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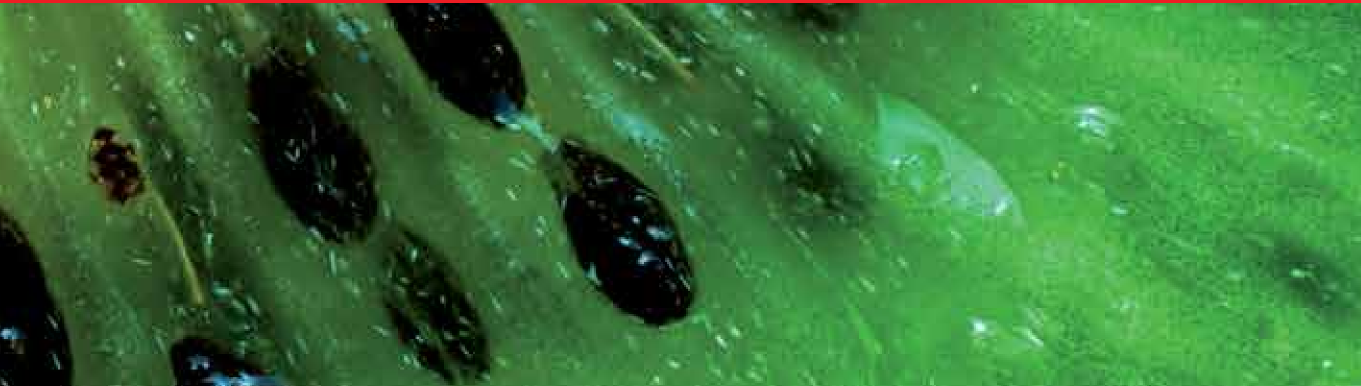
Functional Foods

Edited by Vasiliki Lagouri



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Published in London, United Kingdom

IntechOpen





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http://dx.doi.org/10.5772/intechopen.73983
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First published in London, United Kingdom, 2019 by IntechOpen
IntechOpen is the global imprint of INTECHOPEN LIMITED, registered in England and Wales, registration number: 11086078, The Shard, 25th floor, 32 London Bridge Street
London, SE19SG – United Kingdom
Printed in Croatia

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

Additional hard and PDF copies can be obtained from orders@intechopen.com

Functional Foods
Edited by Vasiliki Lagouri
p. cm.
Print ISBN 978-1-83881-149-5
Online ISBN 978-1-83881-150-1
eBook (PDF) ISBN 978-1-83881-151-8

Meet the editor

Vasiliki Lagouri (BA, MSc, PhD) received her three degrees from the Aristotle University of Thessaloniki and the National and Kapodistrian University of Athens, Greece. She has research and academic experience spanning from 1992 to 2018 from the Chemistry Department of Aristotle University of Thessaloniki, the Food Technology Department in Technological Educational Institute of Thessaloniki, the Department of Organic Chemistry and the Faculty of Chemistry. Her current post-doctoral position is in the Department of Pharmacognosy and Chemistry of Natural Products, Faculty of Pharmacy, School of Health Sciences at National and Kapodistrian University of Athens. She has over 30 publications in international journals, conference proceedings and has written two book chapters on food chemistry, natural antioxidants and olive oil and olives as functional foods (more than 400number of citations). She has research experience in experimental designs and applications of different methods to study the chemistry of natural sources; and the isolation, identification and quantification of biologically active polar and non-polar compounds. She offered her services as a reviewer for the following journals: International Journal of Food Properties; Journal of the Science of Food and Agriculture; Central European Journal of Chemistry, Separation Science and Technology; Natural Products Research; Nutrients; Molecules. She is a member of the American Chemical Society, the Society Free-Radical Research-Europe (SFRR-E), the Oxygen Club of California (OCC), the ISEKI-Food Association: European Association for Integrating Food Science and Engineering Knowledge Into the Food Chain and the Greek Chemist's Union and she is included in the Who's Who of America.

Contents

Preface

This book consists of chapters that summarize the scientific research that connects functional foods with the active components and important health benefits. The health benefits of functional foods should be based on accurate scientific data and the issues of safety and efficacy should be taken into consideration. We must remember that functional foods are foods and not drugs or dietary supplements and any adverse effects with other pharmaceuticals should be thoroughly studied. In the Introductory Chapter 1, we see that it is important to communicate to the consumers the definitions of functional foods, the categories and how they can be prepared and used in our daily diet. In recent years, there has been growing interest in plant sources, vegetables, fruits, and medicinal plants rich in vitamins, fibers, and various categories of phytochemicals that have beneficial effects on human health, such as preventing or reducing the risk of chronic diseases. Olive oil is considered as a key component of the Mediterranean diet due to its fatty acid, especially monounsaturated fatty acid oleic acid, vitamin, and polyphenol composition. There are over 200 minor components in olive oil with biological activities. The most abundant antioxidants in olive oil are tocopherols, β-carotene, lutein, squalene, and lipophilic and hydrophilic phenols. Chapter 2 “Olive Oil: Antioxidant Compounds and Their Potential Effects On Health” overviews the chemical composition and health effects of the active components in olive oil. In Chapter 3 “Olive Oil Phenols”, the structure and the significant biological activities of the four most abundant phenols in extra virgin olive oil (oleocanthal, oleacein, lingstroside aglycon, and oleuropein aglycon) are extensively described. An olive-oil-rich diet protects human health from cardiovascular diseases (cardiometabolic markers such as blood pressure, glycaemia, and dyslipidemia, LDL cholesterol, and LDL oxidation), type-2 diabetes, obesity, cancer, inflammation, and oxidative stress. The challenges of the new development of probiotic fermented products based on vegetables and fruits are presented in Chapter 4 “Fermented Functional Beverages” using scientific data from research studies. The scientific data, including the methods and the results, is presented in Chapter 5 “Functional Properties of Snack Bars” describes extensively the development of snack bars, which are consumer-friendly, with bioactive ingredients, and functional properties. Fish belongs to the basic food group of a healthy diet and is rich in important fatty acids, proteins, vitamins, and minerals. These are the key issues addressed in Chapter 6 “Fish as an Important Functional Food for Quality Life”. New food processing technologies have been developed in order to stabilize the final functional product and preserve its bioactive properties and these are being used by food manufacturers. This is the key issue of Chapter 7. “Instant Controlled Pressure-drop DIC as a Strategic Technology for Different

Types of Natural Functional Foods". It is a process that improves both performance of the drying process and high-quality functional foods.

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Section 1

Introduction

Chapter 1

Introductory Chapter: Functional Foods

Vasiliki Lagouri

1. Functional foods definitions

The first definition of functional foods has been established in Japan. In 1991, the Japanese law entered the work definition "foods for specified health use" (FOSHU) which allowed the first health claims on the food labeling. The FOSHU can be foods which exhibit health effect, used as foods in a diet, and are in the form of foods not as supplements [1].

A second definition of functional foods developed by the "Functional Food Science in Europe" (FUFOSE): "Functional food is a food with certain beneficial effects on one or more target functions in the body beyond the basic nutritional effects with a result the improved health state and well being or reduction of risk of diseases. It is consumed as a part of a normal diet and is not used in the form of pill or capsule or any other form of dietary supplement" [2].

Recently, the Functional Food Center (FFC) introduced a new definition for functional foods as: "Natural or processed foods that contains known or unknown biologically-active compounds; which, in defined, effective non-toxic amounts, provide a clinically proven and documented health benefit for the prevention, management, or treatment of chronic disease" [3]. In this definition, first functional foods can be natural or processed. Second, bioactive compounds, which are considered to be the source of the functionality of the foods, are secondary metabolites occur in food usually in small amounts that act synergistically to benefit health. Specifically, bioactive compounds may "exert antioxidant, cardio-protective and chemo-preventive effects" [4].

US does not have a formal definition for functional foods. The terms nutraceuticals or dietary supplements or medical foods are often used, thus functional foods cannot be regulated differently from other food products. Despite the government agencies, national and international organizations proposed their own definitions for functional food. The lack of a consistent definition between countries has led to unregulated publishing of health claims in functional foods and there exists an overall unclear definition of what "functional food" is between scientists, government officials, and the consumers. It is imperative that the food scientists should reconsider the meaning of functional food and agree upon a new formal definition for functional food.

In practice, a functional food can be a natural food, a food to which a health-promoting component has been added or from which a component for specific health reasons has been removed, a food in which a component has been modified by technological or chemical means to provide a specific health benefit, or a food in which the bioavailability of a component has been modified, or a combination of any of them.

Although the terms "nutraceutical" and "functional food" are used commonly around the world, there is no consensus on their meaning. According to the Bureau of Nutritional Sciences, of the Food Directorate of Health Canada, the following definitions have been proposed: A functional food is similar in appearance to, or may be, a conventional food, is consumed as part of a usual diet, and is demonstrated to have physiological benefits and/or reduce the risk of chronic disease beyond basic nutritional functions. Nutraceutical is a product produced from foods but sold in powders, pills, and other medicinal forms not generally associated with food and demonstrated to have physiological benefits or provide protection against chronic disease. Functional food is clearly a different category than a nutraceutical, a pharmafood, or a dietary supplement. It is a food not a drug since it has beneficial health effects usually disease preventive and not therapeutic properties [5].

2. Functional foods categories

The functional foods of plant or animal origin according to their action can be categorized as:

1. Vitamins and minerals fortification (e.g., vit C, folic acid, calcium, iron).

2. Cholesterol reduction (e.g., omega-3 fatty acids, phytosterols).

3. Dietary fiber (e.g. nondigestible carbohydrates and lignin).

4. Probiotics, prebiotics, and synbiotics (e.g., yoghourt, kefir, fruits, vegetables).

5. Phytochemicals (e.g., phenolic compounds, carotenoids, lycopene) [6].

Functional foods can be in many forms. Some may be conventional foods with bioactive components that can now be identified and linked to positive health effects. Some may be fortified or enhanced foods, specifically formulated to reduce disease risk. Consumers can already choose from a wide variety of foods that contain functional components either inherently (e.g., soy protein, fish, olive oil) or through fortification (e.g., folate-fortified milk). As additional bioactive components are identified, the opportunities for developing functional foods will be broad [7]. Foods that naturally provide a bioactive substance may be enhanced to increase the level present in the food (e.g., eggs with increased levels of omega-3 fatty acids). On the other side, foods that do not naturally contain a bioactive substance can be fortified (e.g., calcium-fortified orange juice).

3. Functional foods development

According to the FCC, a few steps have been suggested to be followed in order to bring the functional foods to the market [3]:

1. Study the link between the particular food component and health benefits.

2. In vitro and in vivo studies with nonliving and animal specimens.

3. Human studies which involve human appropriate dosages of bioactive compounds and testing for adverse side effects.

4. Development of the appropriate food vehicle.

5. Marketing the product to the public and educating about the health benefits.

6. Long-term studies on populations for the overall product effectiveness.

7. Measurement of the public attitudes toward functional food.

Scientific understanding of the way in which specific food components affect body processes involved in health and well-being enables the development of markers that could confirm the impact of the new food products and could also be used in their safety assessment [8]. The development of functional foods using the innovative food technology and biochemical methods can offer beneficial effects to the consumers for well-being and reduction of the risk of disease. The design and the operation of such studies need to be carefully performed in order to give the scientific evidence for the approval of the health claims and the successful production of new functional foods. The development of functional foods, with their accompanying health claims, will proceed with progress in food regulation, which is the means to guarantee the validity of the claims as well as the safety of the food. Science in itself cannot be regulated and functional food science provides only the scientific basis for these regulations [9].

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Section 2

Functional Foods - Properties and Technology

Chapter 2

Olive Oil: Antioxidant Compounds and Their Potential Effects over Health

Seray Kabaran

Abstract

Olive oil is considered as a key component of the healthy property of the Mediterranean diet due to its fatty acid, vitamin and polyphenol composition. High monounsaturated fatty acids, and in particular oleic acid, are responsible for the benefits obtained from consuming olive oil. Also, the known benefits are considered to be due to a combination of several phytochemicals. There are more than 200 minor components in olive oil with biological activities. The most abundant antioxidants in olive oil are tocopherols, β-carotene, lutein, squalene, lipophilic and hydrophilic phenols. Phenolic acids and derivatives (vanillic acid, gallic acid), phenolic alcohols (tyrosol, hydroxytyrosol), secoiridoids (oleuropein, oleocanthal), lignans (pinoresinol), and flavones (luteolin) are phenolic compounds of olive oil. Olive oil polyphenols have antioxidant, anti-inflammatory, antimicrobial, antiviral, anti-atherogenic, anti-thrombotic, anti-mutagenic and hypoglycemic characteristics. Hydroxytyrosol, tyrosol, oleuropein and oleocanthal are the phenolic compounds that are mainly responsible for antioxidant activity, protection from blood lipid oxidation, anti-inflammatory activity, the anticarcinogenic potential, the oxidative stress resistance, and other positive impacts over human health. Additionally, olive oil contains oleocanthal, which may have an effect on several inflammatory diseases. Olive oil rich diet protects human health from cardiovascular diseases (cardiometabolic markers such as blood pressure, glycaemia and dyslipidemia, notably by reducing LDL cholesterol and LDL oxidation), type-2 diabetes, obesity, cancer, inflammation, and oxidative stress.

Keywords: olive oil, oleic acid, minor components, phenolic compounds, health benefits

1. Introduction

Olive oil is one of the basic components of Mediterranean diet with health protective characteristics [1]. It has been used for centuries due to its preventive and therapeutic characteristics [2, 3]. Olive oil have positive effects on preventing or improving atherosclerosis, cardiovascular diseases, serum lipoprotein levels, oxidative stress, obesity, type 2 diabetes, inflammation and cancer [4–8].

Health protective effect of olive oil is based on its chemical composition [4, 5, 9, 10]. Olive oil's chemical composition may be divided into major and minor components. Major components of olive oil are related with its fatty acid content.

Primary monounsaturated fatty acid (MUFA) of olive oil is oleic acid [3]. Minor components of olive oil constitute nearly 2% of the weight of olive oil and include more than 230 minor chemical compounds [3, 10]. These chemical compounds include aliphatic alcohols, triterpene alcohols, sterols, hydrocarbons, pigments, volatile compounds, and phenolic compounds [2, 3]. Olive oil has at least 30 phenolic compounds. These are phenolic acids and derivatives, phenolic alcohols, secoiridoids, lignans and flavones [10–12].

Oleic acid, which is the basic fatty acid of olive oil [8, 13], and the minor compounds of olive oil, including tocopherols, β-carotene, lutein, squalene, lipophilic and hydrophilic phenols, are considered to be responsible for its positive impacts on human health [3, 14]. Olive oil protects human health by changes in epigenetic, metabolic and physiologic mechanisms [2]. This chapter reviews the fatty acid composition and minor components of olive oil and their effects on human health.

2. Fatty acid content of olive oil

Triglycerides constitute 98–99% of total weight of olive oil. Basic fatty acid of olive oil is oleic acid (55–83%), which is one of the MUFA. Besides, olive oil contains fatty acids such as palmitic acid, stearic acid, linoleic acid and α-linolenic acid (**Table 1**) [3, 10].

Positive impact of olive oil over human health is related with its oleic acid content [9]. MUFA in olive oil is considered to reduce hypercholesterolemia, hypertension, atherosclerosis and cardiovascular mortality [8, 13]. Besides, olive oil consumption increases MUFA intake rather than saturated fatty acids (SFA), which, in turn, protects from cardiovascular diseases [15–17].

In 1985, it was noticed that the replacement of SFA with MUFA intake in diets reduce low-density lipoprotein (LDL) cholesterol level [18]. It was found that the replacement of carbohydrates in diet with MUFA reduced triglycerides (TG), very low-density lipoprotein (VLDL) cholesterol, blood pressure, C-reactive protein (CRP)

Fatty acids	Common name
Saturated	Myrictic acid
	Palmitic acid
	Margaric acid
	Stearic acid
	Arachidic acid
	Behenic acid
	Lignosceric acid
Monounsaturated	Palmitoleic acid
	Heptadecenoic acid
	Oleic acid
	Eicosenoic acid
Polyunsaturated	Linoleic acid
	α-linolenic acid

Table 1.
Fatty acids composition of olive oil.

and increased high-density lipoprotein (HDL) cholesterol and apolipoprotein A1 (Apo-A1) levels [19–21]. In an another study with the replacement of SFA with olive oil, which has the same amount of energy in diet, LDL cholesterol levels decreased whereas HDL cholesterol levels did not change [22]. Replacement of partially hydrogenated vegetable oil with MUFA had positive impact on cardiovascular risk parameters, such as LDL cholesterol, TG, Apo-A1 and Apo-B levels [23]. It was indicated that following a MUFA rich diet increased HDL cholesterol levels and decreased TG levels [24]. In a meta-analysis it was found that replacement of SFA with MUFA or polyunsaturated fatty acids (PUFA) significantly reduced total and LDL cholesterol levels [25]. In an another meta-analysis it was determined that consuming diets high in MUFA can improve metabolic risk factors among patients with type 2 diabetes [26]. In a meta-analysis of 12 randomized controlled studies high MUFA diets (>12%) were compared to those with low MUFA diets (≤12%). Significant differences between high- and low-MUFA diets were determined with respect to fat mass, systolic blood pressure and diastolic blood pressure. Therefore, high MUFA diets are important dietary regimens for obesity and cardiovascular disease [27].

Such positive impacts of olive oil on human health are related with high oleic acid, proper amount of linoleic and α-linolenic acid, and limited amount of SFA that it contains. High amount of oleic acid and proper amount of linoleic acid helps cells to protect their integrity and slows down the process of aging. Besides, low levels of α-linolenic acid demonstrate anti-inflammatory and vasodilatory effects [2].

3. Minor compounds of olive oil

Olive oil is rich in terms of minor compounds with antioxidant characteristics, such as polyphenols, carotenoids, squalene and tocopherols. Tyrosol, hydroxytyrosol, flavonoids (apigenin, luteolin), oleuropein and oleocanthal are among the phenolic compounds of olive oil with antioxidant characteristics (**Table 2**) [2, 6].

The amount of squalene, which is the basic hydrocarbon in olive oil ranges between 0.8 and 13 g/kg. Squalene has antioxidant activity and helps to lower serum cholesterol levels. Regular squalene intake by using olive oil in diets protects human health from cancer and cardiovascular diseases [28]. The most important carotenoids in olive oil are luteolin and β-carotene. These compounds have antioxidant characteristics that maintain the neutralization of reactive oxygen species (ROS) [2].

Triterpenes have also antioxidant and anti-inflammatory effects [11]. Regular consumption of olive oil maintains antioxidant intake. These compounds reduce

Minor components

• Non-glyceride esters and waxes
• Aliphatic alcohols
• Triterpene alcohols: erythrodiol and uvaol
• Sterols: β-sitosterol, campesterol, sigmasterol
• Hydrocarbons: squalene, volatile hydrocarbons, carotenoids
• Pigments: chlorophylls and pheophytins
• Volatile compounds
• Phenolic compounds
    • Lipophilic: tocopherols and tocotriends
    • Hydrophilic

Table 2.
Minor components of olive oil.

free radicals and prevent damages to the cellular membrane, mitochondria, and DNA, with beneficial effects on aging and cancer risk. Especially, phenolic compounds in olive oil have strong antioxidant effect [2, 6].

3.1 Phenolic compounds of olive oil

Polyphenols are compounds with diverse characteristics, which protects human health from chronic diseases [6]. They are described as phenolic compounds, which consists of one or more hydroxyl groups and aromatic rings [10]. Phenolic

Phenolic compounds	Common compound name
Flavonoids	
• Flavones	• Apigenin • Luteolin
• Flavonol	• (+)-Taxifolin
Lignans	• (+)-Pinoresinol • (+)-1-Acetoxypinoresinol • (+)-1-Hydroxypinoresinol
Phenolic acids and derivatives	
• Phenolic acids-benzoic acid derivatives	• Benzoic acid • p-Hydroxybenzoic acid or 4-Hydroxybenzoic acid • Vanillic acid • Gallic acid • Syringic acid • Protocatechuic acid • Gentistic acid
• Phenolic acids-cinnamic acid derivatives	• Cinnamic acid • o-Coumaric acid • p-Coumaric acid • Caffeic acid • Ferulic acid • Sinapinic acid
• Other phenolic acids and derivatives	• p-Hydroxyphenylacetic acid • 3,4-Dihydroxyphenylacetic acid or Dopacetic acid • 4-Hydroxy-3-methoxyphenylacetic acid • 3-(3,4-Dihydroxyphenyl) propanoic acid
Phenolic alcohols	• Tyrosol or p-hydroxyphenyl-ethyl alcohol or p-HPEA • Hydroxytyrosol or 3,4-dihydroxyphenyl-ethyl alcohol or 3,4-DHPEA • Tyrosol acetate • Hydroxytyrosol acetate
Secoiridoids	• Oleuropein • Oleuropein aglycon or 3,4-DHPEA-EA • Ligstroside aglycon or p-HPEA-EA • Dialdehydic form of oleuropein aglycon • Dialdehydic form ligstroside aglycon • Dialdehydic form of decarboxymethyl elenolic acid linked to 3,4-DHPEA or 3,4-DHPEA-EDA or oleacein • Oleocanthal or Dialdehydic form of decarboxymethyl elenolic acid linked to p-HPEA or p-HPEA-EDA

Table 3.
Phenolic compounds in olive oil.

compounds in olive oil are classified as phenolic acids, flavonoids, secoiridoids, lignans, and phenolic alcohols (**Table 3**).

Phenolic compounds in olive oil may have lipophilic and hydrophilic characteristics. Tocopherols are among the lipophilic phenols. Alpha-tocopherols are the most common type of tocopherols in olive oil. Tocopherols especially prevent lipid oxidation in cellular membrane. Due to this reason, they are considered as the most important antioxidant agents in structures that contain lipid [14]. Tocopherols may be found in other oil types. However, hydrophilic phenols (phenolic acids and alcohols, secoiridoids, flavonoids and lignans) do not exist in oil types other than olive oil [3, 10]. Oleuropein, hydroxytyrosol and tyrosol are among the important phenolic compounds of olive oil [2, 6].

On average, olive oil consists of 500 mg/kg phenol [29] and the amount of phenol in different types of olive oil may range between 40 and 1000 mg/kg [10]. A study conducted in Spain found that daily polyphenol intake from olive and olive oil was 90.4 mg, which constitutes 11% of total daily polyphenol intake [30].

Phenolic compounds display a board spectrum of health promoting characteristics, including lipid-improving, anti-oxidant, anti-inflammatory, anti-atherogenic, anti-thrombotic, anti-mutagenic, anti-microbial effects [6–8]. Beneficial effects of olive oil's phenolic compounds on human health include improvements in oxidative stress, lipid metabolism, platelet and endothelial functions, and inflammation [6, 8, 14]. Oleuropein and hydroxytyrosol are principal minor phenolic components of olive oil and these antioxidant components prevents diabetes, cardiovascular diseases, neurodegenerative diseases, cancer, inflammation and oxidative stress through its nutrigenomic and immunomodulatory effects [4, 5]. Also oleacein has antioxidant, anti-inflammatory, anti-proliferative and antimicrobial properties and it may play a special role in decreasing the progression of atherosclerosis [31].

A study conducted on 200 healthy male participants, administered 25 ml/day of three olive oils that had low (2.7 mg/kg), medium (164 mg/kg) and high (366 mg/kg) phenolic content. The study found that higher phenolic content was associated with decrease in oxidative stress markers and improvements in lipid profile [32].

Phenolic compounds in olive oil have strong antioxidant characteristics and radical scavenging activities [29]. Regular olive oil consumption maintains phenolic compound intake and protects human health [14]. Taking these into consideration, we may suggest that biological characteristics of olive oil decrease the prevalence of chronic diseases [6, 8, 14].

4. Olive oil and potential effects over health

Olive oil rich diet protects human health from cardiovascular diseases, hypertension, inflammation, oxidative stress, obesity, type-2 diabetes, and cancer [4–8].

4.1 Olive oil consumption and cardiovascular diseases

Cardiovascular diseases arise from malfunctioning of heart and blood vessels and include problems, such as coronary heart disease, atherosclerosis, cerebrovascular diseases, peripheral artery disease, congenital heart disease, deep venous thrombosis, pulmonary embolism, myocardial infarction and stroke. Eating habits, and especially total fat and fatty acid intake are among the reasons of cardiovascular diseases [33]. 'Prevención con Dieta Mediterránea' (PREDIMED) study that conducted in Spain and randomly assigned participants, who were at high cardiovascular risk, to one of three diets: a Mediterranean diet supplemented with extra-virgin olive oil (EVOO), a Mediterranean diet supplemented with mixed nuts, and a control diet that was advised to reduce dietary fat. Compared to the control group, the Mediterranean diet supplemented with EVOO or mixed nuts was associated with 30% lower risk of major cardiovascular events for a period of 5 years [34]. In an another study, it was found that olive oil consumption, specifically EVOO, is associated with reduced risks of cardiovascular disease and mortality in individuals at high cardiovascular risk. For each 10 g/day increase in extra-virgin olive oil consumption, cardiovascular disease and mortality risk decreased by 10 and 7%, respectively [35].

A study that followed stroke incidence in three French cities for an average of 5.25 years found that the participants with high olive oil consumption had a 41% lower risk of stroke compared to those who never used olive oil. The same study found that higher plasma oleic acid was associated with lower stroke incidence and that the participants with higher plasma oleic acid levels had a 73% reduction of stroke risk compared to the participants with lower plasma oleic acid levels [36]. Another study, which followed Italian women for an average of 7.85 years, found that cardiovascular disease risk was lower for women in the highest quartile of olive oil intake (35.0 ± 0.1 g/day) compared to those in the lowest quartile of olive oil intake (16.8 ± 0.1 g/day) [37].

Another study conducted in five Spanish regions compared non-consumers of olive oil with participants that consumed ≥29.4 g/2000 kcal/day and found that the highest quartile of olive oil consumption was associated with a 26% reduction in risk of overall mortality and a 44% reduction in cardiovascular disease mortality. The study also found that for each increase in olive oil intake of 10 g/2000 kcal/day, there was a 7% decreased risk of overall mortality and a 13% decreased risk of cardiovascular disease mortality [38].

EVOO that is frequently consumed in Mediterranean countries, tends to produce a less prothrombotic environment, promoting antioxidant and anti-inflammatory effects with a greater endothelial protective capacity, which in turn, prevents cardiovascular diseases [22]. Besides, another study in which, healthy participants were administered virgin olive oil (VOO) for 3 weeks found that VOO supplementation altered the expression of 10 genes related to atherosclerosis development and progression [39].

Phenolic compounds of olive oil protects blood lipids from oxidative damage [8]. LDL oxidation is among the main risk factors that contribute to the development of atherosclerosis and cardiovascular diseases. Oxidation of LDL results in the formation of plaque within the arterial wall. Oxidized LDL levels should be taken into consideration as an indicator of oxidative damage and subclinical atherosclerosis. Oxidation of lipids and LDL apolipoproteins is taken by scavenger receptors on monocytes, smooth muscle cells and macrophages in an uncontrolled process, which, in turn, leads to formation of foam cells as an early feature of atherosclerosis [40]. Phenolic compounds delay atherosclerosis by reducing the expression of oxidized LDL and cellular adhesion molecules [2, 14]. Consumption of VOO, which is rich in terms of phenolic compounds significantly decreased LDL cholesterol levels in 1 week [41].

