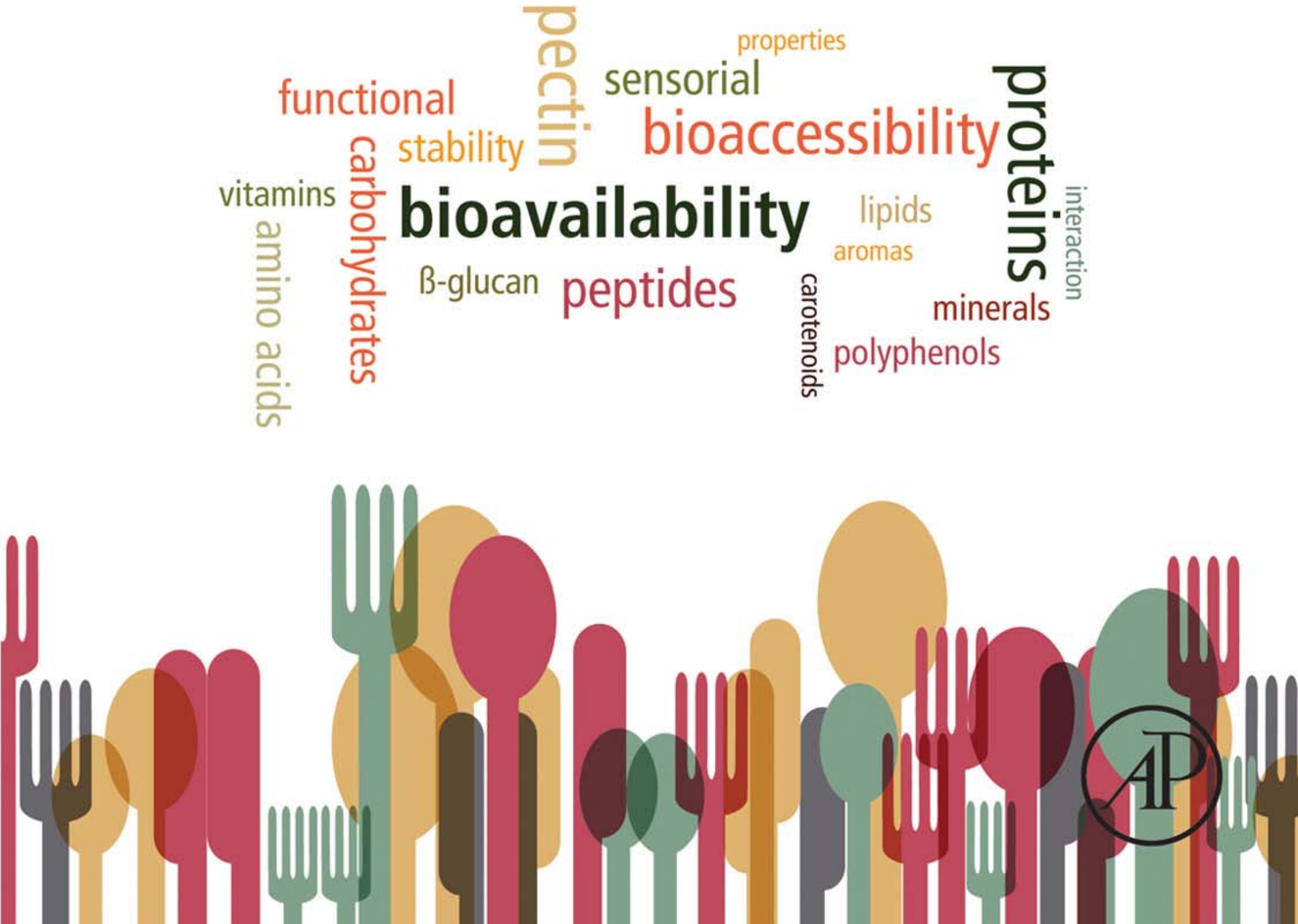
Nutraceutical and Functional Food Components

Effects of Innovative Processing Techniques

Edited by
Charis M. Galanakis



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Academic Press is an imprint of Elsevier

