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Functional Foods and Nutraceuticals: Chemistry, Health Benefits and the Way Forward

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Foreword

The exploration of functional foods and nutraceuticals represents a captivating journey into the heart of our well-being. It is my pleasure to write the foreword for the book entitled *Functional Foods and Nutraceuticals: Chemistry, Health Benefits and the Way Forward*. I introduce this illuminating volume, a comprehensive guide delving into the complex chemistry, health-promoting benefits, and the exciting trajectories that lie ahead in this dynamic food field. In an era defined by an ever-growing awareness of the profound connection between what we consume and how it influences our health, this book emerges as an inspiration of knowledge. It is a testament to the collective efforts of experts who, with scientific rigor and dedication, unravel the molecular ambiguities behind functional foods and nutraceuticals, offering a panoramic view of their transformative potential.

As we traverse the chapters within, a captivating tapestry unfolds, revealing the chemical complexity that make certain foods not just sources of sustenance but powerful agents in the pursuit of optimal health. From phytochemicals to bioactive compounds, the authors meticulously explore the building blocks that underpin the health benefits, providing readers with a deeper understanding of the alchemy that occurs within the nexus of food and medicine. What distinguishes this book is its unwavering commitment to not only disseminate knowledge but also to connect the dots between chemistry and tangible health outcomes. The exploration of the health benefits of functional foods and nutraceuticals transcends the theoretical realm, extending into the practical aspects of preventive and therapeutic nutrition. This bridge between theory and application is essential for empowering both professionals and enthusiasts alike to make informed choices in an era marked by a deluge of information.

Moreover, this book does not merely dwell on the present; it casts a discerning eye toward the future. In an age where scientific discoveries unfold at an unprecedented pace, these insights into future trends and potential breakthroughs offer readers a glimpse into the exciting possibilities that await. As we immerse ourselves in the pages that follow, may we be inspired not only by the science but by the profound impact that functional foods and nutraceuticals can have on our health, our communities, and the broader tapestry of global well-being. This book is more than

a collection of chapters; it is a catalyst for change, a call to action to embrace the transformative potential that lies within our plates.

May this volume spark curiosity, foster interdisciplinary dialogue, and catalyze a collective journey toward a future where functional foods and nutraceuticals are not just components of our diet but pillars supporting a healthier, more resilient world.

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Preface

This book, *Functional Foods and Nutraceuticals: Chemistry, Health Benefits and the Way Forward*, presents valuable information on the rapidly growing field of functional foods and nutraceuticals in the prevention and management of chronic and infectious diseases. Functional foods and nutraceuticals play a major role in combating and mitigating various lifestyle-related illnesses and disorders. This book delves the role of functional foods to human health and the probable mechanisms of nutraceuticals in the prevention, treatment, and management of diseases. This book is designed to address the increasing cases of metabolic diseases and high rates of deaths resulting from the lack of proper knowledge or deviation from good eating habit. The contents of the book specifically document the therapeutic roles of functional foods and its ingredients and explains their bioavailability and accessibility. The book reports the recent advancements and future prospectus in chemistry and health benefits of different functional foods. With regard to the functional foods, it also provides a thorough understanding of bioavailability of fortificants, their mechanism of action, extraction techniques, effect of processing, nutraceutical and nanomaterial development, and legislation. The book also provides current information on fortification techniques, their bio-accessibility, trends, and the use of nanotechnology in developing functional foods. The book is a multidisciplinary resource suitable for professionals in food science and technology, biotechnology, pharmaceuticals, and related fields, and it addresses a crucial area of academic research. Topics on regulations and safety were also taken into consideration. The chapter contributors of this book are respected authors and professionals from key institutions. The motivation to compile this book arises from a thoughtful awareness of the significant role that functional food plays in shaping the health and well-being of populations, especially those in vulnerable and resource-limited.

We extend our gratitude to the dedicated authors and contributors who have shared their expertise and experiences to make this book possible. We also thank the readers for their interest in this critical topic, and we hope that the knowledge imparted here will catalyze positive change in the way we think about and utilize functional foods.

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I extend my heartfelt gratitude to all those who contributed to the realization of this book on functional foods and nutraceuticals. Writing this comprehensive guide would not have been possible without the support and collaboration of numerous individuals and institutions.

I express my sincere appreciation to the authors, whose expertise and dedication played a pivotal role in shaping the content of this book. Special thanks are also due to the team at Springer, whose commitment to excellence and attention to detail helped bring this project to fruition.

I am grateful to the researchers, scientists, and professionals in the field of nutrition and food science whose groundbreaking work paved the way for the development of functional foods and nutraceuticals. Your contributions have significantly enriched the content of this book.

I would like to acknowledge the invaluable feedback and insights provided by my colleagues and peers during the writing process. Your collaborative spirit and thoughtful suggestions have undoubtedly enhanced the quality of this publication.

To my family and friends, thank you for your unwavering support and understanding during the long hours spent researching and writing. Your encouragement has been a source of inspiration.

Lastly, I extend my deepest appreciation to the readers of this book. It is my sincere hope that the information presented here proves to be informative and beneficial in the exploration of functional foods and nutraceuticals.

