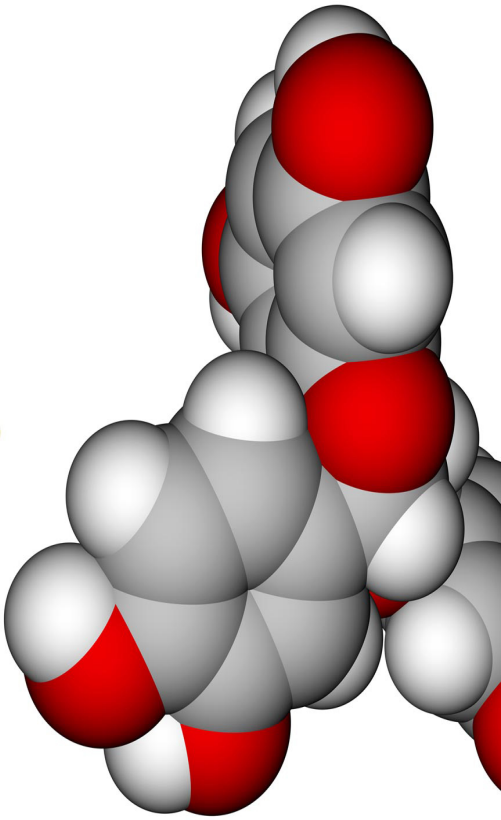
eISBN: 978-1-68108-239-4
ISBN: 978-1-68108-240-0

NATURAL BIOACTIVE COMPOUNDS FROM FRUITS AND VEGETABLES AS HEALTH PROMOTERS

PART 1



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Natural Bioactive Compounds from Fruits and Vegetables as Health Promoters

Part I

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ISBN (eBook): 978-1-68108-239-4

ISBN (Print): 978-1-68108-240-0

Published by Bentham Science Publishers – Sharjah, UAE.

First published in 2016.

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CONTENTS

FOREWORD

For centuries, humans have considered food only as an "energy" source for survival. Clarification of nutritional relevant components, as protein, fat, carbohydrates, minerals and vitamins, was determinant to understand metabolic needs, and to adjust consumption patterns. However, this oversimplified definition of food resulted in processed foods composed by mixtures of ingredients rich in these components, while diet is increasingly claimed as being responsible for the most common diseases of modern society: cardiovascular diseases, obesity, and cancer.

When we look upon food from this simplified perspective, it is as if we are regarding food without its "soul". Indeed, although being difficult to demonstrate causality between food and health, there is now appreciable epidemiologic evidence for the protective role of diets rich in fruits and vegetables, being the Mediterranean diet an interesting example. These foods have thousands of components without nutritional essentiality that have been neglected. The interest in these components has increased tremendously in the last two decades, seeking to identify the dietary bioactive components (*i.e.*, those that have a measurable impact on human health), their amounts, and availability. Simultaneously, it is also becoming clear that each one of these components has different effects and potencies when ingested alone or when taking its part in the complex network of molecules present in whole foods. These are amazing days for food scientists because we are closer to understand these bioactive compounds, while the consumer is following closely scientific advances, being increasingly interested in the health properties of foods.

The editors took an enormous and successful effort to assemble a huge variety of knowledge on different natural bioactive components in foods, bringing together experts working in different fields of food composition and health. This first issue was written to provide readers a comprehensive review of bioactive constituents in fruits from different parts of the world. This assembled knowledge allows the reader to attribute a "health-value" to these foods in a more clear way, understand the care needed to preserve their bioactivity, while also adding value to fruits residues (peels, pulp, seeds, and stones) that are frequently neglected by industry. Therefore, this book is designed for food scientists, nutritionists, pharmaceuticals, physicians, food industrials, as well as for health-conscious consumers. More similar comprehensive reviews on other natural food products will be certainly welcomed by readers.

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PREFACE

Plants have been widely used as food and medicines, since they provide, not only essential nutrients required for human life, but also other bioactive compounds which play important roles in health promotion and disease prevention, commonly known as phytochemicals. Moreover, in the recent years, the impact of lifestyle and dietary choices for human health has increased the interest in fruits and vegetables, as well as in foods enriched with bioactive compounds and nutraceuticals. In fact, epidemiological studies have consistently shown that the Mediterranean diet, characterized by the daily consumption of fruits and vegetables, is strongly associated with reduced risk of developing a wide range of chronic diseases, such as cancer, diabetes, neurodegenerative and cardiovascular diseases.

Phytochemicals are secondary metabolites present in fruits and vegetables in low concentrations that have been hypothesized to reduce the risk of several pathological conditions. There are thousands of dietary phytochemicals, namely flavonoids, phenolic acids, glucosinolates, terpenes, alkaloids, between many other classes of compounds, which present different bioactivities, such as antioxidant, antimutagenic, anticarcinogenic, antimicrobial, anti-inflammatory, hypocholesterolemic, hypoglycemic and other clinically relevant activities. The evidence suggests that the health benefits of consuming fruits and vegetables are attributed to the additive and synergistic interactions between these phytocomponents. Therefore, nutrients and bioactive compounds present in fruits and vegetables should be preferred instead of unnatural and expensive dietary supplements.

In this ebook, we provide an overview about the different classes of phytochemicals commonly found in fruits and vegetables, highlighting their chemical structures, occurrence in fruits and vegetables, biological importance and mechanisms of action. Part (I) is particularly focused on Mediterranean and Tropical fruits.

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CHAPTER 1

Bioactive Compounds and Health-Promoting Properties of *Ficus carica* (L.): A Review

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Abstract: *Ficus carica* (L.), also known as fig, is a deciduous tree belonging to the Moraceae family, and was one of the first plants cultivated. Figs, *F. carica* fruits, are an important component of the Mediterranean diet and can be consumed either fresh or dried, or used for jam production. Notably, this fruit has a great economic importance in many countries, including Portugal, due to its nutritional value and medicinal properties. This botanical species is a good and low cost natural source of bioactive compounds, such as organic acids, phenolic compounds, minerals, amino acids, fibers and others. Several biological activities of *F. carica* have been reported illustrating a high beneficial health potential for this species. In this chapter, we will discuss the phytochemical composition, nutritional value and biological activities of F. carica, particularly the leaf, fruit and latex. The potential use of *F. carica* to prevent and treat a wide range of diseases will also be discussed. This natural product may be a promising candidate for the development of new nutraceuticals and food supplements. However, despite the advances in phytomedicine area, the molecular mechanisms by which fig

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derivatives contribute to health improvement remain largely unknown.

