Charis M. Galanakis *Editor*

Food Bioactives and Health

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Preface

Over the past few years, food bioactives have gained attention due to their potential in reducing the risk of diseases, such as obesity, cardiovascular disease, diabetes, and cancer. This potential is attributed to the antitumor, anti-inflammatory, antihyperlipidemic, antioxidative, antihypertensive, and antiviral activities of bioactives, in addition to their essential nutritional functions. The effectiveness of food bioactives depends on different parameters such as bioactivity, bioavailability, metabolomics, nutrigenomics, and stability within the food matrix. For instance, bioactives' delivery via the oral route is restricted by gastrointestinal enzymes, harsh pH, the epithelium, and the mucus layer. Lately, researchers have investigated bioactive compounds, bioaccessibility, and functions in detail, whereas the development of nutraceutical applications has attracted considerable interest. Functional, "super," and "tailor-made" foods are generated after manufacturing typical or traditional food products with ingredients that modify their properties (e.g., by binding, changing structure, or interface) and provide health benefits to them.

The Food Waste Recovery Group provides insights into all scientific and technological aspects dealing with food and the environment. The group has published several books dealing with biobased products and industries, sustainable food systems, saving food, as well as technologies and applications (for commodities such as cereals, coffee, grape, olive, and meat) for food waste recovery. Others are handbooks that deal with innovations strategies in the food and environmental sectors, nonthermal processing, food shelf-life and quality, nutraceuticals, and food ingredients such as polyphenols, carotenoids, proteins, lipids, glucosinolates, and dietary fiber.

Following the above considerations, the book covers food bioactives' properties and health effects given the new trends in food science and technology. It aims at supporting the scientific community that aspires to understand the role of food bioactives in health and develop applications in personalized nutrition, in functional foods, nutraceuticals, and personalized nutrition.

The book consists of 10 chapters. **Chapter 1** describes the principal sources of polyphenols and then correlated them with their properties (health), particularly absorption (bioavailability), metabolism, gut flora, and chronic disease (cardiac health, obesity, diabetes, cancer, among others). Polyphenols are a very diverse and multifunctional group of phytochemicals widely found throughout the plant kingdom. The main classes of polyphenols are tannins, lignans, phenolic acids, phenolic alcohols, flavonoids, stilbenes, coumarins, and chalcones. The remarkable chemical structure of polyphenols leads to their biological and physiological activities, mainly due to the antioxidant activity that allows them to be used as additives in food products, delaying the oxidation process.

Chapter 2 discusses the biochemistry and health properties of glucosinolates, their physiological significance, as well as the hydrolysis process in the plant response to different abiotic stresses. Glucosinolates are a group of sulfur- and nitrogen-containing glycosides found in plants such as broccoli, cabbage, radish, and cauliflower, among others. Their hydrolysis byproducts, namely isothiocyanates, are responsible for the distinct aroma and pungent taste of cruciferous species, most of which contain species-specific glucosinolates. They are considered as beneficial to human compounds with several confirmed health effects. At the same time, a significant amount of research work has been carried out recently to identify those mechanisms and synergisms that are responsible for the activities of glucosinolates, as well to reveal physiological aspects in the plant–environment interactions.

Chapter 3 reviews updated scientific reports about food-derived bioactive peptides and proteins and about their potential preventive or alleviating role in the deadliest noncommunicable diseases. Cardiovascular diseases, cancer, diabetes, neurodegenerative disorders, as well as oral cavity diseases as a predisposing factor to the development of other essential illnesses are addressed. The objective is to provide useful information to readers involved or interested in the fields of pharmacology and food technology, with the hope that it can serve as an introductory guide to recognize the immense potential of peptides and proteins as therapeutic agents.

Chapter 4 discusses the actual state of research concerning the effect of dietary fiber on health and the pathways by which this nutrient develops its action. In the last years, dietary fiber has gained attention as a bioactive due to its potential health benefits in reducing the risks for many diseases, such as cancer and cardiovascular ones. This effect is linked to its action against inflammation, oxidation, hyperlipidemia, and other physiological disorders. Although research in this area is extensive, the elucidation of the mechanisms involved in this bioactivity is not yet conclusive.

Chapter 5 provides information on substances of lipid origin that have had important effects on the treatment or prevention of diseases such as cancer, diabetes mellitus, cardiovascular disorders, and obesity, among others. Information associated with metabolites of plant origin, as well as lipids of animal origin and food lipids, that have demonstrated hypoglycemic, anti-inflammatory, antiproliferative, hypocholesterolemic, antihyperlipidemic, and antihypertensive effects is presented. The chapter also discusses topics dealing with the chemical structures of the reported lipids, their origin, synthesis, preclinical studies (in vitro, in situ), and clinical studies, detailing dosage, method of administration, biochemical, molecular, and genetic studies, and mechanisms of action.

Chapter 6 provides a brief review of marine bioactives, including peptides, proteins, vitamins, sterols, fatty acids, polyphenols, saccharides, amino acids, and minerals. It also discusses the bioactives derived from marine bacteria as well as different techniques used for marine bioactives recovery. Marine organisms are a rich source of bioactive compounds. Bioactive compounds are compounds with health-promoting effects. Consumption of these compounds may lower the risk of diseases such as heart diseases, cancer, diabetes, osteoporosis, and other complications. Recently, marine bioactives have attracted much attention due to their enormous health benefits.

Chapter 7 deals with food bioactives that reduce the risk of cardiovascular diseases. Bioactive peptides derived from fish, milk, meat, and plant derivatives demonstrated a significant antihypertensive and lipid-lowering effect in randomized clinical trials. Some polyphenols isolated from foods or plants exert anti-inflammatory and antioxidant activity, which could strengthen the prevention of chronic diseases. Furthermore, polyunsaturated fatty acids, lycopene, alliin, plant sterols, monacolin k, and berberine could be considered to support cardiovascular risk patients in clinical practice.

Chapter 8 discusses bioactives with neuronal and immune functions. Healthy diets are low in saturated fats and carbohydrates and high in fiber and antioxidants such as polyphenols and monounsaturated and omega-3 fatty acids, phytosterols, and probiotics. It has been shown that polyphenols are interfering with immune cell regulation, gene expression, and pro-inflammatory cytokines synthesis. As such, these molecules are associated with extended health benefits, playing an essential role in the prevention and treatment of various chronic conditions, such as neurological disorders. Omega-3 fatty acids are known for their positive health effects through their anti-inflammatory properties as well as for being essential in neuronal/brain functioning and its immunomodulatory properties. Intestinal immune stress associated with low omega-3 availability might also be involved in the development of neuroinflammation and the progression of related diseases.

Although many foods that are in the market are marked as functional foods, the problem with bioactive compounds, in and from food sources, is that the health claims and their bioavailability are still not fully explored. There are many examples of bioactive's functionalization health claims connected to their functional properties and their interactions in foods. **Chapter 9** leads the reader from the necessary steps of acquiring bioactive compounds to their bioavailability analysis, protection, and further improvement of their functional properties. The chapter also takes into account the fortification of foods with bioactive compounds as a strategy to reduce the occurrence of chronic illness as well as challenges that lie ahead for scientists dealing with all the aspects of bioactives, from processing to health claims.

Chapter 10 discusses the requirement and regulatory aspects of bioactive compounds from food for health claims. It also includes the fundamental processes on the health claims for bioactive compounds from vegetables, fruits, spices, nuts, cereals, herbal products, legumes, medicinal plants, probiotics, prebiotics as well as those from fungal, algal, and animal sources, and other natural antioxidants. These requirements are meant to protect consumers from frauds perpetrated by producers/manufacturers on nutraceutical products. Bioactive compounds' requirements for health claims range from laboratory findings to systematic clinical trials to guarantee safety and provide bioavailability and efficacy of nutraceutical products.