Due to vessel damage, endothelial adhesion molecule expression, platelet activity and aggregation is stimulated. Circulating macrophages and other molecules are adhered to the endothelium, which scavenge LDL and TG, becoming foam cells [42]. Phenolic compounds in olive oil prevent endothelial adhesion molecule expression and platelet aggregation. Hydroxytyrosol, oleuropein, aglycon and luteolin are crucial to prevent platelet aggregation [8]. Oleocanthal-rich extra virgin olive oil may influence platelet aggregation responses in healthy male adults [43]. Oleacein by inhibiting neutral endopeptidase activity, adhesion molecules expression and elastase release might play a role in the protective effects of olive oil against endothelial injuries [44]. Oleacein enhances anti-inflammatory activity of human macrophages by increasing CD163 expression. It could play a potential role in the prevention of inflammatory disease related to atherosclerosis [45]. Additionally, oleacein possess ability to diminish the destabilization of carotid plaque and it could be useful in the reduction of ischemic stroke risk [46]. For that reasons it is possible to emphasize that olive oil rich diet protects human health from cardiovascular diseases.

4.2 Olive oil consumption and hypertension

Positive effects of EVOO consumption on blood pressure have been noticed. EVOO intake contributes to the decrease in diastolic and systolic blood pressure in hypertensive individuals. When compared with vegetable oil that is rich in terms of PUFA, EVOO consumption has a positive effect on blood pressure [47]. A study conducted in five European countries found that consumption of 25 ml/day olive oil significantly decreased systolic blood pressure [48].

In a meta-analysis conducted in the recent years compared dietary regimes with a high amount of MUFA (>12%) with those ≤12% for a period of more than 6 months and found that diets with high amount of MUFA decreased systolic blood pressure, and diastolic blood pressure [27].

Antioxidant effect of EVOO is related with the fact that EVOO consumption reduces the generation of ROS. This effect prevents endothelial dysfunction, which is responsible for hypertension [49]. Related with this, the comparison of EVOO with olive oil or corn oil reveals that inflammatory markers (TXB2 and LTB4) decreased and serum antioxidant capacity increased only in the group of participants, who were administered EVOO [50].

4.3 Olive oil consumption and oxidative stress

Increase in oxidative stress causes an increase in ROS. Superoxide anion (O_2^-), hydroxyl radical (OH), and hydrogen peroxide (H_2O_2), which are also known as ROS, are the oxidizing agents that highly aggressive against the principal biological components of the organism, including lipids, proteins, mitochondria, and DNA. When lipids in the cell membrane are subjected to this action, oxidation that alters membrane permeability takes place. This, in turn, results with early aging of cells. When enzymes, mitochondria and proteins are subjected to this phenomenon, they can lead to metabolic disorders and inflammation in blood vessels, heart, kidney or joints. On the other hand, if DNA undergoes oxidation, the risk of cancer increases. Minor components of olive oil protects mitochondria and DNA from oxidation and decreases the generation of free radicals [2, 11]. Both oleuropein and oleacein are important antioxidant compounds of olive oil and they are stronger scavengers of O^{-2} and H_2O_2 [51].

Increase in ROS is associated with atherosclerosis, cancer and neurodegenerative diseases. Oxidative stress increases the levels of lipid peroxide and oxidized glutathione (GSSG), and decreases the levels of glutathione (GSH) and glutathione peroxidase (GSH-Px). Consumption of olive oil that is rich in terms of phenols improves the balance of GSH and GSSG, increases GSH-Px levels and decreases lipid peroxide levels. Consequently, cellular oxidative damage may be decreased by consumption of olive oil with high phenol content [32, 52]. In a controlled before and after supplementation trial with 45 healthy adults found that regular consumption of 50 ml/day EVOO rich in phenolic compounds during 30 days increases plasma antioxidant capacity and antioxidant enzyme activity (catalase and superoxide dismutase). Also it was observed increase in superoxide dismutase and decrease in catalase gene expression [53].

Cell aging, atherosclerosis, diabetes, rheumatoid arthritis, pulmonary emphysema, cataract, Alzheimer and Parkinson diseases, dementia, and development of breast, prostate, colon and skin cancers are related with continuous oxidative damage of cells. Oxidative damage may be partially prevented when the activation of free radicals is inhibited by nutrients, such as minor compounds of EVOO [2, 11]. In order to protect aging that is caused by the damage of free radicals, EVOO intake should start during the early childhood period [54].

4.4 Olive oil consumption and inflammation

EVOO may prevent inflammation when chronic inflammation is associated with pathological cases, such as obesity. Anti-inflammatory effects of EVOO is depends on its fatty acid content and antioxidant compounds [54]. In a randomized controlled trial in healthy adults found that VOO consumption decreased plasma oxidative and inflammatory status and the gene expression related with both inflammation and oxidative stress [55].

Increase in the concentration of inflammatory markers is associated with a higher risk of cardiovascular disease. Plasma thromboxane B2 (TXB2) and leukotriene B4 (LTB4) are known as the pro-inflammatory agents. TXB2 increases platelet aggregation in blood whereas LTB4 leads to cellular damage [56]. Bogani et al. [50] determined that consumption of EVOO that is rich in phenolic components decreases the concentration of inflammatory markers such as TXB2 and LTB4 and increases the serum antioxidant capacity whereas no such decrease was found for other oil types such as olive oil and corn oil.

Interleukin-6 (IL-6) and CRP, which are among the inflammatory markers increase in case of cardiovascular diseases. Olive oil with high phenolic compounds has anti-inflammatory effect and decreases CRP and IL-6 levels in circulation [57]. Oleocanthal, which is among the phenolic compounds of olive oil, prevents cyclooxygenase-1 (COX-1) and cyclooxygenase-2 (COX-2) activities, which have roles in the inflammation process. Inhibition of cyclooxygenase (COX) enzymes results in the reduction of arachidonate to the eicosanoids, prostaglandins and thromboxane [58]. It have been proven to possess that oleacein have antioxidant and anti-inflammatory activities. Oleacein enhances anti-inflammatory activity of human macrophages by increasing CD163 expression [45]. For that reasons, anti-inflammatory effects of olive oil enables protection from diseases that are related with inflammation [8].

Additionally, EVOO reduces the expression of genes involved in the inflammatory response, including intercellular adhesion molecule-1 (ICAM-1), vascular cells adhesion molecule-1 (VCAM-1) and monocyte chemotactic protein-1 (MCP-1), and interferes with the activation of major transcription factor that controls the inflammatory endothelial activation, namely nuclear factor kB (NF-kB). It was known that minor compounds of EVOO, such as phenols, carotenoids and tocopherols, prevent the activation of NF-kB at cellular level [2].

The anti-inflammatory effects that arise from the consumption of olive oil phenolic compounds have been shown to provide protection against inflammatory diseases. Thus, due to the reduction of the risk of inflammation, it can be said that the Mediterranean populations have low rate of cardiovascular mortality and certain types of cancer [8].

4.5 Olive oil consumption and obesity

Positive effects of olive oil consumption over weight control are widely known. Olive oil increases postprandial thermogenesis. Besides, it may contribute to an increase in fat oxidation. Furthermore, oleic acid may increase satiety, thus reducing food intake. The effect of fatty acids over weight gain may be related with neurotransmitters, intestinal peptides or thermogenesis [59]. The presence of fatty acids in the small intestine lumen induces a number of changes in the gastrointestinal function and inhibits appetite and energy intake. Gastrointestinal hormones, including cholecystokinin, glucagon-like peptide-1 and peptide YY are crucial to regulate appetite and control nutrition intake [60]. One of the studies found that oleic acid caused a slower gastric emptying, promoted the release of cholecystokinin and peptide YY, and a lower subsequent energy intake for both normal weight and obese participants [61].

Comparison of EVOO with cream, which has the same amount of energy but higher SFA levels indicated that olive oil significantly promoted postprandial fat oxidation and stimulated diet-induced thermogenesis [62]. Due to this reason, SFA may be replaced by MUFA for overweight and obese persons in order to lower body weight and fat weight [63].

Oleoylethanolamide (OEA), which is a by-product of oleic acid, acts as a hormone and may lead to satiety and decrease meal frequency. Nutritional intake of oleic acid stimulates the activation of OEA mobilization in the proximal small intestine, which, in turn, leads to satiety. Oleic acid in diets is precursor of OEA synthesis in erythrocytes. OEA decreases during fasting and increases after meals [64]. OEA production in small intestine serves as a molecular sensor linking fat intake to satiety [65]. In addition, OEA resembles to *endocannabinoid anandamide in structural terms*. Anandamide has an appetizing effect and activates cannabinoid receptors (CB1). Nevertheless, independent of the cannabinoid receptors, OEA has anorectic effect and increases satiety between meals [65].

OEA regulates satiety and appetite, thus contributes to a decrease in body weight. This effect is related with the engagement of peroxisome proliferator-activated receptors-α (PPAR-α). Following food intake, activation of PPAR-α receptor in intestine plays a role in the stimulation of vagus nerves, creating satiety in paraventricular nucleus (PVH) of hypothalamus [64]. OEA decreases meal frequency, increases lipolysis, and modulates the inflammatory response together with PPAR-α by reducing the activity of nuclear factor NF-kB activity, and increasing the catabolism of LTB4 in macrophages [2]. For that reasons, it has been suggested that the increase in OEA production may prevent overnutrition [2].

Additionally, proinflammatory cytokines, such as leptin, tumor necrosis factor alpha (TNF-α), MCP-1, and IL-6 are released from adipose tissue and this phenomenon triggers chronic inflammation [66]. EVOO prevents inflammation in cases such as obesity, which are associated with chronic inflammation [54]. EVOO consumption by obese individuals may reduce inflammatory responses [22]. Anti-inflammatory effect of EVOO may be related with its fatty acid content and antioxidant compounds [54].

In addition to all these characteristics, the consumption of olive oil together with legumes, vegetable dishes and salads is believed to have positive effects on digestive system, glycemic responses and weight control [59]. A 3 years follow-up of a Mediterranean diet supplemented by VOO and nuts found that Mediterranean diet, especially rich in VOO is associated with higher levels of plasma antioxidant capacity and the reduction in body weight after 3 years of intervention in a high cardiovascular risk population [67]. All these reflect the fact that olive oil consumption together with a Mediterranean diet may prevent weight gain [8, 13].

4.6 Olive oil consumption and type 2 diabetes

Olive oil with its MUFA content improves glucose metabolism [8, 13]. When high-MUFA diets were compared with high-PUFA diets, there was a significant reduction in fasting plasma glucose level [26]. In addition, it was determined that decreases of SFA levels and increases of oleic acid levels in cellular membranes do not change insulin secretion but improves insulin sensitivity [2].

Prevention of diabetes might be attributable to the antioxidant property of EVOO, thus, oxidative stress seems to be implicated in β-cells dysfunction and eventually diabetes [68]. After 6 hours of consumption of 50 ml VOO, significant changes occurred in gene expression related with insulin sensitivity [69]. On the other hand, four cohort studies, including 15,784 T2D cases and 29 trials, were included in a recent meta-analysis, which indicated that the highest olive oil intake showed a 16% reduced risk of type 2 diabetes compared with the lowest intake. Additionally, in case of patients with type 2 diabetes, olive oil supplementation resulted in a significant reduction of HbA1c and fasting plasma glucose compared to the control group [70]. Additionally, change from polyunsaturated to monounsaturated diet in type 2 diabetes reduced insulin resistance [71]. For these reasons, olive oil could be beneficial for the prevention and management of type 2 diabetes [70].

Obesity causes an increase in inflammation [54]. Additionally, free fatty acids and glycerol release from adipocytes. Increase in the levels of proinflammatory cytokines, ROS and free fatty acids, result with risk of insulin resistance, which, in turn, may lead to type-2 diabetes [66]. Olive oil consumption contributes to weight loss, which is one of the strongest risk factors for type 2 diabetes [72]. All these reveal that olive oil, which is the fundamental ingredient of Mediterranean diet, may have a preventive role for type 2 diabetes [4–8].

4.7 Olive oil consumption and cancer

Epidemiologic studies found that cancer incidence was lower in countries such as Greece, Italy and Spain, which are characterized by high EVOO consumption [54]. Meta-analysis of 19 case-controlled studies reveals that cancer risk for the highest olive oil consuming group was 60% lower than the lowest olive oil consuming group. Besides, the study demonstrated that the increase in olive oil consumption was associated with protection from breast and gastrointestinal cancer [73].

High corn oil diet allows the development of malignant adenocarcinomas in rats whereas high EVOO consumption does not have such an effect. Excessive intake of oleuropein, which is one of the phenols in olive oil, has no toxic effects. Additionally, it has antimicrobial, antioxidant, hypotensive, hypoglycemic and *antiangiogenic* properties. Due to this reason, it is believed that oleuropein has anti-tumor activities. In case of rats with one or more large tumors (>2 cm diameter), addition of 1% oleuropein to drinking water showed strong antineoplastic effects and lead to the disappearance of tumor within 9-to-12 weeks due to antiangiogenic mechanisms that have direct inhibitor effects over cells. The study found that oleuropein in olive oil is an important compound with antineoplastic activity [74].

EVOO has antineoplastic effect on breast cancer in females. EVOO consumption reduces breast cancer risk in postmenopausal women [72]. In the presence of high levels of fatty acid synthase enzyme, oleic acid inhibits the oncogenic effect of epidermal growth factor receptor (HER_2) gene by reducing the transcription activity of this gene. Furthermore, EVOO had a strong tumoricidal action on HER_2 as a result of phenols, mainly oleuropein aglycon, which is related to inhibition of HER_2 gene [75].

Oxidative damage of DNA starts carcinogenesis. Consumption of olive oil that is rich of phenols may inhibit oxidative DNA damage [76]. Cell proliferation and prevention of cell death are among the other factors that lead to tumor formation and development. Hydroxytyrosol in olive oil may prevent cell proliferation. Besides, oleuropein and hydroxytyrosol induce the death of breast cancer cells [77]. Due to these reasons, phenolic compounds in olive oil maintains the integrity of cells and prevents the development of tumors [8, 77].

Compounds of EVOO may show antitumoral effects as a result of metabolic and pathophysiological mechanisms, and may prevent the transformation of human cells into malignant cells and form metastases [2].

5. Conclusion

Olive oil has protective effects against inflammation and oxidative stress. Besides, it protects human body from various diseases, including, cardiovascular diseases, hypertension, obesity, type 2 diabetes and cancer. The basic fatty acid of olive oil, namely oleic acid, and minor compounds of olive oil, primarily phenolic compounds with their antioxidant activities, are responsible for the positive effects of olive oil over human health. Olive oil polyphenols have antioxidant, anti-inflammatory, antimicrobial, antiviral, anti-atherogenic, anti-thrombotic, anti-mutagenic and hypoglycemic characteristics. Hydroxytyrosol, tyrosol, and oleuropein are the phenolic compounds that are mainly responsible for antioxidant activity of olive oil. Through antioxidant and anti-inflammatory mechanisms, olive oil leads to epigenetic, metabolic and physiologic changes, which protects human health. Due to this reason, regular consumption of olive oil may be effective to decrease the risk of chronic diseases.

Abbreviations

MUFA	monounsaturated fatty acids
SFA	saturated fatty acids
LDL	low-density lipoprotein
TG	triglycerides
VLDL	very low-density lipoprotein
CRP	C-reactive protein
HDL	high-density lipoprotein
Apo-A1	apolipoprotein A1
PUFA	polyunsaturated fatty acids
VOO	virgin olive oil
EVOO	extra-virgin olive oil
PREDIMED	Prevención con Dieta Mediterránea
ROS	reactive oxygen species
O_2^-	superoxide anion
OH	hydroxyl radical
H_2O_2	hydrogen peroxide
GSSG	oxidized glutathione
GSH	glutathione
GSH-Px	glutathione peroxidase
TXB2	thromboxane B2

LTB4	leukotriene B4
IL-6	interleukin-6
COX-1	cyclooxygenase-1
COX-2	cyclooxygenase-2
COX	cyclooxygenase
ICAM-1	intercellular adhesion molecule-1
VCAM-1	vascular cells adhesion molecule-1
MCP-1	monocyte chemotactic protein-1
NF-kB	nuclear factor kB
OEA	oleoylethanolamide
CB1	cannabinoid receptors
PPAR-α	proliferator-activated receptors-α
TNF-α	tumor necrosis factor alpha
HER_2	epidermal growth factor receptor

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Chapter 3

Olive Oil Phenols

Christos Papanikolaou, Eleni Melliou and Prokopios Magiatis

Abstract

Olive oils contain numerous substances that have a beneficial role in human health. Phenols are natural compounds that are present in extra-virgin olive oil (EVOO), and they are produced at the malaxation step of the olive oil production. The four most abundant phenols in EVOO are oleocanthal, oleacein, ligstroside aglycon, and oleuropein aglycon. These phenols exhibit significant biological effects in many diseases, participating in various cellular and biochemical processes. Oleocanthal can protect and prevent against the Alzheimer disease, demonstrates acute antiplatelet effects, which has a vital role against cancer, and can act like ibuprofen. Oleacein has antioxidant and anti-inflammatory activities and helps against atherosclerosis. Moreover, it acts as an antiaging factor and as a 5-lipoxygenase inhibitor. Ligstroside aglycon implicates to mechanisms against breast cancer, while oleuropein aglycon shows activities against the Alzheimer disease and breast cancer.

Keywords: EVOO, phenols, oleocanthal, biological activities, functional foods

1. Introduction

In the fourth century B.C., Hippocrates said: "Let food be thy medicine and medicine be thy food," as he wanted to point the meaning of choosing the right human diet. Nowadays, food science has focused on this sentence by rethinking many prospects about foods and their relationship with human health. The concept of developing food to promote health and reduce the risk of disease to the people was, first, introduced in Japan in the decade of 1980. This consideration led to the birth of the term functional foods. This term is not quite specified yet, but generally as functional foods, they are considered foods that are basic in human diet, and they contain components with significant biological activities. Foods are a large deposit of natural compounds with health effects on humans, and scientists work on this base to develop foods and products based on these compounds.

2. Mediterranean diet and extra-virgin olive oil

The Mediterranean diet (MD) is referred to the food consumption habits around the Mediterranean basin. The particular kind of diet usually includes, at its traditional form at least, high, and daily consumption of vegetables, legumes, nuts, fruits, and other plant foods or plant derivatives like olive oil [1]. On the other hand, in the Mediterranean diet, there is less meat and dairy product consumption and a medium rate of fish feeding. Comparing with other types of diet, the

Mediterranean diet is characterized as unique in two basic elements. First, there is a high fat uptake as a result of extra-virgin olive oil existence in daily basis to the table and also from fishes and nuts [2]. The second uniqueness of this diet is the alcohol consumption, and particularly the red wine, upon meals [3]. But the real question is why the Mediterranean diet is so important for the people's lives?

2.1 Healthy effects of the Mediterranean diet

The observation of long living people in the Mediterranean area, especially in various places in Greece and Southern Italy, intrigued the scientific community leading to the association with the Mediterranean diet and a general healthy way of living [4]. Moreover, the observation of the low percentage of the cardiovascular diseases in these populations strongly improved the initial image of diet-caused health of humans [5, 6]. Worldwide, studies took place setting as goal to discover the results of the Mediterranean diet in human health. Scientists found a wide range of situations that Mediterranean diet improved health, including, cardiovascular diseases [7, 8], type 2 diabetes protection and generally metabolic syndrome [9, 10], malignancies such as breast and gastric cancer [11, 12], depression [13, 14], and cognitive impairment [15, 16]. The Mediterranean diet also helps people to control their body weight and in obesity to improve the weight of the patient [17].

2.2 Extra-virgin olive oil in the Mediterranean diet

The Mediterranean diet is mostly plant-based and includes a high consumption of cereals, vegetables, and fruits, while red meat and sweets are rarely consumed. In MD, there is a daily consumption of dairy, fish, and poultry. Olives and red wine are moderately consumed, as well as with nuts and seeds. Less added salt sources are often consumed like herds, garlic, and onion. All of the above are supported on the basis of high water intake and regular physical exercise. Extra-virgin olive oil (EVOO) has a central place in Mediterranean diet as it shows in the Mediterranean diet pyramid below. Extra-virgin olive oil has a significant role in cardiovascular disease decreasing the risk in human that enclose it to their diet [1]. Moreover, anti-inflammatory and antioxidant properties have been attributed to EVOO [18]. EVOO is the main source of fat in the Mediterranean diet and especially of the unsaturated fats that are more beneficial than saturated fatty acids [19].

3. Functional foods, extra-virgin olive oil, and phenols

Plant foods can provide many basic nutrients to humans, participating in many ways to a healthy state of the human body [20]. Secondary metabolites are compounds synthesized in plants, with crucial roles such as the adaptation of plants to their environment [21]. These phytochemicals (PCs) are very essentials for the human diet but, also, exhibiting considerable biological activities [22, 23], leading to the usage of PCs as potential pharmaceuticals [24]. PCs have some serious advantages like their accessibility, the specificity of their response, and their low toxicity [25]. On the other hand, the negatives of these compounds are the low bioavailability and the fast metabolism in humans.

In the last decades, many pharmacological studies have been applied to secondary metabolites, guiding industries to the design of new drugs [26]. Many studies involving compounds of natural sources have shown that secondary metabolites have many actions in the human body, such as antitumor, antibacterial, and anti-inflammatory. A proper diet, like the Mediterranean, involves food consumption that supplies the human body with many beneficial nutrients, resulting in good tolerance of the body's health, and provides natural resources, with pharmaceuticals properties, for health protection and improvement [27].

3.1 Phenols in EVOO: structure, chemistry, and biosynthesis

About 98% of EVOO consists of triacylglycerols (TGAs), a group of glycerol esters containing different fatty acids. Oleic acid is the major fatty acids, while there are also palmitic acid, linoleic acid, stearic acid, and palmitoleic acid [28] (**Figure 1**). Moreover, there are minor compounds that are lipophilic or amphiphilic like phytosterols such as

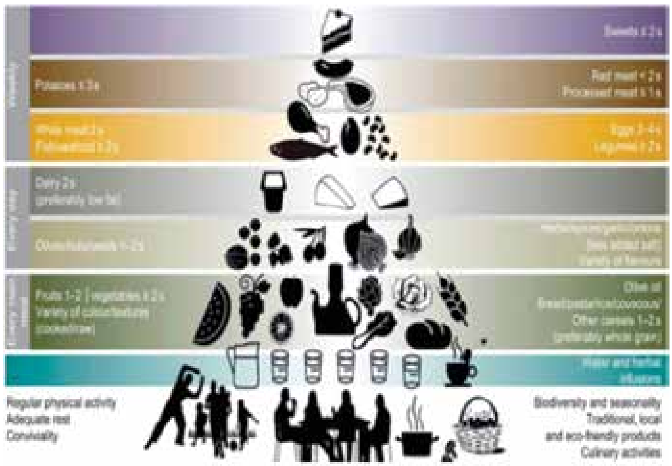

Figure 1.
The Mediterranean diet pyramid. (Picture taken from: Trichopoulou et al, 2014 Definitions and potential health benefits of the Mediterranean diet: views from experts around the world. BMC Med. 2014 Jul 24;12:112).

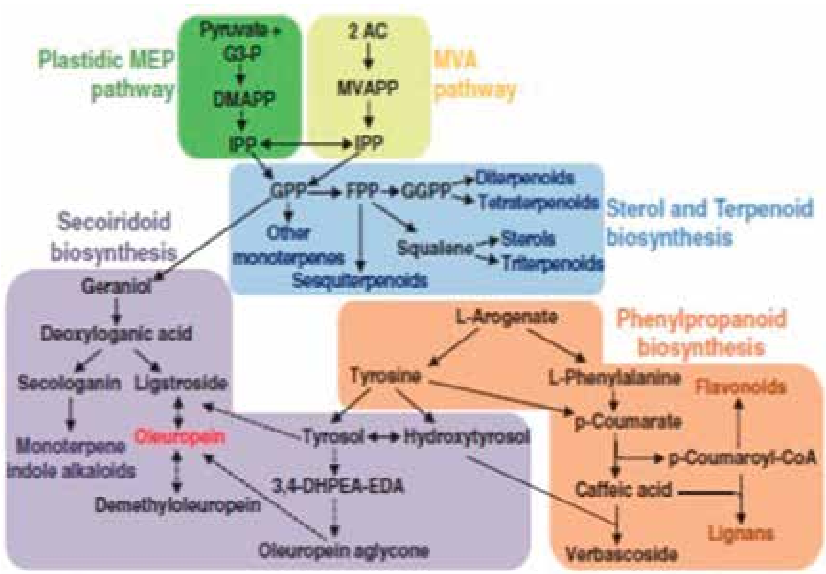

Figure 2.
Production pathway of phenolic compounds in plants. G3P: glyceraldehyde 3-phosphate; DMAPP: Dimethylallyl diphosphate; IPP: Isopentenyl diphosphate; AC: Acetyl-CoA; MVAPP: Mevalonate diphosphate; GPP: Geranyl diphosphate; FPP: Farnesyl diphosphate; and GGPP: Geranyl geranyl pyrophosphate. Dotted arrows indicate uncertain biosynthetic steps. (Picture taken from: Alagna F, et al, 2012. Olive phenolic compounds: Metabolic and transcriptional profiling during fruit development. BMC Plant Biology 12(1):162).

β-sitosterol, campesterol, and 4-methylsterols and hydrocarbons such as squalene and β-carotene. There are also fatty alcohols, triterpenic alcohols, and triterpenic acids, like erythroidol, oleanolic, and maslinic acids. There are, also, tocopherols such as α-tocopherol and pigments. Other minor components of EVOO are sterol esters, glyceroglycolipids, phosphatides, waxes, sterol esters, and mono- and diacylglycerols [29].

Another group of molecules present in EVOO, of a high impact in diet, are the phenolic compounds or as usually are called, polyphenols, such as tyrosol and hydroxytyrosol and their derivatives [30]. The phenolic cluster of EVOO can be further divided into several subclasses [31]. There are the lignans like taxifolin, luteolin, apigenin, and other molecules [32]. EVOO contains simple phenols that include tyrosol, hydroxytyrosol, and phenolic acids. Another subgroup is the secoiridoids that are derivatives from tyrosol, hydroxytyrosol, and elenolic acid, like the dialdehydic form of elenolic acid linked to hydroxytyrosol (3,4-DHPEA-EDA or oleacein) and tyrosol (p-HPEA-EDA or oleocanthal). The secoiridoids subgroup includes also the oleuropein and ligstroside aglycons (3,4-DHPEA-EA, p-HPEA-EA, respectively) and their isoforms oleomissional and oleokoronal [33] (**Figure 1**).