Keywords: *Ficus carica*, Fig, Organic acids, Phenolic compounds, Volatile compounds.

INTRODUCTION

Plants have been used since ancient times as foods and medicines to prevent and treat diseases, due to their nutritional role and chemical properties [1]. In the last years, modern societies have recognized the interest of phytotherapy as an attractive alternative to conventional medicine [2, 3].

The bioactive compounds of plants have served as basis for the development of new drugs and biological products. On the other hand, they are an attractive alternative option to conventional drugs [2, 3]. Noteworthy, a large number of natural products have been introduced over the last years in the pharmaceutical industry [4]. According to the World Health Organization (WHO), treatments with herbal medicine or vegetable extracts are practiced by approximately 80% of the world's population [5]. Several studies of our team have been performed to explore the medicinal properties of natural products and their bioactive compounds, particularly of tea (*Camellia sinensis*), quince (*Cydonia oblonga*), walnut (*Juglans regia*), olive (*Olea europaea*), and fig (*Ficus carica*) and their main phytocomponents, against oxidative stress (OS) and related diseases, including diabetes mellitus (DM), cardiovascular diseases (CVD), male infertility, neurodegenerative disorders, and cancer [6 - 33]. These studies have provided compelling evidence that the antioxidant compounds present in plant infusions, fruits, and vegetables are effective against these illnesses, protecting the organism from oxidative damage.

F. carica is a deciduous tree belonging to the Moraceae family, and one of the earliest cultivated fruit trees. The common fig is a tree native to southwest Asia and the eastern Mediterranean. The *F. carica* fruit is an important harvest worldwide, and it is part of the Mediterranean diet [34] and may be consumed fresh, dried or used to prepare jams. Besides fruits, other parts of the plant like leaves, seeds, bark, tender shoots, and latex also have phytomedicinal potential. In

the last decade, several studies have been performed to determine the chemical composition of this species, namely in leaves, fruits, and latex. It was shown that this plant is an excellent source of phenolic compounds, organic acids, volatile compounds, phytostherols, dietary fiber, sugars, among others [34 - 37]. Of note, some authors reported that figs have even higher phenolic content than tea or red wine [38] which are well-known for their great content in polyphenols and consequently strong phytomedicinal properties. In traditional medicine, *F. carica* leaves, fruits, and roots, have been used to treat gastrointestinal, respiratory, cardiovascular, and inflammatory disorders [39]. Nowadays, several biological properties of *F. carica* components have been evaluated and confirmed [40, 41]. For example, it has been reported that the consumption of figs helps and prevents vein blockage [42], and that the decoction of its leaves has an hypoglycemic action in type 1 diabetic individuals [36]. These pharmacological properties are at least in part due to fig's high content in antioxidants. The pharmaceutical industry is giving more attention to medicinal plants and its chemical properties that may translate into biological activities relevant for human health. In fact, fruits and vegetables may represent a precious resource for the development of new drugs/therapies against several health problems. Throughout this chapter we will discuss the recent findings concerning the phytochemical composition, nutritional value, and biological properties of *F. carica*, focusing on the fruits, leaves and latex. The relationship between *F. carica* phytochemical composition and the health effects already reported will be highlighted.

FICUS CARICA ORIGIN AND PRODUCTION

F. carica belongs to the Moraceae family. Moraceae is an angiosperm plant family with more than 800 species of trees, shrubs, hemiepiphytes, climbers, and creepers, that exists in the tropics and subtropics worldwide [43]. It is a tree native to southwest Asia and the eastern Mediterranean countries, growing in mediterranean and dryer warm-temperate climates [44]. It is one of the oldest fruit trees cultivated, being an important crop worldwide [45]. Countries like Turkey, Egypt, Morocco, Spain, Portugal, Greece, California, Italy, Brazil and others with typically mild winters and hot dry summers are the major producers of edible figs [39]. *F. carica* is a deciduous tree with numerous spreading branches, and its root system is typically shallow and spreading. Its foliage is single, alternate and large,

CHAPTER 2

Bioactive Compounds of Citrus as Health Promoters

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Abstract: Citrus are a group of fruit species, quite heterogeneous in many aspects, including chemical composition of the fruit. Since ancient times, some citrus fruits were used to prevent and cure human diseases. In the recent decades, it has been demonstrated that fruits can actually help prevent and cure some diseases and above all, they are essential in a balanced diet. Citrus fruits, as one of the groups of fruit species, with greater importance in the world, have been studied for their effects on human health. Some species of citrus were referred as potential antioxidant based therapy for heart disease, cancer and inflammation. Fruit peels and seeds have also high antioxidant activity. The health benefits of citrus fruit have mainly been attributed to the high level of bioactive compounds, such as phenols (*e.g.*, flavanone glycosides, hydroxycinnamic acids), carotenoids and vitamin C. These compounds are present in the fruit pulp and hence in the juice. But some bioactive compounds can be found in parts of the fruit which usually are not used for human food. The content of bioactive compounds depends on the species and cultivar, but also depends on the production system followed in the orchard. Citrus fruits, their derivatives and their by-products (peel, pulp and oil) are reach in different bioactive compounds and its maturity, postharvest and agroindustry processes influence their composition and concentration. The aim of this chapter was to review the main bioactive compounds of the different components of citrus and their relationship to health.

Keywords: Ascorbic acid, Clementine, Coumarin, Grapefruit, Hesperidin, Lemon, Lime, Mandarin, Narirutin, Orange.

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INTRODUCTION

Since ancient times the citrus fruit have been considered important to human health. In some older books, they were even considered as a medicine.