It is hoped that this book will assist food chemists, food scientists, food technologists, nutritionists, and biochemists as well as researchers, academics, and professionals working in the food industry. It also concerns individuals and stakeholders in the food sector (including small startups) interested in developing nutrition-based products. Moreover, university libraries and institutes could use it as a textbook for undergraduates and postgraduate level multidiscipline courses dealing with food science, food chemistry, and food technology.

At this point, I would like to thank all the authors for their fruitful collaboration as well as for the fact that they remained dedicated to the timeline and editorial guidelines. I would also like to acknowledge the acquisition editor Daniel Falatko and the book manager Aravind M. Kumar, and all colleagues from Springer's production team, for their assistance during the preparation of this book. Finally, I have a message for all the readers: those collaborative efforts contain hundreds of thousands of words and thus may contain errors. Thus, constructive comments and even criticism are always welcome. In that case, please contact me to suggest any changes.

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Contents

Chapter 1
Polyphenols

Bianca Chieregato Maniglia, Evertan Antonio Rebelatto, Katia Suzana Andrade, Acácio Zielinski, and Cristiano José de Andrade

Abstract Polyphenols are a very diverse and multi-functional group of phytochemicals, widely found throughout the plant kingdom. Their basic monomer chemical structure comprises a phenolic ring—a benzene ring(s) with at least one hydroxyl group attached to it. The main classes of polyphenols are tannins, lignans, phenolic acids, phenolic alcohols, flavonoids, stilbenes, coumarins and chalcones. Flavonoids are the most plentiful classes of polyphenols, since they represent ≈4000 out of 8000 polyphenols already identified. Polyphenols are also classified, merely, as flavonoids and non-flavonoids. Flavonoids are chemically composed of backbone of two benzene rings linked by a 3 carbon atoms in a chain from the pyran ring. The oxidation state of central carbon can be used to subclassify them (flavonoids): flavanones, flavanols, flavonols, isoflavonoids, flavones, and anthocyanidins. Rich sources of phenolic compounds include grape pomace, apple, berries, oranges, pomegranate, tomatoes, coffee, tea, wine, olive oil, among others. The remarkable chemical structure of polyphenols leads to their biological and physiological activities, mainly due to their antioxidant activity. Regarding the effects of polyphenols on human health, the phenolics have many health-promoting benefits, including antimutagenic, antihypertensive, hypoglycemic and antihyperglycemic, anticancer and antiapoptotic, antimicrobial, and inflammatory effects. Furthermore, when the phenolic antioxidants are added in food products, they can delay the generation of toxic products (oxidation), to act as rancidity regulator and maintaining nutritional quality of foods, among others. This chapter describes the principal sources of poly-

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phenols and then correlated their properties (health), particularly absorption (bioavailability), metabolism, gut flora, chronic disease (cardiac health, obesity, diabetes, cancer, among others).

Keywords Polyphenols · Nutraceuticals · Flavonoids · Sources of polyphenols · Effect of polyphenols on human health

1.1 Introduction

The plants as fruits, vegetables, herbal teas, and seeds, are rich sources of polyphenols with a wide range of chemical structures (Abbas et al. 2017). These compounds are secondary metabolites which show a wide range of function such as protection, color and flavor in particular astringency and bitterness (Shahidi and Ambigaipalan 2015). Furthermore, many health-promoting benefits have been reported, including antioxidant, anticancer, antimicrobial, antihypertensive, hypoglycemic and antihyperglycemic effects (Teixeira et al. 2014; Gani et al. 2012).

It is worth noting that the plants and their processed products stand out as the main sources of polyphenols that are consumed by the population. Polyphenols are widely related to human health benefits. Currently, World Health Organization (WHO) has recommended ≈0.4 kg per day of vegetables and fruits (5 daily portions) (WHO 2019). In addition, the polyphenols also have been applied in food and pharmaceuticals products with the aim to supplement them mainly in their levels of antioxidants (Vuorela et al. 2004).

The chapter summarizes the classification and chemical structure of polyphenols, their main vegetable sources and effects on human health.

1.2 Polyphenols; Classification and Chemical Structure

1.2.1 Polyphenols

Phenolic compounds or polyphenols are natural biologically active compounds found in plant based-food and that show a wide range of complex structures (Abbas et al. 2017). In plants, they exhibit different functions as bio stimulating for plant growth or as defense compounds. These compounds are also acknowledged as strong natural antioxidants, and it was shown in the literature important biological and pharmacological properties such as anti-inflammatory, anticancer, antimicrobial, antiallergic, antiviral, antithrombotic, hepatoprotective, food additive, signaling molecules, etc. (Kumar and Goel 2019).

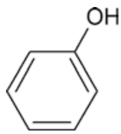
In plants, the most of polyphenols is chemically bounded to sugars, which is named glycosylated. Polyphenol skeletons can show carbohydrates and organic acids bound in different positions (Manach et al. 2004).

Polyphenols show as basic monomer a phenolic ring (structure in Fig. 1.1). Generally, these compounds are classified according to the structures shown as the number of phenolic rings, substituents linked to the rings, and the structural elements that bind these rings to each other. In this way, there are four main groups of polyphenols: phenolic acids, flavonoids, stilbenes, and lignans (Manach et al. 2004).

1.2.1.1 Phenolic Acids

Phenolic acids are related to phenolic compounds that have one carboxylic acid group and they are rarely found as free form, normally they are associated with amides, esters, and mainly glycosides (El Gharras 2009). Phenolic acids are widely found in food, in particular in cereals, herbs, vegetables, legumes, fruits, oilseeds, and beverages. These compounds show antioxidant capacity and it occurs by scavenging hydroxyl radical, several organic radicals, peroxyl radicals, superoxide radical anion, several organic radicals, singlet oxygen, and peroxynitrite. Moreover, phenolic acid can act as reducing agents, chain-breaking antioxidants, and they are important compounds to change cell signaling pathways (Chandrasekara 2019). There are two classes of phenolic acids: hydroxybenzoic acid (e.g. syringic acid, gallic acid, gentisic acid, and vanillic acid) and hydroxycinnamic acid (e.g. ferulic acid, caffeic acid, and *p*-coumaric acid) (Córdova and Medina 2014). Figure 1.2 shows the chemical structures of phenolic acids: hydroxybenzoic and hydroxycinnamic acids.

Fig. 1.1 Phenolic ring structure



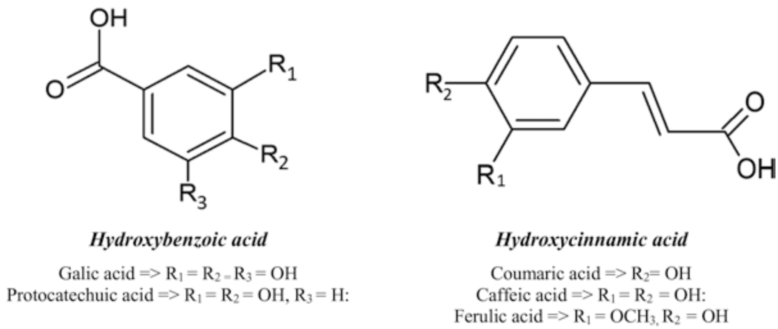


Fig. 1.2 Chemical structures of phenolic acids

Generally, the content of hydroxybenzoic acid in edible plants is very low. However, some red fruits, onions, and black radish show higher concentrations (around tens of milligrams per kilogram fresh weight). In addition, complex structures such as hydrolysable tannins are composed of hydroxybenzoic acids (e.g. ellagitannins in red fruit such as raspberries, strawberries, and blackberries, and gallotannins in mangoes) (Manach et al. 2004).

According to Manach et al. (2004), hydroxycinnamic acid are more common than are the hydroxybenzoic acids, and it is represented, mainly, by *p*-coumaric, caffeic, ferulic, and sinapic acids.