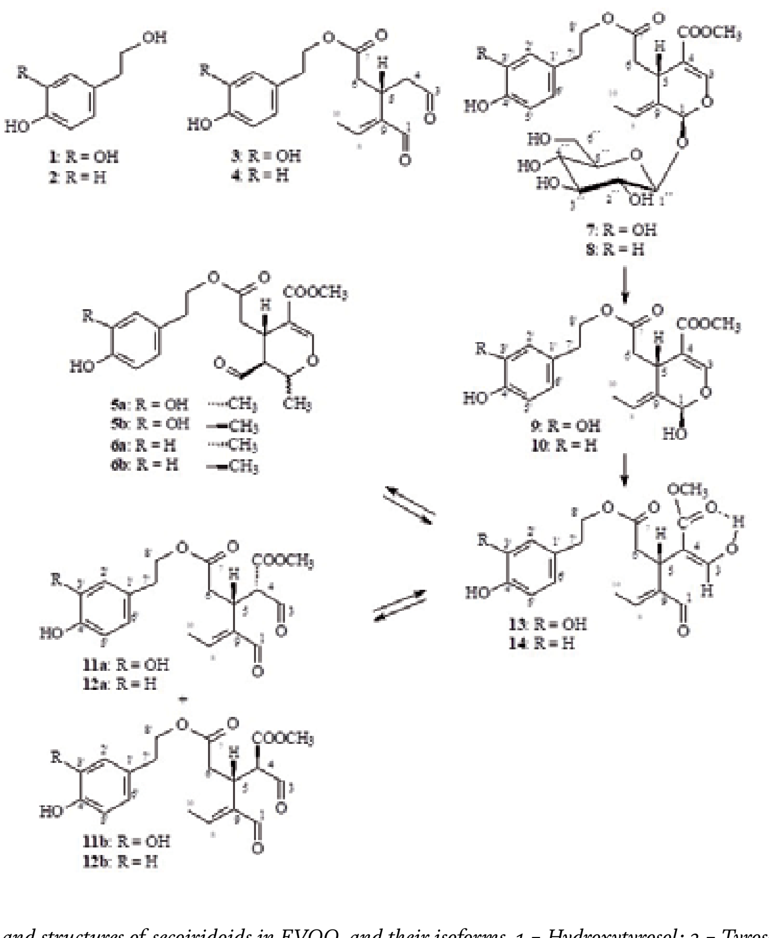

Figure 3.
Production and structures of secoiridoids in EVOO, and their isoforms. 1 = Hydroxytyrosol; 2 = Tyrosol; 3 = Oleacein; 4 = Oleocanthal; 5a&5b = Closed ring monaldehydic forms of oleuropein aglycon; 6a&6b = Closed ring monaldehydic form of ligstroside aglycon; 7 = Ligstroside; 8 = Oleuropein; 9&10 = Unstable forms of oleuropein and ligstroside aglycons; 11a&11b = Open ring dialdehydic forms of oleuropein aglycon, or oleuropeindials; 12a&12b = Open ring dialdehydic forms of ligstroside aglycon, or ligstrodials; 13 = Enolic form of the oleuropein aglycon; 14 = Enolic form of the ligstroside aglycon. The group of 13, 11a and 11b compounds is defined as oleomissional, as they exist in continuous balance. The same balance exists between compounds 14, 12a and 12b, and they are named as oleokoronal. (Picture taken from: Diamantakos et al, 2015. Oleokoronal and oleomissional: new major phenolic ingredients of extra virgin olive oil. OLIVAE No 122).

The majority of EVOO phenols belong to the secoiridoids tyrosol and hydroxytyrosol subgroup, contributing to the bitter taste and the throat burning sensation [34]. **Figure 2** shows the metabolic pathway of phenolic compounds biosynthesis in plants. In plants, the production of secondary metabolites is initiated by the mevalonate (MVA) and 2-C-methyl-d-erythritol 4-phosphate (MEP) pathways. These two pathways lead to the production of sterols and terpenoids. Secoiridoids are produced by the MEP pathway but presumably derived from tyrosine proceeding via tyrosol. Arogenate decarboxylated is the precursor of tyrosine in the phenylpropanoid metabolism, while hydroxytyrosol is synthesized from tyrosine that is produced through the dopamine pathway. Flavonoids, lignans, and verbascoside are products of the phenylpropanoid pathway, while verbascoside could be a product of tyramine via dopamine or coming from tyrosol via hydroxytyrosol [35].

Phenols are organic molecules characterized by the existence of a hydroxyl group attached directly to the benzolic group of the compound. Secoiridoids are the primary phenolic compounds present in EVOO, and their molecules are based on a phenylethanoid structure, such as oleuropein and ligstroside, as shown in **Figure 3** [29]. In EVOO these compounds are present as esters of hydroxytyrosol and tyrosol, respectively, as their initial forms are hydrophilic and are the most predominant phenols. The biosynthesis of all secoiridoid derivatives in EVOO has as start point these two compounds: oleuropein and ligstroside, the predominant phenols in olives [36]. During the process steps in EVOO production and in particular in the crushing and malaxation steps, these molecules are transformed due to β- glucosidase [37], into their aglycon forms, as shown in **Figure 3**. The aglycon forms of oleuropein and ligstroside are very unstable, and they further transform to closed-ring monoaldehydic or open-ring dialdehydic forms [33]. At the malaxation step, the dialdehydic forms undergo demethylation and decarboxylation leading to the production of oleacein and oleocanthal.

4. Phenols and their biological aspects

For many years, the phenolic cluster of EVOO focuses the interest of researchers, as it was suspected that the products of the secondary metabolism have beneficial effects in human health. To prove this, many studies took place around the world, either with EVOOs or with purified polyphenols, at the level of cellular process, animal studies, and clinical trials in humans. By time, the suspicion approved real, and this led to a widespread research of the biological aspects of the most abundant phenols [28]. The majority of the studies proved that benefits of EVOO consumption is mostly due to the phenolic alcohols and their secoiridoid derivatives, and in particular oleocanthal, oleacein, ligstroside aglycon, and oleuropein aglycon, leading to the naming of these compounds as nutraceuticals, and the EVOO and the olives that contain them are named as functional foods [38]. The Functional Food Center (FFC) defines foods as "Natural or processed foods that contain known or unknown biologically-active compounds; these foods, in defined, effective and non-toxic amounts provide a clinically proven and documented health benefit for the prevention, management or treatment of chronic diseases" [39]. These four molecules act to a wide range of biological paths, as shown in **Figure 4**.

It becomes obvious that polyphenols are very important for human health participating in all these biological processes, increasing life expectancy [40]. Studies have shown anticancer properties of polyphenols [41, 42], while they exhibit astonishing strong antioxidant activities [43]. One of the most important discoveries about polyphenols was the neuroprotective role [44] and particularly the effects against Alzheimer's disease [45]. A very important issue of polyphenols is the efficacy in heart diseases [19], like atherosclerosis [46, 47]. Studies showed that polyphenols are able to reduce LDL oxidation in vivo and in vitro [48–50]. EVOO polyphenols, also, are effective in autoimmune inflammatory situations like rheumatoid arthritis and systemic lupus erythematosus [51].

4.1 Oleocanthal

Oleocanthal (OC) is the molecule with the most studies among the four most abundant olive oil phenolic compounds, and several studies have been conducted from researchers about OC's biological actions. One of the most important roles of OC in humans is to act as neuroprotective agent. Thus, OC quickly used in studies associated with the Alzheimer disease (AD). AD is caused mainly by the malfunction of two important processes: the amyloid-β oligomer (Aβ) concentration in the blood-brain barrier (BBB) and the tau protein fibrillization and aggregation into neurofibrillary tangles. Aβ oligomers clearance normally happens through the BBB. The amyloid-β1–42 peptide (ADDL) is a neurotoxin that causes the concentration of Aβ oligomers to the BBB, resulting to AD development. Moreover, P-glycoprotein and LDL lipoprotein receptor-related protein-1 (LRP1) are two proteins that participate in Aβ transport and clearance through BBB in normal situations. As shown in **Figure 5**, OC is able to affect both processes contributing to Aβ clearance of the brain through the blood-brain barrier (BBB) [52], either by altering the assembly state of soluble ADDL oligomers [53] or by increasing expression of P-gp and LRP1 proteins [54]. In comparison with control ADDLs, oligomers formed in the presence of OC (Aβ-OC) showed equivalent co-localization at synapses but exhibited greater immunofluorescence as a result of increased antibody recognition,

Figure 4.
Biological activities of phenols in humans. (Picture taken from: Cicerale S et al, 2010. Biological activities of phenolic compounds present in virgin olive oil. Int J Mol Sci. 2010 Feb 2;11(2):458-79).

and direct detection of fluorescently labeled ADDLs showed an overall reduction in ADDL signal in the presence of OC. On the other hand, in vitro and in vivo studies with increased P-gp and LRP1 protein expression in the brain microvessels and inhibition studies confirmed the role of upregulation of these proteins in enhancing Aβ clearance after OC treatment, which leads to Aβ degradation.

Neurodegenerative diseases can be caused by another factor, the tau protein, which is a part of the microtubule-associated protein (MAP) family, with the other two members to be the MAP1 and MAP2 proteins. In the adult's brain, tau is the most expressed protein, and it is found in six isoforms [55]. Tau is a phosphoprotein, and its role is the assembly of tubulin from microtubules and their stabilization. Tauopathies are called the neurodegenerative diseases associated with tau malfunction are called tauopathies, where there is abnormal hyperphosphorylation and aggregation of the protein. In AD, this abnormal activity of tau protein leads to neurofibrillary tangles. OC can affect the fibrillization and lead to their stabilization, locking the tau protein to its unfolded state. OC interacts with lysine amino groups of tau protein and especially with tau441 amino acid leading to a steady secondary structure of the protein and interferes with tau aggregation [56]. The inhibitory activity of OC is due to the two aldehyde groups existing to the molecule [57]. In AD, inflammation induced by Aβo is characterized by interleukin-6 (IL-6) increase and glial fibrillary acidic protein (GFAP) upregulation. These proteins are downregulated by OC, which also affects negatively the regulation of two Aβo-induced synaptic proteins, SNAP-25 and PSD-95, in neurons and glutamine transporter (GLT1) and glucose transporter (GLUT1) in astrocytes [58].

Many years now, OC was found to have an active role in cardiovascular diseases (CDs) and inflammatory situations. OC shows interesting role in acting like ibuprofen as an anti-inflammatory agent contributing in platelet function [59]. In inflammatory situations, the phenolic cluster of EVOO acts through the cyclooxygenase (COX) pathway in humans. Although structurally dissimilar (**Figure 6**), both OC and ibuprofen inhibit the same cyclooxygenase enzymes in the prostaglandin biosynthesis pathway. Both enantiomers of oleocanthal exhibited a dose-dependent inhibition of COX-1 and COX-2 activities, with no effect on lipoxygenase activity, much as observed with ibuprofen, making OC a very good anti-inflammatory agent [60].

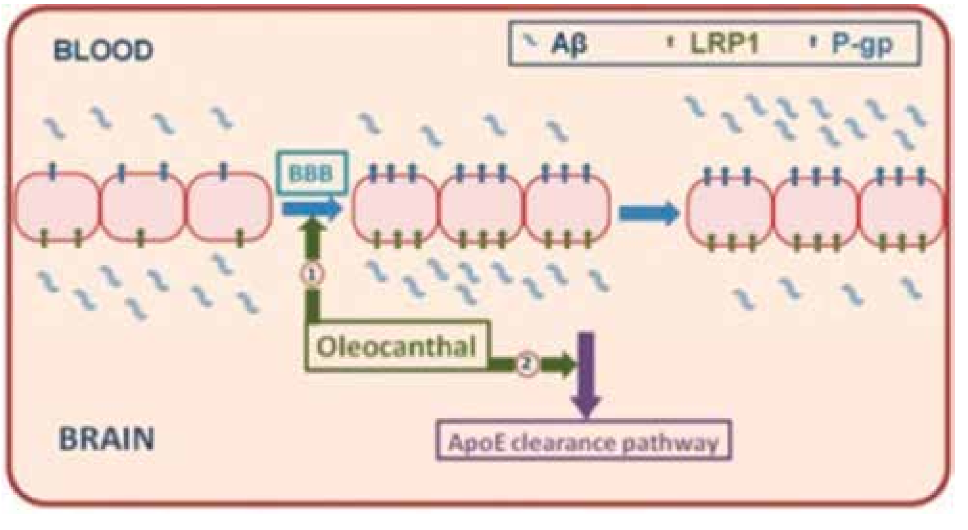

Figure 5.
Oleocanthal is a significant agent against Alzheimer's disease acting through various mechanisms (Picture taken from: Qosa H et al, 2015. ACS Chem Neurosci. 2015 Nov 18;6(11):1849-59).

As OC was recognized as an anti-inflammatory agent, researchers turned their attention to the possible role of OC in cancer states in humans. Cancer is a state of uncontrolled cell proliferation and migration that is caused by various genetic alterations leading to altered protein functions. OC has been found to play important roles in various types of cancer in human. Various studies showed and approved that OC is a molecule that can play an important inhibitive role in cell proliferation and migration and invasion. OC can interact with various proteins, crucial for the cancer development, such as c-Met and STAT3 proteins. c-Met is a protein that is responsible for various carcinomas in humans [61]. c-Met is a receptor tyrosine kinases (RTK), which is expressed mainly in epithelial-endothelial origin cells. Normally, c-Met is responsible for downstream signaling pathways that lead to cell growth, invasion, and angiogenesis [62], and the overexpression of c-Met levels has a crucial role in cancer pathophysiology [63]. OC has been found to be a c-Met inhibitor in breast and prostate cancers [64], capable to inhibit c-Met phosphorylation and the proliferation and invasion of epithelial cells, with IC50 in the μM range (4.47 and 4.8 μM, respectively). In breast cancer, OC exerts its effects through the Hepatocyte growth factor—/c-Met-mediated pathway inhibition by blocking the epithelial-to-mesenchymal transition (EMT) and affects the G1/S cell cycle control [65]. Moreover, OC can reduce the expression levels of estrogen receptors contributing to the suppression of cancer growth [66].

Signal transducer and activator of transcription 3 (STAT3) belong to the STAT protein family and has a central role on gene expression related to cell differentiation, proliferation, and apoptosis [67, 68]. In various tumors has been noticed a highly constitutive activation of STAT3 resulting in cancer development [69], setting STAT3 as a potential target in therapeutics of malignancies. OC can play a significant role in cancer by blocking activation of STAT3 [70]. In hepatocellular carcinoma, for example, OC inhibits EMT through downregulation of STAT3 pathways cascade and also reduced STAT3 nuclear translocation and DNA binding activity. OC is able to downregulate the downstream effectors of STAT3, like Cyclin D1, the antiapoptotic proteins Bcl-2 and survivin, and the invasion-related protein MMP2. Another way that OC inhibits STAT3 activation is through the JAK21/JAK2 pathway decreasing their activities, while on the other hand increases in the activity of SHP-1 overexpression of constitutively active STAT3 partly reversed the anticancer effects of oleocanthal, which inhibited STAT3 activation by decreasing the activities of

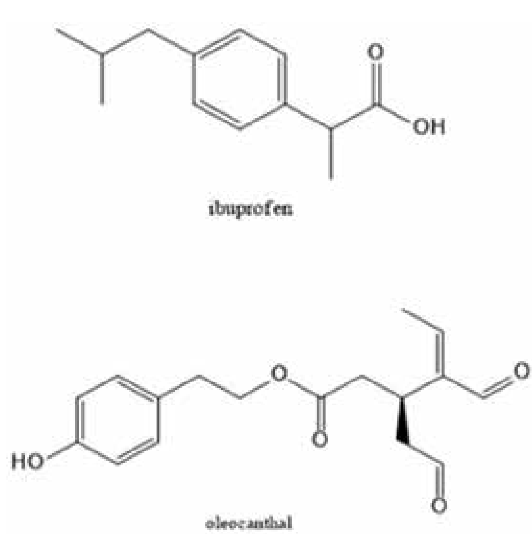

Figure 6.
Structures of ibuprofen and oleocanthal.

JAK1 and JAK2 and increasing the activity of SHP-1, a nonreceptor protein tyrosine phosphatase and a tumor suppressor gene. Testing the effects of OC to melanoma studies showed that OC acts through the same way against STAT3 pathway and the gene expression of STAT3 targets, like Mcl-1, Bcl-xL, MMP-2, MMP-9, VEGF [71], and Bcl-2 [72]. A very important fact is that OC causes cell death to the cancer cells but not to normal ones [73]. Heat shock proteins are involved in cancer development as well. Heat shock proteins though can interact with OC, so they are possible targets for cancer treatment [74]. Another way that OC can be used, as antitumor agent, is through targeting and downregulating mTOR, a protein that was found to participate in cancer, and especially to breast cancer, with the IC50 of OC to be in the range of nM [75].

Comparative with other anti-inflammatory agents, like ibuprofen, indomethacin, and nimesulide, experiments showed OC to be more effective against cancer [76]. The anti-inflammatory properties of OC led scientists to test the molecule behavior in joint diseases, like osteoarthritis. This situation is caused by elevated nitric oxide production (NO) in cells. As OC acts like ibuprofen, experiments showed that OC decrease NO production from cells, whereas there is no significant affection of cell viability [77].

4.2 Oleacein

Oleacein is a polyphenol found in EVOO, in various concentrations. Studies about the biological function of this molecule revealed multiple fields of action in humans, such as antimicrobial, antiproliferative, and anti-inflammatory activities [78]. Oleacein is a powerful natural antioxidant agent, showing high activity against oxidation even more than oleuropein [79] and hydroxytyrosol [80]. Oleacein acts as a protective agent against the oxidative damage of erythrocytes that happens as a result of ROS-induced oxidative stress. In epithelial progenitor cells, intracellular ROS formation is decreased upon the presence of oleacein, while proliferation of cells is increased, when they are impaired by angiotensin II. This action is related to the Nrf2/heme oxygenase1 (HO1) pathway activation by oleacein [81].

Oleacein is a very potent compound acting against inflammatory situations, like atherosclerosis. Oleacein is able to enhance anti-inflammatory activity of hemoglobin/haptoglobin complexes through increasing the expression of certain receptors, such as CD163, IL10, and HO1 [82]. Moreover, oleacein targets directly 5-lipoxygenase, an enzyme that participates in inflammatory situations, by catalyzing the initial steps of the biochemical pathway of pro-inflammatory leukotrienes synthesis [83]. Another recent and interesting finding in biological action of oleacein is the attenuation of carotid plaque destabilization. This action could be useful in cases of ischemic stroke, as could reduce the risk of the disease [84].

4.3 Ligstroside aglycon

Ligstroside aglycon is the third of the fourth most important and abundant phenols, present in EVOO. There is no extensive data about studies testing the biological activity of this molecule. Mainly, ligstroside aglycon was checked about possible anticancer function. Molecules like ligstroside aglycon are excellent scaffolds for the design of agents that act against the c-Met protein in breast cancer. Ligstroside aglycon had great effect against migration, as generally approved for tyrosol esters [85]. Ligstroside aglycon can, also, interact and modulate HER2, a tyrosine kinase receptor oncoprotein, in breast cancer cells. It is able to inhibit the gene expression in a very high percentage but with very low doses, at the same time, setting ligstroside aglycon as very potent agent against malignancies [86].

4.4 Oleuropein aglycon

Oleuropein is a very antioxidant compound and has been investigated thoroughly, but its derivative, oleuropein aglycon has paid less attention about its functional purpose. Nevertheless, oleuropein aglycon seems to have crucial biological actions in human. Oleuropein aglycon was found to have a significant role in Alzheimer's disease. This compound can reduce the levels of β-amyloid and, also, the deposition of Aβ plaques. Animal studies showed a higher level of autophagy, while cell culture experiments suggest that probably oleuropein aglycon regulates mTOR protein [87]. Recent studies confirmed the activity of oleuropein aglycon against amyloid aggregation by modification of the conformational and biophysical properties of amyloid fibrils and of the cell bilayer surface properties at the same time, remodeling the aggregation and helping the association between the protein and the membrane [88]. In AD situation, it was observed various Aβ peptides in amyloid plaques were observed, characterized by N-terminal truncation. The products of this truncation and subsequent cyclization of the N-terminal region of Aβ peptides, by two or ten amino acids, lead to the creation of shortened peptides named as pyroglutamylated peptides (pE-3Aβ and pE-11Aβ) that are more neurotoxic and aggregate faster than normal. Oleuropein aglycon is a compound that can reduce the pE-3Aβ production via lowering expression of the glutaminyl cyclase enzyme that is catalyzing the modification described above [89]. Experiments showed that, even in later stages of AD, can activate autophagy of neurons by increasing the acetylation of histones 3 and 4, improving the synaptic function.

Oleuropein aglycon, also, increases autophagy response and expression of markers associated with autophagy, setting oleuropein aglycon capable of the heart protection in cases of cardiac stress caused by autophagy dysfunction [90]. Monoamine oxidase A (MAO-A) degrades catecholamine and serotonin resulting in hydrogen peroxide production (H_2O_2), that is responsible for oxidative stress, autophagic flux blockade, and cell necrosis. Oleuropein aglycon reverses the cytotoxic effects of MAO-A by increasing autophagy and restoring the autophagic flux. In addition, studies revealed that oleuropein aglycon can interfere with amylin preventing its cytotoxicity. When oleuropein aglycon is present, amylin aggregation cannot react with the cell membrane, driving to skip the pathway that causes the formation of toxic prefibrillar aggregates [91]. Another field, where oleuropein aglycon has an active role is breast cancer [86]. The mechanism in this case is exactly the same with the one that acts in ligstroside aglycon, pointing that polyphenols are physical agents that can be used in cancer treatment.

5. Conclusions

The Mediterranean diet is beneficial for human health as it includes consumption of foods that contain biological active substances. The central position in the MD, for fat intake, is the olive oil. Extra-virgin olive oil is basic at the meals of people around the Mediterranean Sea and, especially, for Greece, Spain, and Italy. Humans around the Mediterranean Sea seem to have a long life prediction probably due their diet. EVOO contains very essential compounds of high importance for the body's health. Besides the obvious body weight balance, it seems that daily consumption of EVOO contributes to the protection and improvement of serious diseases, such as atherosclerosis, inflammatory states, and cancer. EVOO contains some very crucial molecules named phenols or polyphenols that belong to a larger compound family, the secoiridoids. These molecules are produced during olive oil production and exhibit stunning biological effects in humans. The most abundant phenols in EVOO are oleocanthal, oleacein, ligstroside aglycon, and oleuropein aglycon along with the aglycon isoforms. Many studies have shown their important role in neurodegenerative diseases, like Alzheimer's disease and in metabolic syndrome. The four phenolic compounds are natural antioxidants and have very powerful anti-inflammatory and anticancer activities. Moreover, these compounds are very active agents in cardiovascular diseases and act against LDL oxidation. All these activities made the phenols potential nutraceuticals and a good matrix for drug design. EVOO is a very strong functional food that supplies the human body with phenols that are crucial for health, so product development arising from EVOO with high concentration of phenolic compounds can be used for health improvement. Pharmaceutical companies, knowing the dynamics of the natural phenols, have started to produce products based on phenols. High phenolic EVOO, in conclusion, is a powerful natural functional food, and all people should consume it daily.

Acknowledgements

This work has been supported by INTERREG MED EU programme under the ARISTOIL project.

Conflict of interest

Authors declare no conflict of interest.

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Chapter 4

Functional Properties of Snack Bars

Oana Emilia Constantin and Daniela Ionela Istrati

Abstract

Nowadays, people spend more time and effort to gain greater control over their health by exploring alternative or herbal medicines and natural health products to prevent disease or for a healthier life. It is known that people who consume a diet rich in natural foods, such as fruits, vegetables, nuts, whole grains, and fish, tend to lead a life free of diseases. Recent studies suggest that regular or increased consumption of fruits and vegetables can reduce the risk of chronic diseases, and these health benefits are believed to be primarily due to their natural antioxidants and dietary fiber content. At present, consumers prefer foods with health benefits and, at the same time, convenient for consumption, storage, and handling. In this sense, ready-to-eat nutritious products, such as snack bars, are highly appreciated for their convenience. Snack bars are versatile products often made, with cereals, fruits, and nuts being an ideal food format to deliver healthy nutrients, bioactive compounds, and dietary fiber to the consumers.

Keywords: snack bar, health benefits, functional food, bioactive compounds, dietary fiber

1. Introduction

Globally, a relatively substantial number of terms were used to define the natural health-developed food products. For this purpose, the names of functional foods, nutraceutical foods, pharmaceutical foods, designer foods, farmafoods, vitafoods, foodaceutical, etc. were used [1]. Other terms, often grouped separately, may be included in the same regulations: medical foods, dietary supplements, fortified foods, and botanicals.

There are definitions around the world for functional foods, but there is no official or accepted definition; the functional foods are more of a concept than a defined food product group. Therefore, a functional food can be a natural food, a food in which a component has been added or has been removed, a food in which the nature of one or more components has been altered, or any combination of these possibilities [2]. Functional foods can be those foods made up of distinct, fortified, and enriched elements that provide health benefits apart from the supply of essential nutrients (e.g., vitamins and minerals) when consumed at effective levels within a varied diet [3]. A food may be functional for all individuals or for certain population groups, which can be defined, for example, by age or genetic constitution.

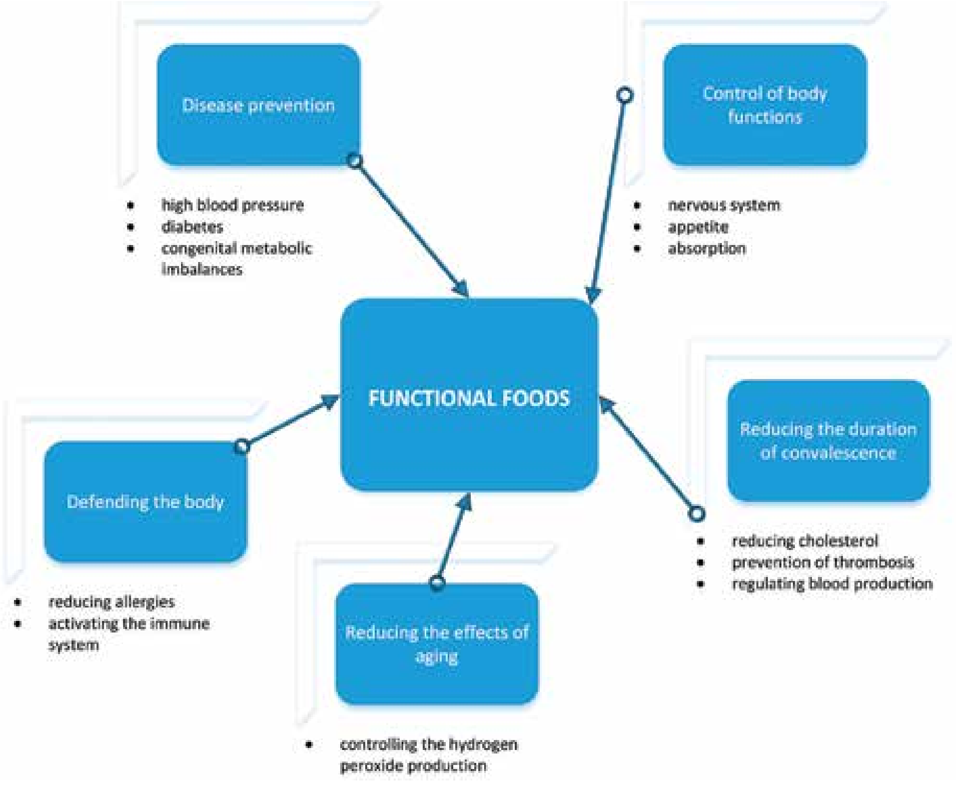

Figure 1.
The role of functional foods in regulating processes in the body.