Thank you all for being a part of this journey.

Editors

Contents

Chapter 1
Introduction to Functional Foods and Nutraceuticals

Iqra Qureshi, Mehvish Habib, Khalid Bashir, Kulsum Jan, and Shumaila Jan

1.1 Introduction

Food is a term which is basically related to the component necessary for several life-sustaining functions like production of energy, supply of nutrients, support of various metabolic activities besides growth, and maintenance of the body. The term functional food was first introduced in Japan in the 1980s which refers to processed foods containing ingredients that aid specific body functions in addition to being nutritious. Till date, Japan is the only country that has formulated a specific regulatory approval process for functional foods (Kaur and Das 2011). A functional food, according to the National Academy of Sciences' Food and Nutrition Board (FNB), is one that includes "any modified food or food ingredient that may give a health advantage beyond that of the traditional nutrients it contains" (Thomas and Earl 1994). Although there are several definitions, the general consensus is that functional food is any healthy food that looks similar to conventional foods, is consumed as part of a regular diet, and is claimed to have physiological benefits such as health-promoting or disease-preventing properties in addition to its basic function of supplying nutrients. *Let the Food Be Medicine* is an ancient proverb but holds merit today as well, especially the post-COVID-19 scenario. The pandemic has forced the humankind to re-evaluate the eating habits, and the demand for functional foods has increased manyfold. A list of functional foods that have been proposed to provide

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Table 1.1 A list of functional foods and their effects

Foods	Physiological effect
Garlic, cranberry, kale, spinach, broccoli, apple	Increased drug detoxification
Green tea, garlic, onion	Antimicrobial
Carrot, eggplant, oats, mushroom, ginger	Antihyperlipidemic
Fennel, cabbage, soya bean	Anti-estrogens

health benefits are presented in Table 1.1. Fruits, vegetables, and nuts contain several phytochemicals which reduce the risk of many diseases like heart diseases, cancer, and hypertension. Some foods also reduce the risk of heart diseases as well as cancer (Milner 1999).

1.2 Classification of Functional Foods

- Foods that are filled with a variety of substances that have a beneficial effect on disease and health, e.g., calcium-fortified bread, ω-3-fortified breads, or phytosterol-fortified spreads (Holmes and Gates 2003).
- Food raw materials which are enhanced by increasing specific components by changed feeding of animals, e.g., eggs or meats high in ω-3 fatty acids, beef high in conjugated linoleic acid or some other nutrients/food raw material (fruits and vegetables) in which a health-contributing factor has been increased by some postharvest treatment, e.g., functional grapes with higher antioxidant developed by ultraviolet irradiation (Cavia-Saiz et al. 2011).
- Foods liberated to counter anti-nutritional compounds produced by processing, e.g., a toxic compound or a food allergen (Siro et al. 2008).
- Nutraceuticals are dietary supplements that contain a concentrated form of a putative bioactive ingredient from a food, packaged in a non-food matrix, and used to improve health in dosages that are higher than those found in normal diets (Zeisel 1999). The concept of "nutraceutical" arose and first originated from the United Kingdom, Germany, and France, where diet was rated higher by the consumers, then exercise or hereditary factors to achieve a good health (Pandey et al. 2010). Nutraceuticals, according to De Felice, are "foods (or parts of foods) that give medicinal or health advantages, including illness prevention and therapy." On the other hand, Health Canada defines nutraceutical as "a product ready from foods, but sell in the form of pills, or powder (potions) or in other medicinal forms, not usually associated with foods" (Wildman et al. 2016). Nutraceuticals are found in a mixture of products emerging from (a) the food industry, (b) the herbal and dietary supplement market, (c) the pharmaceutical industry, and (d) the newly merged pharmaceutical/agribusiness/nutrition conglomerates. It may range from isolated nutrients, herbal products, dietary supplements, and diets to genetically engineered "designer" foods and processed

products such as cereals, soups, and beverages (Malik et al. 2008; Dureja et al. 2022). Nutraceuticals covers most of the therapeutic areas such as anti-arthritic, cold and cough, sleeping disorders, digestion, and prevention of certain cancers, osteoporosis, blood pressure, cholesterol control, pain killers, depression, and diabetes (Verma and Mishra 2016).

1.3 Sources of Functional Foods

1.3.1 Plant Source

A plant-based diet can reduce the incidence of chronic diseases, including cancer, according to overwhelming evidence from epidemiologic (in vivo, in vitro, and clinical trials) data. Block et al. (1992) found that persons who ate a diet high in fruits and vegetables had half the risk of cancer as those who ate fewer of these foods. Other than standard nutrients, it is now evident that there are components in a plant-based diet that can reduce cancer risk. Steinmetz and Potter (1991) identified more than a dozen classes of these biologically active plant chemicals, now known as "photochemical." The most important phytochemicals are phenolics and carotenoids in fruits and vegetables and lignans, β-glucan, and inulin in cereal-based products. Prevention of cancer and CVDs, reducing tumor incidence, lowering of blood pressure and the risk of heart disease and cholesterol, and delaying gastric emptying are some of the important protective effects of plant-based foods. Some of the following foods are as follows:

- **Rice**

Rice is a key cereal and a staple diet for about half of the world's population (Wani et al. 2012). Until recently, rice was just considered as a source of carbohydrates; however, rice bran, a valuable by-product, contains high concentration of nutritionally important compounds. Rice bran is high in dietary fibers (glucan, pectin, and gum), tocotrienols, oryzanol, and sitosterol, all of which aid in decreasing plasma levels of certain lipid profile measures (Chaturvedi et al. 2011). It includes α-lipoic acid, which aids in the metabolism of carbs and fats, decreasing the glycemic index and helping to maintain weight control. It contains natural antioxidants such as tocopherols, tocotrienols, and oryzanol, which could be beneficial to our health. Rice bran antioxidants have the potential to meet the demand for effective and cost-effective natural antioxidants, and this is an exciting field of research.

- **Garlic**

There are so many health benefits of *Allium* vegetables; in particular, garlic (*Allium sativum*) has its origin in ancient times. Garlic has a wide range of health benefits, including cancer chemoprevention, antihypertensive, and cholesterol-lowering characteristics, free radical scavenging activities, immunological activation, CVD treatment, and anti-infectious qualities (Srivastava et al. 1995; Singh

et al. 2007). Its promise in fighting lifestyle-related problems such as hypercholesterolemia, dyslipidemia, and high blood pressure, all of which lead to a variety of cardiovascular diseases (Mahmoodi et al. 2006; Kojuri et al. 2007; Butt et al. 2009).

Garlic's distinctive flavor and pungency are attributed to an abundance of sulfur-containing oil- and water-soluble components, which are likely responsible for the plant's medical properties. Intact, undisturbed garlic bulbs, on the other hand, contain only a few medicinally active components (Block et al. 1992). Fresh garlic has a distinct odor due to this latter component (Butt et al. 2009). In numerous experimental models, garlic components have been found to prevent carcinogenesis (Reuter 1996). However, additional reports have shown garlic to be ineffective. Inconclusive results are likely due to differences in the type of garlic compounds or preparations used by various investigators. Considerable variation in the quantity of organosulfur compounds available in fresh and commercially available garlic products has been demonstrated by Lawson et al. (1991).

- **Flaxseed**

Flax (*Linum usitatissimum*) is an important oil seed crop, and among the primary seed oils, flaxseed oil includes the omega-3 fatty acid and α-linolenic acid in the majority (57%) (Oomah 2001). Recent study has focused more particularly on fiber-associated compounds known as lignans. Flaxseed is the most abundant source of lignan precursors in mammals (Thompson et al. 1991). It is a good source of omega-3 fatty acids, linolenic acid, and the phenolic component lignan; therefore incorporating it into the diet for the production of functional foods with specific health benefits has been appealing. Enterodiol and its oxidation product, enterolactone, are the two primary mammalian lignans. Because enterodiol and enterolactone are structurally similar to both natural and synthetic estrogens and have been demonstrated to have weak estrogenic and anti-estrogenic activity, they could help prevent estrogen-dependent malignancies (Setchell et al. 1981).

- **Soya Beans**

Soya beans are nutrient-dense, fiber-rich, and high in protein and have recently come under scrutiny for their potential role in the prevention and treatment of degenerative diseases when included in the diet (Anderson 1995). Soya beans include isoflavones (genistein and daidzein), which have a variety of biological effects. It is assumed to play a role in the prevention and treatment of cardiovascular disease, cancer, osteoporosis, and the relief of menopausal symptoms (Potter 1995).

- **Tea**

After water, tea is the most popular and extensively consumed beverage in the world (Awasom 2011). The polyphenolic contents of tea, particularly green tea, have received a lot of attention (Harbowy et al. 1997). Polyphenols, particularly flavonoids, are key components of green tea. Polyphenols can account for up to 30% of the dry weight of fresh tea leaves. Catechins are the most common and important of all tea polyphenols (Graham 1992). Epigallocatechin-3-gallate, epigallocatechin,

epicatechin-3-gallate, and epicatechin-3-gallate are the four primary catechins found in green tea (Hayat et al. 2015).

1.3.2 Animal Origin

Although plants include a large number of naturally occurring health-promoting compounds, animal products contain a number of physiologically active components that demand consideration for their potential involvement in good health.

- **Dairy Products**

Dairy products are functional foods without any doubt, milk in itself being a complete food (Rogeli 2000). They are a good source of calcium, an important vitamin that can help prevent osteoporosis and colon cancer (Alvarez-León et al. 2006). In addition to calcium, however, recent study has particularly focused on other components of dairy products, specifically fermented dairy products, known as probiotics. Probiotics are live microbial feed supplements that benefit the host animal by enhancing the microbial balance in its intestine (Fuller 1994). Traditionally, they have been used to restore disrupted intestinal microbiota and reduce gastrointestinal illnesses like diarrhea and bowel problems. The idea of creating beneficial health effects through the ingestion of living bacteria has been primarily derived from original studies reported by Metchnikoff (1908), claiming that the regular consumption of fermented dairy products was responsible for certain ethnic groups' superior health and longevity. Probiotics have been linked to a number of health advantages, with their anti-carcinogenic, hypocholesterolemic, and antagonistic effects on enteric pathogens and other intestinal organisms receiving the most attention (Mitall and Garg 1995).