In wine, there is one natural hydroxycinnamic acid present in an esterified form with tartaric acid, named tartaric *p*-coumaroyl ester (Salameh et al. 2008). Among the phenolic acid in fruits, caffeic acid (free and esterified form) is the most abundant compound present (75 until 100% of the total hydroxycinnamic acid content) (Cutrim and Cortez 2018).

In cereal grains, ferulic acid is the most abundant hydroxycinnamic acid found. For other side, ferulic acid can be found in free form in beer or tomatoes, and in this way, this compound is more efficiently absorbed (Bourne and Rice-Evans 1998; Bourne et al. 2000).

Spices, berry fruits, citrus, and vegetables show a bioavailable phytoconstituent named sinapic acid (Idehen et al. 2017). According to Vuorela et al. (2004), sinapic acid is becoming to be explored in the pharmaceutical, cosmetic, and food industries because of its inflammatory, preservative, antioxidant, and antimicrobial activities.

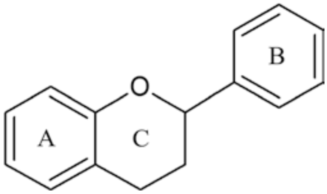
1.2.1.2 Flavonoids

Flavonoids show the structure composed of two aromatic rings (indicated as A and B in Fig. 1.3), linked by three carbon atoms and one oxygen, forming an oxygenated heterocycle (ring C in Fig. 1.3). The flavonoids can be classified according to the oxidation state of central carbon (C ring, Fig. 1.3) that is involved. In this way, there are six classes of flavonoids named: flavanones, flavanols, flavonols, isoflavones, flavones and anthocyanidins (Abbas et al. 2017).

1.2.1.2.1 Flavanones

Flavanones show the structure composed by a single bond in the positions of the C-ring, C_2 and C_3 with an oxygen atom in C_4 position, and a disaccharide in C7 (Fig. 1.4) (Liu et al. 2008). Flavanones are contained in citrus fruits, cherries, grapefruits, and tomatoes (Asakura and Kitahora 2018). Tomás-Navarro et al. (2014), reported that flavonoids show strong antioxidant capacity, and has been investigated for prevention of some cardiovascular disorders and certain kinds of cancer, and reduction of certain chronic diseases. These same authors showed that flavanones could also exhibit anti-inflammatory, antimicrobial, and antiviral activities, which can result in beneficial properties for the health human.

Fig. 1.3 Flavonoid skeleton structure



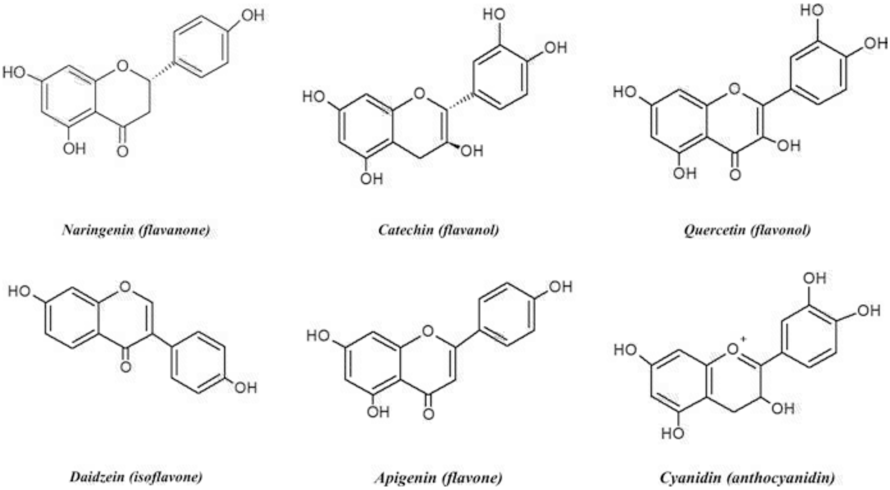


Fig. 1.4 Examples of flavanone, flavanol, flavonol, isoflavone, flavone, and anthocyanidin structures

1.2.1.2.2 Flavanols

Flavanols show a fully saturated heterocyclic ring with a hydroxyl substituent at position C_3 (Fig. 1.4). According to Bonetti et al. (2017), cocoa powder and chocolate, grapes, and teas show in it composition, flavanols and it polymerization products as epigallocatechin, catechin, epicatechin, gallocatechin, gallate derivatives, and proanthocyanidine.

1.2.1.2.3 Flavonols

Among the flavonoids, flavonols are the most found in foods, being kaempferol and quercetin the most representatives. Flavonols are present in glycosylated forms, they show 3-hydroxyflavone backbone, existing in the form of mono-, di-, or triglycosides *in vivo* (Stracke et al. 2007). Di Matteo et al. (2007) showed that the richest sources in flavonols: onions (up to 1.2 g/kg fresh weight), red wine and tea (contain up to 45 mg flavonols/L), leeks, curly kale, blueberries, and broccoli. In the literature (Kelsey et al. 2010; Mecocci et al. 2014) was reported that flavonols have shown antioxidant and anti-inflammatory properties.

1.2.1.2.4 Isoflavones

Isoflavones are compounds with the structure in the B-ring connected to the C-ring by the position C_3 (Figs. 1.3 and 1.4) (Liu et al. 2008). The most representative isoflavone is the daidzein (4′,7-dihydroxy-isoflavone) that is, mainly, found in food such as beans, apples, onions, and peas (Ying-Hui et al. 2017). According to Song et al. (2016), daidzein shows antioxidant, anti-inflammation, and antiestrogen functions. The authors also reported that the due the pharmacological activities of this isoflavone, daidzein has been applied in treating osteoporosis, autoimmune diseases, breast cancer, and cardiovascular disease.

1.2.1.2.5 Flavones

Within the flavonoids, flavones consist of one of the largest subgroups, it can be found in all parts of the plants as: leaves, stem, buds, heartwood, bark, thorns, rhizomes, roots, flowers, fruit, and seeds (Zuk et al. 2019). Flavones are synthesized from flavanones (direct biosynthetic precursor) in the branch point of the anthocyanidin/proanthocyanidin (Martens and Mithöfer 2005). Observing the Fig. 1.4, flavones differ from other flavonoids because show saturation of ring C which is named as c-pyrone (Atif et al. 2015).

Flavones show structures diversified, which guarantees a variety of functions, such as color control on vegetables and fruits to protect them from UV radiation and infectious attacks by microorganisms. (Harborne and Williams 2000). Flavones are also important for human nutrition and health, representing an abundant class of phytochemicals present in our daily diet (fruits, edible vegetables, seeds and nuts) (Martens and Mithöfer 2005). Rice-Evans et al. (1997) reported that polymethoxylated flavones, such as nobiletin and sinensetin can be found, mainly in citrus fruits as orange peel. Currently, flavone-containing food has attracted considerable scientific and therapeutic interest because of the beneficial effect for prevention of some human diseases. Agah et al. (2017) reported that flavones show structural features that make them among the strongest food-derived anti-inflammatory compounds. These authors observed that cereal derived flavones show strong synergistic interaction with derived flavonols against inflammation, and Yang et al. (2014) reported that flavones can also protect against estrogen-linked colon carcinogenesis.

1.2.1.2.6 Anthocyanidins

Anthocyanidins show structure with hydroxyl groups in the positions of C_3, C_5, and C_7 in the B ring (Fig. 1.4), however each structure may have its own characteristic hydroxyl or methoxyl groups (Swanson 2003). Anthocyanidins are mainly found conjugated with glucose moieties and they are found in large concentrations in wine, grapes and berries (Stalmach 2014).

The Fig. 1.4 shows some examples of flavanone, flavanol, flavonol, isoflavone, flavone, and anthocyanidin structures.

