid and lower level of sugars which is important to industrially processing foods. More significantly elderberry is one of the richest sources of bioactive compounds like flavonols, flavanols, phenolic acids, proanthocyanidins, and anthocyanins (Table 1). Elderberries have been reported to have high level of anthocyanins containing total anthocyanin levels upto 1816 mg/100g FW. Major anthocyanins in elder berries are cyanidin-3-O-sambubioside-5-glucoside, cyanidin-3,5-diglucoside, cyanidin-3-O-sambubioside, yanidin-3-rutinoside, cyanidin-3-glucoside, cyanidin-3-sambubioside, pelargonidin 3-glucoside, pelargonidin 3-sambubioside, and delfinidine-3-rutinoside. However, their levels vary with different cultivars. Some other anthocyanins are also present in trace amounts. Major flavonols in elderberries were derivatives of quercetin, kaempferol and isorhamnetin. In the quercetin group quercetin 3-rutinoside and quercetin 3-glucoside were found to be in significant level. Among phenolic acids chlorogenic, crypto-chlorogenic and neochlorogenic acids were identified as major while small amounts of ellagic acids were also available in elderberry fruits. Proanthocyaninidins with monomers, dimers, and trimers, and tetramars have been found in elderberries (Veberic, Jakopic, Stampar, & Schmitzer, 2009; Mikulic-Petkovsek, et al., 2014; Sidor, & Gramza-Michałowska, 2015; Młynarczyk, Walkowiak-Tomczak, & Łysiak, 2018;).

2.11.3 Health benefits

Elderberry has been used as folk medicine for the treatment of common cold, fevers, allergies, and ailments. Several reports demonstrated that elderberries are associated with antioxidant, anti-inflammatory, antibacterial, antiviral, and inflammation properties and various health beneficial properties (Sidor & Gramza-Michałowska, 2015; Porter & Bode, 2017; Olejnik, et al., 2015). Antioxidant activities of elderberries and its extracts were confirmed by *in vitro* antiradical activity assays viz., DPPH, ABTS, hydroxyl, and peroxyl. However, the potency of antioxidant activities depended on the assay, method of extraction bioactive compounds as well as type of elderberry cultivars. In some studies, it showed a less activities than choke berries and black berries and whereas in some other studies it showed higher than other berries (Viskelis, Rubinskienė, Bobinaitė, & Dambrauskiene, 2010; Wu et al. (2004)). Wu et al. (2004) investigated ability of elderberry extract to scavenge the peroxyl radical (ROO•) in the ORAC assay and reported upto 5783 µmol TE/g extract which was higher than the activity of other extract of berries in the respective assay (Wu, Gu, Prior, & McKay,2004). *In vivo* studies showed that an enhanced plasma and serum antioxidant activity was observed after consumption of elderberry (Netzel et al. (2005).

Several studies indicated the antidiabetic properties of elderberry extract. Administration of elderberry extract to diabetic rats helped to maintain glycemic index and reduced the increase in glycemia (Badescu, Badulescu, Badescu, & Ciocoiu, 2012). Bhattacharya et al., (2013) reported the possible role of elderberry in the prevention and treatment of diabetes via the increasing in the secretion of insulin (Bhattacharya et al., 2013). Ho et al., (2017 a, b) reported that elderberry extracts showed high stimulation of glucose uptake in human liver cells and human skeletal muscle cells and inhibitory effect towards carbohydrate hydrolyzing enzymes after treatment with elderberry extracts (Ho, Nguyen, Kase,Tadesse, Barsett, & Wangensteen, 2017). *In vivo* studies with STZ-induced diabetic rat fed with high fat diet Salvador et al., (2017) found that polar extract of elderberry modulated glucose metabolism by correcting hyperglycemia and in other way the lipophilic extract lowered insulin secretion (Salvador et al., 2017). Elderberry extract reported to boost immune system (Badescu, Badulescu, Badescu, Ciocoiu, 2015). Anti-inflammatory properties by elderberry extracts were evident from the findings that elderberry stimulated the production of proinflammatory cytokines IL-1β, IL-6, IL-8 and TNF-α (tumour necrosis factor) as well as anti-inflammatory cytokine IL-10 (Barak, Birkenfeld, Halperin, & Kalickman, 2002). Several studies indicated elderberry extract for antimicrobial and antiviral activity against human pathogenic bacteria as well as influenza viruses (Krawitz, Mraheil, Stein, Imirzalioglu, Domann, Pleschka, &Hain, 2011). Elderberry flower extract inhibited the influenza A virus (H1N1)-induced Madin–Darby canine kidney (MDCK) cell infection (Roschek, Fink, McMichael, Li, & Alberte, 2009). Recently it was reported that *Sambucus Formosana* Nakai stem ethanol extract displayed strong anti-HCoV-NL63 related to respiratory tract illnesses including runny nose, cough, bronchiolitis, and pneumonia (Weng et al. 2019). A significant study demonstrated the anticancer properties of elderberries including European and American elderberry fruits which demonstrated chemopreventive potential through strong induction of quinone reductase and inhibition of cyclooxygenase-2 (Thole et al, 2007).

3. Conclusion

A wide spectrum of *in vitro* and *in vivo*, and human studies has proven the berries antioxidant status and potential health benefits including cardiovascular, neuroprotective, anticarcinogenic potential, and antidiabetic properties. However, the bioavailability of polyphenolic compounds appears to be different with their structure, composition, and diet sources. Abundancy of polyphenols may not correlate strongly with the bioavailability. A thorough knowledge of the bioavailability of the series of polyphenolic compounds will help in promoting healthy choices for maximum health benefits. Further studies in profiling bioavailability and medicinal value are needed for potential application.

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