- **Fish**

Fish eating has been linked to a number of health benefits in addition to supplying high-quality protein, vital fatty acids, and other nutrients. Omega-3 (n-3) fatty acids are a type of polyunsaturated fatty acid (PUFA) that is mostly found in fish oil. Since the omega-3 fatty acids found in fish oil are thought to have anti-inflammatory properties, there may be a link between consuming fish and inflammation-related disorders like rheumatoid arthritis (Simopoulos 1991). This has prompted researchers to investigate the role of n-3 fatty acids in a variety of disorders, including cancer and cardiovascular disease, as well as early human development. There is evidence that eating a lot of fish when pregnant will lengthen your pregnancy and result in a higher birth weights (Daviglus et al. 2002).

- **Meat**

Meat and meat products are important parts of many people's diets in industrialized countries, and their consumption rises as the population's economic status improves. Despite the fact that these foods are good sources of high-quality proteins

and a variety of micronutrients (such as vitamin A, iron, and zinc), there is compelling evidence linking them to an increased risk of cardiovascular disease. Despite public health experts' recommendations that this situation may increase the relative contribution of nutrition to the development of chronic diseases, a growing consumption of meat products is foreseen, despite the fact that a lower intake of these foods, along with an increase in fruit and vegetable consumption, would be beneficial (cancer, CVD, and obesity) (Olmedilla-Alonso et al. 2006).

- **Egg**

Because of concerns about their negative impact on blood cholesterol levels, eggs have not historically been considered a functional food. Furthermore, it is now well accepted that there is little, if any, link between dietary cholesterol and blood cholesterol levels and that eating one or more eggs per day has no negative impact on blood cholesterol levels. Therefore, eggs are a good source of both essential (protein, sphingolipids, choline, and n-3 PUFA) and non-essential (lutein/zeaxanthin) nutrients that may help you live a healthier life. As a result, the egg will continue to play a key role in the evolution of functional meals (Dorsch-Häsler et al. 1990).

1.4 Health Benefits

Human health and well-being are largely determined by consumption of nutritious foods. The emergence of foods with health benefits is an excellent chance to enhance public health; as a result, the scientific community, consumers, and food manufacturers have paid close attention to these compounds in recent years (Table 1.2).

Several epidemiologic studies conducted over the last 50 years have conclusively demonstrated that diets high in fruits, vegetables, and dietary fibers (plant-based foods) prevent and reduce the risk of chronic diseases (e.g., CVDs, obesity,

Table 1.2 Examples of functional foods and their health benefits

Functional foods	Health benefits/nutraceutical potential
Fruits and vegetables	Various malignancies and heart disorders are less likely to occur
Garlic	Reduces the risk of heart disease and cancer, as well as cholesterol levels
Flaxseed	Reduces the risk of heart disease and cancer, lowers triglycerides, and improves the blood glucose level
Fish	Reduces the risk of heart diseases as well as the levels of cholesterol and triglyceride
Black and green tea	Decreases the risk of cancer
Dairy products	Colon cancer risk is reduced, and diarrheal and eczema symptoms are controlled
Fish oil with omega-3 fatty acids	Heart disease risk is reduced
Milk	Osteoporosis and osteomalacia risk were reduced

diabetes, and so on) while also promoting good human health. The accumulation of scientific studies linking plant-based foods to health has led to the recognition that plant bioactive compounds have favorable health effects (Balsano and Alisi 2009; Cencic and Chingwaru 2010). High consumption of fruits, vegetables, and whole grains is linked to a lower risk of chronic diseases including cancer and cardiovascular disease, which are the leading causes of mortality in Europe and the United States (European Food Safety Authority) (EFSA) (Liu 2004). One-third of all cancer deaths in developed countries might be avoided with proper dietary formulations, according to estimates. This shows that dietary behavioral adjustments, such as increasing fruit, vegetable, and whole grain consumption, as well as related lifestyle improvements, are effective methods for reducing cancer incidence (Terry et al. 2001).

- **Cancer**

The development of cancer is a dynamic and long-term process involving many complex factors with stepwise progression, eventually leading to an uncontrolled growth of cancerous cells throughout the body, called metastasis (Cencic and Chingwaru 2010). Epidemiologic research have established that dietary variables can influence carcinogenesis (Liu 2004; Alisi et al. 2009). The mechanisms by which phytochemicals present in plant foods have anti-carcinogenic effects are varied but generally include antioxidant effects, increased activity of enzymes that detoxify carcinogens, effect on cell differentiation, inhibition of N-nitrosamine formation, change of estrogen metabolism, change of colonic milieu, maintenance of DNA repair, preservation of intracellular matrices, and effect on DNA methylation (Lampe 1999; Liu 2003; Surh 2003).