Academic Press is an imprint of Elsevier
125 London Wall, London EC2Y 5AS, United Kingdom
525 B Street, Suite 1800, San Diego, CA 92101-4495, United States
50 Hampshire Street, 5th Floor, Cambridge, MA 02139, United States
The Boulevard, Langford Lane, Kidlington, Oxford OX5 1GB, United Kingdom

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress

ISBN: 978-0-12-805257-0

Publisher: Nikki Levy
Acquisition Editor: Megan Ball
Editorial Project Manager: Jaclyn Truesdell
Production Project Manager: Nicky Carter
Designer: Mark Rogers

Typeset by MPS Limited, Chennai, India

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Preface

Foods contain major and minor components as well as bioactive compounds that are of primary importance for human nutrition. The importance of these compounds accelerated the development of innovations in the food industry, generating the so-called *functional foods* and *nutraceuticals*. Whole foods like fruits and vegetables represent the simplest example of functional foods, as they are rich in bioactive compounds and have a well-established protective role against the development of diseases. Nutraceuticals represent any substance that provides medical or health benefits, including the prevention and treatment of diseases. Contrarily to functional foods, nutraceuticals are commodities derived from foods used in the medicinal form of pills or capsules. The preparation of foods fortified with functional components requires integration of diverse aspects under evaluation. These include, for instance, separation techniques, toxicological assessments, and stability and activity tests. On the other hand, processing has an impact on the final food products. Applied technologies may influence the content and effectiveness of nutrients, e.g., loss of bioactive compounds or diminution of their functionality typically increases more and more as foods are processed, stored, and transported.

Novel, nonthermal technologies (e.g., ultrasounds, high-hydrostatic pressure, pulsed electric field, high voltage electrical discharge, cold plasma) promise to treat foods without destroying their nutritional components and sensorial characteristics, which are normally affected during heat treatment. The latest techniques are today applied in both research institutes and food industries, promising to shorten processing times, control Maillard reactions, improve product quality, and enhance functionality. The implementation of these technologies together with other trends and practices of the food industry (e.g., nanoencapsulation, food waste recovery, emerging need for innovations, etc.) have brought new developments, data, and state-of-the-art in the field. Indeed, this renaissance has changed the way food components are incorporated inside foods and thus consumed. As a result, food technologists that deal with the development of functional foods and nutraceuticals must consider:

1. the effect of thermal and nonthermal processing technologies on food components in spite of their functional properties and preservation ability;
2. the available and optimized extraction and formulation processes; and
3. the innovative and sustainable applications in foods.

Thus there is a need for a resource that covers the latest developments in the food industry and their trends and practices therein. This text hopes to fill in this gap by highlighting the impact of recent food industry advances on different parameters of food components (e.g., nutritional value, physical and chemical properties, bioavailability and bioaccessibility characteristics) and the final products (e.g., applications, shelf-life during storage, sensory characteristics).

The book consists of 10 chapters. Chapter 1, Introduction, provides a state-of-the-art in nutrition, prior to discussing the current trends of the food industry in relation to functional foods and nutraceuticals development. Detailed definitions of *bioavailability*, *bioaccessibility*, and *bioactivity*, and the factors affecting them are provided in order to understand better these key functions. Chapter 2, Proteins, Peptides, and Amino Acids, discusses respective food compounds as well as their modifications during processing with emerging technologies. Chapter 3, Carbohydrates, discusses the respective effect of innovative technologies on carbohydrate properties, giving special attention to compounds with a chain length up to nine carbon atoms, inulin, starch, and dietary fibers such as pectin and β-glucan. Chapter 4, Lipids, deals with the impact of nonthermal technologies on the bioaccessibility of lipids and their stability against oxidation. Similarly, Chapter 5, Minerals, focuses on particularly iron, zinc, and calcium which typically show low bioavailability in consumption. Methodologies to estimate in vivo and in vitro bioaccessibility of minerals as well as to measure bioavailability in humans are also discussed. The implementation of emerging technologies to improve the stability and bioaccesibility of vitamins, polyphenols, and carotenoids in foods through their metabolism and health-promoting activities are described in Chapter 6, Vitamins, Chapter 7, Polyphenols, and Chapter 8, Carotenoids, respectively. Innovative extraction techniques for the recovery of these bioactive compounds from food sources and by-products as well as their effects on functional properties are also highlighted. Chapter 9, Food Aroma Compounds, provides an overview of the main natural and technology-derived food aroma compounds, with a critical focus on the novel extraction methods, delivery strategies, and the effects of innovative processing technologies on the acceleration of Maillard reactions. Finally, Chapter 10, Interaction of Compounds, deals with the interactions of food compounds (as discussed in previous chapters) induced by the application of nonthermal technologies.