Moreover, the functional food, besides its basic nutritional effect, has also beneficial effects on human body functions (improving the general physical state, decreasing the risk of disease evolution, etc.) [1, 4–6]. The main roles of functional foods in regulating processes in the body are presented in **Figure 1**.

For several years now, there has been a substantial interest in fast food and snack food production, due to changes on people's lifestyles. Consumers have the tendency to look for easily prepared food, such as snacks, which are defined as alternatives to quick meals with or without substantial nutritional value. According to Bower and Whitten [7], numerous products are classified as "snacks," and in this category, mini-pizzas, cakes, popcorn, cereals, and cereal-based bars can be included.

Generally, snack bars are not recognized as functional foods, mainly due to their nutrient-poor composition. In the last years, there is an interest in making new types of snack bars with functional components. Therefore, snack bars can also be included in the functional product category and to consider consumer's acceptable and suitable ready-to-eat products.

2. Snack bar types

According to a report regarding the snack food consumption in the USA [8], the snack, cereal, and nutrition bars may be classified in three main categories: health and wellness snack, organic snack bars, and energy and nutrition bars. A complex classification of functional bars is difficult to obtain, and the focus has generally been on consumption. Therefore, snack bars can be consumed as a meal part (as part of breakfast, lunch, or dinner or as a snack between meals), as a dessert (after lunch or dinner), or as a meal replacement (breakfast, lunch, or dinner).

The consumption of the snack bars is usually influenced by the age, gender, and the nutritional knowledge of the consumers. According to the International Markets Bureau market indicator [8], the consumption of the snack bars is also influenced by the following aspects: satisfying the need for sweets; saving time; using as an energy source; using for weight loss; and using for the protein, fiber, vitamin contents, etc.

3. Snack bar processing

3.1 Snack bar production process

The simplified flowcharts of snack bar production processes are shown in **Figure 2**. For the baked bar products, dry and wet raw materials are mixed together. This mixture is portioned and subjected to baking.

The baking parameters (time and temperature) differ according to the specific characteristics of the finished product. For cold-formed bar production, the ingredients are also mixed together, and the resulting mixture is portioned in the desired shape without a baking step. For both types of snacks, there may also be additional operations, e.g., filling, coating with various glazes, drying bars, etc. Despite the bar type obtained, the final operation in the technological chart is packing.

3.2 Formulation and physicochemical evaluation of snack bar ingredients

The bars are often made using a base of cereals such as oats, rice, corn, or proteins (milk dairy proteins, soy, or whey) and fortified with vitamins, minerals, and other nutrient- or energy-rich ingredients [9, 10]. Snack bars are not just popular

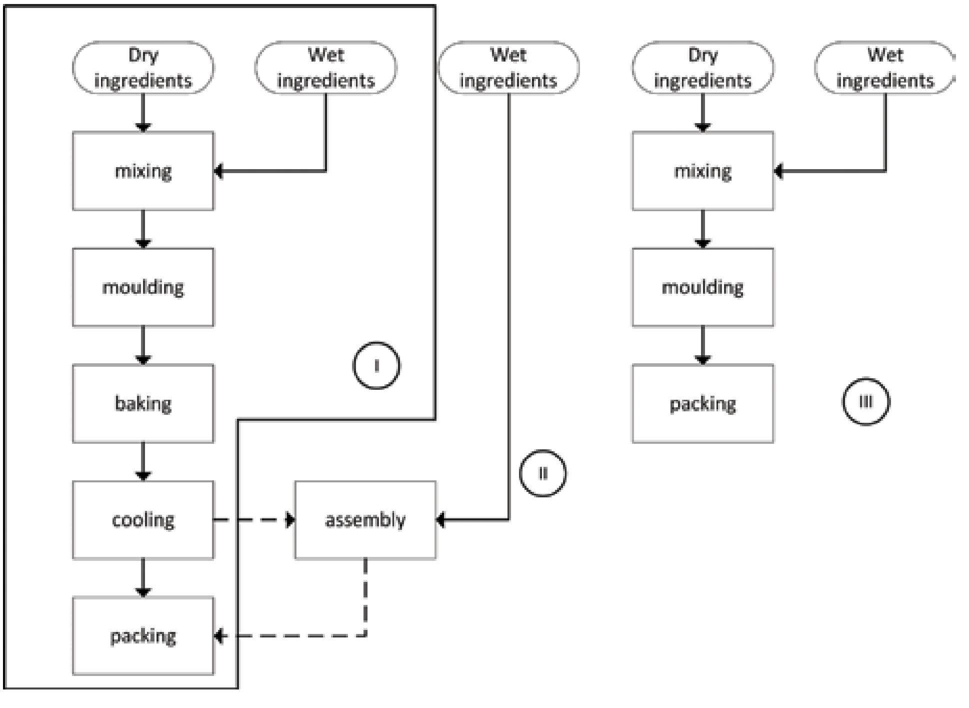

Figure 2.
Flowchart of snack bar production process (I, baked bars; II, baked bars with filling; III, cold-formed snack bar).

for their portability but also for the health implications associated with their consumption. Trends in health and wellness in food and beverages have increased more and more in recent years, as consumers are turning to less processed and more natural alternatives than regular products. Furthermore, nutritional snacks are suitable products that can provide energy and micronutrients to both healthy people and people from areas affected by famine of the world [10].

Cereal bars are very adaptable products made from processed cereals mixed with a variety of ingredients depending on the target population group [7]. Wheat and/or soy snack bars were designed as nutritional bars to provide the nutrients to consumers on the run [10]. Walnuts were successfully used in the manufacture of snack bars with good nutritional (significant amount of raw fibers and lipids) and sensory quality [11].

In recent years, the demand for high-protein snack bars has grown significantly by the people engaged in sports activities and dieting and as meal substitutes. These snack bars provide a healthy alternative to conventional snacks due to its high content of protein (15–35%, w/w) and other nutritionally beneficial ingredients [12]. In **Table 1**, different formulations for snack bars are shown.

The tendency to eat more nutritious foods instead of sweet products has led to the development of different snack bar types. Since cereal consumption extends beyond breakfast at any time of the day, these products have become an excellent vehicle for delivering ingredients to functional foods on the market. Cereals have an increasingly important role in modern lifestyle due to the convenient forms they can use such as ready-to-eat food products, snack bars, and energy bars [14].

People who are interested in getting healthier foods and maintaining good body fitness have changed their eating habits, which have promoted growth in the cereal bar market of 20% per year [18]. Therefore, snack bars can be considered as a reliable source of high-quality proteins, fibers, vitamins, and minerals. The nutritive composition of selected snack bars is presented in **Table 2**.

From the data presented in **Table 2**, the chemical composition of the snack bars varies greatly depending on their destination. The variation of snack bar composition gives the consumers the possibility to select the proper bar to purchase. Therefore, corn flake crust with fruit breakfast bar is a good source of vitamin A, thiamine, riboflavin, niacin, and vitamin B6, while formulated bar (power bar with chocolate) is a good source of protein, vitamin E (alpha-tocopherol), calcium (covers 50% of the recommended daily dose), iron, magnesium, phosphorus, zinc, and copper. Moreover, the power bar is a very good source of vitamin C (covers 154% of the recommended daily dose), thiamine (covers 537% of the recommended daily value), riboflavin, niacin, vitamin B6, folate, vitamin B12, pantothenic acid, and manganese [19].

Also, formulated bar, marathon protein performance bar and caramel nut rush, is a good source of protein (covers 50% of the recommended daily dose), calcium, iron, magnesium, zinc, copper, and manganese and a very good source of vitamin C, vitamin E (alpha-tocopherol), thiamine, riboflavin, niacin, vitamin B6, folate, vitamin B12, and pantothenic acid [19], while snack bar with soy can be considered as a good source of high-quality proteins, fibers, and B-complex vitamins [10].

Researchers reported that snack bars with a high ratio of protein/carbohydrate can improve post meal and diurnal glucose profiles in patients with type 2 diabetes and insulin resistance [20]. In addition, proteins can have a very positive effect on the human body, helping to control blood pressure, and the effect has been dependent on the type of protein [18]. Champ et al. [21] reported that the demand to increase dietary fiber content in the daily diet is justified by the positive role of fibers in health and disease prevention, especially in digestive health, energy balance, cancer, and heart and diabetes problems. According to the data presented in **Table 2**, some formulated snack bars contain higher amounts of minerals and

Snack bar type	Formulation and Functionality	References
Fruit-based snack bar	**Ingredients**: Base: rice crisps, glucose syrup, honey, vegetable oil, quick-cook rolled oats (or natural apple dietary fibre or inulin), glycerol, whey protein concentrate, maltodextrin, pectin; Filling: pectin, sugar, citric acid, glucose syrup, honey, vegetable shortening, glycerol, and apple purée. **Process:** Base: the dry and wet ingredients were mixed, moulded and baked at 130°C/15 min; Filling: ingredients were heated with stirring to 84-86% soluble solids content; Assembly: the filing was placed between base parts **Functionality:** increased polyphenols and dietary fibre contents	[13]
Wheat- or soy-based bar	**Ingredients:** water, corn syrup, glycerine, brown sugar, Arabic gum, emulsifier, puffed wheat, wheat germ, commercial coatings, shortening, soy nuggets, soy protein, soy fibre, vanilla extract **Process**: ingredients (water, corn syrup, glycerine, brown sugar, Arabic gum, emulsifier, shortening, vanilla extract) were mixed and blended in different proportions to obtain wheat bar; wheat bar with coating; wheat and soy bar with coating; soy bar with coating; wheat bar with glycerine. The puffed wheat, wheat germ, soy nuggets, soy protein, soy fibre, were heated at 85°C/4 min. All the ingredients were mixed together and moulded. The bars were cooled at room temperature. Some bars were coated and cooled supplementary. **Functionality:** high quality proteins, fibres and B-complex vitamins contents	[10]
Cereal snack bar	**Ingredients**: corn starch biscuit (or marolo flour), skimmed milk powder, rice flakes, oat flakes, corn syrup **Process**: dry ingredients were mixed and then syrup was added. The bars were manually sealed, cooled for 8 h and then cut and packed in aluminium-coated cellophane **Functionality:** the marolo flour provided an increase in dietary fibre content, vitamin C, minerals, and antioxidant activity.	[14]
Fruit and vegetable-based snack bar	**Ingredients**: Sweet: fruit and vegetable flour, rice flour, oat flakes, linseeds, sucrose syrup, brown sugar, cocoa powder Salty: fruit and vegetable flour, rice flour, oat flakes, linseeds, egg white, olive oil, condiments **Process**: Sweet: the sucrose syrup heated was mixed with dry ingredients; Salty: ingredients were mixed, moulded into bars and baked at 160°/10 min, and reposed for 6h at room temperature until cold; Both types were coated in aluminized bags, sealed **Functionality:** high fibre, protein and mineral contents	[15]
Cereal snack bar	**Ingredients**: crushed corn starch biscuit (or jerivá flour), oat, skimmed milk powder, rice flakes, corn syrup **Process:** dry ingredients were mixed, adding the syrup (corn glucose and honey) and mixing. The mixture was plastic-coated and reposed for 8h, then moulded **Functionality:** increasing in total dietary fiber, vitamin C, mineral contents and antioxidant activity	[16]
Vegetable based snack bar	**Ingredients**: bean flour, oat flakes powder, water and soy lecithin **Process**: the ingredients were mixed, and the dough obtained was coated and cut to a standard size. The snacks were baked using convection oven at 120°C/30 min, cooled at room temperature and packed in metallic bags **Functionality:** increasing in protein and dietary fiber content and the antioxidant capacity	[17]
High-protein snack bar	**Ingredients**: milk protein, high fructose corn syrup and glycerol **Process**: the ingredients were mixed, and the mixture obtained was moulded into plastic cups. **Functionality:** increasing in protein content	[12]

Table 1.
Several snack bars formulation.

Nutrients	Unit/100g	1	2	3	4	5	6	7	8
Proteins	g	9.8	4.4	14.2	18.5	25	21.9	17.5	12.46
Lipids	g	17.6	7.5	3.1	13.2	10	10.8	17.5	14.82
Carbohydrates	g	66.7	72.9	69.6	55.1	53	50.3	52.5	62.01
Total fibers	g	3.1	2.1	5.7	2.8	10	6.7	5	20.84
Minerals									
Calcium, Ca	mg	60	41	504	953	625	754	15	~
Iron, Fe	mg	3.18	4.9	11.7	14.7	10.1	16.3	5	~
Magnesium, Mg	mg	101	27	248	255	175	317	0	~
Phosphorus, P	mg	277	103	614	455	375	455	2.5	~
Potassium, K	mg	326	197	362	~	300	351	~	~
Sodium, Na	mg	251	167	308	418	225	383	125	~
Zinc, Zn	mg	1.6	4.1	10	9.6	6.6	11.9	0	~
Vitamins									
Vitamin C, total ascorbic acid	mg	1	0	92.3	144	75	490	0	~
Thiamine	mg	0.28	1.0	8.06	2.7	1.9	29	0	~
Riboflavin	mg	0.11	1.1	1.92	3.1	2.1	3.3	0	~
Niacin	mg	1.75	13.5	32.6	36.4	25	45.2	0	~
Vitamin B-6	mg	0.35	1.4	2.2	3.6	2.5	4.5	0	~
Folate, DFE	μg	81	108	1046	727	500	816	0	~
Vitamin B-12	μg	0	0	5.6	10.9	7.5	12.2	0	~
Vitamin E (alpha-tocopherol)	mg	0.82	0.8	8.28	24.6	125	27.5	0	~
Moisture	g	4.1	14.5	9.8	8.0	9.0	14.0	~	6.8
Ash	g	1.8	0.8	3.3	3.1	3.0	3.0	~	3.89
Energy value	Kcal	464	377	363	406	402	386	450	347.9

1, breakfast bars, oats, sugar, raisins, coconut (include granola bar); 2, breakfast bar, corn flake crust with fruit; 3, formulated bar, power bar, chocolate; 4, formulated bar, marathon multi grain crunch bar; 5, formulated bar; protein performance bar, caramel nut rush; 6, formulated bar, marathon energy bar; 7, snack bar with soy; 8, snack bars with beans and oat flour; ~ n.a., not analyzed.

Table 2.
Chemical composition of selected snack bars made with cereal, fruits, nuts and/or chocolate [10, 17, 19].

vitamins. Micronutrients are necessary compounds for a proper physiological state of the body that can be administered orally in the diet, and it is necessary to maintain an adequate balance [21, 22]. Minerals must be supplied from foods because they cannot be synthesized, and given the global deficiencies in different minerals, it is worthy to offer convenient food with sufficient amounts of minerals [23].

4. Functional properties of snack bar compounds

From the compounds present in snack food, only a few, through their specific action, are essential to life and are usually known as biologically active compounds.

Proteins, polyunsaturated fatty acids, vitamins, and minerals as well as food fibers or probiotics may be included in this category.

4.1 Proteins

The importance of dietary protein, as a bioactive factor, is determined deficit terms, by decreasing of metabolic capacity, reduction of energy metabolism, inhibition of biosynthesis processes, diminution of immunity, and the body resistance to external agent's actions. Proteins are necessary to support growth, tissue repair, and protection [24]. Usually, the protein necessary is influenced by the gender, age, activity level, body health, or physiological states [25, 26]. The conventional protein sources are plants and animals, e.g., meat, milk, whey egg, fish, soy, etc. [26]. In general, protein-based snack bars contain the following proportion of ingredients: soy or dairy proteins (20–40%), carbohydrates as sugar syrups (10–50%), and fats (10–15%) [27, 28]. Protein bars in addition to basic ingredients may contain other components such as flavors and stabilizers [29].

4.2 Fat and fatty acids

In addition to their role as a source of high calories, as a biomembrane construction material, or as a vehicle of fat-soluble vitamins, lipids are important by their intake in polyunsaturated fatty acids, phosphatide, and substances physiologically active, such as prostaglandin, prostacyclin, etc. [30]. The omega-3 (n-3) and omega-6 (n-6) polyunsaturated fatty acids are essential for human health and are obtained exclusively from the nutrition [31]. In recent years, emphasis has been placed on obtaining functional foods supplemented with $n - 3$ fatty acids. At present, there is a wide range of omega-3-enriched food products such as bakery products, dairy products, juices and soft drinks, meat products, etc. [32]. Usually, the natural sources of n-3 fatty acids are seed and fish oils [31, 33]. Snack bars with a high content of essential fatty acids are generally those that contain crop seeds and vegetable oils (canola, soybeans, corn, and sunflower oils); these are the major sources of linoleic acid (LA, C18: 2) but with a low proportion of α-linolenic acid (ALA, C18: 3) [34]. ALA sources are chia and flaxseed [34, 35]. The flaxseeds have a high antioxidant potential and omega-3 α-linolenic acid content [36, 37]. The addition of milled flaxseed in snack products, such as bars, is explained by their preventive and functional properties, such as vascular function improvement [38], anti-arrhythmic, anti-atherogenic, and anti-inflammatory functions [38–40].

4.3 Minerals

Mineral elements have a biological key role because they participate in all the vital processes of the body. Mineral substances can have different roles in vitamins and enzyme functionality, having either an activating role (calcium, magnesium, etc.) or an inhibitor (copper), and can be a part of enzyme structure as specific (sulfur, iron, copper, zinc, etc.) or unspecific (magnesium, zinc, cobalt, etc.) elements [41]. The commercial snack bars usually contain the following minerals in different intakes (**Table 2**): calcium, iron, magnesium, phosphorus, potassium, sodium, and zinc.

4.4 Vitamins

Vitamins are biologically active compounds of organic nature, with variable and complex structure. Vitamins are needed in very small quantities for the normal development of many metabolic processes, including assimilation and the use of nutrients brought by food, growth, and tissue restoration.

Usually, snack bars commercialized on the market are rich in vitamins such as vitamin B1 (thiamine), vitamin B2 (riboflavin), vitamin B5 (pantothenic acid), vitamin B3 (niacin), vitamin B6 (pyridoxine, pyridoxal, pyridoxamine), folic acid (pteroylglutamic acid, vitamin B9), vitamin B12, vitamin C, vitamin A, and vitamin E (alpha-tocopherol).

Vitamin B1 is found in the outer layers and germ of cereals, nuts, whole grains, brewer's yeast, etc. Vitamin B1 exhibits several functions within the body, such as essential for maintaining appetite and normal digestion and necessary for growth, fertility, and lactation [42], as well as for the normal functioning of the nervous tissue [43]. According to the nutrition data [19], the bars with the highest content in thiamine are formulated bar, power bar, chocolate (8 mg/100 g), and formulated bar, marathon types: honey nut oat bar; energy bar, all flavors; chewy chocolate peanut bar; and multigrain crunch bar (~3 mg/100 g), with high daily values for adults between 197 and 537%.

Vitamin B2 is widely found in food products. Sources rich in B2 are beer and bakery yeast, meat, eggs, fish, and dairy products. In the body, vitamin B2 fulfills certain metabolic functions, as phosphorus esters are part of the flavin enzyme structure involved in biological oxidation–reduction reactions [44]and together with pyridoxine is involved in the conversion of tryptophan to nicotinic acid.

Vitamin B5, in the form of coenzyme A, is vital in the metabolism of lipids, carbohydrates, and nitrogen compounds [44]. Sources rich in pantothenic acid that are used in snack bar composition are wheat germ, mushrooms, broccoli, cauliflower, oats, dried peas, soybean, etc.

Vitamin B6 is found in large quantities in beer and bakery yeast and raw cereals. Fruits and vegetables have a lower content of vitamin B6. Pyridoxal phosphate and pyridoxamine phosphate are coenzymes involved in transamination, decarboxylation, deamination, etc. [45].

In the body, folic acid as a coenzyme is involved in accepting and transferring one carbon, from a metabolite to another [46], interfering with the synthesis of purines and pyrimidines necessary for nucleic acid formation [47]. Folic acid is mainly found in green leaves, whole grains, soybeans, wheat germ, soybeans, oranges, avocado, etc. [47, 48].

Vitamins E performs several functions in the body such as Krebs cycle regulator, a regulator of nucleic acid metabolism with implications for cell maturation and differentiation, a regulator of porphyrin and heme biosynthesis, a regulator of protein and amino acid metabolism, etc. The main nutritional function is a biological antioxidant for oxidizable vitamins and lipids [44]. Tocopherols are found in almost all foods, the richest sources usually used for bar production being vegetable oils (corn germ oil, wheat germ oil), cereal products, and eggs.

Vitamin C is acting as biochemical antioxidant and as enzyme cosubstrate [44], interfering with numerous processes, including formation of stromal proteins (collagen, elastin), maintaining capillary integrity, etc. Sources rich in vitamin C are rosehips, white sea buckthorn, citrus fruits, tomatoes and tomato juice, cabbage, parsley, nettle, spinach, cauliflower, red and green pepper, red cabbage, eggplant, broccoli, strawberries, etc. [45, 49]. In a study conducted by Sung et al. [50], a cereal bar with welsh onion extracts was obtained, rich in vitamins C, B2, B3, and B9 and with high-protein content. The study also demonstrated the nutraceutical potential of the bars for the obesity and metabolic disorder's control.

Description	Thiamine (mg/100 g)	Riboflavin (mg/100 g)	Vitamin C (mg/100 g)
Formulated bar, power bar, chocolate	8.06	1.92	92.3
Formulated bar, snickers marathon			
Honey nut oat bar	3.394	3.846	176.4
Energy bar, all flavors	2.949	3.343	489.9
Chewy chocolate peanut bar	2.727	3.091	144.4
Multigrain crunch bar	2.727	3.091	144.3
Protein performance bar, caramel nut rush	1.875	2.125	75
Formulated bar, meal bar, milk chocolate peanut	1.7	1.9	96.6
Snack, balance, original bar	1.628	1.708	11.2
Snacks, crisped rice bar, almond	1.323	1.499	11.5
Snacks, nutri-grain cereal bars, fruit	1.153	2.067	7.8
Breakfast bar, corn flake crust with fruit	1	1.1	0
Snacks, granola bar, with yogurt coating	0.905	0.542	0
Formulated bar, mixed flavors	0.75	1.7	120

Table 3.
Classification of snack bars according to the content of thiamine, riboflavin and vitamin C [51].

USDA Food Composition Databases [51] provides the selection of snack bars according to deficiency in one or more vitamins or any nutrient that must be reintroduced into the diet. As an example, a selection of the snack bar products according to the content of thiamine, riboflavin, and vitamin C is shown in **Table 3**.

4.5 Food fiber

In the food industry, fiber plays a significant role in preventing obesity, diabetes, and cardiovascular disease [52]. Fiber is incorporated into different foods for both nutritional benefits and functional properties, as well as low-cost and noncaloric partial replacements for fat and/or sugar flour [52, 53]. Cereals contain quantities of insoluble fiber, except for oats, whereas fruit and, in particular, citrus fruit and apples contain substantial amounts of soluble fiber. Lentils are also used in snack bar development, especially for their dietary fiber and the essential amino acid contents and for the folic acid and iron addition [54].

Lately, emphasis has been placed on the use of resistant starch (RS) in products as a potential functional ingredient. RS may increase the dietary fiber content [55] and promote the probiotic bacteria activity [56]. Aigster et al. [57] studied the addition of RS in granola and cereal bars, to determine the RS health significance and also the consumer acceptability. The study concluded the increasing of dietary fiber intake by the addition of RS.

5. Conclusions

In recent years, consumers are constantly changing their eating habits, wanting to improve their diet with nutritious and safe food products that are easy to consume but, at the same time, improving health and well-being. Therefore, food industry specialists have continuously changed formulations and ingredients, and thus, new technologies to produce foods with increasing nutritional value and safety that fully meet consumers' requirements. Due to their versatility, snack bars can be used by wide categories of individuals: athletes, people dieting or with nutritional problems, or irregular meals. Snack bars allow the consumers to get necessary energy and the nutritional benefits (high-quality proteins, polyunsaturated fatty acids, minerals, vitamins, and fibers) in one convenient and easy to store package.

Conflict of interest

The authors declare no conflict of interest.

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Chapter 5

Fermented Functional Beverages

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Abstract

Functional foods are intensively studied and promoted by various organizations in the field of food and nutrition. They are foods that, by their initial, fortified, enriched, or improved composition, offer health benefits. At global level, there is a great interest in promoting fruit varieties, vegetables, and pseudocereal consumption in order to improve our health. Due to their content in essential compounds such as antioxidants, important amounts of fruits and vegetables should be included in our daily diet. New food matrixes, such as fruit and vegetable juices, have been tested for their ability to deliver probiotic microorganisms and results were promising. Technological progress made possible the use of fruits and vegetables as ideal substrates for probiotics development, due to their content in minerals, vitamins, fibers, and antioxidants. Probiotic products based on vegetables have a continuous development due to the increase in popularity of vegetarianism and the growth of lactose intolerance among the entire world population.

Keywords: functional foods, fermented juices, probiotic microorganisms, antioxidants, health benefits

1. Introduction

In the last decade, preventive medicine has made significant progress, demonstrating the crucial role of nutrition in preventing diseases, especially those related to diet. The concept that foods have health promotion effects beyond their nutritional value has been increasingly accepted in recent years, and the specific effects of nutrition prevention on disease have led to the discovery of functional foods.

Functional foods are those foods that can be eaten in the normal diet and contain biologically active compounds with potential for improving health or reducing the risk of diseases. Examples of functional foods include foods that contain minerals, vitamins, fatty acids, food fibers, and food with the addition of biologically active substances such as the antioxidants and probiotics.

2. Functional foods

The concept of functional foods emerged in the 1980s in Japan when the medical authorities in the country recognized that an increase in life expectancy and in the number of elderly people should be accompanied by an improvement in the quality of life. The main aspect that enhances the quality of life is food. Thus, the concept of foods developed especially for the purpose of promoting health and reducing the risk of disease occurrence.

Currently, many healthy products are known, defined as functional foods or nutraceuticals. Functional foods are foods that, by way of the nutrient intake, contribute to maintaining and improving the health of consumers. These foods offer the opportunity to reduce, directly or indirectly, the medical costs associated with various cortical conditions such as diabetes, coronary heart disease, cancer, etc. [1, 2].

The products in this category experienced a real expansion, now at the beginning of the twenty-first century worldwide, whereas, at the end of the last millennium, only a few countries such as USA, Canada, Japan, and some European countries developed such products. Generally, within the existing regulations in different countries, it is accepted that the term functional food can be used for products similar to conventional foods, while the term nutraceutical is intended for the concentrated form. Both forms should be considered as natural products with obvious health benefits.