- **Cardiovascular Diseases**

In Western countries, cardiovascular disorders, such as heart disease and stroke, are the leading cause of death. In economically developed countries, CVDs and malignancies together account for more than 60% of mortality (Stramba-Badiale et al. 2006). In economically developed countries, CVDs have acquired an endemic proportion and exceed infectious diseases in mortality. Recent studies associate reactive oxygen species (ROS) in the pathogenesis of both acute and chronic heart diseases as a result of cumulative oxidative stress (Wang et al. 2007). Obesity, high blood cholesterol, high blood pressure, and type 2 diabetes are all important risk factors for CVD. CVD risk is enhanced not just by poor dietary habits but also by lifestyle choices such as smoking and alcohol drinking. It has been discovered that persons who eat nutritious foods, exercise regularly, smoke less, and avoid alcohol excessively have a lower risk of cardiovascular disease (Riccioni et al. 2008). Diets that raise serum total cholesterol, LDL cholesterol, and triacylglycerol levels while lowering high-density lipoprotein (HDL) cholesterol levels have also been linked to a lower risk of coronary artery disease. Controlling blood pressure is critical for preventing heart disease, renal disease, and stroke. Atherosclerosis, renin-angiotensin system abnormalities, and hyperinsulinemia all influence blood

pressure, with the latter increasing salt retention in the body and speeding up atherosclerosis (Lampe 1999)

When consumed in sufficient proportions, functional foods can help reduce the risk of CVDs through a variety of methods. Lowering blood cholesterol levels, reducing plaque formation, reducing lipoprotein oxidation, enhancing arterial compliance, scavenging free radicals, and preventing platelet aggregation are just a few of the benefits (Hasler 2000)

- **Obesity**

Obesity is a multifaceted issue that results from various interactions between genes and the environment. It's crucial to pinpoint components of behavior that reduce excessive energy intake while increasing energy expenditure. Obesity can be reduced by making appropriate dietary choices, embarking on good eating behavior, and having an active lifestyle (International Obesity Task Force (IOTF). Fiber-rich foods can have promising effects in tackling this menace since fiber contributes more to food weight than to calorie intake. Increasing fiber intake is thought to help with weight management and obesity issues (Pereira and Ludwig 2001) (Fig. 1.1).

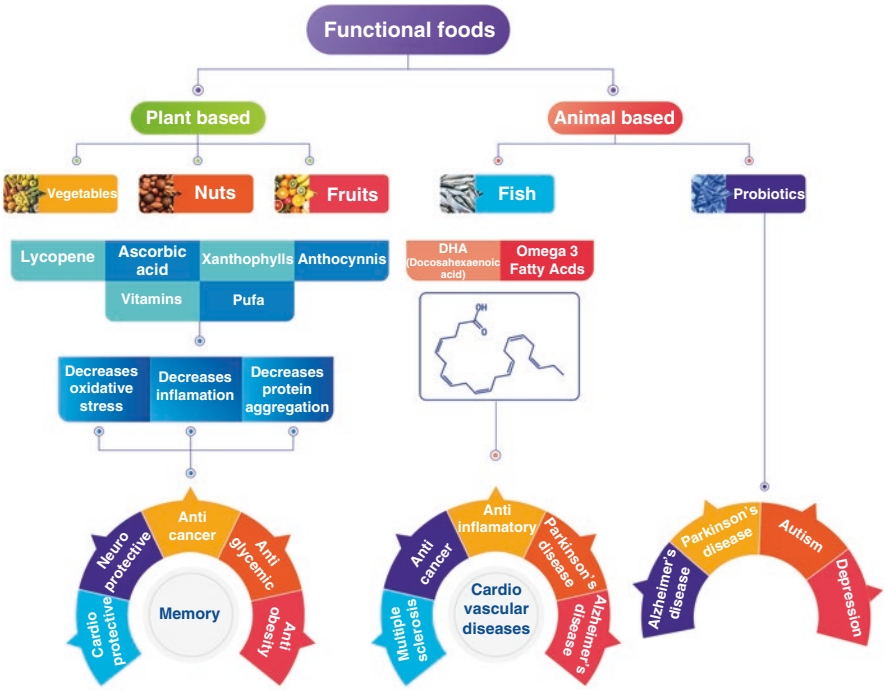

Fig. 1.1 Health benefits of plant and animal-based functional foods

1.5 Factors Affecting Bioavailability

While food processing usually results in a drop in vitamin levels—the more rigorous the procedure is, the greater the reduction—in some cases, processing has a profound impact on availability. Diet influences the absorption of specific nutrients and phytochemicals. Lipophilic individuals absorb significantly more readily from a lipid-rich diet. When frying tomatoes in oil, the uptake of lycopene is significantly increased when compared to eating fresh tomatoes. Raw carrots, which contain a lot of pro-vitamin A (carotenoids), aren't as good as gently cooked carrots when it comes to betacarotene. Cooking or processing increases the bioavailability of certain trace elements, such as the improved bioavailability of iron in canned spinach. The chemical form of a phytochemical found in food has a significant impact on its absorption through the gastrointestinal tract. The glucoside of quercetin is easier to absorb than the aglycone quercetin. Isorhamnetin—glucoside, which is structurally similar to quercetin but differs only by a single methoxyl group—is absorbed significantly more easily. Rutinosides (rhamnosyl-(1–>6)-glucosides) are flavonoid rutinosides that are difficult to absorb. When examining the biological relevance of individual chemicals and their amounts in the diet, the chemical form of the phytochemical is critical. While some phenols may be greater antioxidants than others when evaluated in vitro, this is of little consequence in terms of human health. It's all about whether the compounds are easily absorbed, don't break down quickly in tissues, and can reach the target areas. Flavonoids that are not absorbed are degraded extensively by gut bacteria, and they may only serve a minor function in preventing oxidative damage in the colon (Williams et al. 2004)