This book is intended to support food scientists, technologists, engineers, chemists, and professionals working in the food science field as well as researchers and product developers dealing with food processing and innovative applications. It could be used as textbook and/or ancillary reading in graduate- and postgraduate-level courses on food science and related technologies.

I would like to take this opportunity to thank all the authors and contributors of this book for their high-quality work in bringing together theoretical and technical issues in an integral and comprehensive text. I consider myself fortunate to have had the opportunity to collaborate fruitfully with so many knowledgeable colleagues from Argentina, China, Croatia, India, Iran, Italy, Malaysia, Portugal, Serbia, Spain, and the United States. Their acceptance of the editorial guidelines and their dedication to the book's concept is highly appreciated. I would also like to thank the acquisition editor Megan Ball for our collaboration on this project and all of the Elsevier team, particularly Jacklyn Truesdell and Karen Miller for their assistance during editing and Nicky Carter during the production process.

Finally yet importantly, a message for you, the reader. In a collaborative project of this size, it is impossible for it not to contain errors. Thus if you find errors or have any objections to its content, I would really appreciate it if you would contact me.

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CHAPTER

INTRODUCTION

1

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1.1 STATE-OF-THE-ART IN NUTRITION

Food manufacture is currently attracting significant scientific and public interest due to extensive media coverage of diet-related diseases and their influence on the health and well-being of communities (Day, Seymour, Pitts, Konczak, & Lundin, 2009). As a result, more and more consumers believe that foods contribute directly to their health (Mollet & Rowland, 2002). According to the World Health Organization and the Food and Agriculture Organization, certain dietary patterns along with lifestyle habits constitute major risk factors in relation to the development of chronic diseases (WHO, 2003). A major problem facing affluent societies and the rest of the world is reduced activity and lack of exercise, which can lead to obesity and the so-called "metabolic syndrome" (Moebus & Stang, 2007). Changes in eating habits, consumption of fast foods, and environmental factors can also adversely affect the health of humans around the world (Shahidi, 2009).

This approach has led to increased consumer demand for healthy and nutritious foods with not only balanced calorific content, but also with additional health-promoting functions (Bech-Larsen & Scholderer, 2007; Hasler, 2002). To date, the primary concern of the food industry has been to provide consumers with safe food. However, while safety is still of paramount importance the nutritional and caloric composition of foods is becoming equally concerning (Day et al., 2009). Foods are now intended to prevent nutrition-related diseases as well as to improve physical and mental well-being (Betoret, Betoret, Vidal, & Fito, 2011). Governments and consumers worldwide endorse this trend by accepting that high-quality healthy products that are also convenient need to be developed through innovative multidisciplinary research programs (Day et al., 2009).