There are currently no separate regulations for functional foods in the United States and other countries except for Japan. The academic scientific community in Japan used to define the food that performs three functions as a functional food in the early 1980s. The first function is nutrition. The second function is the sensory function or sensorial satisfaction. The third is a tertiary psychological function. In short, Japan back in 1984, defined ad hoc the term functional food as a food with physiological functions, including regulation of biorhythm, nervous system, immune system, and self-defense of the body beyond nutritional functions.

In 1991, the Japanese Ministry of Health, Labor and Welfare (MHLW) established the "Foods for Specified Health Uses" regulatory system (FOSHU) to approve the statements on food labels as regards the effects of food on the human body. Foods that are subject to FOSHU approval are scientifically analyzed to determine their effectiveness and safety by the Council of Pharmaceutical Affairs and Food Hygiene under MHLW leadership [3].

In 1998, in the U.S.A., there were 11 Food and Drug Administration (FDA)-approved correlations among foods or their components and diseases. These include:

- correlations between foods with high calcium content and decreased risk of osteoporosis,
- correlations between foods with low fat content, saturated fat, low cholesterol, and reduced risk of coronary heart disease, and
- correlations between products containing sugar alcohols and the risk of tooth decay reduction.

These are claims for the relationship between high calcium content foods and a reduced risk for osteoporosis; claims for low fat saturated foods, cholesterol lowering and fat lowering and the risk of coronary artery disease reduction; and a demand for sugar alcohols in relation to the reduced risk of dental cavities. The mention for diets containing soluble fiber with a potential to reduce the risk of coronary artery disease has been altered twice in order to allow recognition of the beneficial effects of soluble fiber provided by oats and psyllium bran [4].

In Europe, the interest in functional foods emerged in the second half of the 1990s. The European Commission has generated an activity entitled Functional Food Science in Europe (FuFoSE) to explore the functional concept of food based on a scientific approach. Thus, the European Commission has determined that "a food can be considered functional if, together with the basic nutritional impact, there are also beneficial effects for one or more functions of the human body either by improving the general and physical conditions or by reducing the risk of disease progression" [5, 6].

Examples of functional foods include foods containing specific minerals, vitamins, fatty acids, or dietary fibers; foods containing added biologically active substances such as phytochemicals or other antioxidants; and probiotics containing live beneficial cultures. Therefore, a functional food can be as follows:

- an unprocessed natural food product;
- a food product in which a component has been improved by special breeding, reproduction, or biotechnological means;
- a food product to which a component has been added to provide benefits;
- a food product from which a component has been removed by technological or biotechnological means;
- a food in which a component has been replaced by an alternative component with favorable properties;
- a food in which a component has been modified by enzymatic, chemical, or technological means to provide a benefit;
- a food in which the bioavailability of a component has been altered; or
- a combination of any of the above [7].

The scientific community continues to increase its understanding of the functional foods potential and their role in maintaining and optimizing health. As regards the benefits to be validated and the requirements to be met, approval from a strong and trustworthy scientific research entity is required to confirm the benefits of each food product or component. For functional foods to provide potential public health benefits, consumers should be able to rely on the scientific criteria that are used to document such health statements and claims.

3. Vegetables and fruits with functional role

Many plants or their compounds with physiologically active role have been investigated for their role in disease prevention and health assurance. The components of food products of plant origin that have been scientifically proven to bring benefits to human health are numerous. Naturally, fruits and vegetables are rich in carbohydrates, dietary fiber, mineral vitamins, polyphenols, and phytochemicals; they are designated as healthy foods as many researchers have reported the beneficial effects of juices on health [8].

Tomatoes and processed tomatoes, by their high content of lycopene and β-carotene—powerful antioxidants—can help reduce prostate cancer. According to the clinical studies conducted on patients in the Health Professionals Follow-Up Study (HPFS) during 1986–1992, it was found that administering over 10 servings/week processed tomatoes or tomatoes reduces the risk of prostate cancer by 35%, and in the case of serious forms of prostate cancer, a reduction of 53% was found [9]. The most important aspect is that out of 46 evaluated fruits and vegetables, only tomatoes have been associated with reducing the risk of prostate cancer [9]. A balanced diet containing broccoli, carrots, spinach can help reduce the risk of macular degeneration with age or cataracts [10].

Cherries, red grapes, forest fruits, and other red- and violet-colored fruits and vegetables are rich in flavonoids (anthocyanins—cyanidin, pelargonidin, and malvidin), bioactive compounds with an important role in preventing and reducing the risk of various cancers and cardiovascular diseases, considering that their consumption supports antioxidant cellular defense.

Apples and pears are an important source of phenolic compounds to support heart health. However, the pears have a smaller amount of phenolic compounds, around 30 mg/100 g, as compared to fresh apples that may contain 357 mg/100 g [11]. By their high content of insoluble fiber, especially the skin and shell, fruits and vegetables, contribute to maintaining the health of the gastrointestinal tract, while soluble fiber in beans, apples, and citrus can reduce the risk of coronary affections [12].

Forest fruits are rich in anthocyanins and broad-spectrum antioxidants on biomedical functions. These include cardiovascular disease, oxidative stress induced by aging, inflammatory response, etc. [1].

Potassium content in bananas and beans helps lowering blood pressure when their consumption is associated with a low-fat diet. Also, in beans, salads, and spinach, there are folates—that is folic acid—which play an important role in preventing the birth of children with different spinal and cerebral disorders.

Most fruits are rich in vitamin C, predominantly the citruses, kiwi, and berries. The role of vitamin C is well known for its antioxidant action and the prevention of free radical formation in the body that can promote the emergence of different cancers. Vitamin C also helps the immune system fight different pathogenic agents.

Fenech et al. [13] have demonstrated the positive effect of eating nine micronutrients easily found in fruits, namely, calcium, retinol, vitamin E, folic acid, nicotinic acid, riboflavin, pantothenic acid, β-carotene, and biotin on the damage and the repair of the genome.

The above listed are just a few functional features of some vegetables and fruits: scientific studies in this field being very diverse and elaborate.

4. Microorganisms used in producing fermented beverages of plant origin with a functional role

The gastrointestinal microflora is made up of a complex of microorganisms that form a particularly important part of the organism. These microorganisms interfere with each other and with the host organism in the intestinal tract where they exist. The normal intestinal microflora may undergo changes by way of diet, medication and/or environmental factors. These imbalances can be remedied by two methods:

- Oral administration of live microorganisms (probiotics)
- Oral administration of some bacterial stimulants for certain indigenous (prebiotic) microflora components

According to FAO/WHO (2001), probiotics are living microorganisms (mainly bacteria and certain yeast strains) that influence the host organism by improving microbial intestinal balance. Probiotics have numerous beneficial effects on the body of which we can mention:

- increased lactose tolerance and digestion,
- positive influence on intestinal microflora,
- reduction of intestinal pH,
- improvement of intestinal functions,
- reduction of cholesterol,
- reducing the level of ammonia and other toxic compounds,
- production of folic acid,
- restoring normal intestinal microflora after antibiotic treatments,
- treatment and prevention of diarrheal seizures due to rotaviruses, and
- stimulating the immune system response.

Fruit, cereals, vegetables, and soy beverages have been reported as a suitable medium for probiotic cultures due to the essential nutrient content [14]. Fruit, grain, vegetable, and soy beverages have been proposed as novel products containing probiotic strains; essentially, fruit and vegetable juices have been reported as a new suitable support for probiotics. Nevertheless, maintaining viability (the recent trend is to have 1 billion viable cells/100 g of product) and maintaining the activity of probiotics in these products by the end of the product shelf-life are two important criteria to be met in juices where low pH is a disadvantage [15].

At present, there are numerous studies on the production of functional beverages, with researchers in the field tackling many variants to obtain them. Different approaches could be grouped as follows:

- Exploiting the functionality of microorganisms
- Optimizing the production and formation of new functional beverages
- The use of prebiotics and symbiotics
- The use and processing of natural ingredients
- The use of the by-products from the fruits and food industry as functional ingredients

In addition to that, some works focus and propose the application of new technologies to improve the production of functional beverages without compromising their sensory and functional properties [5].

Many researchers have investigated the possibility of using various fruit and vegetable juices such as tomatoes, mangoes, oranges, apples, grapes, peaches, pomegranates, watermelons, carrots, beetroot, and cabbage as raw materials for the production of probiotic juices or drinks. The most commonly used probiotics include different strains of *Lactobacillus* spp. (*Lb. acidophilus, Lb. helveticus, Lb. casei, Lb. paracasei, Lb. johnsonii, Lb. plantarum, Lb. gasseri, Lb. reuteri, Lb. delbrueckii* subsp. *bulgaricus, Lb. crispatus, Lb. fermentum, Lb. rhamnosus); Bifidobacterium* spp. *(B. bifidum, B. longum, B. adolescentis, B. infantis, B. breve, B. lactis, B. laterosporus);* and other species such as *Escherichia coli Nissle, Streptococcus thermophilus, Weissella* spp., *Propionibacterium* spp., *Pediococcus* spp., *Enterococcus faecium, Leuconostoc* spp. și *Saccharomyces cerevisiae* var. *Boulardii* [14, 16, 17]. Most probiotic microorganisms are lactic bacteria belonging to *Lactobacillus* spp. and bifidobacteria. Nevertheless, other types of microorganisms are used as probiotics: *Enterococcus faecalis, Lactococcus lactis*, and *Saccharomyces boulardii* [18].

5. Functional beverages based on fruits and vegetables

5.1 General aspects

The probiotics market is currently dominated by fermented dairy products. These are the best environment for developing and maintaining the viability of probiotic microorganisms. However, there is a trend of increasing demand for probiotic vegetable products due to negative aspects of dairy consumption. Lactose intolerance, proteins with allergenic potential, and cholesterol content may adversely affect human health [19].

Vegetables are a suitable substrate for the development of probiotic microorganisms because they contain vitamins, minerals, and fibers, but the development of a probiotic drink having a vegetal substrate involves many stages. The factors that may have a negative influence on the viability of microorganisms in vegetable products are as follows: organic acids, pH, compounds with antimicrobial activity, temperature, and the storage time of the fermented food product. The optimal storage temperature of fermented products is 4–5°C [20].

Also, another important challenge is to obtain a product with sensory properties acceptable to the consumer. The combination of substrate with probiotic microorganisms can lead to undesirable volatile compounds.

5.2 Nondairy fermented beverages: from traditional to commercial foods

Since ancient times, fermentation has been used to preserve vegetables as well as to improve their nutritional and sensorial qualities. Most products are fermented at ambient temperature with the existing microflora, with no strict control of fermentation and microorganism development (**Table 1**).

These are mainly consumed due to sensory characteristics. There are few researches on the composition and safety of these beverages. Starting from traditional beverages, many researches focused on the development of vegetarian probiotic beverages (**Table 2**). In order to improve the stability of the products obtained and their nutritional value, prebiotics are added in their composition. The applicability of laboratory studies led to the development of commercial products (**Table 3**). Although their cost is high, companies selling such products are on the rise.

In order to maintain the innocuity and the functional value of vegetal probiotic products, special packaging was created to meet the challenges posed during storage in the shelves of the shops. Most manufacturers recommend storing at 4°C, with the indication that packaging deformities may occur due to the high CO_2 content resulting from the fermentation process. After unpacking, the product should be stored, refrigerated, and consumed in the shortest possible time.

Beverage name	Origin	Substrate	Microorganisms isolated
Boza	Bulgaria, Albania, Turkey and Romania	Wheat, rye, millet, maize, and other cereals mixed with sugar or saccharine	*Lactobacillus plantarum, L. acidophilus, L. fermentum, L. coprophilus, L. brevis, Leuconostoc reffinolactis, Leuconostoc mesenteroides, Saccharomyces cerevisiae*
Bushera	Uganda	Sorghum	*Lactobacillus* spp., *Lactococcus* spp., *Leuconostoc* spp., *Enterococcus* spp., *Streptococcus* spp.
Mahewu	Africa and some Arabian Gulf countries	Maize	*Lactococcus lactis*
Togwa	Africa	Maize, millet	*Lactobacillus* spp., *Streptococcus* spp.
Hardaliye	Turkey	Red grapes	*Lactobacillus paracasei, L. casei, L. brevis, L. pontis, L. acetotolerans, L. sanfrancisco. L. vaccinostercus*
Kombucha	China	Tea	*Gluconacetobacter* spp. *(G. xylinus), Acetobacter* spp., *Lactobacillus* spp., *Zygosaccharomyces* spp., *Hanseniaspora* spp., *Torulaspora* spp., *Pichia* spp., *Dekkera* spp., *Saccharomyces* spp.
Water Kefir	Mexico	Water, sucrose	*Lactobacillus* spp. (*L. lactis), Leuconostoc mesenteroides, Zymomonas* spp., *Dekkera* spp., *Hanseniaspora* spp., *Saccharomyces cerevisiae, Lachancea fermentati*, *Zygosaccharomyces* spp.

Table 1.
Traditional probiotic beverages [19, 21].

Substrate	Probiotic microorganisms	References
Tomato juice	*Lactobacillus acidophilus* LA39, *Lactobacillus casei* A4, *Lactobacillus delbrueckii* D7, *Lactobacillus plantarum* C3	[22]
Beet juice	*Lactobacillus acidophilus* LA39, *Lactobacillus casei* A4, *Lactobacillus delbrueckii* D7, *Lactobacillus plantarum* C3	[23]
Cabbage juice	*Lactobacillus casei* A4, *Lactobacillus delbrueckii* D7, *Lactobacillus plantarum* C3	[24]
Carrot, celery, and apple cocktail	*L. acidophilus* LA-5	[25]
Olives	*L. paracasei* IMPC2.1	[26]
Honeydew melon juice	*L. casei* NCIMB 4114	[27]
Cereals and grape juice	*L. plantarum* 6E și M6	[28]
Malț	*L. plantarum* NCIMB 8826, *L. acidophilus* NCIMB 8821	[29]
Herbal mate	*L. acidophilus* ATCC 4356	[30]
Sapodilla, grapes, orange, and watermelon juice	*L. acidophilus*	[31]
Pineapple juice	*Lactobacillus casei* NRRL B442	[32]
Peach juice	*Lactobacillus plantarum* DSMZ 20179, *L. delbrueckii* DSMZ 15996, *L. casei* DSMZ 20011	[33]
Germinated seeds and sprouts of lentil and cowpea,	*Lactobacillus plantarum* VISBYVAC	[34]
Cereals, vegetables, and soymilk	*Lactobacillus acidophilus* NCDC14	[35]
Cereals	*Lactobacillus acidophilus* NCIMB 8821, *Lactobacillus plantarum* NCIMB 8826, *Lactobacillus reuteri* NCIMB 11951	[36]
Soymilk, almonds, and peanuts	*Lactobacillus rhamnosus* GR-1	[37]
Rice	*Lactobacillus fermentum* KKL1	[38]

Table 2.
Studies regarding the production of probiotic beverages.

5.3 Current trends in the development of probiotic beverages based on vegetable products

The industry of probiotic vegetable products is in its early stages, as the first commercial product appeared on the market in 1994. Increasing the availability of these products on the market, improving the existing technologies, and increasing the consumer's interest make this segment a promising one [21].

Probiotics can be inoculated directly into fruit or vegetables juices due to existing aseptic dosing technologies. In order to maintain the viability of probiotics throughout the life of products, microencapsulation, vacuum impregnation, and prebiotics are used [19]. Of a high importance is the relationship between different probiotic cultures, especially yeasts and bacteria.

A possible solution to the increase in probiotic resistance in new food matrices is their genetic modification, although in many countries, there is a low acceptability of these microorganisms [39]. Lactic fermentation is often used for preserving vegetables, so the best approach at this time is to develop probiotic products using known strains [40].

An important aspect in the development of new products is the acceptability from the sensorial point of view. Consumers want nutritious and tasty products for an affordable price. Traditional fermented products are a basis for developing

Beverage name	Origin	Substrate	Probiotic microorganisms
Proviva	Sweden	Orange, strawberry, or blackcurrant juice	*Lactobacillus plantarum 299v*
GoodBelly	U.S.A.	Mango, blueberry acai, pomegranate, blackberry, tropical green, cranberry, watermelon, tropical orange, and coconut water juices	*Lactobacillus plantarum* 299v
Biola	Norway	Orange-mango and apple-pear flavors	*Lactobacillus rhamnosus GG*
Biola	Finland	Seven varieties of juices	*Lactobacillus rhamnosus* GG
Gefilus	Finland	Fruit juice	*Lactobacillus rhamnosus GG, Propionibacterium freudenreichii ssp. shermanii JS*
Good Belly	U.S.A.	Fruit juice	*Lactobacillus plantarum* 299v
Kevika	U.S.A.	Sparkling lemon ginger probiotic drink	*Bacillus coagulans, L. rhamnosus, L. plantarum, L. paracasei*
Rela	Sweden	Fruit juice	*Lactobacillus reuteri* MM53
Healthy life probiotic	Australia	Apple and mango juice	*Lactobacillus paracasei* and *Lb. plantarum*
Malee probiotic juices	Thailand	White grape and orange juice	*Lactobacillus paracasei*

Table 3.
Commercial probiotic vegetable and fruit beverages [5, 14, 15].

new probiotic products in a manner that ensures their innocuity and stability. For the future, new research is needed in order to understand the microbiological and nutritional potential of traditional products [41].

Due to the high costs involved in the development of probiotic products, a collaboration between academia and the industry partners could lead to a much faster development of new products [42]. The use of vegetable residues and by-products resulting from different technological processes (e.g., vegetable pulp) would have beneficial effects on the environment and add value to finished products. Although they have shown good viability in new food matrices, clinical studies are required to demonstrate adherence to the intestine and viability of probiotics following the consumption of probiotic-based vegetable products.

6. The benefits of drinking functional vegetable and fruit beverages

Beverages are the most active category of functional foods because of the convenience and the ability to meet consumers' demands in terms of content, size, shape, and appearance of the packaging, as well as, the ease in distribution and better storage for the refrigerated products. Beverages represent also an excellent medium to incorporate necessary nutrients and bioactive compounds [43–45]. Therefore, beverages based on fruits and vegetables have been proposed as a novel suitable carrier for probiotics delivery. Since fruits and vegetables are naturally rich in essential macro- and micronutrients (carbohydrates, dietary fibers, vitamins, minerals, polyphenols, and phytochemicals), the incorporation of probiotics into juices makes them healthier [8]. Juices fortification with probiotic is a challenge and a frontier objective, because juices can combine nutritional effects with health benefits by way of adding probiotic strains.

Fruits and vegetables are the key component of a healthy diet, and if consumed in sufficient quantities every day, it could help prevent major diseases [46]. Instead, low fruit and vegetable consumption is a risk factor for chronic diseases such as cancer, coronary artery disease, stroke, and cataract formation [47]. Fruits and vegetables are important sources of vitamin C, thiamine, niacin, pyridoxine, folic acid, magnesium, iron, riboflavin, zinc, calcium, potassium, and phosphorus [48]. Some components of fruits and vegetables (polyphenols and phytochemicals) are strong antioxidants. The antioxidants act as radical scavengers and help turn the radicals into a less reactive species. Antioxidants represent the first line of defense against damage caused by free radicals and are essential for maintaining an optimal health and well-being. Antioxidants modify the metabolic activation and detoxification/disposition of carcinogens and may even influence processes that may change the course of the tumor cells [48]. Regular consumption of fruits and vegetables has been recognized as reducing the risk of chronic diseases [49]. Ranadheera et al. [50] reported on the beneficial health effects of fruit juices. According to experimental data obtained, the berries, such as blueberry, blackberry, and raspberry, have shown negative effects on some pathogenic microorganisms, improving, instead, the growth of beneficial bacteria.

Fruit and vegetable intake has been shown to have positive effects in terms of weight management and obesity prevention [51, 52]. Several studies reported a reverse relationship between the intake of fibers from fruits and vegetables and the risk of developing coronary heart disease [52, 53]. Also, diets rich in fruits and vegetables, which improved blood glucose control and lowered the risk of developing type-2 diabetes [54], have a strong protective effect against several types of cancer (oropharynx, esophagus, stomach, colon, and rectum) [55, 56] and promote detoxification of the human body [57].

Our digestive system is made up of beneficial bacteria that are responsible for assisting our digestive system to digest food, absorb nutrients, fight against harmful bacteria, and eliminate toxins. When these bacteria are killed, intestinal health is impaired. Consumption of fermented food and avoiding unhealthy food that feeds bad bacteria can help nourish healthy intestinal bacteria and balance the relationship between beneficial and bad bacteria, which will be reflected ultimately in our health and wellness.

The health benefits of probiotic bacteria depend on their viability. According to International Federation for Dairy (IDF), at least 107 probiotic bacterial cells should be alive at the time of consumption per gram or milliliter of product [58]. Beneficial effects attributed to probiotics are the enhancement and maintenance of well-balanced intestinal microbiota. The probiotics can be used in prevention and treating diseases and health disorders such as lactose intolerance, serum cholesterol, high blood pressure [59], irritable bowel syndrome, Crohn's disease, peptic ulcers, antibiotic-associated diarrhea [60–63], and cancer [64, 65]. Also, probiotics offer higher immune protection [66, 67].

7. Conclusion

As consumer awareness grows, fermented foods are becoming more and more popular and tend to be one of the largest functional food markets. The most important reason for the development and acceptance of fermented foods as probiotic fruit and vegetable beverages are related to preservation, improved nutritional properties (vitamins, minerals, fibers, and antioxidants), better taste, flavor and aroma, food products with high biological value, and improved health benefits. Also, probiotic fruit and vegetable beverages do not have allergens as lactose or casein and are cholesterol free. However, the development of probiotic fruit and vegetable beverages is still in the early stages nowadays.

Conflict of interest

The authors declare no conflict of interest.

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Chapter 6

Fish as an Important Functional Food for Quality Life

Ch. Sarojnalini and Abdul Hei

Abstract

If the principle of "enhanced function" and "reduced risk of disease" claim is valid regarding the definition of functional foods, then fish must be chosen as one of the most important functional foods. Functional foods are foods that have potentially positive effects on health beyond basic nutrition. Fish contains components that can improve physical and mental health, and even can reduce the risk of diseases such as heart disease, cancer, diabetics, dementia, osteoporosis, psoriasis, lupus, arthritis, retinopathy, and other chronic and inflammatory diseases. Fish and fish products are a rich source of important components such as proteins, lipids, vitamins, minerals, and antioxidants, which are of significant nutritional values. Example of functional food components are important n-3 fatty acids EPA and DHA which have anti-inflammatory property and many health related roles. So, fish in human nutrition is required for growth, development, maintenance, and optimum health. As consumers of the age become more health conscious, the demand and market values for health promoting functional foods are expected to grow. The present study is to review the efficiency of functional food components of fish and fish products including safety for promotion of quality of human life.

Keywords: fish, functional food, n-3 fatty acids, EPA, DHA, amino acids, minerals

1. Introduction

Interest in nutrition science and the relationship between diet and health have increased the demand for information about functional foods. Improper diet is believed to increase susceptibility to civilization-related diseases. The demands for foods with positive impact on human health and wellness have come globally over the past two decades. This growth is driven by socio-economics and scientific factors, including increases in population, disposable income, life expectancy, and healthcare costs. The markets will need more continuous supply promoted by our increased understanding of the functional foods and their effects on various aspects of human health at a system and molecular level.

The questions for clear ideas are – what is a functional food? Is fish really a functional food? Clear concept, which is free from blurriness, will be important in assessing health and market values of quality products of this resource and in sustainable management.

1.1 Fish in the boundary of functional foods

The terminology and concept of functional foods are reported to have originated in Japan in 1880's [1] and functional foods are termed as "Foods for specified health use (FOSHU)". In Japan, the FOSHU organization states that functional foods are "processed foods containing ingredients that aid specific body function in addition to being nutritious". The limitation to this definition is that all imposed and whole foods are excluded. The American Dietetic Association (ADA) states that functional foods include "whole foods and fortified, enriched, or enhanced foods have a potentially beneficial effect on health when consumed as part of a varied diet on a regular basis at effective level" [2]. "The limitation to this definition is that for a food to be functional, it must be consumed as a part of a varied diet" [2]. However, a functional food retains its functionality as part of any diet. Thus, ideas of functional foods spread to Europe, America, and rest of the world. Numerous different definitions of functional food have been developed. Functional foods must not be taken only for fortified food nor any pill or tablet.

The most acceptable definition given by experts after reviewing different definitions of functional foods is: "The functional food is or appears similar to any conventional food. It is a part of standard diet and is consumed on a regular basis, in normal quantities. It has proven health benefits that reduce the risk of specific chronic diseases or beneficially affect target functions beyond its basic nutrition work" [3].

Now, it is clear that fish is also a functional food considering principle of reduced risk, enhanced function and basic nutrition, and its validity. Researchers say, "Eat fish, live longer". Fish is where there is water. Fish is a great food in quality and quantity. The quality of fish as a food can be known from the statement: "If we have to prepare a pill for complete health, we would have taken all the ingredients from salmons".

The vast aquatic areas of seas and oceans of more than 71% of this planet's surface abound in this resource of fish. Moreover, inland waters, lake, rivers, and streams in hills and mountains are good sources of this food, though they have quality with variation. Water gives so much resource to human beings as a good source of high-quality protein. Fish and fishery by-products can be used as functional ingredients so as to improve health status of consumers promoting performance ability and well being.

Before 2500 years ago, Hippocrates taught the mankind with the tenet – "Let your food be your medicine and your medicine be your food."

The movement of functional foods from 1980s renews the ideas of food and health. There has been more growing interest in the idea–"Functional food is food that provides health benefits beyond basic nutrition." With support from the scientific and governmental communities bringing functional foods to markets will help billions suffering from chronic illness and general health problems.

1.2 Health aspects of nutrition science

Better early development and growth, health maintenance, reduced risk of obesity, and reduced risk of chronic diet-related diseases are aspects of nutrition science. Fish is a source of many vital ingredients: protein, carbohydrate, minerals and vitamins, peptides and lipid, and essential fatty acids.

2. Fish as a good source of proteins and peptides

The importance of protein and peptides is central in cell biology. Protein is the major functional and structural component of all the cells of the body; for example, all enzymes, membrane carriers, blood transport molecules, the intracellular matrices, hair, fingernails, serum albumin, keratin, and collagen are proteins, as are many hormones and a large part of membranes. Moreover, the constituent amino acids of protein act as precursors of many coenzymes, hormones, nucleic acids RNA, DNA, and other molecules essential for life. Thus, an adequate supply of dietary protein is essential to maintain cellular integrity and function, and for health and reproduction [4].

Unless amino acids are present in the diet in the right balance, protein utilization will be affected [5]. In the world as a whole, protein-energy malnutrition (PEM) is fairly common in both children and adults [6], and is associated with the deaths of about 6 million children each year [7]. Protein deficiency has been shown to have adverse effects on the immune system, resulting in a higher risk of infections [8]. Protein deficiency has also been shown to adversely affect kidney function, where it has adverse effects on both glomerular and tubular function [9]. Obviously, protein deficiency has adverse effects on all organs [10]. In infants and young children, it has been shown to have harmful effects on the brain and may have long-term effects on brain function [11].