1.6 Implementation of Health Claims

Functional foods can be divided into two groups based on their intended effects: those that try to improve physiological functioning and those that aim to lower the risk of specific diseases. Gut health, immune system activity, and mental performance have been chosen as foods that improve physiological processes, whereas cancer, cardiovascular disease, diabetes, and osteoporosis are the main focuses of functional foods aimed at preventing certain pathologies. The verification of the efficacy of functional foods is a crucial issue in their development. A relevant and quantitative marker must be indicated to verify specific physiological relevance of food consumption. This marker should be firmly related to the physiological effect(s) that can be assessed using a reliable, well-established, and widely accepted approach. For example, plasmatic low-density lipoprotein (LDL), cholesterol concentration, or simple blood pressure can be tested to validate the efficacy of a meal aimed at reducing the risk of cardiovascular disease. On the other hand, choosing a reliable marker to validate a functional food's ability to boost mental performance is a difficult task, and the potential outcomes will be easily critiqued by the scientific community (Fogliano and Vitaglione 2005)

1.7 Consumer Perception

The perceived hazards and complexity of functional food choices are increasing among consumers. Risk and complexity arise primarily as a result of the increasing flow of information on functional meals, as well as the potentially confusing messages that this information may include (Falguera et al. 2012). Labels, quality assurance methods, and traceability have been found to have a negative impact on consumer acceptability of food goods by adding complexity to food selection options (Gellynck et al. 2006). Another source of difficulty is consumers' lack of information about current advances in food technology (Siegrist 2000). Consumers' willingness to try functional meals appears to be influenced by risk (O'Connor and White 2010). More specifically, sources of risk for consumers can be found at two levels: at the institutional level, where there is a risk of poorly functioning institutional systems related to food production and distribution, and at the product level, where there is a risk of food product safety and quality (Poppe and Kjærnes 2003)

Risk and complexity lead to a lack of trustworthiness in functional foods and nutraceuticals, which has been cited as one of the reasons for consumers' aversion to such foods (Siro et al. 2008) and subsequent market failures (Onwezen and Bartels 2011). Food neophobia, or the fear of trying new foods, might be considered as a result of a lack of social trust to some extent. Adding functional attributes to foods can create novelty (Urala and Leahteenmeaki 2004) and thus complicates consumer perceptions

1.8 Regulations of Functional Foods and Nutraceuticals

- **General Food Law Regulation**

Foods having added functional features (e.g., "functional foods," "nutraceuticals," dietetic foods, and food supplements) are covered under the Regulation's broad principles, which apply to all foodstuffs. A number of aspects of general food law are especially relevant for these types of foods (Coppens et al. 2006).

- **Regulation of Functional Foods in Selected Asian Countries**

Chronic disorders linked to food, such as coronary heart disease and diabetes, have been on the rise across Asia's Pacific Rim countries. Due to the adoption of Western-style diets and a faster pace of life, this is especially noticeable in urban areas. Nutritional trends have shifted drastically in the previous two decades to address chronic diseases. There has been a greater emphasis on the significance of nutrition and food with health advantages, such as functional foods, in preventing disease. In response to consumer demand, the industry increased efforts to produce foods which acquire "specific healthcare abilities"; other countries, such as China, Japan, and Europe, also imported functional foods. Other countries have either

implemented existing global regulations or are still working on developing a new system (Zawistowski 2008).

- **Regulation of Functional Foods and Nutraceuticals in India**

The Food Safety and Standard Act 2006, a modern integrated food law that will serve as a single point of reference for the regulation of food products such as nutraceuticals, dietary supplements, and functional foods, was recently passed in India. To match the worldwide standards of the United States and Europe, the Food Safety and Standard Act needs to be far more substantive, with infrastructure and adequate supervision. The passing of this act in India is a significant first step, but much more has to happen to abolish the confusing overlap with old laws and regulations. However, unlike the United States, Europe, and Japan, India does not categorize functional foods/nutraceuticals individually. Furthermore, the term "functional food" has varied meanings in different nations. Functional foods are defined in Japan, for example, by their use of natural ingredients. However, in the United States, functional foods can include biotechnology-derived components (Keservani et al. 2014).