1.2 FUNCTIONAL FOODS AND NUTRACEUTICALS

Foods contain major and minor components as well as bioactive compounds (e.g., antioxidants, peptides, carbohydrates, lipids, and glucosinolates) that are important for human nutrition. Consequently, their importance has initiated a surge of research and product development in the food industry. In order to adapt to these consumer drivers and enhance the physiological functionality of inherent nutrients, the food industry is developing so-called "functional foods" (Day et al., 2009),

Nutraceutical and Functional Food Components. DOI: http://dx.doi.org/10.1016/B978-0-12-805257-0.00001-6

a term that was first used in Japan. Indeed, the Japanese were the first to observe that food could play a role beyond gastronomic pleasure and nutrient supply to the human organism. Japan was also the first country to legislate these products in the FOSHU (Foods of Specified Health Use) legislation, and it has the highest number of functional foods on the market. Europe and the Americas later incorporated this concept (López-Varela, González-Gross, & Marcos, 2002). The American Dietetic Association (ADA) has classified all food as functional at some physiological level, pointing out that "the term functional food should not be used to imply that there are good and bad foods." In addition, it states that "all food can be incorporated into a healthful eating plan—the key being moderation and variety" (ADA, 2004). Whole foods like fruits and vegetables represent the simplest example of functional foods since they are rich in bioactive compounds, which protect the body's cells against oxidative damage and reduce the risk of developing certain cancers (Day et al., 2009). It is important to note that functional food must be a food (not a drug), and beneficial effects should be obtained by consuming it in normal amounts within the regular diet.

The lack of consensus between Europe and the United States for concrete definitions has led to the use of different terms, increasing confusion among professionals and consumers. In general, the United States prefers the term "nutraceutical" (López-Varela et al., 2002), which refers to any substance, food, or part of a food that provides medical or health benefits, including the prevention and treatment of diseases (Kaur & Das, 2011). However, in contrast to functional foods, nutraceuticals are commodities derived from foods used in the medicinal form of pills, capsules, potions, and liquids and again render demonstrated physiological benefits. The term nutraceutical has now been grouped together with herbal and other natural health products (Shahidi, 2009).

The average consumer prefers natural products over chemical versions since people want to eat food with the desired health benefits rather than take medicine separately (Betoret et al., 2011). The increasing demand for functional foods can be explained by the increasing cost of healthcare, the steady increase in life expectancy, and the desire of older people for improved quality of life (Roberfroid, 2007). In many cases, it is believed that certain unprocessed or minimally processed foods have better health benefits than their processed counterparts. However, this assumption may not hold when considering particular phytochemicals, e.g., lycopene in tomato (Shahidi, 2009).

Food components with functional properties are extracted and used as additives in foodstuff due to their ability to provide both advanced technological properties and health claims to the final product (Galanakis, Markouli, & Gekas, 2013). Epidemiological studies have shown that health benefits (e.g., reduced risk of coronary heart disease and stroke, diabetes, obesity, and cancer) may be attributed to the consumption of both macro- and micronutrients. For instance, macromolecules like soluble dietary fiber is known for its ability to lower blood lipid level and at the same time shows advanced gelling properties. Therefore it can be used to replace fat in foods, stabilize emulsions, and improve the shelf-life of food products (Elleuch et al., 2011; Galanakis, 2011, 2015; Galanakis, Tornberg, & Gekas, 2010c; Patsioura, Galanakis, & Gekas, 2011; Rodríguez, Jiménez, Fernández-Bolaños, Guillén, & Heredia, 2006). Proteins have also been used as fat replacements in milk products, flavor enhancers in confectionaries, and as food and beverage stabilizers (Galanakis, Chasiotis, Botsaris, & Gekas, 2014; Kristinsson & Rasco, 2000; Pogaku, Seng, Boonbeng, & Kallu, et al., 2007; Prakash, 1996).

Natural antioxidants typically include smaller compounds (e.g., polyphenols, carotenoids, tocopherols, and ascorbic acid) that have been connected to both nutritional (reduction of oxidative stress, prevention of cancer, arteriosclerosis, aging processes) and functional (preservative of vegetable oils and emulsions) properties (Galanakis, 2015; Galanakis, Kotanidis, Dianellou, & Gekas, 2015; Moure et al., 2001). Other compounds of interest include glucosinolates and its derived forms (isothiocyanates), which are potent antimicrobials and have been associated with important health benefits (e.g., the reduction of degenerative diseases like cancers of the lungs and alimentary tract). Additionally, some of them can also be used as unique flavorings (e.g., in mustards) (Deng et al., 2015).