The nutritional value or quality of structurally different proteins varies and is governed by amino acid composition, ratio of essential amino acid, susceptibility to hydrolysis during digestion, source, and the effects of processing [12]. Functional amino acids (AA) are those AA that participate in and regulate key metabolic pathways to improve health, survival, growth, development, lactation, and reproduction of the organisms. Functional AAs play great roles in prevention and treatment of metabolic diseases, maintaining health and performance ability.

Fish proteins are highly digestible compared to other terrestrial animal and plant proteins. The protein in oily and white fish breaks down on digestion into polypeptides, peptides, and amino acids. Many of these compounds have bioactive properties.

2.1 Health benefits of important essential amino acids

Histidine, in addition to protein building is a precursor to histamine. It has anti-inflammatory role to help ease joint pain and stiffness, and antifungal functions [13]. Leucine helps increase muscle mass and helps muscle recover after exercise, regulates blood sugar, and supply the body with energy. Leucine is used clinically to help the body heal, and it also affects brain functions [14]. Isoleucine is found in lots of fish proteins. It is particularly recommended to professional athletics, body builders, as the primary function of isoleucine in the body is to boost up the energy levels and to assist the body in recovering from strenuous physical activity. It is important in hemoglobin synthesis [15]. Methionine is also used for increasing the acidity of urine, treating liver disorders, improving wound healing, treating depression, alcoholism, allergies, asthma, copper poisoning, radiation side effects, schizophrenia, drug withdrawal, and Parkinson's disease [16]. Threonine aids in the synthesis of glycine and serine that help in the production of collagen, elastin, and muscle tissue. Threonine supports cardiovascular, liver, central nervous, immune system functions and the growth of thymus, and helps in maintaining strong bone and tooth. It also speeds up wound healing and reduces accumulation of fat in the liver. Threonine is useful in treating Lou Gehrig's disease. Research shows that symptoms of multiple sclerosis (MS), another disease that affects nerve and muscle, are alleviated with threonine treatment [17]. Tyrosine is used for the treatment of a genetic disorder known as phenylketonuria. Tyrosine supplements can also help suppress appetite, promote weight loss, increase mental alertness, improve memory, and enhance athletic performance [18]. Phenylalanine promotes balanced neural and cognitive function, and also plays a role in regulating your mood. It may help reduce mild pain symptoms, joint discomfort, and even out skin tone [19]. Tryptophan has gained recognition as an important remedy in orthomolecular medicine and is an important natural mood lifting substance and gets converted into serotonin, the "happy hormone." Targeted supplements containing this essential amino acid can also encourage weight loss and help overcome sleep disorders [20]. Valine is associated with muscle metabolism, tissue repair, mental vigor, muscle co-ordination, and calm emotion [21]. Lysine is used to make medicine for preventing and treating cold sores. Lysine is also taken by mouth to improve athletic performance [22].

2.2 Health benefits of important non-essential amino acids

Aspartic acid is important in the development of nervous system. It has also been implicated in a variety of other outcomes, including: enhancing secondary calcium-dependent neurotransmission signaling, decreasing risks factors for developing cardiovascular disorders; increasing testosterone levels; helping to gain lean muscle mass and decrease fat stores; stimulating increase in muscle power; promoting hormone synthesis; increasing fertility; and enhancing spermatogenesis [23]. Glutamic acid, in addition to protein synthesis, has several key functions within the body and is critical for healthy brain development and function [24]. Glycine helps to form new muscle and also aids in muscle recovery. It is referred to as the anti-aging amino acid. It also helps to prevent cartilage loss, which especially is an issue in aging population [25]. Alanine plays a key role in maintaining glucose and nitrogen levels and thus energy is supplied in the body. Alanine has been shown to help protect cells from being damaged during intense aerobic activity, when the body cannibalizes muscle protein to help produce energy [26]. Arginine is anti-inflammatory, fight migraines, help phosphorus and calcium build bones and teeth. It is essential for spermatogenesis, embryonic growth, fetal and neo fetal growth, immune and tissue integrity [27, 28]. Proline is a vital element in the formation of the connective tissue structure, collagen. An additional benefit of stronger collagen is healthier, age-defying skin. Skin contains collagen, which helps to give it its' elastic properties [29]. Serine provides crucial health benefits. It plays roles in protein, fatty acid, genetic code carriers (DNA and RNA) synthesis, and muscle build-up. Serine is a constituent in the brain and is a protective cover of nerves. Therefore, serine is an important amino acid for the proper functioning of the brain and nervous system. Furthermore, serine boosts healthy immune system by aiding the production of antibodies [30]. Cysteine is a protogenic amino acid having positive roles in immune system, skin and hair, male fertility, inflammation, osteoporosis, anti-aging, and general well-being of body [31]. Taurine is one of the most essential substances in the body. It increases the action of insulin, improves glucose tolerance, and acts as an antioxidant. It is vital for the proper functioning of the minerals, potassium, calcium, magnesium, and sodium. Taurine is found in large amount in the brain, retina, heart, and blood cells, and platelets. The best food source is fish and meats. Taurine is more than a performance boosting. Taurine benefits many common mental and physical conditions, such as anxiety, depression, insomnia, and diabetes, as well as athletic performance. Researchers in Europe have shown that taurine is beneficial for cardiovascular health. Taurine is very essential for the health of heads, hearts, muscles, ears, and eyes [32, 33]. Ornithine is important for detoxification and indirectly supports muscle growth. This amino acid can also help with wound healing and combat stress and fatigue, promoting better sleep [34]. Carnitine can help those with heart conditions by increasing glucose metabolism, increasing blood flow, correcting abnormal heart rhythms, and reducing toxicity [35].

2.3 Health benefits of fish collagen peptides

Fish collagen peptides are known to have the best absorption and bioavailability due to their similar smaller particle size compound to other animal collagens. It is a type-I collagen, which is the most abundant collagen in human body. Fish collagen is a complex structural protein with a high concentration of glycine, hydroxyproline, and proline. It has maintained the strength and flexibility of skin, ligaments, joints, bone muscles, tendons, blood vessels, gums, eyes, nails, and hairs. Type I is best known for providing the foundation for beautiful skin, strong connective tissues, and sturdy bones. So, fish collagen has very important roles in (1) anti-aging, (2) bone healing and regeneration, and (3) wound healing [36].

3. Carbohydrates

Though the fish is a protein food, carbohydrate is present in good amounts. So, it gives energy and structural components with mono, di, and poly carbohydrates.

4. Vitamins

Consumption of fish has many benefits of different vitamins–A, E, B, etc., promoting healthy vision and skin and immune system, and is important in the reproductive process, and enables heart, kidneys, lungs, and other organs to work properly [37, 38]. Vitamin D helps absorb calcium and keeps the bone strong and healthy, and is important in the immune system, brain, and nervous system, regulates insulin levels and aids diabetes management, supports lung function and cardiovascular health, influences the expression of genes involved in cancer development [39]. Vitamin E is a potential anti-oxidant with anti-inflammatory properties, fights free radicals and prevents disease [40]. Vitamin B complex, the eight B vitamins, play an important role in keeping our bodies running like well-oiled machines. These essential nutrients help convert our food into fuel, allowing us to stay energized throughout the day [38]. While many of the vitamins work in tandem, each has its own specific benefits — from promoting healthy skin and hair to preventing memory loss or migraines.

5. Benefits of fish as a dietary source of mineral elements

Fish is an important source of mineral elements. Their consumption contributes to the mineral deficiency of women and infants. Presence of minerals in addition to protein, lipid with essential fatty acids and vitamins makes it an important diet for human beings [41]. Different factors influence the contents of minerals. Fish contains a wide spectrum of macro and micro elements.

Lack of adequate information about the composition of varied food resources is a major drawback to their utilization rather than real shortages. The importance of mineral elements in human beings cannot be neglected. Their deficiencies cause a variety of diseases and failure in human health. Discussion of biochemical functions and the importance of the mineral elements in human health and disease will be helpful in determining in understanding the value and benefits of fish consumption. Significance of the elements included in the present study was reviewed.

5.1 Calcium (C)

Calcium is the most common mineral in human body. About 99% of the calcium in the body is found in bones and soft tissue. Calcium levels in the blood and fluids surrounding the cells must be maintained within a very narrow concentration range for normal physiological functioning. The physiological functions of calcium are so vital for survival that the body will demineralize bone to maintain normal blood calcium levels when calcium intake is inadequate [42]. Calcium plays a role in mediating the construction of relaxation of blood vessels, nerve impulse transmission, muscle contraction, and the secretion of hormones like insulin [43]. It is also required for membrane permeability, involved in blood clotting and enzyme activation.

Calcium deficiency causes rickets in children due to insufficient calcification by calcium phosphate of the bones in growing children. In adult, it causes osteomalacia. It may also contribute to osteoporosis [44]. Calcium deficiency also affects the dentition of both children and adult. Growing, pregnant, and lactating women require liberal amounts of calcium and phosphorus.

5.2 Phosphorus (P)

Phosphorus is an essential mineral that is required by every cell in the body for normal function. Approximately 85% of the body's phosphorus is found in the bone [43]. It functions as a constituent of bones, teeth, adenosine triphosphate (ATP), phosphorylated metabolic intermediates, and nucleic acids. It is practical that every form of energy exchange inside living cells involves the forming or breaking of high energy bonds that link oxides of phosphorus to carbon or carbon-nitrogen compounds [44–46]. A number of enzymes, hormones, and cell-signaling molecules depend on phosphorylation for their activation. Decrease in serum phosphorus is found in rickets, hyperparathyroidism and De Toni-Fanconi Syndrome. Deficiency in children causes rickets and in adult, osteomalacia. Increase in serum phosphorus is found in chronic nephritis and hyperparathyroidism.

5.3 Sulfur (S)

Sulfur is an essential component for all living cells. Sulfur is present in three amino acids, cystine, cysteine, and methionine. Inadequate sulfur intake reduces the feed intake, digestibility, rate of weight gain, and milk production [44]. Connective tissue, skin, hair, and nails are rich in sulfur. Also, thiamine and biotin (member of vitamin B-complex) and co-enzyme A contain sulfur in their molecule [45].

5.4 Potassium (K)

Potassium is an essential dietary mineral and electrolyte [47]. So, potassium is involved in maintenance of membrane potential and as co-factor for a number of enzymes [48]. Hypokalemia is most commonly a result of excessive loss of potassium, for example, from prolonged vomiting, the use of some directives, some forms of kidney disease or metabolic disturbance. Severe hypokalemia may result in muscular paralysis or abnormal heart rhythms (cardiac arrhythmias) that can be fatal [43, 48].

Hyperkalemia occurs in Addisons, advanced chronic renal failure, shocks and dehydration, and symptoms include dilation of heart, cardiac arrest, and small bowel ulcer [49].

5.5 Sodium (Na)

Sodium is the principal cation in extra-cellular fluids. It regulates plasma volume and acid–base balance, involved in the maintenance of osmotic pressure of body fluids, preserves normal irritability of muscles and cell permeability, activates nerve and muscle function and involved in Na^+/K^+ ATPase maintenance of membrane potentials, transmission of nerve impulse and the absorptive processes of monosaccharides, amino acids, pyrimidine and biles salts [44–46].

5.6 Magnesium (Mg)

Magnesium plays important roles in the structure and the function of the human body. Magnesium is involved in more than 300 essential metabolic reactions [50]. It is involved in (1) energy production, (2) synthesis of essential molecules, (3) structural roles, (4) ion transport across cell membranes, (5) cell signaling, (6) cell migration, etc. [51].

5.7 Iron (Fe)

Iron is a key element in the metabolism of almost all living organisms [52] and is required for a number of vital functions, including growth, healing, and immune function. Iron deficiency is associated with alterations in many metabolic processes like neurotransmitter metabolism, protein synthesis, organogenecy etc. and may impact brain functioning [53].

5.8 Copper (Cu)

Copper is a constituent of many enzymes and it plays a role in iron absorption [54]. Cu is an essential micro-nutrient necessary for the hematologic and neurologic systems [55]. It is necessary for the growth and formation of bone, formation of myelin sheaths in the nervous systems, helps in the incorporation of iron in hemoglobin and in the absorption of iron from the gastrointestinal tract (GIT), and in the transfer of iron from tissues to the plasma [45, 46].

5.9 Zinc (Zn)

Numerous aspects of cellular metabolism are zinc-dependent. Zinc plays important roles in growth and development, the immune response, neurological function, and reproduction. On the cellular level, the function of zinc can be divided into three categories: (1) catalytic, (2) structural, and (3) regulatory [56]. Nearly 100 different enzymes depend on zinc for their ability to catalyze vital chemical reactions [43]. The primary roles of zinc appear to be in cell replication and gene expression and in nucleic acid and amino acid metabolism. Vitamin A and E metabolism and bioavailability are dependent on zinc status [57]. It is required for tissue repair and wound healing, plays vital roles in protein synthesis and digestion, and is necessary for optimal insulin action as zinc is an integral constituent of insulin. It is an important constituent of plasma [45, 46].

5.10 Manganese (Mn)

Manganese plays important roles in a number of physiologic processes as a constituent of bone enzymes and an activator of other enzymes [58]. It is involved in (1) antioxidant function, (2) metabolism, and (3) bone development and wound healing, etc. Manganese is a co-factor of hydrolase decarboxylase and transferase enzymes [46]. Consequently skeleton deformities, defects in shell quality occur when the manganese intake is inadequate [59].

5.11 Cobalt (Co)

Cobalt is required as a constituent of vitamin B12 and its metabolism is the same as for vitamin B12. In addition to its role in vitamin B12, cobalt is also a cofactor of enzymes involved in DNA biosynthesis and amino acid metabolism [60]. Vitamin B12 also plays a role in methylating choline and alanine. The latter is required for the synthesis of DNA, which regulates cell division and growth. Co is readily absorbed in the blood stream and excreted primarily in the urine. Deficiency disease is manifested in vitamin B12 deficiency [44].

5.12 Chromium (Cr)

It plays a role in maintaining the configuration of the RNA molecule because Cr has been shown to be particularly effective as a cross-linking agents for collagen [61]. Cr has also been identified as the active ingredient of the glucose tolerant factor [62]. Cr affects the action of insulin in protein metabolism [63]. Cr deficiencies may exist particularly in children suffering from protein-caloric malnutrition [64].

5.13 Selenium (Se)

Selenium increases immunity, takes part in antioxidant activity that defends against free radical damage and inflammation, and plays a key role in maintaining a healthy body. Selenium is essential for successful male and female fertility and reproduction, and also reduces the risk of cancer, autoimmune, and thyroid diseases [65, 66].

5.14 Nickel (Ni)

It is found in small amounts in the human body and is believed to play a part in our overall health and bodily processes. Nickel may help as a critical cofactor to enzymes to speed up the normal chemical reactions in the body. It is found in our RNA and DNA, where it interacts with these nucleic acids. Too much nickel is toxic, and can have severe side effects [67].

6. Benefits of fish as dietary sources of lipids and essential fatty acids

Omega-3 (n-3) fatty acids such as docosahexaenoic acids (DHA) and eicosapentaenoic acid (EPA) are essential elements in human nutrition. The primary source of DHA and EPA are fatty fish and oils from the tissues of such fishes. DHA is a vital component of the phospholipids in the cell membranes throughout the body but particularly abundant in the brain, retina, and sperms. The fluidity of cell membrane is associated with DHA and aids in facilitating cell functions. Omega-3 fatty acids, in particular, DHA and EPA from fish and fish oil are essential for human development and in the prevention and amelioration of many common human disorders [68].

6.1 Cardiovascular diseases

Early studies starting from the Eskimos, to Japanese, Dutch, USA, still more researches show that regular consumption of fish reduces the risk of heart diseases

[68–71]. Fish consumption has a significant association with a low mortality in population groups with a high risk for coronary heart disease (CHD), whereas in low risk populations, this association is less impressive [70]. Dietary n-fatty acids aid to prevent heart disease through a variety of mechanisms [68].

Research at the University of Washington found that men and women, who consumed fatty fish just once in a week, reduced their risk of cardiac arrest by 50%. The American Heart Association published guidelines for patients with CHD recommending a consumption of fish and fish oil, totaling 1 g/day of EPA and DHA.

6.2 Role in the brain development and function

Ackman reports that the folklore about fish being a brain food is true [72]. DHA is essential for the proper development of the brain and retina in the fetus and infant [73]. Tropical fresh water fish is more similar to the composition of brain than any other food. Arachidonic and docosahexaenoic acids are important fatty acids in the brain. According to Dr. L Barbara, a key element in the nutrition for all ages, DHA is the building block of human brain tissues and the primary structural fatty acids in the gray matter of the brain and retina. Low level of DHA has been associated with depression, memory loss, dementia, and visual problem [74].

Although it is important for everyone to have an optimum level of DHA, it is especially important for the development of human brain, which grows at a rapid pace during the late stage of fetal development. The DHA contents of the fetal brain decrease three to five times during the final trimester of pregnancy and triple during the first 12 weeks of life. The brain's gray matter is composed of approximately 14 billion cells and adequate amount of DHA ensures optimal composition in the membranes of these nerve cells.

Dr. Levine Barbara believes that post-partum depression attention deficit hyperactivity disorder (ADHD) and low IQs are linked to brain serotonin levels, which are again connected to an increased tendency to depression, suicide, and violence [74].

Beneficial health outcomes are more likely to result from supplementation with docosahexaenoic acids itself than its precursor alpha–linolenic acid. The significant positive association between maternal docosahexaenoic acid intake during pregnancy and the children's mental processing at 4 years suggest that optimization of the docosahexaenoic acid status of the expectant women may offer long term developmental benefits to their children [75]. The EFAs – n-3 and n-6 fatty acids are increasing to be of value in limiting the cognitive decline during aging. A combined preparation of essential fatty acids helps improve the quality of Alzheimer patients.

6.3 Lupus

Fish oil consumption benefits patient with lupus. Systematic lupus erythromatosus is a chronic inflammatory disease, which manifests symptoms like photosensitive facial rash, fatigue, anorexia, weight loss, and sweat and can progress to life threatening involvement of the heart, lungs, kidney, or central nervous system [76].

6.4 Rheumatoid arthritis

Omega-3 fatty acids help to ameliorate the syntomic condition of rheumatoid arthritis and dietary fish oil supplement should now be regarded as a part of the standard therapy for the rheumatoid arthritis [77, 78], fish oil could potentially replace drug treatment for many RA patients. Fish oil is a cheaper, safer treatment option and could also serve as a preventative measure against RA. Eicosapentaenoic acid (EPA), the main component of the fish oil, is known to inhibit the formation of these inflammatory agents [79].

6.5 Psoriasis

Some studies have shown that oral supplement with fish oils benefits psoriasis patients, which is fairly a common disease characterized by a red inflamed border [80]. Abnormal levels of leukotriene (metabolites of arachidonic acid) are believed to be involved in the development and progression of the disorder. Eicosapentaenoic acid (EPA), a major component of fish oils, is known to dampen the adverse effects of leukotriene and has been proven to have significant anti-inflammatory effects. Fish oil supplementation is useful in the treatment of psoriasis particularly when itching is a major problem [81].

6.6 Crohn's disease

Fish consumption helps patients with Crohn's disease, an inflammatory disease involving intestinal pains, diarrhea, and malabsorption of the nutrients. Elemental diet therapy is the preferred treatment in Japan [82].

6.7 Ulcerative colitis

Research at the Boston Medical Center reports that patients with chronic gastro intestinal disorder have abnormal essential profiles. Research at the Mount Sinai School of Medicine reports oil supplementation is highly effective in alleviating ulcerative colitis [83].

6.8 Asthma

Low level of omega-3 fatty acids in the blood is associated with the autoimmune disorders. Omega-3 fatty acid is proved to be helpful in lung and respiratory disorders like asthma. Inflammation of the airways is an important factor in asthma. Japanese researchers now report that supplementation with fish oil does indeed reduce asthma symptoms in children with long-term bronchial asthma [84].

6.9 Kidney disorders

Donadio et al. report that low dose fish oil therapy is effective in IGA nephropathy, which is a common kidney disorder caused by an inflammation (Glomerulo nephrophritis) in the network of blood capillaries involved in the filtration of waste products from the blood. Arachidonic acid is metabolized to eicosanoids that engender inflammation, while fish oils result in the production of the eicosanoids that combat inflammation. The 'good' eicosanoids likely slow renal disease progression by reducing glomerular and interstitial inflation, mesangial cell contractility, platelet aggregate and vasoconstriction in response to renal injury [85]. The treatment of IgA nephropathy should include a balanced and enhanced intake of essential fatty acids [86].

6.10 Cancers

Long chain fatty acids Omega-3 fatty acids (PUFA) eicosapentaenoic acid (EPA) and docosahexaenoic acids (DHA) from the fish oil help inhibit the promotion and progression of the cancers while omega-6 PUFAs, notably arachidonic acid and its derivatives, help promote the growth of cancer. They believe the n-3 PUFAs exert their beneficial effects in several different ways. They suppress the synthesis of pro-inflammatory eicosanoids from arachidonic acid and thus produce an overall anti-inflammatory effect. They positively affect gene expression, or the activities of signal transduction molecules involved in the control of cell growth, differentiation apoptosis, angiogenesis, and metastasis. They suppress excessive production of nitrogen oxide (NO) during chronic inflammation and thereby help prevent DNA damage and impaired DNA repair. They decrease estrogen production and thus reduce the estrogen-stimulated growth of hormone-dependent cancer cells. Fish oils improve insulin sensitivity and cell membrane fluidity and may help prevent metastasis through these effects [87].

6.11 Women health, pregnancy, and infants

DHA contents of women are higher than men. Adequate amount of n-3 fats is particularly important for women of child bearing age. Since significant brain and eye development occurs in uterus and continues during the first year of life after birth, optimal levels of DHA are crucial for pregnant and lactating women. DHA is the most abundant omega-3 fatty acids in the breast milk. It is also heplful in increasing female breast size. Omega-3 fatty acid from fish oil helps prevent muscular cramp–(dysmenorrhea, menstrual cramp)–the common gynecologic complaint and the leading cause of short term absenticism among school girls. This is the compelling evidence that menstrual pain is caused by the action of the inflammatory prostaglandin and leukotrienes upon the uterus. The inflammatory compounds are derived from the omega-6 fatty acid–arachidonic acid. The researchers conclude that fish oil supplement has a beautiful effect on dysmenorrhea symptoms in adolescents. The polyunsaturated fatty acid status (PUFA) of the developing fetus depends on that of its mother as confirmed by the positive relation between maternal PUFA consumption and neonatal PUFA status. Pregnancy is associated with a decrease in the biochemical PUFA status, and normalization after delivery is slow. This is particularly true for docosahexaenoic acid DHA because, on the basis of the current habitual diet, birth spacing appeared to be insufficient for the maternal DHA status to normalize completely. Lower neonatal PUFA status correlated positively with birth weight, birth length, and head circumference.

Recent studies have shown that an adequate maternal intake of seafood, especially oily fish, or fish oil supplements improves verbal communication skills at 6 and 18 months of age, reduces the risk of pre-term birth (low birth weight), improves an infant's problem-solving capacity and eye and hand coordination, and results in a higher intelligence quotient (IQ) in children at 4 years of age [88]. The researchers conclude that fish oil supplementation in women with PPD is well tolerated and effective in reducing symptoms of depression [89]. Dr. Joseph Hibbeln of the US National Institutes of Health reports that the incidence of post-partum depression (PPD) is clearly linked to DHA status and seafood consumption [90]. The milk of 29 lactating women living in Doromoni near lake Kitangiri (Tanzania) had high contents of AA, DHA, and EPA, and low AA/DHA ratio. These could be traced to lifelong consumption of DHA and AA-rich fish from the nearby fresh water lake, Kitangiri [91].

6.12 Role in bone health

n-3 Fatty acids, especially DHA, are positively associated with bone mineral accrual and thus, with peak bone in young men [92]. The attainment of peak bone mass in adolescence and the prevention of age-related osteoporosis are also potential effects of n-3 fatty acids [92]. Earlier studies have shown that a diet with a low n-3/n-6 ratio may have beneficial effects on bone mineral density.

6.13 Diabetes

The strongest kind of correlation exists between accumulation of body fat and diabetes [93]. Insulin resistance most probably results from increased accumulation of lipids in the peripheral tissues (lip toxicity) due to enhanced release of fatty acids from hypertrophic fat cells [94, 95]. Increased physical activity and dietary manipulation in patients with impaired glucose tolerance has been shown to lower the incidence of Type 2 diabetes by 60% [96, 97]. The researchers note that fish oil supplementation does not impair glycemic control and suggest that regular fish consumption should be considered as an integral part of a healthy diet for the management of diabetes [98].

6.14 Eye health

DHA is abundant in the retina and important for visual acuity. It may be helpful in preventing macular degeneration. Dietary DHA would be the appropriate n-3 fatty acids to use in studies to influence the development of visual impairment and even improve visual function in elderly people [99]. The man who ate fish more than once a week had a 50% lower incidence of late-stage mascular degeneration than did the man who ate fish less than once per month [100].

6.15 Beautiful skin, hair, and nail

Omega-3 fish oil is also important functional ingredient for beautiful, healthy and shiny skin, hair, and nail [101].

6.16 Drug modulation/adjuvant

Simopoulos in a review shows that n-3 fatty acids in combination with drugs for the treatment of diseases is an area of immense interest [102]. Studies suggest that the concurrent ingestion or administration of n-3 fatty acids with drugs lead to potentiation of drugs effects, as with propranolol, which may lead to a decrease both in the dose of n-3 fatty acids and in the drug dose, or as with cyclosporin, to a decrease in toxicity of the drugs [102].

7. Conclusion

Fish as a source providing construction materials for RNA, DNA, numerous other biomolecules, cells, muscle tissues, bones, and organs that perform numerous different structural and functional roles with prevention and reduction of diseases is a super food on this planet. It is an excellent food providing all the essential amino acids, essential n-3 fatty acids, vitamins, and minerals. Fish protein is highly digestible and of high biological value. Fish contains biomolecules that enhance performance ability physically and mentally. Fish is a good food for early development. The review shows that fish contains many biomolecules that prevent and reduce the risks of many diseases. Fish is great as a food in quality and quantity comparing with other foods.

Fish is a food for brain and health that can also be proved from the present review. Human mind is the medium through which the civilization was developed. It is the medium through which any goal and success can be achieved. Human brain can be compared to hardware in a computer while mind is compared to software. Healthy long life, enhanced physical and mental performance ability, well-being are all factors for quality life. So, it is rightly concluded that "fish is an important functional food for quality life" considering the principle of definition of functional food and its validity.

In addition to fish being highly delicious and tasty to sensory organ, the present facts and ideas will motivate more humans to choose fish as one of best functional foods for efficient and quality life.

There are variations in quality of fishes depending on species, habitat, temperature, season, feeding, etc. Special care for safety aspects should be taken in processing, harvesting, and storing effects and about fishes from toxic polluted areas.

Acknowledgements

Authors are grateful to their supporters.