1.9 Future Prospects

The global functional food and nutraceutical market is being driven by consumers' growing awareness of the health advantages of foods and their nutritional benefits for disease prevention and enhancement. Functional foods are foods that have health benefits in addition to providing energy and essential nutrients. Many studies, including several European Commission (EC)-supported initiatives, have contributed to a better knowledge of the potential mechanisms of biologically active components in food, which could improve health and possibly lower illness risk while improving overall well-being. Functional foods and nutraceutical goods are aiding in the improvement of health, the reduction of healthcare expenses, and the growth of rural economies. A growing demand for functional foods is also assisting farmers in diversifying their agriculture and marine-based crops, as well as encouraging research and development. Functional foods are becoming more popular, especially in developed economies, as people become more aware of their health benefits and their disposable money rises. Much more work on how the two interact and complement one another is likely to be done in the near future. Investment in new technology, as well as the use of genetically modified technology in the food business for medical and health benefits, is expected to boost nutraceuticals market revenues even more. Expanding the volume of scientific research that confirms the efficacy and safety of these new items will encourage more investment in technology and implementation. Promising technologies such as nutrigenomics, imaging techniques, and converging technologies are progressively being used in nutrition research. Their enormous potential will aid in the production of foods for specific populations with known risk factors or diseases, such as obesity, diabetes, allergies,

and cardiovascular disease. Food technology's ingenuity may also help further advancements in the development of food products that promote optimal health. The increased consumer awareness of functional foods and nutraceuticals will however drive further revenue growth, globally. International growth across the industry is expected to continue as developing countries increase nutraceutical consumption (Daliri and Lee 2015)

1.10 Conclusion

In conclusion, the introductory chapter on functional foods and nutraceuticals serves as a gateway to the dynamic and evolving field that intersects nutrition, health, and innovation. As we navigate the intricate relationship between diet and well-being, the significance of functional foods becomes increasingly apparent. This chapter has laid the foundation for understanding the pivotal role these foods play in promoting health beyond basic nutrition. By exploring the diverse landscape of bioactive compounds and their potential therapeutic benefits, we embark on a journey that transcends traditional notions of food. As we delve deeper into subsequent chapters, we will unravel the intricate mechanisms through which functional foods and nutraceuticals contribute to preventive healthcare and overall well-being. The evolving science in this realm holds promise for personalized nutrition strategies and novel approaches to address contemporary health challenges

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Chapter 2
Proteins as Functional Foods and Nutraceuticals

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2.1 Introduction

The Greek word "proteios", which means "principal", is where the term "protein" originates. As their name implies, proteins are essential for biological functions. Approximately three-fourths of a person's dry body weight is made up of proteins. Proteins are used in bodybuilding because they serve as the building blocks for all of the body's key structural and functional processes. Anomalies in protein structure lead to molecular diseases with major alterations in metabolic function.

Proteins are primarily composed of carbon, hydrogen, oxygen and nitrogen, whereas sulphur and phosphorus are less important ingredients. Nitrogen is present in large amounts in proteins. The average nitrogen concentration of common proteins is 16% of their weight. All proteins are composed of amino acid polymers and amino acid peptide bonds connect them together. By polymerising amino acids and joining them with peptide bonds, proteins are created. Two amino acids make up a dipeptide, three amino acids make up a tripeptide, four amino acids make up a tetrapeptide, a few amino acids make up an oligopeptide and 10 to 50 amino acids make up a polypeptide. Proteins are voluminous polypeptide chains with more than 50 collected amino acids. There are just 20 amino acids in nature, yet a huge

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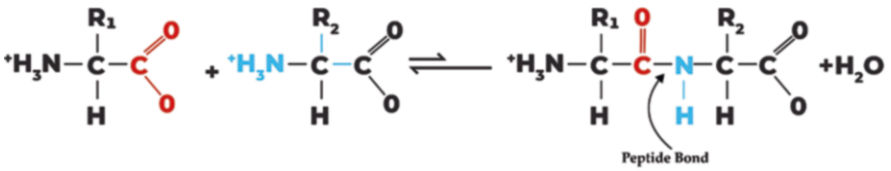

Fig. 2.1 Peptide bond formation

diversity of unique proteins can be created by altering the order in which these amino acids are used.

Functional foods seem similar to conventional foods; however, the latter are consumed as part of a daily diet. Contrary to normal diets, functional foods have proven physiological benefits and can lower the risk of chronic disease in addition to serving basic nutritional purposes like maintaining intestinal health. When food is created with "scientific intelligence", with or without knowledge of how or why it will be utilised, it is referred to as "functional food". Functional food thus gives the body the vitamins, lipids, proteins, carbs and other nutrients it needs for healthy cellular activity.

"Complete protein" refers to foods that have all nine essential amino acids in the right amounts for the body to make protein. Contrarily, incomplete protein, commonly referred to as "limiting amino acid", describes foods that contain all essential amino acids but not in the right amounts (McArdle et al. 1991). When the alpha-carboxyl group of one amino acid combines with the alpha-amino group of another amino acid, a peptide bond, or CO-NH, is created (Fig. 2.1).

2.2 Structure of Proteins: Organisation of Proteins

The four structural levels of proteins are primary, secondary, tertiary and quaternary. The order of the amino acids in the polypeptide chain and the existence or absence of disulphide linkages are both considered to be components of a protein's fundamental structure. The steric connection between amino acids that are close to one another is referred to as secondary structure. Tertiary structure refers to the overall arrangement and interrelationship of the many regions, or domains, of a single polypeptide chain. A protein assumes its quaternary structure when two or more molecular chains are linked together by non-covalent forces (Chothia 1984).