In the past few years, new products based on fruit or vegetable and milk have been appeared in Europe and North American markets. These products have wider consumer acceptance and higher nutritional value, largely due to their higher bioactive compound content and antioxidant capacity (Andlauer & Furst, 2002; Heckman, Sherry, & de Mejia, 2010). However, the design and development of functional foods should not only be carried out based on the desired nutritional function. The appearance and sensory properties of foods are also important attributes to the consumer, thus the color, texture, taste, and mouth feel should also be taken into account (Day et al., 2009). From a manufacturing point of view, the most popular functional food product format is beverages since they are relatively easy to formulate. In the case of soft solid foods, the structure-derived quality aspects (e.g., stability, texture, and taste) are of high importance for consumer acceptance of foods as well as for the bioavailability of micronutrients (Parada & Aguilera, 2007). Food manufacturers face a series of technical challenges during fortification of foods with bioactive compounds. For instance, processes should be selected carefully to maintain both functionality of bioactive compounds as well as the quality and sensory attributes of the food (Day et al., 2009).

1.3 BIOAVAILABILITY, BIOACCESSIBILITY, AND BIOACTIVITY OF FOOD COMPONENTS

The preparation of foods fortified with functional components requires integration of diverse aspects under evaluation. These include selecting the appropriate source, detecting the bioactive compounds, applying separation and recovery techniques, performing toxicological assessments, and finally taking stability, activity, and bioaccessibility measurements (Korhonen, 2002). At this point, it is important to carefully define the terms “bioavailability,” “bioaccessibility,” and “bioactivity” (Fig. 1.1), which are often used indistinctly to express similar functions.

1.3.1 BIOAVAILABILITY

Overall, bioavailability includes gastrointestinal (GI) digestion, absorption, metabolism, tissue distribution, and bioactivity. However, the term has several meanings depending on the research area it is used in. For instance, from a pharmacological point of view, bioavailability is the rate and extent to which the therapeutic moiety is absorbed and becomes available at the drug action site (Fernández-García, Carvajal-Lérida, & Pérez-Gálvez, 2009). From a nutritional point of view (which is of particular interest in the current book), bioavailability refers to the fraction of the nutrient that is stored or is available in physiological functions (Fairweather-Tait, 1993). It is a key term for nutritional effectiveness, as not all the amounts of bioactive compounds are used effectively by the organism (Blenford, 1995). For example, when different foods come into contact with the mouth or digestive tract, various interactions may take place affecting phytochemical bioavailability

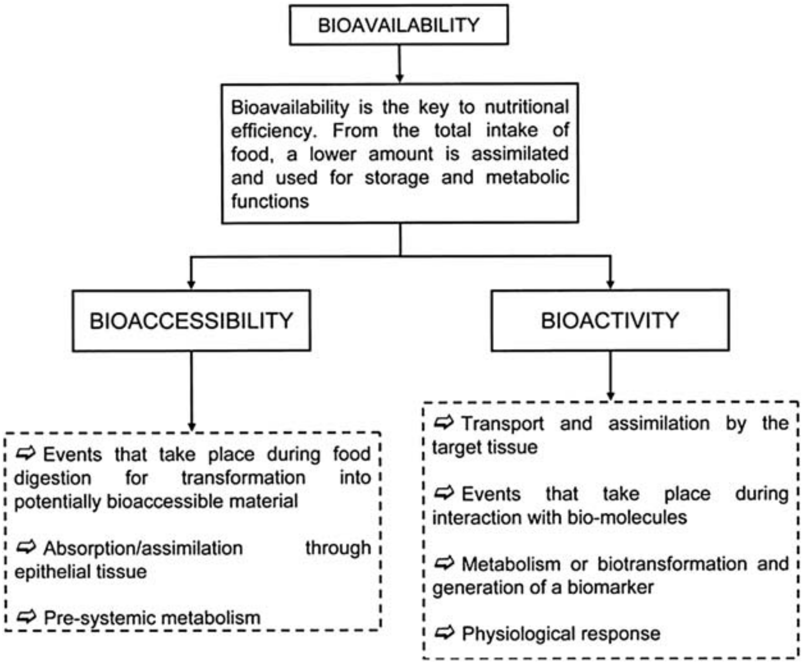

FIGURE 1.1

Definitions of bioavailability, bioaccessibility, and bioactivity. Physiochemical events involved at each stage.