In the Virgil's Georgics, likely published in 29 BC, the author mentions the beneficial effects of citron (*Citrus medica* L.) on health. He wrote that "*Persia yields the acidic juices and lasting flavor of the fruitful citrus tree, none other more efficacious – if ever wicked stepmothers have poisoned the drinking cups by mixing herbs and harmful spells – none better to bring immediate help and drive the lethal toxins from the body. The tree itself grows large and much resembles the bay laurel (and, did it not release its own distinctive scent, would be a bay). No wind can cause its leaves to fall, its flower clings fast indeed, and the Persians use it to sweeten bad breath and treat congestion in the old*." [1]. About a thousand years later, Ibn Sina (Avicenna) in the *Canon of Medicine* completed in 1025, mentioned the citron leaves as one of the drugs to stroke [2]. Although some of the effects have never been proven scientifically, other effects mentioned by the ancient authors have been proven by modern medicine [3].The oldest references mentioned only the citron because it was the only citrus they knew. The orange, lemon, and tangerine trees we know today were then unknown to the authors, because they were only grown in limited areas of Asia or because they only appeared later, as a result of mutations or hybridization between other citrus fruits.

The maritime discoveries were important to the spread of citrus species on all continents. But in addition, during long sea travel, it became clear that inclusion of citrus in the diet of seamen was the solution to prevent or even cure scurvy, a historical killer of seafarers for centuries [4].

The discovery of vitamin C and its high content in the citrus explains part of the beneficial effects of these fruits on health. Moreover, in the recent decades, numerous works on other bioactive compounds present in citrus fruits have been published.

Citrus fruits are characterized by the distinct aroma and delicious taste, and have

been recognized as an important food. They are part of our daily diet, playing key roles in supplying nutrients and energy and in human health promotion [5].

According to Kitts [6], bioactive compounds are "extranutritional" constituents naturally present in small amounts in the food matrix, produced upon either *in vivo* or industrial enzymatic digestion. Ascorbic acid, carotenoids (lycopene and β-carotene), limonoids, flavonoids, essential oils, vitamin-B complex and related nutrients (nicotinic acid/niacin, pantothenic acid, folic acid, thiamine, riboflavin, pyridoxine, biotin, choline, and inositol), and pectin are some examples of bioactive compounds of *Citrus* fruits, useful not only for maintaining human health but also in food industry [7].

The presence and/or the amounts of the bioactive compounds present in citrus fruits depend on the species and cultivars [sweet oranges (*Citrus sinensis* (L.) Osbeck) including acidless, navel and blood oranges, mandarins such as satsumas (*C. unshiu* Marcov.), tangerines (*C. tangerine* Yu.Tanaka), 'Ponkan' (*C. reticulata* Blanco), and clementines (*C. clementina* hort. ex Tanaka), sour/bitter oranges (*C. aurantium* L.) such as 'Seville', lemons (*C. limon* (L.) Burm.f.), limes (*C. aurantifolia* (Cristm.) Swingle and *C. latifolia* Tanaka), grapefruit (*C. paradisi* Macfad) and pummelos (*C. maxima* Burm. f.), hybrids (*e.g.*, tangelos, tangors and limequats), citrons (*C. medica* L.), and many others], part of the fruit (juice, pulp, peel, seeds), developmental stages of fruits, among other factors [7 - 10].

In this chapter, we will focus on the chemistry and biological properties of ascorbic acid, carotenoids, flavonoids, limonoids, coumarins, and essential oils of citrus origin as well as the factors affecting the level of each of these compounds in the fruit.

ASCORBIC ACID

Chemistry

Ascorbic acid (vitamin C) is a water-soluble ketolactone with two ionizable hydroxyl groups (lactone 2, 3, - dienol- L- gluconic acid) having the chemical formula $C_6H_8O_6$. It has two pK_a's, pK_1 is 4.2 and pK_2 is 11.6, being the ascorbate monoanion, $AscH^-$, the dominant form at physiological pH [11].

CHAPTER 3

Bioactive Compounds of Apples and Pears as Health Promoters

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Abstract: Contemporaneous dietary patterns could be best described as in need of improvement. Obesity, diabetes and metabolic syndrome prevalence increased dramatically in the recent years likely due to unbalanced dietary patterns and sedentary lifestyle. "Epidemiological studies have shown that dietary patterns are significantly associated with the prevention of chronic diseases such as heart disease, cancer, diabetes and Alzheimer's disease".

"Fruits and vegetables" have improved the human diet for centuries, enriching it nutritionally and sensorially. A significant amount of vitamins and minerals in the diet come from fruits and vegetables. "Approximately half of the vitamin A, in the form of carotene, over 90% of vitamin C and 40% of folacin come from this food group". Fruits contribute with "considerable amounts of vitamins A, C, B_6, thiamin, niacin and minerals (*i.e.* magnesium and iron)" to our diet. Furthermore, "they supply proteins, starch and sugars, and they are important sources of dietary and crude fiber".

"Epidemiological and clinical investigations demonstrate significant decrease in morbidity and mortality from cardiovascular and other diseases among fruit and vegetables consumers". These benefits have been associated to their content on dietary fiber and different bioactive compounds with anti-atherosclerotic and anticancer effects.

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Apples and pears are some of the most "common and frequently consumed fruits in the world and the most widely consumed fruits by Western populations". A revision of the type and content of bioactive compounds present in these types of fruits, as the main methodologies used for the assessment of their antioxidant potential are presented in this chapter.

Keywords: Antioxidant-potential-indicators, Bioactive-compounds, Cancer, Chronic-diseases, Diabetes, Dietary-fiber, Flavonoids, Heart-disease, *In vitro*assay, *In vivo*assay, Lipid-peroxidation, Low-density-lipoprotein cholesterol, Obesity, Peel, Phenolic compounds, Pulp, Vitamins.

INTRODUCTION

Fruits and vegetables are essential components of a balanced and healthy diet since they are important sources of some essential nutrients and contain phytochemicals, which may lower the risk of cardiovascular diseases [1, 2].

The link between dietary factors and cardiovascular disease (CVD) has been mainly and almost only correlated to lipids, especially saturated fat and cholesterol, namely "low density lipoprotein (LDL) levels resulting in atherosclerotic vascular changes" [3]. CVD have been reported by several international health organizations as one of the main causes of death worldwide [4], and several "epidemiological, clinical and biochemical studies have proved that increased lipid concentrations, namely triglycerides, total cholesterol, low density lipoprotein cholesterol are risk factors to the development of CVD and atherosclerosis" [3].