1.2.1.3 Stilbenes

Stilbenes are an important group of nonflavonoid phytochemicals of polyphenolic structure characterized by the presence of a 1,2-diphenylethylene nucleus (Sirerol et al. 2016). The Fig. 1.5 shows the stilbene skeleton.

According to Chong et al. (2009), the structures of common plant stilbenes showed the follow radicals (being OGlu: *O*-*β*-D-glucopyranoside):

- trans-resveratrol: R_1 = H, R_2 = OH, R_3 = OH, R_4 = OH;
- trans-piceid: R_1 = H, R_2 = OH, R_3 = OGlu, R_4 = OH;
- pinosylvin: R_1 = H, R_2 = H, R_3 = OH, R_4 = OH;
- piceatannol: R_1 = OH, R_2 = OH, R_3 = OH, R_4 = OH;
- pynosylvin monomethylether: R_1 = H, R_2 = H, R_3 = OCH_3, R_4 = OH;
- trans-pterostilbene: R_1 = H, R_2 = OH, R_3 = OCH_3, R_4 = OCH_3;
- astringin: R_1 = OH, R_2 = OH, R_3 = OGlu, R_4 = OH;
- rhapontin: R_1 = OH, R_2 = OCH_3, R_3 = OGlu, R_4 = OH.

Stilbenes are compounds naturally present in grapes and have gained a growing interest due to health-promoting properties reported (Segade et al. 2019). Raposo et al. (2018) reported in recent studies that stilbenes could act as compounds that help in the preservation of wine. Guerrero et al. (2020) explored this property, identifying the stilbene composition and concentration in wines as a quality marker.

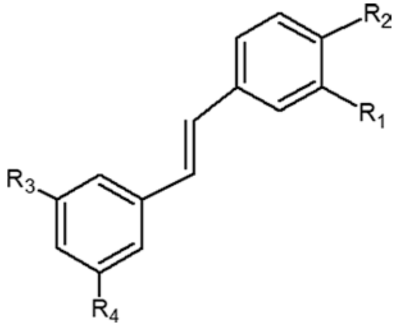


Fig. 1.5 Stilbene skeleton structures

1.2.1.4 Lignans

Lignans are a group of diphenolic compounds (two units of phenylpropane units) linked by a C-C bond between the central atoms of the respective side chains (position 8 or *β*), as we can see in the Fig. 1.6 (Linder et al. 2015). This type of polyphenol is concentrated in the bran layer of cereal grain (Higuchi 2014).

Observing the Fig. 1.7, a compound is considered a lignan if the two units of phenylpropane (in the dimericcase) are linked by a *β*-*β*' bond, subsequently denominated 8–8′ bond (Linder et al. 2015). However, according to Linder et al. (2015), we can found neolignans that consist in units of phenylpropane combined in other way.

According to Das and Devi (2019), we can classify lignans in 8 subgroups based on their carbon skeleton, cyclization pattern, and the way in which oxygen is incorporated in the molecule skeleton. The subgroups consist in: furans, furofurans, dibenzylbutanes, dibenzylbutyrolactones, dibenzocyclooctadienes, dibenzylbutyrolactols, aryltetralins and arylnaphthalenes (Das and Devi 2019). The Fig. 1.8 shows some generic of lignan skeleton structure.

In addition, according Linder et al. (2015), lignans are also classified into three categories in relation to oxygen position: lignans with oxygen at the 9(9′)-carbon, lignans without oxygen at the 9(9′)-carbon, lignans with dicarboxylic acid. There is possible to find some lignan in more than one category and/or there exist different cyclization patterns for a given type. Furan lignans is one example of this behavior, it is a lignin that occur with or without oxygen at the 9(9′)-carbon (Linder et al. 2015).

Foods rich in lignin (seeds, whole-grain cereals, and nuts) have been associated with biological activities such as cytotoxic (Huang et al. 2013), antioxidative (Duan et al. 2009), anti-bacterial (Tago et al. 2008), immunosuppressive (Park et al. 2007), anti-inflammatory (Zheng et al. 2014), anti-HIV (Chen et al. 1996), etc.

Fig. 1.6 Phenylpropane units

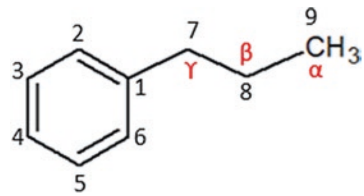
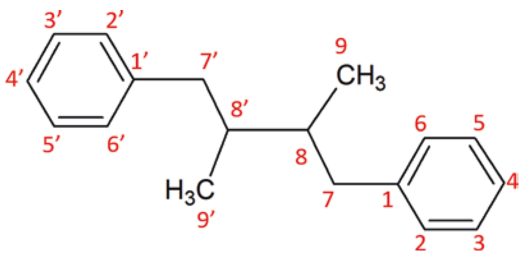


Fig. 1.7 Lignan skeleton



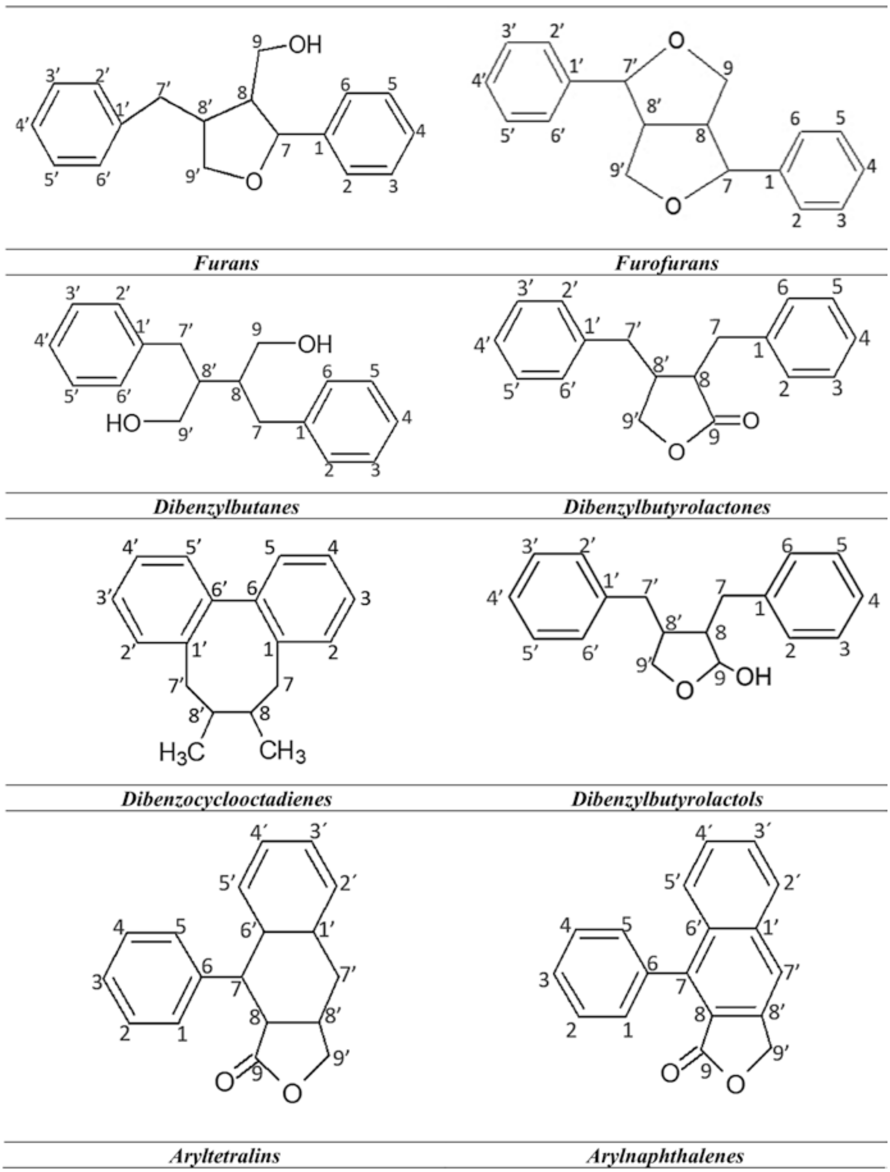


Fig. 1.8 Generic lignan skeletons

Lignans such as secoisolariciresinol and its precursor secoisolariciresinol diglucoside are the most abundant lignans found in the diet (Peirotén et al. 2019). Moreover, other lignans such as matairesinol, and the secoisolariciresinol precursors pinoresinol and lariciresinol, can also be found in some plant foods (Landete 2012).