Adapted from Fernández-García, E., Carvajal-Lérida, I., & Pérez-Gálvez, A. (2009). In vitro bioaccessibility assessment as a prediction tool of nutritional efficiency. Nutrition Research, 29, 751–760.

(e.g., fat enhances quercetine bioavailability in meals) (Lesser, Cermak, & Wolffram, 2006). Therefore bioavailability expresses the fraction of ingested nutrient or bioactive compound that reaches the systemic circulation and is ultimately utilized (Wood, 2005).

Bioavailability is important in all different definitions of functional foods, e.g., when a claim for nutritional and/or health properties is made. First, the nutrient or component that provides this benefit should be efficiently digested and assimilated. Thereafter, once absorbed, it must perform a positive function in the body (Fernández-García et al., 2009). However, there are practical and ethical difficulties when measuring the bioactivity of food components on specific organ sites. In these cases, the term "bioactivity" is not used and bioavailability is defined as the fraction of an oral dose of an active metabolite that reaches the systemic circulation (Schumann et al., 1997). Subsequently, bioavailability is determined using in vivo experiments as the area under the plasma concentration of the compound obtained after administration of an acute or chronic dose (Rein et al., 2013).

1.3.2 BIOACCESSIBILITY

Before becoming bioavailable, bioactive compounds must be released from the food matrix and modified in the GI tract. Thus bioavailability includes the term bioaccessibility (Fernández-García et al., 2009). Indeed, it is important to analyze whether the digestion process affects bioactive compounds and their stability before concluding on any potential health effect (Carbonell-Capella, Buniowska, Barba, Esteve, & Frigola, 2014).

Bioaccessibility is defined as the quantity of a compound that is released from its matrix into the GI tract, becoming available for absorption (e.g., enters the bloodstream) (Benito & Miller, 1998; Heaney, 2001). This term includes digestive transformations of foods into material ready for assimilation, the absorption/assimilation into intestinal epithelium cells as well as the presystemic, intestinal, and hepatic metabolism. However, beneficial effects of unabsorbed nutrients such as calcium binding of bile salts in the tract are missed by definitions based on absorption (Carbonell-Capella et al., 2014). Bioaccessibility is usually evaluated by in vitro digestion procedures, generally simulating gastric and small intestinal digestion, sometimes followed by Caco-2 cell uptake (Courraud, Berger, Cristol, & Avallone, 2013).

Bioaccessibility has not been a priority goal thus far during initial development of functional foods for two reasons. First, the current experimental models do not allow us to distinguish bioavailability effectiveness from bioaccessibility and assimilation. Secondly, there is no consensus among US and European legislations in spite of the requirement to integrate this parameter.

Bioaccessibility is directly influenced by the composition of the food matrix and by the synergies and antagonisms that may be established between the different components, permitting a potentially digested material to be available to the body (Fernández-García et al., 2009).

1.3.3 BIOACTIVITY

Bioactivity is the specific effect upon exposure to a substance. It includes tissue uptake and the consequent physiological response (e.g., antioxidant, antiinflammatory). It also includes information on how the bioactive compounds are transported and reach the target tissue, how they interact with biomolecules, metabolism, and biotransformation characteristics, as well as the biomarker generation and consequent physiological responses (Fig. 1.1) (Fernández-García et al., 2009). Digestibility applies specifically to the fraction of food components that is transformed into potentially accessible matter through all physical and chemical processes that take place in the lumen (Carbonell-Capella et al., 2014). On the other hand, assimilation refers to the uptake of bioaccessible material through the epithelium by some mechanism of transepithelial absorption (Etcheverry, Grusak, & Fleige, 2012). One example where only bioactivity applies concerns nondigestible polysaccharides, oligosaccharides, and dietary fiber. These compounds produce several health benefits, although they are not absorbed (Roberfroid, 2002).