Some studies associated the ingestion of fruits and vegetables with "the reduced risk of chronic diseases like cancer prevention" [5] and with a general decrease in all-cause mortality [6]. An inverse association has been established "between the consumption of fruits and vegetables and the prevalence of CVD". On the other hand, inversely low consumption of fruits and vegetables produce less favorable plasma biomarker profiles predictive of CVD, bone diseases and higher mortality rates (Khaw *et al.*, 2001) [7].

Phytochemicals like phenolics, present in fruit and vegetables, have been

"suggested to be the major bioactive compounds for human health benefits" [8, 9]. "The protective effect of fruits and vegetables has generally been attributed to their antioxidant constituents, including vitamin C (ascorbic acid), vitamin E (α tocopherol), carotenoids, glutathione, flavonoids, and phenolic acids" [10 - 13]. The antioxidant capacity of pears and apples has been associated with their total phenolic content; having a positive influence on lipids metabolism (hypocholesteromic effect and plasma antioxidant potential) [14, 15].

In general pears present lower antioxidant capacity in comparison with apples; such difference was associated to pears' low percentage (76%) of free phenolics in comparison then apples (91.8% of free phenolics) [8]. On the other hand, the percentage of bound phenolics was higher in pears than in apples, 24% and 8.2%, respectively. Nevertheless, "the effect of bound phytochemicals to human health is not clear yet", but some research in this area suggests that bound phytochemical might "survive stomach and small intestine digestion to reach the colon and be digested by bacteria flora to release phytochemicals locally to provide health benefits" [16].

This chapter focuses on the differences in terms of bioactive compounds (phenolic composition, vitamins, fiber) between apples and pears and how these differences may be associated to antiproliferative activities like tumor cancer cell growth and also how the changes that occur during the gastric digestion can influence the bioavailability of apple and pear constituents.

Apples

"Apples are one of the most popular and frequently consumed fruits in the world". This type of fruit is a "good source of polyphenolic compounds such as flavonoids and phenolic acids". In general, the phenolic composition of apple skin has been demonstrated to be significantly higher when compared with the phenolic content of apple flesh extracts [15]. At least twenty-nine phytochemical compounds were identified in apple peels; from those a significant part corresponds to flavonoids (*e.g.* quercetin-3-O-β-D-glucopyranoside and quercentin) which showed potent antiproliferative activity against tumor cell proliferation [17]. The high content of flavonoids together with the concentration of phenolic acids found in apple peels

CHAPTER 4

Stone Fruits as a Source of Bioactive Compounds

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Abstract: Fruits constitute one of the most important sources of phytochemicals in human diet. Stone fruits, such as peaches, plums, almonds, apricots and cherries have been investigated concerning their therapeutic effects in the prevention of a range of diseases. The consumption of these fruits is related with the lower prevalence of diabetes, overweight or general obesity, lower risk for estrogen receptor-negative tumors and cardiovascular protection among others. Phenolic compounds, predominantly flavonoids and phenolic acids, are the main phytochemicals in stone fruits. Considering the importance of stone fruits as a source of biologically active compounds the present chapter aims to provide the current findings in this field and the main implications to human health associated with its consumption.

Keywords: Almond, Anticancer, Antidiabetic, Antiinflammatory, Antioxidant, Apricot, Bioactive Compounds, Cardiovascular protection, Cherry, Flavonoids, Nectarine, Obesity, Peach, Phenolic acids, Phenolic compounds, Plum, Prunus, Stone fruits.

INTRODUCTION

Different studies have demonstrated that a diet rich in fruits and vegetables may decrease the risk of diabetes, cancer, cardiovascular and neurodegenerative diseases (*i.e.* Alzheimer and Parkinson) [1 - 4]. This beneficial effect is associated to

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the nutrients they contain such as fibers, minerals, vitamins and the presence of phytochemicals. Phytochemicals are secondary metabolites produced by plants, in relatively small amounts, where they are responsible for a variety of functions. The ecological role of secondary metabolites production can be related to the potential medicinal effect observed in humans. For example, secondary metabolites in plant defense through cytotoxicity towards microbial pathogens could be useful as antimicrobial drugs in humans, if not very toxic [5].

Phytochemicals compounds have been extensively investigated since they possess a range of activities, which may be involved in the protection against chronic diseases (Fig. **1**). They may also regulate inflammatory and immune responses, inhibit cancer cell proliferation, and protect cells against oxidative damages, caused by free radicals and reactive oxygen species, to macromolecules such as lipids, proteins, and DNA [6]. Examples of phytochemicals present in fruits are phenolic, terpenoids, alkaloids and organosulfur compounds.

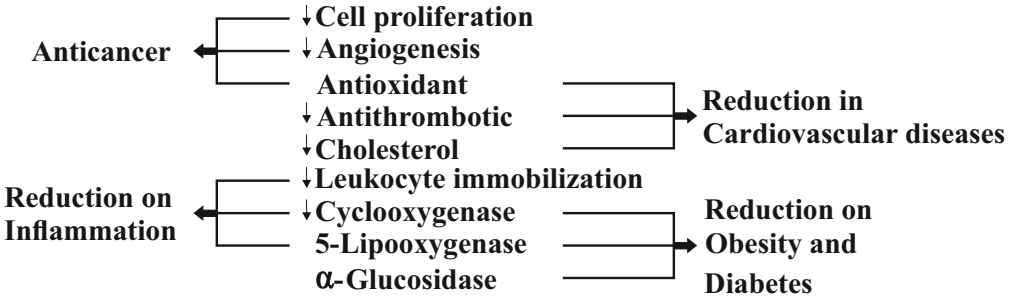

Fig. (1). Relation of phytochemicals actions on different diseases (adapted from [7]).