Summing up, from the main structure surrounding the phenolic ring, there are highly diversified classes of secondary metabolites, named phenolic compounds, distributed widely in the plant kingdom. Moreover, the diversified structures show interesting and different properties that has attracted the attention of many sectors as biochemistry, physiology, human nutrition, and health.

1.3 Rich Sources of Polyphenols

1.3.1 Wine and Grape Pomace

The main sources of phenolic compounds in red wine are found in grape skins, pulp and seeds. During fermentation, important flavonoids (present in the rind, pulp and seeds) are transferred to the wine. Regarding white wine, the mixture is made from free running, without the mixture of grapes, i.e. without contact with the skin of the grape. Thus, when compared to red wine, white wines have lower polyphenol content and lower antioxidant properties (Fuhrman et al. 2001).

Flavonols are the main flavonoids present in wine. Among them, stand out quercetin, kaemppferol and myricetin. Also can be mentioned tannins, proanthocyanidins and flavanols, such as catechin and epicatechin (Shahidi and Ambigaipalan 2015). The concentration of phenolic compounds of red wines made from dark-skinned grapes usually contain about 3500 mg/L, in which the flavonoid portion corresponds to 1000–1800 mg/L (Di Lorenzo et al. 2016).

Wines and grapes also have phenolic acids and stilbenes in their composition. Phenolic acids can be found in both red and white wine. Among them can be mentioned quinic and shikimic and tartaric acid, present in their free form or glycosylated derivatives (Monagas et al. 2005).

Grape pomace is a low-cost source of phytochemicals. Different polyphenols are found in grape pomace. Among them, flavonols such as catechin, epicatechin and proanthocyanidins, as well phenolic acids, tannins and anthocyanins. There are several phenolic compounds found in grape skin, such as proanthocyanidins, ellagic acid, myricetin, prodelphinidins, kaempferol, quercetin and trans-resveratrol. In the grape seed there is catechin, epicatechin, gallic acid, proanthocyanidins and dimeric procyanidin (Brenes et al. 2016).

In grape seeds a higher concentration of phenolic compounds can be found than in grape skin. For example, in seed about up to 16.518 mg of catechin equivalents (EC)/100 g can be found. In the skin the value found was up to 1839 mg EC/100 g. Grape seed is abundant in flavonols (oligomeric and polymeric compounds) that have high antioxidant capacity, while the skin is very rich in anthocyanins (289–935 mg/100 g) (Rockenbach et al. 2011). Flavonols (quercetin 3-*O*-glucuronide and 3-*O*-rutinoside-rutin) were found in grape stems, as well phenolic acids and dihydroflavonols like astribin (Karvela et al. 2009). There are several potential applications grape pomace, however grape pomace is mostly used for the production of animal feed (Celma et al. 2009).

1.3.2 Apple

Apple (*Malus domestica* Borkh) is a widely consumed fruit worldwide—the third largest production, 11.6 million tons (Bondonno et al. 2017; Rabetafika et al. 2014).

The main groups of polyphenols in apple are: phenolic acids, flavanols, anthocyanidins, flavonols, and dihydrochalcones. The major apple flavonoids are procyanidins, catechins, quercetin glycosides, dihydrochalcones, hydroxybenzoic acids and hydroxycinnamic acids and their derivatives (Bondonno et al. 2017; Kalinowska et al. 2014; Khanizadeh et al. 2008; Van Der Sluis et al. 2002).

The total phenolic content in the apple peel is significantly higher and in the tissue located just below the peel, than in the pulp, since apple skin contains ≈46% of the total phenolics in apples (Kalinowska et al. 2014; Kondo et al. 2002; McGhie et al. 2005).

A low concentration of are flavonoids found in apple juice. Regarding commercially available apple juice, the concentration of quercetin is 14 times lower than that found in apples fruits (Hertog et al. 1993).

Substantial fraction of apple fruit production, about 30%, it has used to manufacture processed foods, like beverages and desserts. After production, around 11% of the initial mass of the fruit is transformed into by-products (skin, pulp and seeds), generating annually, about three million tons of waste (Bondonno et al. 2017; Kammerer et al. 2014; Rana et al. 2015). In the apple pomace, there are several polyphenols including flavanols, flavonols and anthocyanins such as cyanidin-3-galactosides (Diñeiro García et al. 2009; Kammerer et al. 2014).

1.3.3 Berries

Among the berries black chokeberry, blackcurrant, black elderberry, blueberry, blackberry, raspberry, blackberry, strawberry and black grapes stand out due to high content of phenolic compounds (Kowalska et al. 2017; Skrovankova et al. 2015; Tylewicz et al. 2018).

One of the largest sources of polyphenols found is black chokeberry pomace. The production of chokeberry juice generates a larger amount of pomace. In addition, seed fractions, have high total dietary fiber content ≈75%, which are rich in proanthocyanidins (12,000 mg/100 g), anthocyanins (1200 mg/100 g) and amygdalin (7–185 mg/100 g), and can be used in the preparation of dietary fibers preparations and/or phenolic extracts (Sójka et al. 2013). Beyond that black elderberry contains a high amount of anthocyanins (813 mg/100 g), besides flavonols and cinnamic acid derivatives (Silva et al. 2017).

Blackberries contain severals polyphenols, in particular, stands out anthocyanins, like cyanidin-3-glucoside (Siriwoharn et al. 2004). Blackberries, raspberries, and strawberries have a similar amount of total phenolic compounds (215–260 mg/100 g) (Pérez-Jiménez et al. 2010). However, when compared to blueberries, blackberries, and raspberries; strawberries have a significant lower content of anthocyanins (Skrovankova et al. 2015).

The anthocyanins present in blueberries are mainly present in the skin. Many of these anthocyanins, exhibit excellent antioxidant activity, such as: delphinidin-3-*O*-galactoside, cyanidin-3-*O*-galactoside, delphinidin-3-*O*-arabinoside (Borges et al. 2010).

Likewise black currants and blueberries, cranberries contain high content of phenolics. Nevertheless cranberries have high content of flavonoids and the main phenolic compounds is ellagic acid (about 51% of the total) (Grace et al. 2014; Skrovankova et al. 2015; Tylewicz et al. 2018).

1.3.4 Orange, Guava and Pomegranate

Orange, including orange juice and their by-products have high levels of flavanones (hesperidin and narirutin) (Roowi et al. 2009).

The manufacture of orange juice leads to the production of various by-products such as seeds, pulp, leaves, peel and whole fruits (Rezzadori et al. 2012). After the juice is extracted, the solid residues of the orange industry represented by the peels, seeds and pulp, equivalent to about 50% of the weight of each fruit and with approximately 82% humidity, are transformed into pelletized bran. This bran is mainly used as a dietary supplement to cattle herds (Tienne et al. 2004). However, the most valuable byproduct of a citrus fruit is found in the orange peel (essential oil), being widely used as food and cosmetic ingredients (Rezzadori et al. 2012).

Guava fruits are rich in anthocyanins, flavonoids, proanthocyanidins and other phenolic classes including phenolic acids, flavonols and tannins (Gülçin 2012; Rojas-Garbanzo et al. 2017; Shi et al. 2005).