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Chapter 7

Instant Controlled Pressure-Drop DIC as a Strategic Technology for Different Types of Natural Functional Foods

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Abstract

The increasing demand for functional foods requires the design, simulation, and further optimization of preservation processes of food with the purpose of keeping as high as possible the functionality of food products. Many studies have shown that the high consumption of fruit and vegetables prevent chronic diseases such as obesity, type 2 diabetes mellitus, cancer, among others. Fruits and vegetables are important sources of nutrients, dietary fibers, and phytochemicals. However, after harvest, they are highly perishable because of their high moisture content of almost 3–9 g H_2O/g db. Solar and airflow drying processes have been the most popular methods to increase the shelf life of these products. Nevertheless, low organoleptic and nutritional quality, hygiene problems, and long drying periods constitute significant barriers to a more widespread use. “Swell-drying” is a special drying process convective airflow drying (CAD) to the instant controlled pressure-drop (DIC) expansion. This process is well-known as guaranteeing (1) the preservation of functional properties; (2) the organoleptic quality; (3) the effective microbiological/fungi decontamination; and (4) a reduced energy consumption and a lower drying time. DIC treatment is a high temperature/short time (HTST) process that improves both performance of drying process and high-quality functional foods.

Keywords: functional foods, swell-drying, instant controlled pressure-drop DIC, antioxidants, decontamination

1. Introduction

Although the term functional food is recently employed, the relation between health and the consumption of fruits, vegetables, and plant parts has been highlighted since ~2500 years ago by the Hippocratic phrase “Let food be thy medicine and medicine be thy food” [1].

The term “functional food” by itself was first used in the 1980s as “any food or ingredient that has a positive impact on an individual’s health, physical performance, or state of mind, in addition to its nutritive value”. Nowadays, this definition remains appropriate, as long as such foods satisfy the three following conditions: (1) they are naturally rich in active ingredients, (2) they are able to be consumed as part of the daily diet, and (3) when they are ingested, they should enhance or regulate a particular biological process or mechanism to prevent or control a specific disease [2]. In this respect, many studies have shown that the consumption of fruits, vegetables, germinated seeds, and some parts of edible plants prevent some chronic diseases such as obesity, type 2 diabetes mellitus, hypertension, coronary heart disease, stroke, cancer, rheumatoid arthritis, eye diseases, among others [3–5]. They also show that fruit and vegetable consumers in most populations have half the risk of developing most types of cancer [5]. Fruit and vegetables are the most important sources of nutrients, dietary fiber, and phytochemicals. However, because of their high moisture content (up to more than 900% db), they are quickly perishable with a shelf life estimated to 2–3 days at the ambient temperature; this estimation greatly depends on the nature of material (without post-harvest processing). Hence, to increase their shelf life and subsequently maintain their functional properties, it is necessary to adopt accurate preservation techniques.

Nevertheless, many researches have shown that, despite the development of various preservation techniques, farmers over the world continue losing more than 40% of their products every year [6], while providing a decreased quality of functional foods.

The main unit operations of food preservation are drying, freezing, and canning. Dried materials are the most used foodstuffs because of: (1) their long shelf life once their water activity is so low that it inhibits chemical, microbial, and fungi (able to generate mycotoxin) activities, (2) their great convenience, and (3) the whole range of drying equipment and processes. However, although drying is the most common technique, its long-processing time at high temperature leads to a quality loss and high energy consumption [7–9].

There are many methods of drying, but sun drying is the most widely used methods throughout the developing countries of Asia, Africa, Central and South America [10]. However, the whole drying period can vary from 8 to 21 days according to the weather (solar radiation: temperature, relative humidity, and wind velocity) [10–13]. Another alternative method which uses the solar energy is called "the solar drying". This process differs from sun drying, by the use of equipment (solar dryers) that can control the direct solar radiation [14]. Through their simple use, sun and solar processes are differently weather dependent and commonly yield poor quality products. Shrinkage and texture compactness, loss of vitamins and bioactive compounds, and discoloration are elements of poor quality [12, 13, 15]. Besides, the dried products may be contaminated by dust, dirt, insects, birds, microorganisms, etc.

Since the eighteenth century, new drying methods such as convective airflow drying (CAD), spray drying, drum drying, lyophilization freeze drying (LFD), microwave drying (MWD), infrared drying (IRD), superheated steam drying (SSD), and some operations of puffing, pooping, or extrusion have been developed to improve conventional drying processes [16].

CAD is the most preservation technology applied for the fruits and vegetables at industrial level. It is known as the process where the heat used to evaporate the product's water is supplied by a stream of hot air [17]. In this process, the food product is exposed to a forced hot air flow at different levels of temperature, between 50 and 100°C, depending on the product's heat sensitivity, until final required moisture content is achieved. Despite its widespread application, this process is highly energy consuming at about 1 kW kg^{-1} of evaporated water. Moreover, the long exposure time to high temperature has a negative effect on color, nutritive value (vitamins, proteins, and fats), antioxidant activity (bioactive compounds), functional properties (rehydration response, water and oil holding capacities), texture, and shelf life.

Therefore, a main part of food engineering research has been devoted to improving the existing preservation techniques, or define innovative operations, to reduce the energy consumption, maintain the functional properties, and ensure the safety of products.

2. Fundamental approach of convective airflow drying CAD

The external driving force of CAD is the gradient of the vapor pressure between the surface of the product (exchange surface) and the surrounding environment. The rate of water evaporation from the product surface depends on the temperature and the water activity of this surface, while the rate of vapor removal from the product surface to the surrounding environment depends on the characteristics of the airflow: temperature (T_{AF}), velocity (v_{AF}), and relative humidity (HR). So, once the operation becomes adequately intensified by adequately increasing T_{AF} and v_{AF}, and reducing HR, the external transfer resistance becomes negligible. With these Negligible External Resistance (NER) conditions, the internal water diffusion controls the drying process with, as driving force, the gradient of water concentration within the matrix. The product temperature referred as the wet bulb temperature (T_{WB}) decreases by increasing the drying rate. Thus, the process intensification normally increases the quality.

2.1 Heat and mass transfer processes during drying

Vapor is generated at the exchange surface. It is worth noting that the relatively low value of the wet bulb temperature (T_{WB}) allows lower vapor pressure in the material matrix. The transfer of mass (water) within the product to the exchange surface occurs mainly on liquid phase [18, 19]. Thus, the two opposite flows of heat dQ/dt and water dm_v/dt occur with the gradients in temperature and vapor pressure, respectively, as the driving forces:

$$\dot{Q} = hA_{eff}(T_{AF} - T_{WB}) \quad (1)$$

$$\dot{m}_v = k_p \rho_v A_{eff} \frac{(p_{v,T} a_{w,s} - p_{v,a} HR)}{P_t} \quad (2)$$

where h is the coefficient of heat convection transfer expressed in W m^{-2} K^{-1} and k_p the mass transfer coefficient expressed m s^{-1}. The heat transferred from the exterior environment to the exchange surface is almost exclusively used for evaporation [20].

$$T_{WB} = T_{AF} - \frac{k_p \rho_v}{h} L \frac{(p_{v,T} a_{w,s} - p_{v,a} HR)}{P_t} \quad (3)$$

When the external conditions control the operation, the drying rate evolves generally with the temperature level and the water activity at the exchange surface, thus defining the vapor pressure $p_{wa} = p_{WT} a_{w,s}$.

After controlling the hot air characteristics and external transfers, the whole operation of drying is controlled by the internal transfers (Negligible External

Resistance (NER) conditions), the intensification could be performed by holding higher wet bulb temperature inside the product which is normally smaller than the external airflow temperature (T_{AF}). The higher the T_{WB} is the higher the water diffusivity. However, this T_{WB} should be limited in order to maintain the quality of the product (texture, color, form, flavor, nutritive value, etc.) (**Figure 1**).

The liquid water diffusion is the main mass transfer occurring within the matrix towards the exchange surface. The liquid water is transferred within the porous matrix by classic diffusion, capillarity, and osmoses throughout numerous cell walls, etc. The transfer of water from the inner tissue to the outside surface involves migration through the cells, the enveloping and porous tissue structure, and then through the outside boundary layers. There are three main potential pathways which water can follow while passing throughout the plant tissue: (a) the apoplastic transport pathway (cell wall pathway), which occurs outside the cell membranes (plasmalemma) and can be defined as water transport through cell walls and intercellular space between cells; (b) the symplastic transport pathway (symplast pathway), inside the plasmalemma, characterized by a sap transport from one cell directly into another cell through small channels (plasmodesmata); and (c) the transmembrane transport pathway (vacuolar pathway), which is defined as a water exchange route between the cell interior (cytoplasm and vacuole) and the cell exterior (cell wall and intercellular space) across the cell membrane [19, 22–24]. The whole process occurs when the product temperature is lower than the water boiling point. To simplify all these phenomena, the whole transfer can be expressed by similar-Fick diffusion law, with an effective diffusivity (D_{eff}) [25]. Thus, by adopting the formulation of Allaf (1982), it can be expressed as:

$$\frac{\rho_w}{\rho_s}(\overrightarrow{v_w} - \overrightarrow{v_s}) = -D_{eff}\vec{\nabla}\left(\frac{\rho_w}{\rho_s}\right) \quad (4)$$

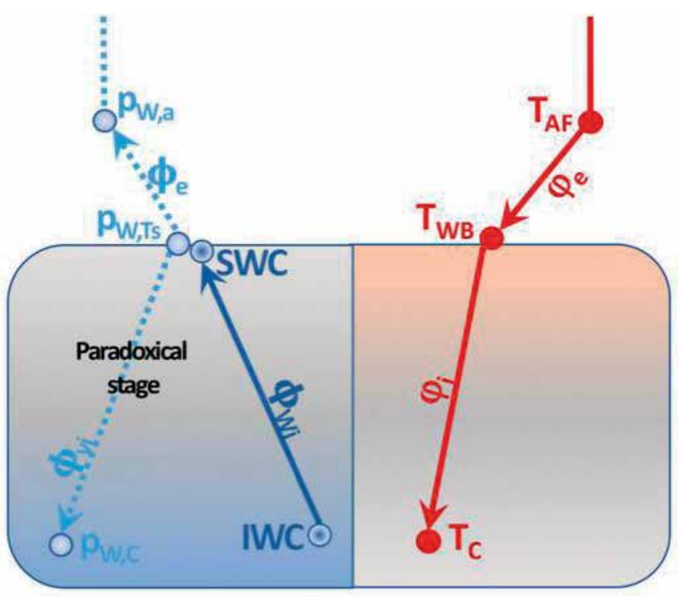

Figure 1.
Schematic representation of heat and mass transfers involved during airflow drying. Adapted from [21]. IWC: internal water content; SWC: superficial water content; $p_{W,a}$*: vapor pressure in the air;* $p_{W,Ts}$*: vapor pressure at the surface;* $p_{W,C}$*: vapor pressure at the core; depending on temperature;* Φ_{vi}*: internal vapor flow;* Φ_{ve}*: external vapor flow;* Φ_{wi}*: internal water flow;* T_{AF}*: airflow temperature;* j_e*: external heat flow by convection;* j_i*: internal heat flow by conduction;* T_{WB}*: wet bulb temperature;* T_C*: core temperature.*

where ρ_w and ρ_s are the apparent densities and v_w and v_s the average velocities of water w and solid s, respectively.

The part of the internal vapor transfer is frail and does not become relatively important before the final stage of drying. This internal vapor diffusion has a specific driving force of the gradient of vapor pressure, which is temperature dependent, while independent on water concentration. Hence, in many cases, the heat and vapor transfers within a porous matrix occur in specific coupled manners with an evaporation/condensation process [18]. The relationship between the temperature and the partial vapor pressure is the fundamental of the CAD paradoxical phenomenon [26].

The three steps of convective airflow drying (CAD) namely: (1) surface evaporation, (2) diffusion coupled with surface evaporation, and (3) paradoxical stage require distinct types of process intensification. Normally, the first intensification concerns an appropriate choice of the air temperature, speed, and relative humidity. These conditions must be managed to avoid both thermal degradation and case-hardening formation. Hence, after adequately increasing external transfers, internal transfer normally becomes the limiting process (NER condition). Subsequently, the expansion of the structure to improve the porosity allows increasing the water

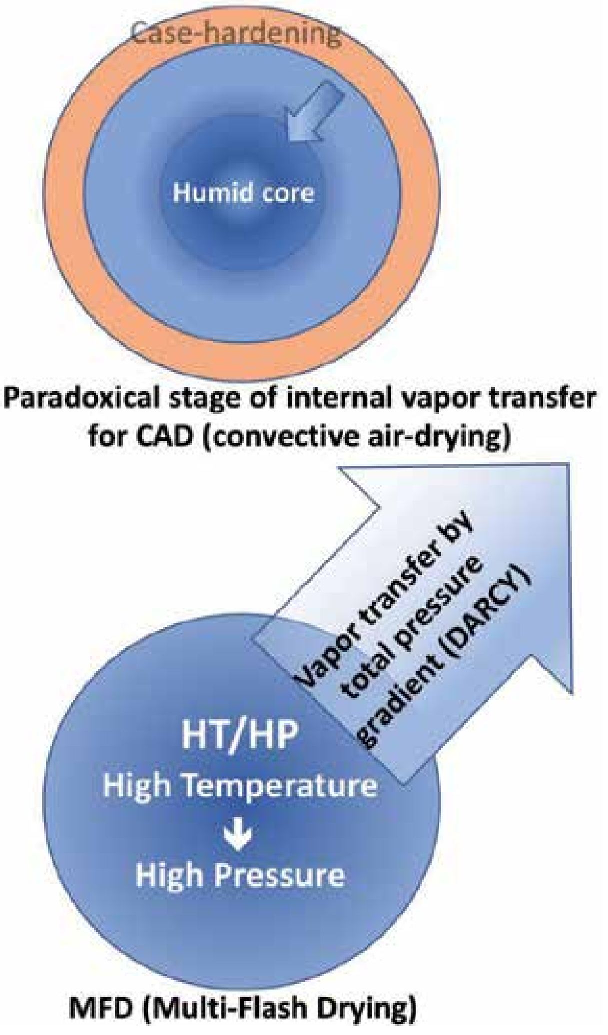

Figure 2.
Schematic description of the intensification of the paradoxical drying stage by MFA process [21].

diffusivity; thus, instant controlled pressure drop (well-known by its French acronym DIC: Détente Instantanée Contrôlée) becomes very interesting and even indispensable.

In the final stage of drying, the residual free or bound water, is merely transferred within the porous matrix as vapor. In the case of high-porous materials, the conductivity is weak with a significant paradoxical effect. To address this paradoxical situation and intensify the drying process, three solutions have been proposed: heating by microwave drying, drying by superheated steam, and drying by Multi-Flash Autovaporization (MFA) (**Figure 2**). In all these cases, Darcy's law can describe the main transfer phenomenon.

$$\rho_v V_v = -\frac{K}{\nu_v}\frac{\partial P}{\partial r} \tag{5}$$

where ρ_v is the vapor density, V_v is the average velocity of vapor, K is the permeability coefficient, and ν_v is the static diffusivity of vapor.

The MFA is defined as a drying process consisting in alternating cycles of high pressure and pressure drops over a relatively short time (typically between 20 and 200 ms), with a very high rate $>5 \times 10^5$ Pa s^{-1}. The cornerstone of this process is to generate a total pressure inside the product higher than at the surface, to avoid the paradoxical situation [27].

3. Instant controlled pressure drop (DIC) process in whole addressing drying issues

DIC is a thermo-mechanical process that consists of subjecting a product to high pressure saturated dry steam (almost between 100 and 1000 kPa according to the product and the objectives) for a short period of time (some seconds), followed by an abrupt pressure drop towards a vacuum (about 5 kPa). This abrupt pressure drops ($\Delta P/\Delta t > 0.5$ MPa/s) simultaneously triggers the autovaporization of the water (produced as a function of the temperature difference between the initial heat stage and the final equilibrium temperature), and swelling, with a possible rupture of cell walls and instant cooling of products, which stops thermal degradation (**Figure 3**). This process involves many perfectly controlled operating process parameters and intrinsic characteristics. They, respectively, are:

Operating process parameters: initial pressure and temperature, total pressure, vapor pressure, initial vacuum pressure, pressure drop rate, thermal processing time, temperature drop rate, volume ratio of the vacuum tank to the processing vessel, intrinsic density or filling ratio, quantity and apparent volume of the product to be processed, etc.

Intrinsic characteristics: shape/size of the raw material, water content, thermal conductivity, specific heat capacity, effective thermal diffusivity, effective mass diffusivity, rheological characteristics such as elasticity, viscosity, glass transition, etc.

Therefore, a wide range of possibilities for the selection and control of the treatment parameters allows optimizing one or more target characteristics in the product and/or the process. In the case of the intensification of airflow drying, to address the compactness of the product, the coupling of DIC expansion to airflow drying has been a solution, commonly known as the "Swell Drying" process (**Figure 6**).

The temperature and pressure levels during a DIC cycle are shown in **Figure 4**. First step: plant material is introduced in a processing reactor in which a vacuum

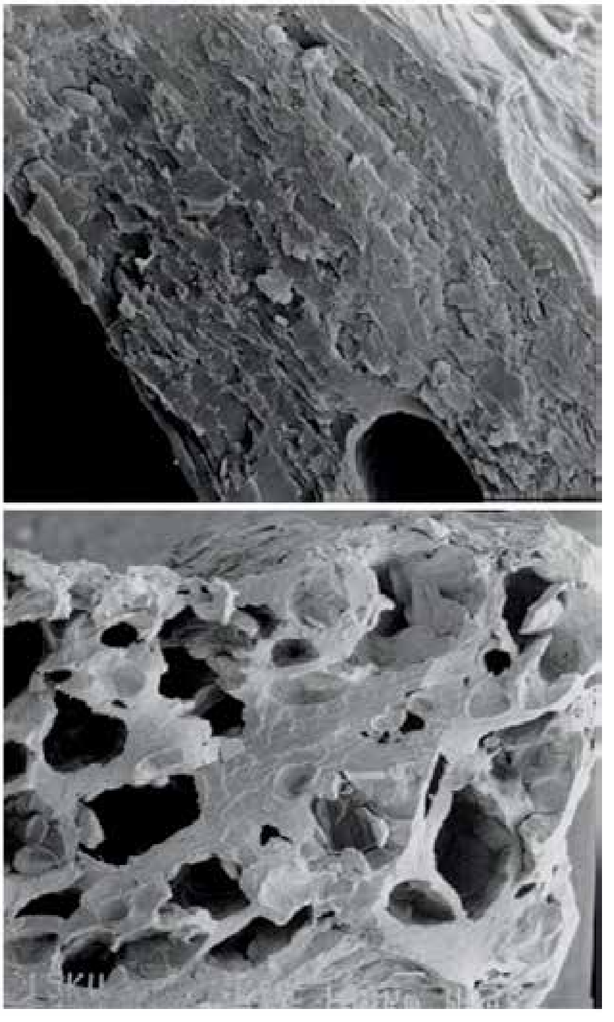

Figure 3.
Scanning electron micrographs of dried potatoes: standard airflow drying (left) and swell drying (right).

of around 4.5 kPa is established (**Figure 4a**). The initial vacuum is carried out to facilitate and mediate the close exchange between the incoming steam and the product surface. Second step: saturated steam is injected into the reactor at a fixed pressure level (from 0.1 up to 0.6 MPa) (**Figure 4b**). Heating transfer is performed mainly by steam condensation, which assures a very high coefficient of heat transfer. Once the levels of temperature and water content are almost homogenized in the material (needing some seconds) (**Figure 4c**), the sample is subjected to an instant controlled pressure-drop ($\Delta P/\Delta t > 0.5$ MPa s^{-1}) towards vacuum (**Figure 4d**); this is the third step of DIC. Fourth step: after a vacuum stage, the pressure is released towards the atmospheric pressure (**Figure 4e**) and the sample is recovered from the reactor [28]. Pressure and time operating parameters are selected according to the plant material.

The expansion of the product depends on the stress caused by the quantity of autovaporized water, the hydro-thermo-rheological (viscoelastic) behavior of the product, and the difference between the internal and external pressures. Thus, this operation is generally achieved when the moisture content results in the glass transition of the material [26].

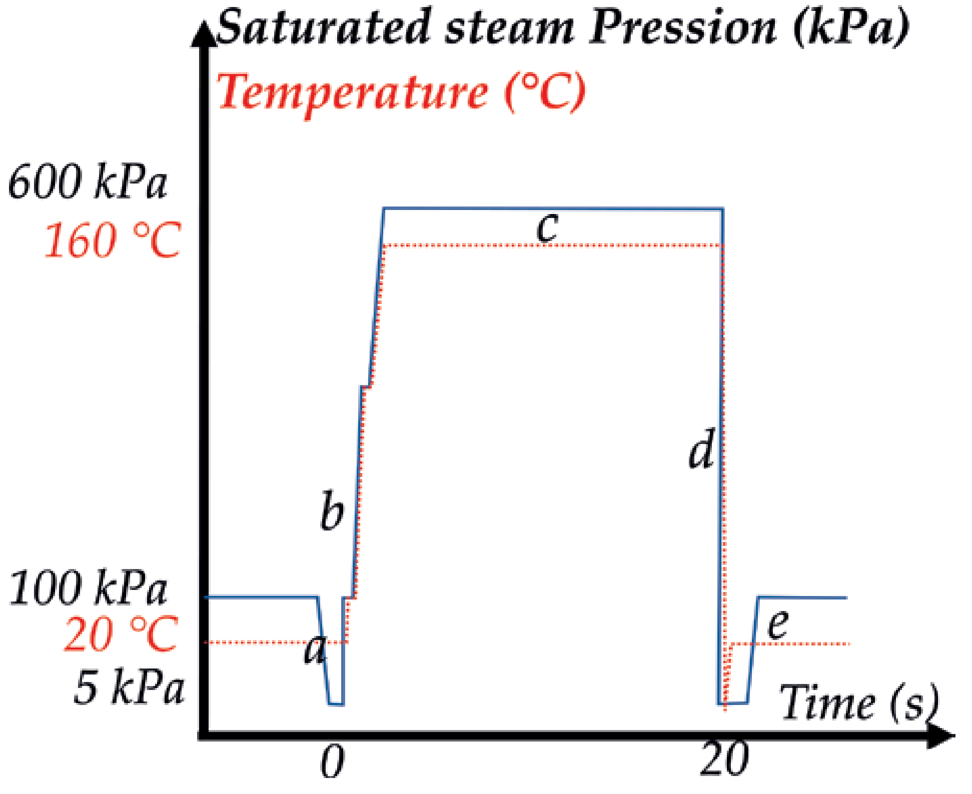

Figure 4.
Typical pressure-time profile for DIC processing cycle. (a): Establishment of an initial vacuum in the processing vessel; (b): injection of saturated dry steam at the selected pressure; (c) maintain of treatment pressure during selected time; (d): instant controlled pressure drop towards a vacuum; and (e): releasing to atmospheric pressure.

4. Applications of DIC as an innovative technology in manufacturing functional foods

In an age of convenient foods and pre-cooked meals, many consumers find that the high consumption of fruits and vegetables is difficult to achieve. For this reason, the production of high-quality dried fruit and vegetables becomes fundamental.

The DIC technology has shown very interesting results on the preservation of functional properties not exclusively in fruits and vegetables, but also on plants, germinated seeds, microalgae, among others foods. The DIC texturing usually makes it possible to increase availability and extractability of high-value biomolecules such as antioxidants. Moreover, the parameters of DIC treatment can be defined to achieve decontamination of bacteria, insects and larvae, fungi, etc., which is extremely important [29–31] mainly against the presence of aflatoxins. Hence, DIC products have a much longer lifetime, good consumer acceptance, and an excellent sensorial, hygienic, and nutritional quality. **Figure 5** shows some examples of swell dried fruits and vegetables snacks.

4.1 Swell-drying in increasing functional availability of active molecules

The generation of reactive oxygen species and other free radicals during metabolism is a necessary and normal process that ideally is compensated by an elaborate endogenous antioxidant system. However, the environment, lifestyle, and pathological situations provoke an excess of radicals, that when accumulate, results in oxidative stress that is related to chronic diseases [32]. Antioxidants have been defined as

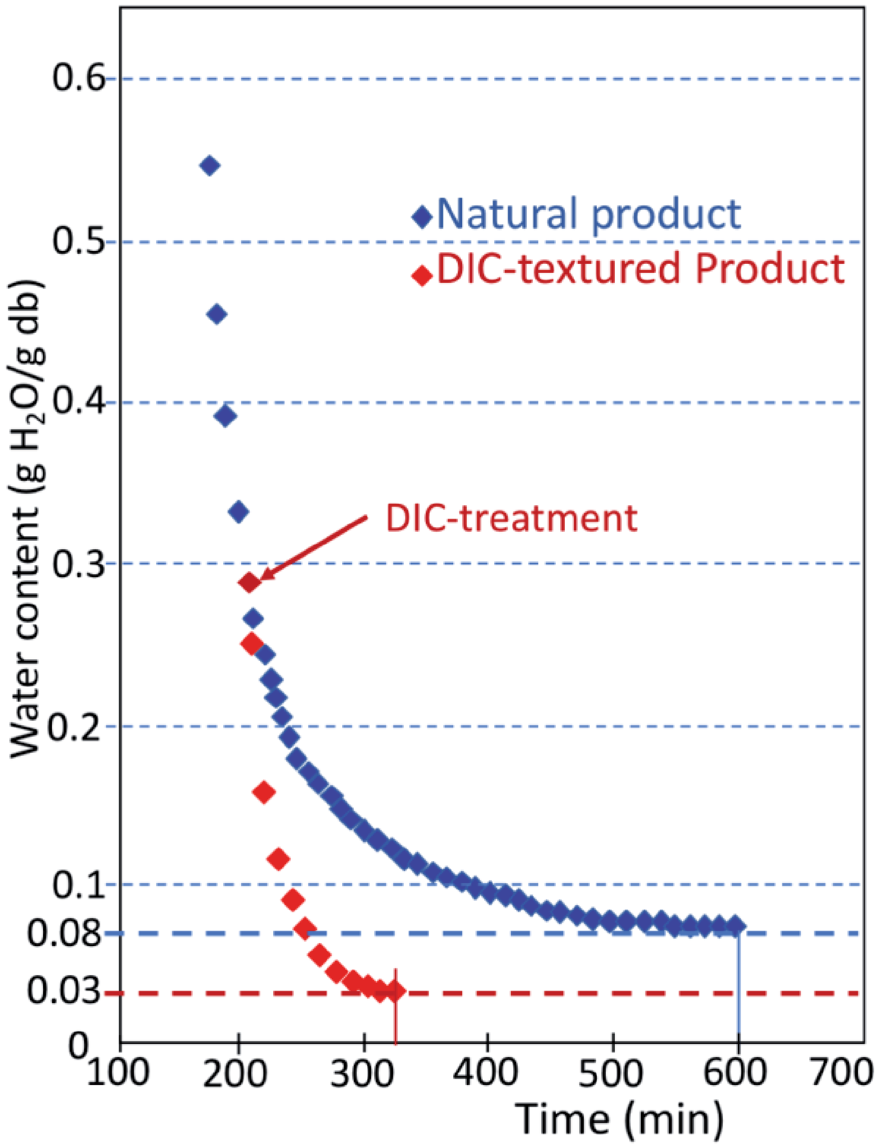

Figure 5.
Comparative study on CAD drying of conventional and DIC-textured apple samples.

any substance that when present at low concentrations compared with those of an oxidizable substrate, significantly delays or prevents oxidation of that substrate [33]. Therefore, during the past few decades, scientific studies have focused on the search of natural antioxidants sources and their preservation. The findings have shown significant evidence of the antioxidant effect on diseases prevention when consumers are feeding fruits and vegetables rather than individual antioxidants [32].