Stone fruits, also known as drupes, are trees and shrubs members of Prunus genus. Peaches (*Prunus persica* (L.) Batsch), nectarines (*P. persica*, var. nectarine), European plum (*P. domestica* L.), Japanese plum (*P. salicina*), apricot (*P. armeniaca* L.), mume or Japanese apricot (*P. mume*), sweet cherry (*P. avium*), sour cherry (*P. cerasus*) and almond (*P. amygdalus*) are examples of stone fruits with economical interest and are highly consumed worldwide [8]. Good nutritional properties are described for these fruits which are also a good source of phytochemicals affording considerable amounts of bioactive phenolic compounds,

mainly flavonoids and phenolic acids.

In the last years, the consumption of fruits has been investigated in different epidemiological studies. Stone fruits consumption was correlated with lower prevalence of diabetes and obesity [9 - 11], cardiovascular protection [12 - 17] and inversely associated with estrogen receptor-negative (ER−) breast cancer [18, 19] and risk of esophageal squamous carcinomas [20]. Moreover, *in vivo* and *in vitro* studies with stone fruits, their extracts, purified fractions and their phytochemicals have been related with these epidemiological evidences on chronic diseases. Considering these facts, we intend to present in this chapter recent research, mostly from the past 10 years, related with epidemiological evidences of the consumption of stones fruits and their health benefits as well as the relationship between these effects and the phytochemicals, mainly phenolic compounds, present in these matrices.

Stone Fruits Bioactive Compounds

Stone fruits can provide different bioactive phytochemicals such as terpenoids, mainly carotenoids, tocopherols and phenolic compounds. In this chapter greater attention will be given to phenolic compounds, since these are the most abundant compounds found in stone fruits. Nevertheless, stone fruits carotenoids and tocopherols, their amounts and their role to human health will be briefly commented.

Carotenoids

Carotenoids are C_{40} terpenoids pigments present in all stone fruits. The carotenoids α- and β-carotene, capsantine, β-cryptoxanthin, lycopene, lutein and zeaxantin, have been reported [21 - 24]. However, there is a large variation on the amounts of these compounds that is dependent of the specie and variety studied. Apricots is the most abundant stone fruit concerning carotenoids with 1512-16500 μg/100g of fresh weight, followed by peaches (up to 1160 μg/100g of fresh weight), plums (231 μg/100g of fresh weight), nectarines (162 μg/100g of fresh weight), being cherries (1.1 μg/100g of fresh weight) the poorest one [25 - 27]. Carotenoids are important to human health since they are precursors of vitamin A, that are implicated in the production of retinoids, vital for human vision [28].

CHAPTER 5

Pomegranate (*Punica granatum*): A Natural Approach to Combat Oxidative Stress-Related Diseases

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Abstract: Pomegranate fruit *(Punica granatum)* has been widely studied as a dietary component that is an important source of biologically active compounds. Mainly in the over the last ten years, much research has been done into what concerns the health benefits of this fruit (peel, seeds and juice) producing encouraging results to prevent and treat specific diseases such as obesity, diabetes, neurodegeneration and cancer. Additionally, the use of pomegranate by traditional medicine as antidiarrheal, anti-helminthic, diuretic and digestive, has been also reported in ethnobotanical studies. Pomegranate is described as containing a very high content of polyphenolic compounds when compared to other fruits or vegetables, namely ellagitannins and hydrolysable tannins and flavonoids (anthocyanins, flavones and isoflavones). These phytochemicals have been identified for their many health benefits including its very high antioxidant activity and anti-inflammatory, antitumor, antimicrobial activities, among others. Considering that polyphenols have been widely reported to counteract the oxidative stress effects in different model systems, this chapter will highlight the phytomedicinal potential of pomegranate by describing its health impact and mechanisms of action in oxidative stress-related conditions. In addition, its origin, production, consumption and traditional uses will be briefly discussed and those related to its phytochemical composition and health promoting properties, namely those related to its antioxidant activity will be detailed.

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The main focus will be the action of pomegranate in oxidative stress-related diseases, including inflammatory processes, cancer, diabetes, cardiovascular diseases and neurodegenerative disorders. Bioavailability aspects will also be presented.

Keywords: Cancer, Cardiovascular diseases, Diabetes, Inflammatory processes, Natural antioxidants, Neurodegenerative disorders, Polyphenols, Pomegranate, Heart-disease, *Punica granatum*.

INTRODUCTION

Oxygen is of vital importance in providing the necessary energy for the survival and normal functioning of most eukaryotic organisms [1, 2]. Through the respiratory chain, oxygen is partly reduced at a low ratio into superoxide. As this is a basic free radical, it can be transformed into other forms of reactive oxygen species (ROS) [1, 2]. Other free radicals can also be generated from nitrogen and therefore classified into the family of reactive nitrogen species (RNS) [1, 2]. At a physiological level, ROS and RNS have been recently shown to mediate a variety of normal functions including the regulation of signal transduction, the induction of mitogenic response and are involved in the defense against infectious agents [1, 2].

ROS are balanced with antioxidant systems to keep their levels constant in living organisms [1, 2]. These antioxidant systems are both enzymatic and non-enzymatic.The imbalance between ROS and antioxidant systems is termed oxidative stress, and can be caused by the over production of ROS and/or the reduction of antioxidants; both situations can be harmful [1, 2]. During oxidative stress, excessive free radicals may freely pass through the plasma membrane, promoting damage in the cell membrane *via* lipid peroxidation. This process modifies the signal and structural proteins leading to misfolding and aggregation as well as the oxidation of RNA/DNA. Due to this, transcription is interrupted resulting in gene mutation [1, 2].

It is commonly accepted that in a situation of oxidative stress, ROS such as superoxide ($O2^{-}$, $OOH^{\cdot}$), hydroxyl ($OH^{\cdot}$) and peroxyl ($ROO^{\cdot}$) radicals are generated [3]. The ROS play an important role in the pathogenesis of various serious diseases, such as neurodegenerative disorders [4], cancer [5], cardio-

vascular diseases [6], atherosclerosis [7], cataracts [8], and inflammation [9].