According to Rojas-Garbanzo et al. (2017), several polyphenols are reported, and 24 compounds were detected for the first time in *P. guajava*. Among them, phlorizin, nothofagin and astringin.

Pomegranate is a source of anthocyanins, ellagitannins and other phenolic substances with antioxidant and antitumor activities. Polyphenols are distributed in the peel, pulp and seeds, however in the peel has the highest polyphenol content (Fischer et al. 2011; Lansky and Newman 2007).

In pomegranate juice, a higher content of polyphenols can be found than in other fruit juices. The main class of polyphenols found is anthocyanins, such as delphinidin-3-glucoside and cyanidin-3,5-diglucoside, followed by elagitanines and gallic and ellagic acids (Aviram and Rosenblat 2012; Bakkalbasi et al. 2009; Gil et al. 2000).

1.3.5 Potatoes, Sweat Potato, Cassava, Tomatoes, Onions and Cabbage

High flavonoid content was found for green and purple sweet potato leaves and onion leaves. In addition, sweet potato green leaves showed high antioxidant activity and reducing potential in comparasion with cabbage, spinach and potato (Chu et al. 2000).

Antioxidant activities have been found in several vegetables as perilla leaf, pepper and ginseng leaf, sweet potato leaf, chinese toon bud, loosestrife, cowpea, lotus root, soybean, that may be important for disease prevention caused by oxidative stress.

In these vegetables were identified phenolic compounds such as chlorogenic and gallic acids. Besides, a positive relationship was observed between antioxidant activity and total phenolic content (Deng et al. 2013).

According to FAO, in 2015, the potatoes represented the fifth largest harvest in the world (Tylewicz et al. 2018). The polyphenols in potatoes are present in flesh and skin. About 50% of the total polyphenol content was located in the tuber, whereas the remaining concentration decreases as it approaches the center of the tubers (Akyol et al. 2016; Friedman 1997).

Phenolic acids represent most of the polyphenols present in potatoes. Among these, chlorogenic acid is the most abundant, followed by caffeic acid, gallic acid, ferulic acid, among others (Akyol et al. 2016; Dao and Friedman 1992). However, the content of chlorogenic acid in potatoes can be reduced with food processing (e.g. heating)., which depends on the nature of the heat source used (Dao and Friedman 1992).

The second largest category of potato polyphenols is flavonoids. The main flavonoids in the tubers were flavanones, naringenin and eriodictyol, flavanols, catechin and epicatechin (Lewis et al. 1998).

The main phenolic compound found in potato peel extract is chlorogenic acid, and the phenolic content found is about 70.82 mg of CE/100 g. (Akyol et al. 2016; Kanatt et al. 2005).

Pigmented potatoes, such as red and purple ones are rich in anthocyanins, which may be used in the food industry, since the potato production cost is not as high compared to other crops. However, potatoes with high anthocyanin concentrations are required for the pigment extraction process (Ezekiel et al. 2013).

The main phenolic acid found in sweet potatoes is chlorogenic acid, and the highest content is present in a white pulp cultivar. Among the other phenolic acids present, can be highlighted 3,5-dicafeoylquinic acid, 3,4-dicafeoiliquinic, 4,5-dicafeoiliquinic and caffeic acids. The highest contents of these acids are found in a variety of purple pulp (Padda and Picha 2008).

Purple-fleshed sweet potatoes are also high in anthocyanins. About 39 anthocyanins have already been identified and they are dominated by cyanidin and peonidin aglycones (Gras et al. 2017; Oki et al. 2002).

Sweet potato leaves are considered processing residues, however, studies indicate that phenolic compounds such as 3,4,5-tri-*O*-caffeoylquinic acid can be found, and these compounds present a high antioxidant potential (Islam et al. 2002; Shahidi and Ambigaipalan 2015).

Regarding cassava, it has been found that polyphenol content in flours ranges from 2.1 to 120 mg/100 g. These polyphenols can form insoluble complexes, inactivating the thiamine enzyme, which will reduce starch digestibility. On the other hand, tannins and also catechins, have antioxidant and anticarcinogenic activities and are beneficial to the cardiovascular system (Chung et al. 1998; Wobeto et al. 2007).

The main polyphenols in tomatoes (range from 0.1 to 18.2 mg/100 g) are naringenin chalcone, rutin and quercetin. Anthocyanins such as delfidine and malvidine can also be found. (Martí et al. 2016; Tylewicz et al. 2018). The main phenolic acids identified in tomato peel are procatchoic and vanillic acid, with concentrations of 5.52 and 3.31 mg/100 g, respectively (Elbadrawy and Sello 2016).

Among the flavonols present in tomatoes, the main ones are quercetin conjugates; however, kaempferol amounts and traces of free aglycones were also found (Crozier et al. 1997).

In the pericarp and pulp of immature green tomatoes a high content of chlorogenic acid can be found. This acid level varies with fruit maturation as the fruit turns pink and then red (Shahidi and Ambigaipalan 2015; Toor and Savage 2005).

Tomato peels and seeds are usually removed during processing. Lyophilized tomato peel extracts showed a total polyphenol yield of 38.67 mg tannic acid equivalent/100 g peel (Sarkar and Kaul 2014).

Several flavonoids are found in onions, in particular quercetin, kaempferol, myricetin, and catechin (Pérez-Gregorio et al. 2014; Shahidi and Ambigaipalan 2015). In onions, monoglucoside quercetin and diglucoside quercetin represent 80% of the total flavonoids. Quercetin glucoside levels are much higher in onions than in other vegetables (Rhodes and Price 1996; Shahidi and Ambigaipalan 2015).

The total phenolic content in yellow onion ranges from 6.06 ± 0.24 to 22.32 ± 1.62 gallic acid equivalents (GAE) mg/g, and from 5.71 ± 0.20 to 18.58 ± 0.62 GAE mg/g dry weight in red onions (Cheng et al. 2013). In onions, low content of phenolic acids are bounded to cell walls., in which protocatechuic acid is the most (Ng et al. 2000). Anthocyanins are part of a lower proportion of flavonoids present in the edible portion of red onion. In this type of onion, the total flavonoid content is generally higher than in white or yellow onion bulbs (Rhodes and Price 1996; Shahidi and Ambigaipalan 2015).

A amount in the range of 600.72–2230.89 mg/100 g of quercetin can be found in onion bagasse, which varies with onion variety (Roldán et al. 2008; Tylewicz et al. 2018).

Cabbage is a good source of polyphenols, also rich in carbohydrates and vitamin C. Brassica vegetables, including all cabbage-like vegetables, are a genus of the Cruciferae family and contribute to the intake of glucosinolates (Chun et al. 2004; Shahidi and Ambigaipalan 2015).

1.3.6 Cereals

A variety of phytochemicals can be found in whole grains such as phenolic compounds, carotenoids, γ-oryzanol, dietary fibers and vitamin E (Okarter and Liu 2010). The main polyphenols found in whole grains are phenolic acids. Other classes of polyphenols are flavonoids and lignans. The ferulic acid is the major phenolic acid found in grains (mainly in the cortical layer). Other acids that may be cited are caffeic, oxalic and *p*-comuraic acids (Deng et al. 2012; Tian et al. 2019).

The phenolic content varies according to grain, for instance wheat (7.99 μg/g), oats (6.53 μg/g), and rice (5.56 μg/g) (Adom and Liu 2002; Tian et al. 2019).

A higher concentration of polyphenols can be found in whole grains when compared to grains that have been processed. In the case of rice for example, the phenolic portion is present mainly in the cortical layer of the grains. When the grain is polished, this part is removed, removing ferulic acid. For this reason, brown rice has more phenols than polished rice. Another factor that can be considered is that in smaller grains of rye, oat, millet and rice there is a higher availability of ferulic acid when compared to larger grains. This is because the acid is bound to the total fiber content (McCarty and Assanga 2018).