The main structure of a protein refers to the quantity and arrangement of its amino acids. The higher layers of organisation are determined by the underlying structure. Each polypeptide chain's amino acid sequence is determined by the genes. The covalent bonding of the peptide linkages preserves the essential structure (Fevzioglu et al. 2020). The configurational connection between residues in the linear sequence that are spaced about three to four amino acids apart is referred to as secondary structure. Protein secondary and tertiary structure is maintained by

non-covalent forces or bonds such as hydrogen bonds, electrostatic bonds, hydrophobic contacts and van der Waals forces (Ruff and Pappu 2021).

The term "tertiary structure" refers to the overall protein's three-dimensional structure. The tertiary structure determines the steric interaction of amino acids that are far apart in the linear sequence yet close in three dimensions. The tertiary structure is maintained by non-covalent interactions such as hydrophobic bonds, electrostatic bonds and van der Waals forces. The most thermodynamically stable structure of a native protein is its tertiary structure. To form a single functional protein, many polypeptides will group together. This is referred to as a quaternary structure. The function of the protein is lost when the subunits are split apart. The forces holding the quaternary structure together are van der Waals forces, electrostatic forces, hydrogen bonds and hydrophobic bonds (Ruff and Pappu 2021).

2.3 Functions of Proteins

Proteins are the building blocks of life. One or more proteins are required for an organism's cellular activity. The following are the numerous roles of proteins:

- **Regulatory Proteins**

These proteins regulate the efficiency with which other proteins carry out their physiological functions. One well-known example is insulin, a hormone that controls how animals use glucose. A small protein called insulin is constructed of two polypeptide chains connected by disulphide cross-bridges. Two other hormones that are proteins are pituitary somatotropin and thyrotropin, which stimulates the thyroid gland (Kanehisa and Sato 2020).

- **Transport Proteins**

These proteins are in charge of transporting specific substances from one place to another. One type of transport is the movement of oxygen from the lungs to the tissues via haemoglobin or the transportation of fatty acids from the adipose tissue to various organs via the blood protein serum albumin. Membrane transport proteins move metabolite molecules from one side of the membrane to the other, where they are released. For instance, transport proteins play a role in the uptake of essential nutrients into the cell, like glucose or amino acids (Wang et al. 2021).

- **Storage Proteins**

Storage proteins are those whose biological function is to act as a reservoir for a necessary nutrient. Because proteins are amino acid polymers and nitrogen is a common resource for growth, organisms have employed them to give enough nitrogen when necessary. For instance, while the developing bird embryo is sequestered inside the egg, ovalbumin, a protein included in egg white, supplies it with nitrogen. Since casein is the most prevalent protein in milk, it serves as the main source of nitrogen for newborn mammals. To make sure that the sprouting seed is

nitrogen-sufficient at this crucial stage of plant development, higher plants' seeds frequently contain up to 60% of stored protein (Parveen et al. 2023).

- **Contractile and Motile Proteins**

Because specific proteins exist in cells, they have unique movement abilities. Examples of how cells move include cell division, muscle contraction and motility. The filamentous proteins myosin and actin, as well as tubulin, the primary building block of microtubules, make up the contractile apparatus of cells (Taskinen et al. 2020).

- **Structural Proteins**

These proteins have the ability to create and maintain biological structures, but they play a passive and vital role in doing so. Structural proteins provide strength and protection to cells and tissues. When monomeric structural protein units polymerise, long fibres frequently result (as in hair). Keratins, insoluble fibrous proteins, are the building blocks of hair, horns and fingernails. In the bone, connective tissue, tendons and cartilage, collagen, an insoluble fibrous protein, produces robust, inelastic fibrils. In vertebrates, collagen makes up one-third of all proteins. Because it is a structural protein with elastic properties, elastin is a crucial part of ligaments. The main component of cocoons (silk) and spider webs, fibroin (α-keratin), is produced by some insects and has a structural purpose (Yadav et al. 2021).

- **Scaffold Proteins: Adapter Proteins**

It was only recently discovered that certain proteins are engaged in the intricate processes of cellular response to hormones and growth factors. The modular nature of scaffold or adaptor proteins allows for the recognition and binding of specific structural elements in other proteins through protein-protein interactions (Manay and Shadaksharaswamy 2008; Satyanarayana and Chakrapani 2017).

2.4 Sources of Protein

- **Plant Source**

Simply said, plant protein is a helpful source of protein that comes from plants and may be consumed. Excellent sources of protein include grains, nuts, fruits, vegetables, legumes, pulses and legume products. Legumes have a higher protein content than vegetables and fruits (Creighton 1993). The correct plant-based diets can be much better than animal products at providing protein and other essential elements. Some plant-based products, including soybeans and quinoa, are complete proteins, meaning they contain all nine of the essential amino acids required by humans. As seen in Table 2.1, several plant parts are suppliers of proteins.