The use of traditional medicine is widespread and plants still present a large source of natural antioxidants that might serve as leads for the development of novel drugs [3, 10]. Several ant-inflammatory, digestive, antinecrotic, neuro-protective, and hepatoprotective drugs have recently been shown to have an antioxidant and/or antiradical scavenging mechanism as part of their activity [3]. Natural antioxidant ingredients of fruits and vegetables could act as protective factors against oxidative damage [11]. According to the recent studies, the antioxidant features of many fruits and vegetables come from their flavonoid and related polyphenolic components [11 - 15]. In human, daily intake of these compounds is approximately between a few hundred milligrams and one gram [11]. Moreover, there are several studies which have demonstrated the bioavailability of the antioxidants in many fruits and plants [16 - 18].

Phenolics are compounds that have one or more aromatic rings with one or more hydroxyl groups [19]. They are common in the plant kingdom and are the most abundant secondary metabolite of plants, with more than 8.000 phenolic structures currently known. They range from simple molecules like phenolic acids up to highly polymerized substances such as tannins [19]. Plant phenolics are usually involved in the defense of the plant against ultraviolet radiation or aggression by pathogens, parasites and predators. They also contribute to the colors of plants. Since they can be found in virtually all the organs of the plants, they are therefore an integral part of the human diet [19]. Still, the health effects of dietary polyphenols have only come to the attention of nutritionists in the recent years [20]. The potent antioxidant properties of polyphenols, their abundance in the diet, and their credible effects in the prevention of various diseases associated with oxidative stresses have resulted in an increasing interest by researchers and food manufacturers [19]. The effects of these secondary plant metabolites, that can help to prevent cardiovascular diseases, neurodegenerative diseases and cancer result from epidemiologic data as well as *in vitro* and *in vivo* results, which have originated several nutritional recommendations [19, 21]. Polyphenols have also been found to modulate the activity of a wide range of enzyme and cell receptors. Thus, in addition to having relevant antioxidant properties, polyphenols have several other specific biological actions that can help to prevent and treat several

CHAPTER 6

Nutritional and Functional Properties of Edible Berries: Implications For Health Claims

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Abstract: The data reported over the last decades on the relevance of fruits and vegetables for human health promotion has increased their use as nutraceutical ingredients. In this connection, berries display an interesting content in a wide variety of nutrients that contribute to a balanced diet such as sugars, essential oils, carotenoids, vitamins, and minerals as well as bioactive non-nutrients namely flavonoids, phenolic acids, stilbenes, and tannins. Bioactive compounds from berries have potent biological activities namely antioxidant, anticancer, antimutagenic, antimicrobial, anti-inflammatory, and antineurodegenerative, which are supported by *in vitro* and, to a lesser extent, by *in vivo* models. This is a comprehensive review on nutritional and non-nutritional compounds present in berries, intended to provide rational information on the health benefits of integrating berries in balanced diets

Keywords: Absorption, Berries, Bioavailaility, Biological activity, Flavonoids, Health, Intestinal microbiota, Metabolism, Nutrients, Phenolic acids, (Poly)phenols.

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INTRODUCTION

Berry fruits, small fruits or berries are generally referred to any small fruit that lacks seeds and can be eaten whole (Fig. **1**), which has been promoted for dietary consumption with resort to their content in bioactive nutrients and non-nutrients. This composition turns berries into very special and healthy foods.

Dietary Guidelines of international experts recommend to increase the fruit intake as part of a healthy diet. Thus, although this dietary habit can be achieved by a large group of forms of fruit, including fresh, frozen, and canned, as well as fruit juices and dried fruit updated and accurate evaluations of the nutritional and phytochemical composition of processing foods is required for rational advice. In this sense, nowadays many of the berry species and subspecies present in the market are understudied, whilst the current trend on health promotion through balanced diets requires further investigations to identify new challenges for dietary interventions towards improved human health [1].

Fig. (1). Common berry fruits.

Berries are widely distributed and include blackberry (*Rubus* spp.), black raspberry (*Rubus occidentalis*), blueberry (*Vaccinium corymbosum*), cranberry (*Vaccinium oxycoccus*), red raspberry (*Rubus idaeus*), chokeberry (*Aronia* spp.), and strawberry (*Fragaria* spp.), among others fruits.

Over the last year these kind of fruits have been related with an interesting content

in a wide variety of nutrients such as sugars, essential oils, carotenoids, vitamins, and minerals as well as healthy non-nutrients such as flavonoids, phenolic acids, stilbenes, and tannins. An overwhelming body of research has now steadily established that their dietary intake exerts a positive and depth impact on health and human performance [2]. Thus, bioactive compounds from berries have potent biological activities namely antioxidant, antimicrobial, anti-inflammatory, anticancer, antimutagenic, and neuroprotector, which have been reported both *in vitro* and *in vivo*. Therefore, an overview about their beneficial effects on health related to their nutritional and bioactive composition is needed.

Berry fruits are usually consumed not only in fresh and frozen shapes but also as derived and processed products including canned fruits, beverages, jams, yogurts, and jellies. Besides to these traditional uses, over the last years there is a growing trend regarding the application of berry parts as ingredients in the development of functional foods and dietary supplements, which can or cannot be combined with other colorful vegetable extracts [3]. Hence, in addition to their consumption in fresh form, berries have been used in the production of several manufactured commodities including juices, marmalades, spirits, or infusions, which consumption has also been promoted based on their preventive properties against degenerative processes [4]. However, in comparison with fresh fruits significant losses of bioactive (poly)phenols have been identified in manufactured products namely blueberry juices [5, 6], raspberry purée and jam [7], strawberry jams [8], canned fruit, and nectar [9]. Hence, Hager *et al*., reported that processing of canned berries in water, purée or syrup decreased the anthocyanin content up to 51% from the fresh berry, on average [10].