In cereal grains, there is no uniform distribution of phenolic compounds. The outer layers of the grain (bark, forehead, pericarp and aleurone) have a higher concentration of phenolics when compared to the endosperm. Usually, the outer layers are used for bran production, and the endosperm layer is used for refined flour production (Kaur et al. 2014; Tylewicz et al. 2018).

In wheat, the main phenolics are phenolic acids and flavonoids. These compounds are mainly found in the outer layer of the grain. There is a variation among wheat genotypes regarding the content of phenolic compounds, flavonoids, lignans and anthocyanins present (Žilić 2016). The main phenolic compounds present in wheat are ferulic acid and *p*-coumaric acid (Žilić et al. 2012).

There are several phenolic acids in wheat grains, such as hydroxybenzoic acids and hydroxycinnamic acids. Among them, ferulic acid is the main one, with concentrations around 1000 μg/g (Hernández et al. 2011). Leoncini et al. (2012) studied six varieties of wheat. The end result showed that the total flavonoid content varies depending on wheat cultivar. It was found in cultivar Rassineto the highest phenolic content (173.48 mg GAE/100 g of grain), which was similar to other cultivars (Andriolo, Gentil rosso, Inallettabile and Verna).

Phenolic compounds of oat are mainly found in the bran layer, although some are present in groats and hulls (Gangopadhyay et al. 2015; Ratnasari et al. 2017). Phenolic compounds in oat, as well in other cereals, are either in free or bound forms (Naczk and Shahidi 2006). The main phenolic compounds in oat grain are phenolic acids, avenatramides and flavonoids. Among the phenolic acids, stand out the gallic, benzoic caffeic and ferulic acids. In the bound fraction, the phenolic concentration is higher, with ferulic acid being the main compound. The flavonoids found in the free fraction are as follows: catechin, rutin, quercetin, and tricin. However, the flavonoid found in the bound fraction is kaempferol (Hitayezu et al. 2015; Tylewicz et al. 2018; Verardo et al. 2011).

A phenolic compound that is only found in oats are avenantramides. It is an antipathogen produced by the plant itself in response to exposure to other pathogens such as fungi.

The avenanthramides are low-molecular-weight soluble phenolic compounds which are not present in other cereal grains, only in oats. These compounds are antipathogens (phytoalexins), which are produced by the plant in response to exposure to pathogens such as fungi. The avenanthramides 2c, 2p and 2f are the main ones found in oats (Hitayezu et al. 2015; Meydani 2009; Verardo et al. 2011).

The sorghum has a diversity of phytochemicals, especially the polyphenols. Several phenolic compounds are found in extracts obtained from white, red and brown sorghum grains. The main family of these compounds are phenolic acids, such as ferulic and caffeic acids (Chiremba et al. 2012; Stanisavljević et al. 2016). There are several flavoinoids found in sorghum, including: luteolin, apigenin, catechin and quercetin. As in other grains the outer layer of the grain is the richest in phenolic compounds (Moraes et al. 2015; Tylewicz et al. 2018).

In rice, various phenolic compounds are found, such as phenolic acids, anthocyanins and proanthocyanins. Phenolic acids include ferulic, *p*-coumaric, isoferulic and caffeic acids. Among them, ferulic acid is the most abundantly found. Proanthocyanidins in rice are usually type B, but recent research shows that type A and B coexist in red and black rice (Shao and Bao 2015).

Several anthocyanins were determined in colored rice grains. The main anthocyanin found in colored rice does cyanidin-3-glucoside, besides red and black rice also shows peonidin-3-glucoside, and in the black rice evidence of cyanidin-3-glucoside was found (Kapcum et al. 2016; Zhang et al. 2010).

In millets, besides micro and macronutrients, can also be found important phytochemicals, especially phenolic compounds. The main polyphenols present in millet are hydroxybenzoic (protocatechuic, phydroxybenzoic) and hydroxycinnamic (*p*-coumaric, ferulic syringic) acids, in addition to flavonoids and proanthocyanidins (Devi et al. 2014; Xiang et al. 2019). In finger millet free fractions, flavonoids such as catechin, epicatechin and quercetin are present. Phenolic acids are also present, but in lower concentration. Ferulic acid is also the major phenolic acid in millet, however *p*-coumaric, caffeic and protocatechuic acids are also present (Xiang et al. 2019). In finger millet of colored pericarp varieties, a higher concentration of phenolic compounds is found when compared to white pericarp varieties (Xiang et al. 2019).

In maize grains, the main phenolic compounds are phenolic acids, however, other phenolics such as anthocyanins, flavonols, and flavanols have been identified in colored maize grains (Salinas-Moreno et al. 2017). Several phenolic acids are present in corn, such as caffeic, vanillic acids, among others. However the main ones are ferulic and *p*-coumaric acids present in soluble form, or attached to the cell wall (Salinas-Moreno et al. 2017). In the bound fraction of maize a higher concentration of phenolic compounds was found (150–300 mg/100 g), when compared to the free fraction (1–5 mg/100 g) (González-Muñoz et al. 2013). Other classes of phenolic compounds found in maize include quercetin, kaempferol, and isorhamnetin, which were found in purple corn. In colored corn cultivars, anthocyanins have been found, including elargonidin, cyanidin, and peonidin (Montilla et al. 2011; Paucar-Menacho et al. 2017; Tylewicz et al. 2018).

In barley, polyphenols may be present in bound, conjugated or free form. The main classes are flavonoids, lignans and phenolic acids (Fogarasi et al. 2015). The main phenolic acids in barley are benzoic and cinnamic acids. These acids are found in greater concentration in the bound form than in the conjugate and free form. The abundance of phenolic acids in barley indicates that it can serve as an excellent source of natural antioxidants (Idehen et al. 2017; Quinde-Axtell and Baik 2006; Zhao and Moghadasian 2008).

In the free form of barley, the concentration of phenolic acids varies between 4.6 and 23 mg/g, while in the conjugate form the value varies between 86 and 198 mg/g. In bound form, this value ranges from 133 to 523 mg/g. (Abdel-Aal et al. 2012; Holtekjølen et al. 2006). The major flavonoids in barley grains are flavanols, anthocyanins, which are located in the pericarp, mostly glycoside derivatives. Proanthocyanins are also present (Abdel-Aal et al. 2012; Idehen et al. 2017).

1.3.7 Coffee and Teas

Teas and coffees are two of the most popular beverages in the world. In both, polyphenols such as flavonoids are present and contribute to taste and health properties (Wang and Ho 2009).

Coffee is a beverage with stimulating power due to the presence of caffeine; however, other compounds are identified in this drink and many of them have health benefits, such as flavonoids, chlorogenic, caffeic, gallic and ferulic acid (Esquivel and Jiménez 2012; Meletis 2006).

Coffee flavor is strongly influenced by the presence of phenolic compounds, and 42 phenolics have been identified as being present in roasted coffee aroma. In coffee beverages, the main phenolic compounds are chlorogenic acids, in the form of various isomers, considered the most important and those present in greater quantities in green coffee beans. In coffee seeds, tannins, lignans and anthocyanins are another phenolic compounds present, but in smaller quantities. In coffee pulp, condensed tannins stands out as the main phenolic compounds (Clifford 1985; Farah and Donangelo 2006).

It was identified chlorogenic, gallic and protocatechuic acids in extracts obtained from spent coffee grounds and husks, suggesting the potential use of these residues in the recovery of phenolic compounds (Andrade et al. 2012).

Tea is a beverage produced from the tea plant (Camellia sinensis), that are rich in polyphenols (Tylewicz et al. 2018). The main polyphenols in tea leaves include flavonoids, particularly flavanols, and phenolic acids (Coe et al. 2013; Wang and Ho 2009).