Bioactivity measurements (in vivo, ex vivo, and in vitro) are based on the events that take place during the time the bioactive component interacts with biomolecules. This interaction generates a metabolite, a signal, or a response that will continue to modulate and amplify until the systemic physiologic response is produced (health benefit). The experimental procedures used to measure bioactivity need to be adjusted to every health benefit claim separately (Vaisberg, Lenzi, Hansen, Keon, & Finer, 2006). The scientific support of claims of what a food can do (healthy properties or reduced risk of disease) is based on bioactivity data. Claims of a food's nutritional content are provided by bioaccessibility without the need for performing bioactivity studies (Fernández-García et al., 2009).

1.3.4 BIOACTIVE COMPOUNDS

Bioactive compounds are phytochemicals found in foods that are capable of modulating metabolic processes and resulting in the promotion of better health. They exhibit beneficial effects such as antioxidant activity, inhibition or induction of enzymes, inhibition of receptor activities, and induction and inhibition of gene expression (Correia, Borges, Medeiros, & Genovese, 2012). The bioaccessibility and bioavailability of each bioactive compound differs greatly, and the most abundant compounds in ingested fruit are not necessarily those leading to the highest concentrations of active metabolites in target tissues (Manach, Williamson, Morand, Scalbert, & Remesy, 2005). Indeed, when studying the role of bioactive compounds in human health, bioavailability is not always well known (Carbonell-Capella et al., 2014).

Bioactive compounds are found in fruits, vegetables, and whole grains (Carbonell-Capella, Barba, Esteve, & Frigola, 2013; Gil-Chávez et al., 2013). They include an extremely heterogeneous class of compounds (polyphenolic compounds, carotenoids, tocopherols, phytosterols, and organosulfur compounds) with different chemical structures (hydrophilic or lipophilic), distribution in nature (specific to vegetable species or ubiquitous), range of concentrations both in foods and in the human body, possible site of action, effectiveness against oxidative species, and specificity and biological action (Carbonell-Capella et al., 2014; Porrini & Riso, 2008). Several factors interfere with the bioavailability of antioxidants, e.g., the food source or the chemical interactions among the phytochemicals and biomolecules present (Parada & Aguilera, 2007). For instance, fruit antioxidants are commonly mixed with different macromolecules such as carbohydrates, lipids, and proteins to form the food matrix. In plant tissue, carbohydrates are the major compounds found, mainly in free and conjugated forms (Manach, Scalbert, Morand, Remesy, & Jimenez, 2004).

1.3.5 FACTORS AFFECTING THE BIOACCESSIBILITY AND BIOAVAILABILITY OF BIOACTIVE COMPOUNDS

After consumption, the nutrients that are present in a food or drink are released, absorbed into the bloodstream, and transported to their target tissues. Different nutrients differ in their bioavailability, which means that they are not utilized to the same extent. Release of the nutrient from the food matrix, effects of digestive enzymes in the intestine, binding and uptake by the intestinal mucosa, transfer across the gut wall to the blood or lymphatic circulation, systemic distribution and deposition, metabolic and functional use, and excretion can affect nutrient bioavailability. The latter is mediated by external (e.g., characteristics of the food matrix, chemical form of the nutrient) and consumer internal (e.g., gender, age, nutrient status, and life stage) factors. The bioavailability of macronutrients (carbohydrates, proteins, and fats) is usually very high, e.g., more than 90% of the amount ingested.

Bioaccessibility is the first step in making a nutrient bioavailable. In this step, the nutrient is liberated from the food matrix and turned into a chemical form that can bind to and enter the gut cells or pass between them. Chewing, enzymatic digestion of the food in the mouth, mixing with acid and enzymes in the gastric juice, and release into the small intestine are the unit operations of the process by which the nutrients are rendered bioaccessible. The small intestine is the major site of nutrient absorption. Enzymes of the pancreatic juice continue breaking down the food matrix. Certain procedures involved in food preparation like cooking, chopping, or pureeing collaborate