CHEMICAL COMPOSITION

The information available on the properties of berries as a source of nutrients and phytochemical compounds has allowed to promote their consumption, which has grown considerably during the last years. Indeed, berries have reported to contain over 190 compounds, with concentrations varying significantly between distinct species and subspecies, according to the origin, climate, and time of harvesting [11]. The composition of berries includes carbohydrates, proteins and amino acids, lipids and fatty acids, organic acids, vitamins (A, B1, B2, B9, C, K, and E)

CHAPTER 7

Bioactive Compounds of Tropical Fruits as Health Promoters

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Abstract: Currently, it is known that ingestion of fruits and vegetables decreases the incidence of several degenerative and aging-related disorders. Plants contain mostly antioxidant compounds that preserve the balance between oxidants and antioxidants in the body. Excess of reactive oxygen species [ROS] can be produced after the so-called "oxidative stress", a process that can damage and even kill the cells. Although antioxidant substances represent one of the most important mechanisms of defense against free radicals, the endogenous antioxidant molecules alone are not effective enough to counteract the injuries caused by ROS, particularly in current times when lifestyles based on smoking, consumption of drugs and/or alcohol, unbalanced diet, pollution, and exposure to solar radiation, among others, can facilitate free radical formation. For this reason, increasing the intake of dietary antioxidants is of great importance for a good health, as it is evidenced by studies on food with high antioxidant contents as well as with anti-inflammatory properties. Among these foods are tropical fruits which include a large number of plants that grow in tropical and subtropical climates above 4°C.

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As Latin America and Asia are the main regions that produce this kind of fruits for human consumption, we described some of the phytochemical properties, biological activities and bioactive compounds of several tropical fruits from the Latin American region. The aim of this review was to present them as potential health promoters and their use for prevention and treatment of several neurological diseases.

Keywords: Antioxidants, Health promoters, Phytochemicals, Tropical fruits.

INTRODUCTION

The influence of diet in the prevention and treatment of diseases is becoming stronger to date. This is attributed to many substances present in food that act synergistically on intermediary and xenobiotic metabolism. Among these substances are those with antioxidant capacity which eliminate or inactivate free radicals, preventing the development of oxidative stress related diseases as diabetes mellitus II, cardiovascular disease (CVD), neurodegenerative diseases and cancer. The antioxidant benefit of fruits and vegetables has been supported by many analytical (bioactive), epidemiological (protector) and interventional (dose-response) studies, where the consumption of fruits, particularly tropical fruits and berries increased these antioxidant effects. The beneficial effects of plants have been associated with the presence of essential and non-essential bioactive compounds, which are found in nature and are part of the food chain, and also have effects on human health [1].

Tropical fruits are known as fruits native to the tropical or subtropical climate. They have in common not withstanding the cold or temperature falls below 4°C. Tropical fruits are not characterized by the geographical area where they grow but rather the surrounding climate. Many tropical fruits are grown in areas that are not classified as tropical or subtropical, but enjoy a warm, constant temperature at an average of 27°C [2]. In regard to tropical fruits and their products attention is growing mainly because their appearance and interesting taste to consumers worldwide (Fig. **1**). The tropical fruit exporting countries are in Asia, Middle East, Latin America, the Caribbean and, to a lesser extent, in Africa. The five fruits with the major export volume are banana, mango, pineapple, papaya and avocado. Major tropical fruit production was reported by the Food and Agriculture Organization (FAO) to be over 184 million tons in 2013 [3]. Bananas are

extensively available in all markets, with a production of 93 million tons in 2008 and 100 million tons in 2013. Major banana producers are the countries of Central America and the Philippines. On the other hand, mango production rose by 25% since 2007, when it was less than a third of that of bananas [3, 4].

Fig. (1). As global consumers demand and are willing to pay for new appealing and exotic foods, tropical fruits are being intensively investigated for their several properties and bioactive compounds, such as carotenoids that produce their attractive colors.

Many of the tropical fruits remain unknown to consumers due to a lack of communication, poor storage and bad transportation that causes a short useful life.

CHAPTER 8

Bioactive Compounds from Amazonian Fruits and their Antioxidant Properties

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Abstract: An adequate intake of fruits has long been correlated to a lower occurrence of chronic degenerative diseases triggered by oxidative stress. These health benefits are extensively claimed in the literature to be owing to the scavenging capacity of some bioactive compounds, such as ascorbic acid, tocopherols, carotenoids and phenolic compounds, against the oxidizing effect of reactive oxygen and reactive nitrogen species with physiological relevance. The Amazon is the largest reserve of biodiversity in the world and is also the largest Brazilian biome, occupying almost half of Brazil (49%). In this way, Amazon hosts numerous fruit species, which are consumed by the local population and distributed through the local economy at trade markets, but most of them are unknown to the wider population. Analysis of bioactive compounds has an essential role in the study of biodiversity, and in the evaluation of food safety and nutritional properties. To contribute for a better knowledge of Amazonia biome, this chapter gathers scientific information concerning the phytochemical composition of some Amazonian fruits with potential biological properties.

Keywords: Amazonian biome, Ascorbic acid, *Astrocaryum aculeatum*, *Bactris gasipaes*, *Byrsonima crassifolia*, Carotenoids, *Caryocar villosum*, *Endopleura uchi*, *Eugenia stipitata*, *Euterpe oleracea*, *Mauritia flexuosa*, *Myrciaria dubia*, *Oenocarpus bacaba*, Oxidative stress, Phenolic compounds, Reactive nitrogen

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species, Reactive oxygen species, *Solanum sessiliflorum*, *Theobroma grandiflorum*.

INTRODUCTION

The Amazon, characterised by the Amazon River basin, is an area predominantly covered by dense and moist tropical forest, with inclusions of several other vegetation types, such as floodplain forests, savannas, swamps, grasslands, palm forests and bamboos.

Fig. (1). Amazon biome and Amazon basin shared by Brazil, Peru, Bolivia, French Guiana, Suriname, Guyana, Venezuela, Colombia and Ecuador (modified from [1]).

The biome covers an area of 6.7 million km^2 and comprises nine countries, namely Brazil (which houses ≈ 60% of total area), Peru (≈ 13%), Bolivia, French Guiana, Suriname, Guyana, Venezuela, Colombia and Ecuador (Fig. **1**) [1]. The Amazon biome drains 20% of the world's fresh water and is the largest reserve of biodiversity in the world and is also the largest Brazilian biome (49%). It is dominated by a warm, humid climate, with an average temperature of 25 °C and torrential rains that are well distributed throughout the year [2]. Considering all these particular characteristics, the Amazon hosts a huge number of fruit species that are consumed by the local population and distributed through the local economy at trade fairs, but mostly unknown to the wider population [2].