Green tea is a minimally processed product obtained from freshly harvested leaves of the *Camellia sinensis* plant. Immediately after harvesting, tea leaves are heat treated to inactivate polyphenol oxidase, which preserves the freshness of the tea and its monomeric polyphenol profile (Bruno et al. 2014; Frei and Higdon 2003).

In green tea, about 42% of soluble solids are catechins such as epigallocatechin gallate, epigallocatechin, gallocatechin and epicatechin (Bradfield and Bate-Smith 1950; Graham 1992).

Black tea is a processed product obtained from the complete fermentation of fresh tea leaves and is characterized by the orange-brown color. This feature comes from the presence of teaflavins and thearubigins. In addition to color, these compounds are responsible for the flavor of black tea (Ferruzzi 2010). The polyphenols concentration in the black tea decreases during fermentation, then, the longer the processing time, the lower the polyphenols content in the tea (Astill et al. 2001).

Oolong teas are produced from the partial fermentation of tea leaves. The process is carried out in various ways and the products vary with respect to the degree of catechin oxidation that is observed. Because it is only partially fermented, it retains a considerable number of original polyphenols. Oolong tea composition is estimated to be intermediate between green and black teas (Graham 1992; Wang and Ho 2009).

1.3.8 Olive Oil

In olive oil, the main phenolic compounds are secoiridoids followed by phenolic alcohols, lignans and flavones (Bendini et al. 2007; Brenes et al. 2000).

The secoiridoids are only found in plants of the *Olearaceae* family. They are compounds produced by metabolism secondary of terpenes. One of the characteristics of these compounds is the presence of elenolic acid in their molecular structure (Bendini et al. 2007). The most abundant secoiridoids of virgin olive oil are the dialdehydic form of elenolic acid (Montedoro et al. 1992a, b, 1993). Tyrosol and hydroxytyrosol are the main phenyl alcohols found in olive oil (Oliveras-López et al. 2007).

The main phenolic acids present in olive oil are: protocatechuic, gallic, vanillic, caffeic acid, among others (Franco et al. 2014; Tylewicz et al. 2018).

In olives and virgin olive oil, natural lignans as (+) - pinoresinol and 1-acetoxypynoresinol are found. Pinoresinol (+) was found in other plants, however, 1-acetoxypynoresinol is often found only in olives. It is widely accepted that lignan consumption has beneficial health effects. Therefore, these two compounds are of great interest based on their properties (López-Biedma et al. 2016).

Flavonoids are important part in the polar fraction of olive oil. Among these flavonoids, luteolin, apigenin and diosmetine can be highlighted (Kelebek et al. 2017).

The main difference between olive leaves composition for olive oil can be considered the presence of oleuropein, as well ligstroside and several other flavonols in their glycoside form, that are not found in oil (Talhaoui et al. 2015).

As in olive oil, secoiridoids are the main class of phenolic compounds found in olive leaves. The component with the highest phenolic fraction in olive leaves is oleorupine (24.7 and 143.2 × 103 mg/kg). Olive leaves have a higher concentration of phenolic compounds (10,000–82,000 mg/k), when compared to olive oil (40–1000 mg/kg) (Bajoub et al. 2017; Loubiri et al. 2017; Talhaoui et al. 2014; Tylewicz et al. 2018).

1.4 Effect of Polyphenols on Human Health

Regarding nutraceuticals, polyphenols have been drawn attention, for instance Blackcurrant (*Ribes nigrum*) berrie have been named "superfruits" due to the presence of important sources of phytochemicals that have huge potential as immunomodulators, antimicrobials and anti-inflammatories, inhibiting low density lipoprotein and reducing cardiovascular disease. It has been cultivated for use in beverages and has a reputation for excellent health characteristics due to its high antioxidant content (Nour et al. 2013; Shahidi and Ambigaipalan 2015). Therefore, polyphenols consumption plays a fundamental role on human health, for instance antioxidant, anti-inflamatory, diabetes controller, microbiome modulator, anti-aging, antihypertensive and anticancer - briefly described below:

1.4.1 Antioxidant

Superoxide radical, peroxynitrite radical, nitric oxide, hydroxyl radical, and hydrogen peroxide, are ubiquitous molecules knows as reactive oxygen species, since reactive oxygen species are inherently produced by all living cells - metabolism. Reactive oxygen species are highly reactive molecules, short-lived derivatives of oxygen metabolism. Reactive oxygen species, at low concentrations, are essential to regular metabolism, more specifically intracellular communication, cell differentiation, apoptosis, antimicrobial and immunity properties. An oxidative stress condition occurs when the living cells have high reactive oxygen species rate and/or a depression of their antioxidant systems (unbalanced) (Roberts and Sindhu 2009).

Aerobic organisms produce, primarily, superoxide radical which is highly cytotoxic. Reactive oxygen species can react with biomolecules, for instance reactive oxygen species can damage DNA which may lead to chances on protein conformation; induce nucleic acid modifications or enhance lipid peroxidation. Oxidized and nitrated reactive oxygen species compounds usually affect cell signaling and basal cellular functions. These disorders are related to health problems such as atherosclerosis and inflammation. Therefore, reactive oxygen species show harmful effects on human health, in particular metabolic syndrome, type 2 diabetes and cardiovascular diseases (coronary and hypertension) (Roberts and Sindhu 2009).

According to Huang et al. (2005), antioxidant activity is related to oxidation lipids, proteins, among other biomolecules that occurs by reducing the oxidative chain reactions, in particular propagation stage. Free radicals are directly scavenged by primary antioxidants, whereas secondary antioxidants act indirectly, restricting the production of free radicals by Fenton reactions. In this sense, polyphenols have remarkable antioxidant properties, since they are efficient scavengers of reactive oxygen species.

High intakes of polyunsaturated fatty acids lead to generation of toxic lipid oxidation species. Lamothe et al. (2019) investigated the effects of grape juice and tea (polyphenol-rich beverages) and milk on generation of toxic lipid oxidation species. Significant reductions of 4-hydroxyhexanal and 4-hydroxynonenal (toxic lipid oxidation species) were observed due to milk or polyphenol-rich beverages; 60% and 75% respectively.

Higher content of phenolic compounds with associated antioxidant activity was related to white guava (*P. guajava* L.) and red guava (*P. guajava* L.) leaves, when compared with other vegetables. On the other hand, between the white and red leaves of guava, the highest concentration of total phenolics is found in the pyrifera variety (Díaz-de-Cerio et al. 2016; Wang et al. 2007).

The antioxidant potential of cabbage was already widely reported in the literature. Red cabbage exhibits greater antioxidant capacity than white cabbage. In general, when compared to green cabbage, Chinese cabbage and Chinese white cabbage, red cabbage has the highest antioxidant activity (Abu-Ghannam and Jaiswal 2015; Amin and Lee 2005; Jaiswal et al. 2011).

In red cabbages, cyanidine glycosides are the main pigments found. Studies have shown that cyanidine made an excellent contribution to antioxidant capacity, and also to total flavonoid and phenolic content (Chun et al. 2004).

Oats have high concentration of β-glucan that are widely known for its health properties. Oats also have $\geq$20 exceptional (unique), for instance phenolic alkaloids (avenanthramides) (Meydani 2009).

Therefore, polyphenols are essential to balance antioxidant systems, that is, they are an excellent assistant for human health.

1.4.2 Anti-Inflammatory

Inflammation is a defense mechanism towards tissue imbalances. It is the immune system's response to harmful stimuli including pathogens, toxic compounds, lesions, osmotic stress, etc. Thus inflammation restores tissue homeostasis. It is worth noting that some diseases such as cardiovascular, cancer and chronic inflammatory are inflammation based diseases (Bollmann et al. 2014).