The usual diet of fruits and vegetables provides, in addition to macro and micronutrients, some chemical compounds that may have potent biological activities. These compounds are called bioactive compounds (or sometimes phytochemicals) and may play many important roles in human health. The bioactive compounds from plants may be grouped into primary and secondary metabolites. Briefly, primary metabolites are necessary for the basic metabolism and growth in all plants, such as carbohydrates, lipids, and amino acids, whilst secondary metabolites (1-5% of the dry weight), such as phenolic compounds, carotenoids, tocopherols and ascorbic acid are not essential, but they are pivotal compounds for the wellbeing of plants by interacting with the ecosystems. In human health, dietary ingestion of bioactive compounds from fruits and vegetables has been linked to the immune system improvement and decrease of the risk of development of chronic degenerative diseases, such as macular degeneration, cataracts, cardiovascular diseases and also certain types of cancer [3]. In general, these observed health effects are attributed to the capacity of some bioactive compounds in inhibiting the oxidizing effects of reactive oxygen species (ROS) and reactive nitrogen species (RNS). Due to the high importance of their biological activities, secondary metabolites of plants have been applied for centuries in traditional medicine practices. Currently, they find applications in fine chemicals, cosmetics and more recently in functional food or nutraceutics [3].

Dietary antioxidants have a broad scope and may be defined as substances that significantly decrease the deleterious effects of ROS/RNS on the human normal physiological functions [4]. These ROS/RNS are generated as a consequence of

CHAPTER 9

Bioactive Compounds of Banana as Health Promoters

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Abstract: Bananas (*Musa* spp) are sources of income and food for people who have been cultivating them all over the world. Banana is assumed to be a fruit with nutraceutical properties, mainly the pulp which is worldwide consumed. In the traditional medicine of some countries the treatment of burn wounds and the prevention of depression, for example, have been reported by compounds from banana peel. Banana peel is an under-explored waste from the food industry and could be considered a source of bioactive compounds with potential application in health care, for instance. This chapter provides updated information about *Musa* spp fruit and peel as chemically complex matrices sources of high-value secondary metabolites with claimed health promoters properties. Bananas are source of antioxidant compounds such as phenolic acids, biogenic amines (*i.e.*, L-dopa and dopamine), and pro-vitamin A carotenoids, which are important for the treatment of wounds, Parkinson's disease, and as dietary supplement, respectively. Therefore, the pulp and peel of banana fruits are biomasses riches in human health promoters compounds with biotechnological importance.

Keywords: Amine compounds, Bioactive compounds, Carotenoids, Flavonoids, *Musa* spp, Parkinson's disease, Phenolic compounds, Pro-vitamin A, Wound healing.

INTRODUCTION

The term *banana* describes hybrid plants of the genus *Musa* known as dessert bananas and plantains [1, 2].

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Bananas have sweet flavor, exuberant appearance, and nutraceutical properties which makes them a fruit worldwide appreciated.

The differences among the genotypes of bananas reveal important particularities in their nutritional potential (Table **1**). Bananas have been one of the most commonly eaten fruit in Europe, North America, and in the tropics where are usually grown. In addition, bananas are forwarded to the food, pharmaceutical, and cosmetic industries as a high added-value raw material [3].

Table 1. Nutritional composition (100g of pulp) of banana cultivars typically grown in Brazil [4].

Composition	Maçã cultivar (AAB*)	Nanica cultivar (AAA*)	Prata cultivar (AAB*)
Calories (kcal)	97.70	99.00	100.00
Protein (g)	1.44	2.56	2.30
Fat (g)	0.20	0.29	0.20
Carbohydrates (g)	26.4	20.80	29.60
Calcium (mg)	0.30	0.02	0.01
Iron (mg)	60.00	1.00	0.60
Potassium (g)	0.03	0.03	0.03
Vitamin A (UI)	127.00	127.00	127.00
Vitamin B1 (mg)	0.40	0.37	0.79
Vitamin B2 (mg)	0.30	0.78	0.90
Vitamin C (mg)	12.70	4.10	17.30

Source [4]. * Genomic group

Banana has a high nutritive status as source of carbohydrates, mostly starch, vitamin A, iron, calcium, and neuroamines, *e.g.* serotonin and dopamine [5, 6].

Plants have been used as sources of bioactive compounds since a long time ago for the development of medicines to treat human beings diseases [7]. Banana peel could be considered a biomass with health promoter properties, despite being an under-explored residue (*i.e.* pomace) from the food industry, due to its chemical composition rich in bioactive compounds.

In the Brazilian folk medicine, the banana peel's inner face when applied topically

on a wound, mainly caused by burns, acts as a healing promoter [8], reducing the pain and swelling [9].

This chapter provides updated information about *Musa* sp. fruit pulp and peel as matrices complex in their chemical compositions and sources of high-value secondary metabolites of interest for human health. Emphasis is given on the banana's peel and pulp chemical profiles as to their phenolic and carotenoid compounds, as well as biogenic amines. Besides, the biological activities of those secondary metabolites as health promoters, *e.g.* wound healing and for the treatment of depression are also addressed.

BANANAS AS SOURCE OF BIOACTIVE COMPOUNDS

Phenolic Compounds and Flavonoids

Phenolic compounds are chemically characterized by having in their structures one or more benzenic rings and one or more hydroxyl groups linked to the ring as substituents, as well as methyl, methoxyl, and amino groups (Fig. **1**). Most of them occur naturally as glycosides, forming conjugates with monosaccharides and polysaccharides. Phenolic compounds may be esters and methyl esters which are functional derivatives [10]. They can be found in several plant species with a typical electron transfer function related to their ability of capturing hydroxyl and superoxide radicals [11].

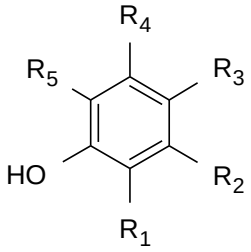

Fig. (1). General structure of phenolic compounds. R1, R2, R3, R4, and R5: benzenic ring, hydroxyl, methyl, methoxyl, amino groups, and/or mono-(poly)saccharides [10].

Since bananas are sources of bioactive phenolics relevant to the food industry, a series of studies has addressed the analysis of *Musa* spp genotypes cultivated in

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