By DIC treating the partially dried material following an initial partially drying stage, the material becomes more porous and the tortuosity also increases. Water diffusivity usually increases, the final water content decreases, and drying time dramatically drops. Moreover, this implies a reduction of energy consumption compared with freeze-drying, but also with hot air drying. **Figure 6** shows the impact of DIC texturization on CAD kinetics of apples (**Figure** 7).

Respect to DIC treatment, various studies have shown that it has a direct positive impact on active molecules and their functional activity. Mounir et al., [30, 35]

Figure 6.
Swell-drying in manufacturing functional snacking [from www.abcar-dic.com].

studied the impact of DIC treatment on the onion and apple flavonoids and drying kinetics. Their results showed that in the case of apples, quercetin was the major flavonoid, followed by myricetin, kaempferol, and luteolin. And, in the onions, they were quercetin, myricetin, and kaempferol. Moreover, by measuring quercetin concentration before and after DIC treatment (0.3 MPa and 80 s), results showed that DIC apple samples reached up to 8 times more quercetin concentration compared to untreated samples. In the case of DIC onion samples, it was 31 times more. Additionally, the DIC texturing significantly improved the drying kinetics of both products. Drying time was reduced from 10 h (traditional airflow drying) to 5 h (swell-drying) in the case of apples, and from 11 h (traditional airflow drying) to 2.5 h (swell-drying) for onions.

Alonzo et al. [36] also studied the impact of airflow drying (HAD), freeze-drying (FD), and swell-drying (SD, DIC-assisted airflow drying) on the total phenol, total flavonoid, and total anthocyanin content of strawberries (*Fragaria var. Camarosa*). Their results showed that the optimum conditions of DIC to obtain the highest levels of phenols, flavonoids, and anthocyanins, as well as antioxidant activity were 0.35 MPa and 10 s. Moreover, there was no significant difference in total phenol and flavonoid content among FD and SD strawberry samples, which implies that DIC samples afford the same quality of freeze-drying at lower cost and in a shorter time. Additionally, the main anthocyanins in strawberries are pelargonidin-3-glucoside (Pe-3-Gl) and cyanidin-3-glucoside (Cy-3-Gl), and this study showed that the highest content of these anthocyanins was obtained after DIC treatment, being the saturated steam pressure parameter, the most important to be controlled. Additionally, by comparing the antioxidant capacity of HAD and FD to SD treated samples, antiradical activity (ARA) was determinate by using 2,2-diphenyl-1-picrylhydrazyl free radical (DPPH), showed that DIC increased by 9 and 10%, respectively, the antioxidant capacity of strawberries.

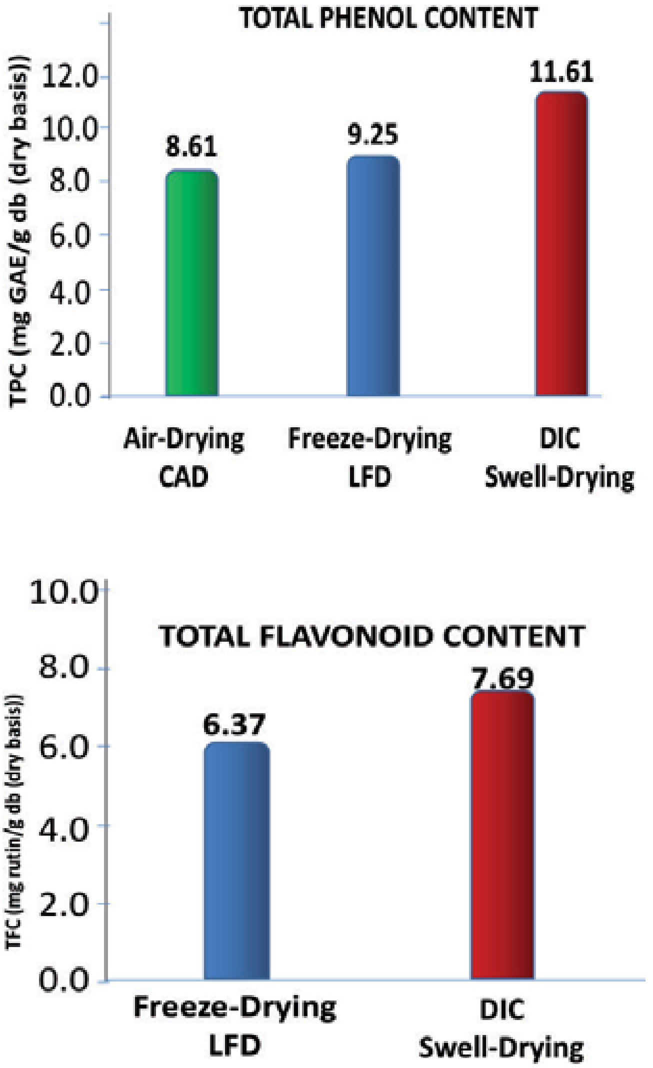

Figure 7.
Comparison of total phenol content (TPC) and total flavonoid content (TFC) of green pepper differently dried [34].

Amor and Allaf [37] also studied the effect of DIC treatment on the extraction of Roselle (*Hibiscus sabdariffa*) anthocyanins. Results showed that compared to water distillation (WD), DIC treatment improved both the kinetics and the yield of extraction of anthocyanins from Roselle calyces. Anthocyanins extraction time was reduced to one-third, from 10 min (WD) to 3 min (DIC). Moreover, DIC texturing improved the total monomeric anthocyanin [31] content of Roselle by up to 135%. TMA of raw material was of 8.96 mg/g db (dry basis), and TMA of DIC-treated samples was of 11.72 mg/g db. The main anthocyanins in the Roselle extract were Dp-3-sam (69–76%) followed by Cyn-3-sam (24–31%).

Téllez-Pérez et al. [34] evaluated the effects of drying and freezing couple to the DIC process on the phytochemical content and the antioxidant activity of Green Poblano Pepper (*Capsicum annuum, L.*). Traditional airflow drying (HAD), freeze drying (FD), and traditional freezing (TF) were studied as controls. Results showed that the total phenol content (TPC) varied widely according to different drying and freezing conditions. Compared to raw material (RM), both DIC and frozen samples presented the highest content of TPC. Moreover, the total flavonoids content (TFC) of swell-dried pepper samples, which included a DIC texturing at (0.45 MPa for 40 s) showed the same performance as FD. In these two types of samples, TFC exhibited an increase of 1.20 times higher than RM. With respect to the antiradical activity (ARA) of peppers, swell-dried samples with DIC texturing at (P: 0.45 MPa, t: 40 s), FD and TF being, respectively, 1.05, 1.13, and 1.26 times higher than RM. Finally, by regarding the antioxidant capacity of the Trolox Equivalent Antioxidant Capacity assay (TEAC), results showed an increase in the antioxidant activity with respect to RM for HAD (1.36 times), FD (1.62 times), DIC couple to drying (1.69 times, P: 0.41 MPa, t: 54 s), and DIC coupled to freezing (2.89 times, P: 0.15 MPa, t: 40 s). DIC-assisted airflow drying and DIC-assisted freezing allowed both increasing of the availability of bioactive compounds while enhancing the antioxidant activity of peppers.

Santiago-Mora et al. [38] also evaluated the impact of freeze-drying (FD) and instant controlled pressure drop (DIC) on bioactive compounds and antioxidant capacity of berrycacti (*Myrtillocactus geometrizans*), a fruit of a perennial Cactaceae plant native to Central Mexico. Berrycacti is considered as functional food thanks to its antioxidant capacity. Then, its drying efficacy, phenols, non-extractable polyphenols, tannins, betalains, color, and antioxidant capacity were determined. Results showed that both freeze-dried and swell-dried samples showed the highest in-vitro antioxidant capacity compared to the fresh fruit. After both drying treatments, the results showed an increase of non-extractable polyphenols and condensed tannins; moreover, both had a good retention of betalains and ascorbic acid. In fact, both freeze-dried and DIC swell-dried samples exhibited effective preservation of antioxidant properties and retention of bioactive compounds, while DIC was greatly preserving color parameters and being the most cost-effective technology.

Sahyoun et al. [39] studied the impact of blanching, freezing/thawing, steaming, and DIC as pretreatment methods for carrots drying. Traditional airflow drying was employed as a control. And to evaluate the performance of each treatment on the functional properties of dried carrots, phospholipids, diacyl-glycerols, provitamin A, and carotene content were measured. Results showed that compared to the control, both freezing/thawing and DIC pretreatment coupled to vacuum drying preserve better the lipid content of dried carrots. Moreover, DIC samples showed thrice concentration of carotene compared to control.

Melki et al. [40] also studied the impact of DIC treatment on vitamins A, B1, B3, and B8 of fenugreek (*Trigonella-foenum-graecum*) and carob *(Ceratonia siliqua)* germinated seeds. As germination promotes the increase of biogenic compounds of seeds, DIC was applied to ensure its preservation. In the case of fenugreek germinated seeds, results showed that DIC increased vitamin B1, B3, and B8 content; and slightly decreased the vitamin A concentration. In the case of carob germinated seeds, results showed that DIC increased the vitamin A content by 82.54%, and slightly decreased B vitamins. In both cases, DIC allowed to increase the bioavailability of the vitamins, thanks to the cellular expansion, and allowed the decontamination of germinated seeds. Moreover, for both materials, the best DIC treatment conditions to guarantee cellular expansion and decontamination of seeds were found under 0.4 MPa steaming pressure for 30 s.

Namir et al. [41] also examined the effect of DIC texturing on the bioactive compounds and functional properties of cactus pear peel (*Opuntia ficus-indica*). Results showed that by comparing to traditional airflow drying, DIC treatment allowed more availability of phenolic compounds and β-carotene by 83 and 551%, respectively. Moreover, by using the 1,1-diphenyl-2-picrylhydrazyl ($DPPH^{\cdot}$) radical scavenging test, it was observed that the antioxidant activity of DIC-treated peels was increased up to 53%. The best treatment conditions were defined under 0.6 MPa of steaming pressure for 15 s.

Allaf et al. [42] evaluated the impact of DIC technology in the sequential extraction of orange peel essential oil and antioxidants. Results showed that DIC technology enabled both essential oil extraction and matrix expansion, which improved solvent extraction of antioxidants. While orange peel essential oils (EO) extraction by hydrodistillation (HD) was achieved in 4 h to obtain a yield of 1.97 mg/g db, DIC-treated samples (after optimization) only 2 min were necessary to obtain a yield of 16.57 mg/g db. On the other hand, the solid residue was recovered to extract antioxidant compounds (naringin and hesperidin) by coupling DIC technology to solvent extraction (SE) and ultrasound UAE. Obtained results showed that by combining DIC and UAE, it was possible to enhance kinetics and yields of antioxidant extraction. Indeed, DIC/UAE results in 1 h extraction of 0.8 ± 1.6 g/g db of hesperidin and 6.45102 ± 2.3104 g/g db for naringin compared to 0.64 ± 2.7102 g/g db and 5.7 ± 1.6 g/g db, respectively, with conventional solvent extraction SE.

Mkaouar et al. [43] also studied the effect of DIC on the kinetics extraction of olive leaves (*Olea europaea* L.) polyphenols. Results showed that DIC-assisted solvent extraction allowed reducing the extraction time from 120 to 15 min while increasing the extracted yields. Furthermore, the ultra-performance liquid chromatography (UPLC) allowed following the extraction kinetics of the main phenolic compounds of olive leaves: apigenin-7-glucoside, hydroxytyrosol, luteolin-7-glucoside, oleuropein, tyrosol, vanillic acid, and verbascoside. And in almost all the cases, the extracted quantities were more important for DIC-textured olive leaves than untreated ones, with the exception of vanillic acid, which remained almost the same. Oleuropein was the major phenolic compound of olive leaves, reaching a maximum concentration of 84.9 mg/g dry matter after DIC texturization.

Berka-Zougali et al. also improved the extraction kinetics of natural antioxidants of myrtle (*Myrtus communis* L.) and buckthorn (*Rhamnus alaternus* L.) leaves through DIC [28, 44, 45]. For myrtle leaves, by comparing with untreated samples, DIC texturing clearly enhanced the extraction kinetics of both anthocyanins and flavonoids. In the case of anthocyanins, after 2.6 h of solvent extraction, DIC-treated leaves showed the same yield as untreated samples after 24 h. And in the case of flavonoids, after only 14 min, DIC-treated leaves showed the same yield as untreated samples after 112 min. Moreover, the antioxidant activity of myrtle leaves extracts was 3.57 times higher than one of the most common food preservatives, butylhydroxytoluene (BHT). In the case of buckthorn leaves, the extraction kinetics of phenols and flavonoids, and the antioxidant activity of both the dried leaves and the extracts were studied. Results showed that in only 3 min, DIC buckthorn leaves achieved the same yield of flavonol aglycones as untreated samples after 150 min. Aglycones are very important since they seem to be having a great therapeutic potential. Furthermore, the antioxidant activity of DIC buckthorn leaves was 68 times higher than BHT.

Many other reports have also shown that DIC technology induces modifications on the microstructure of food materials, which improves not only the availability of bioactive compounds but also it allows to reduce anti-nutritional and allergic factors.

4.2 Swell-drying to reduce anti-nutritional and allergic factors of foodstuffs

Legumes, as peas, chickpeas, lentils, beans, among others, are an important source of food proteins. They contain high amounts of essential amino acids, and they are a rich source of dietary fiber, minerals and vitamins [46]. Moreover, numerous studies suggest that consumption of legumes may have potential health benefits as reducing the risk of cardiovascular disease [47], cancer [48], diabetes [49], hypertension [50], among others. Even though legumes provide health benefits, however, the possible presence of anti-nutritional factors (ANF) as phytates, trypsin inhibitors and oligosaccharides, causes some undesirable physiological reactions such as flatulence, low digestibility, and inhibition of vitamins absorption [51, 52]. ANF are defined as compounds which reduce the nutrient utilization and/or food intake of plants or plant products used as human foods or animal feeds [53]. For example, IgE-binding proteins have been also identified in majority on legumes, they can cause allergic response from mild skin reactions to life-threatening anaphylactic reaction [54].

Hence, to reduce or even eliminate the anti-nutritional and allergic legumes factors various treatments such as fermentation, precipitation, washing and filtration, heating, among others have been applied [51]. Among all these treatments, heating is the most commonly used [51, 54]. However, the final nutritional value of vegetables can be damaged by high-intensity heating. In this sense, the effect of DIC as a high temperature/short time (HTST) treatment has been evaluated in the case of some legumes on the ANF and allergic factors, achieving good results.

4.3 Effect of DIC on anti-nutritional factors

The effect of DIC on anti-nutritional factors has been studied on trypsin inhibitors of soybean seeds (*Glycine max*), and on phytates of lupin seeds (*Lupinus albus* and *Lupinus mutabilis*). Trypsin inhibitors (TIs) are the most important ANF of soybean seeds because they strongly inhibit the activity of key pancreatic enzymes trypsin and chymotrypsin, thereby they reduce digestion and absorption of dietary, even in the presence of high amounts of digestive enzymes [55]. To evaluate the effect of DIC treatment on TIs, Haddad et al. [51] submitted soybeans seeds with an initial trypsin inhibitor content of 41.6 IU/mg to different hydro-thermo-mechanical treatments varying three operating parameters: steam pressure (P) between 0.3 and 0.7 MPa, treatment time (t) between 20 and 60 s, and initial water content (W) between 30 and 50 g water/100 dry matter. Results showed that according to applied operating parameters, DIC treatment could achieve different reduction ratio of TIs, being remarked that the higher the pressure, the lower the TIs content. The best conditions to reduce TIs to a 94% were P = 0.7 MPa, t = 60 s, and W = 50 g water/100 dry matter. Heating causes the partial denaturation of proteins and generally gradually diminishing trypsin inhibitor levels in a time-temperature dependent mode [55]. Then, DIC as a very short hydro-thermo-mechanical treatment becomes an interesting technology to reduce the TIs content of soybeans seeds at industrial level.

Phytic acid or inositolhexa-phosphoric acid (IHP) is one of the most common heat resistant ANF in plants. IHP chelates micronutrient and reduce its bioavailability for monogastric animals, including humans, this, because the lack of phytase enzyme in their digestive tract. To reduce the phytic acid content in food, several pre-treatment methods such as soaking, germination, enzymatic treatment, and heating have been developed [56]. In the case of heating, according to some studies, to reduce the phytate content by 10%, it is necessary a thermal treatment of 30 min [57, 58]. Then, to evaluate the performance of DIC on the reduction of IHP content, lupin seeds were studied by Haddad et al., [52]. *Lupinus albus* and *Lupinus mutabilis* seeds with an initial IHP content of 18.36 and 23.54 mg/g dry matter, respectively, were cracked, dehulled, and moistened before DIC treatment. Evaluated DIC operating parameters were: steam pressure (P) between 0.4 and 0.7 MPa, treatment time (t) between 40 and 60 s, and initial water content (W) between 0.30 and 0.50 g H_2O/g db. Results showed that DIC treatment could reduce the total phytate content by 16% (*L. albus*) and 19% (*L. mutabilis*) in only 60 s. Moreover, the decrease in total phytate content rises to 55% (*L. albus*) and 60% (*L. mutabilis*) for a 7 min treatment. For both varieties of lupin seeds, the best conditions to reduce IHP were P = 0.7 MPa, t = 60 s, and W = 0.50 g H_2O/g db.

4.4 Effect of DIC on allergic factors

Food allergies are adverse reactions to an otherwise harmless food, that occur when the immune system reacts to one or more proteins present in food that are recognized as foreign [54]. Legumes are essential constituents of human diets, contributing to both dietary protein and processed vegetable oil for human consumption. However, they are also an important source of food allergens such as 2S albumin, 11S legumin-type globulins, and the 7S vicilin-type [59]. Various studies have demonstrated that thermal processing as autoclaving, canning, steaming, among others can reduce, eliminate, or even enhance the allergenicity of legumes [60]. Thus, for each kind of thermal processing as well as for each legume, it is highly important to define the optimal heating conditions to eliminate or at least reduce the allergic factors. In the case of DIC technology, promising results have been found to reduce the legumes allergens [61–63].

Guillamón et al. [62] studied the effect of DIC treatment on Lupin (*Lupinus albus* var. Multolupa) in vitro allergenicity. Lupin cotyledons with an initial water content of 0.101 g H_2O/g db matter, were subjected to five different DIC treatments: DIC 1 (P = 0.3 MPa for 1 min), DIC 2 (P = 0.6 MPa for 1 min), DIC 3 (P = 0.45 MPa for 2 min), DIC 4 (P = 0.3 MPa for 3 min), and DIC 5 (P = 0.6 MPa for 3 min). To evaluate the impact of DIC on Lupins allergens, the IgE immunoreactivity of raw and DIC-treated extracts was evaluated by Western blot using a serum pool from 19 sensitized patients. Results showed that after DIC treatment, a reduction in the total IgE-reactive bands could be achieved. In fact, under DIC 5 treatment no IgE-immunoreactive band was found in soluble or insoluble protein fractions. According to the results, lupin allergens are relatively heat stable, and to eliminate their allergenic potency a combination of heat and pressure is required. A similar result was found by Álvarez et al. [64], who submitted lupins to an autoclaving treatment at 0.26 MPa for 30 min. At this respect, compared to autoclaving, DIC become an advantageous technology due to the reduction of time and energy.

Cuadrado et al. [63] researched the impact of DIC treatment on raw and roasted peanuts (*Arachis hypogaea*), lentils (*Lens culinaris*), chickpeas (*Cicer arietinum*), and soybeans (*Glycine max*) IgE antibody reactivity. Legume seeds with a constant initial water content of 50 g of water/100 g of dry matter were submitted to four DIC treatments: treatment A (P = 0.3 MPa for 1 min), treatment B (P = 0.3 MPa for 3 min), treatment C (P = 0.6 MPa for 1 min), and treatment D (P = 0.6 MPa for 3 min). To evaluate the impact of DIC on the studied legumes allergens, SDS-PAGE and immunoblotting analysis were applied.

In the case of peanuts, results showed that raw, roasted, and DIC-treated A and B peanuts presented no changes in the SDS-PAGE protein band pattern and minimal changes (decrease/increase) in the immunoreactive band pattern. Contrary, for DIC treatments C and D, a decrease in the band intensity in the range 15–65 kDa was observed, being more marked in roasted peanuts. On the other hand, in the case of lentils, chickpeas, and soybeans, all DIC treatments presented an important reduction of the major allergens and other minor immunoreactive proteins. Moreover, in the specific case of soybeans, under DIC treatment D almost all immunoreactive proteins were eliminated. According to the authors, significant alterations in protein structure may occur during heat treatment, and the nature and extent of which depend on the temperature and duration of the thermal processing.

Particularly, DIC treatment was able to produce an important decrease in the overall immunoreactivity of peanut, lentil, and chickpea extracts and a marked reduction in IgE recognition of soybean protein extract.

4.5 Swell-drying: a technology for food products decontamination

Even though, there is evidence that functional foods can play an important role in disease prevention and/or health promotion, guarantee the safety and quality of these products are very important aspects prior its commercialization and further utilization. Millions of cases of food-borne illnesses occur annually in the world, which ranging from mild aggravations to life-threatening situations. In general, food-borne illnesses are caused by the consumption of contaminated food by bacteria, viruses, or parasites, and symptoms as vomiting, diarrhea, and nausea typically last for 2–3 days. However, some patients can develop severe complications as hospitalization due to sepsis, stillbirths, hemolytic uremic syndrome, nerve paralysis, or even death [65]. Therefore, the complete elimination of pathogens from functional foods, without damaging its functional biomolecules, is imperative.

Decontamination has been defined as the elimination or reduction of microorganism's level. In general, foodstuffs decontamination methods can be divided into three categories: (a) thermal methods such as pasteurization, microwave, radiofrequency, infrared heating, among others; (b) chemical decontamination methods with chlorine dioxide, ozone, electrolyzed oxidizing water, organic acids, and dense phase CO_2, and (c) non-thermal decontamination methods such as high hydrostatic pressure, irradiation, pulsed electric fields, power ultrasound, and non-thermal plasma [66]. Among these methods, DIC showed satisfactory results on the decontamination of heat-sensitive and powders food products.

Setyopratomo et al. [31] studied the impact of DIC treatment on dehydration kinetics, product physical properties (water and oil holding capacity), and microbial decontamination of Cassava (*Manihot esculenta*) flour. Also, Mounir et al. [30] and Albitar et al. [29] evaluated the impact of DIC treatment on the decontamination of onions. Fresh Syrian white onions were peeled, washed, and cut into 50 mm length and d_p = 5 mm. For control, fresh onion slices were hot-air dried until final dehydration. For DIC-treated samples, onion slices were pre-dried until a moisture content of 0.3 g H_2O/g db. Pre-dried samples were submitted to DIC treatment following a two-variable central composite rotatable experimental design. Studied DIC operating parameters were: "P" = 0.20–0.5 MPa and "t" = 5 and 15 s. To evaluate the decontamination rate, total count plate method was used. Decontamination rate was expressed by log **F** of total microorganism content. Results showed that, under the selected operating conditions of DIC, the ratio log *F* ranged between 1.7 and 3.9. According to the statistical analysis, the higher the steam pressure "P", the higher the log *F* rate reduction of microorganism. Under 0.35 MPa and 15 s, DIC treatment allowed the total microorganism content to reduce from 875,000 germs/g (fresh onions) to 100 germs/g.

Debs-Louka et al. [67] evaluated the impact of DIC on the microbial destruction of *Bacillus stearothermophilus* spores. Results showed that DIC treatment enhance the spore destruction (**Figure 8**), giving a $D_{121.1°C}$ = 2.6 min and a thermo-resistance *z* of 7.6°C, instead of 4.2 min and 8.8°C, respectively [68]. Thermo-mechanical effect of DIC treatment leads the explosion of microorganism cells (vegetative or spores forms). Then, the higher the amount of generated steam within the cell and the smaller the pressure drop time, the more efficient the decontamination.

Finally, even if the correct selection of DIC operating conditions, steam pressure and treatment time have performed good results to decontaminate food products,

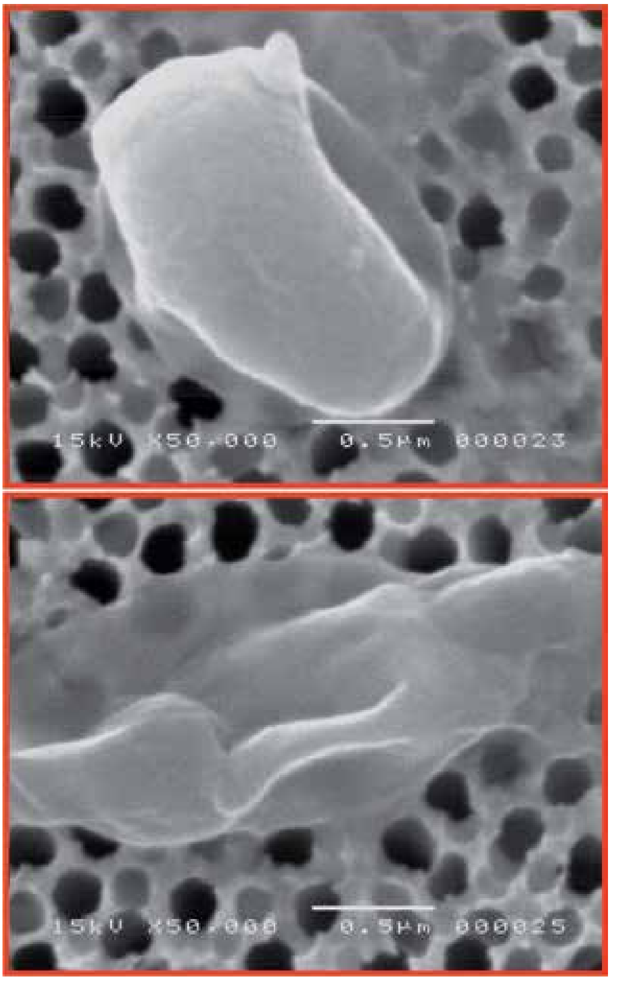

Figure 8.
The impact of DIC on spore destruction is coupled thermal and mechanical (explosion) effects.

Multi-Cycle DIC decontamination has demonstrated that decontamination ratio could not only be in function of temperature and time, but also in function of the number of DIC cycles. A study on skim milk powder showed an improvement decontamination concerning spores as well as vegetative forms [28].

5. Closing conclusion

By processing agricultural raw materials as functional food, industries must adopt processes able to satisfy various categories such as (1) preservation of functional properties, (2) good organoleptic quality of products, (3) safety and hygiene by perfectly bacterial decontamination and removing of fungi, (4) low energy consumption, (5) low time processing, and (6) friendly environmental processes. Convective airflow drying (CAD) is the most popular method to increase the shelf life of food products. However, traditional methods such as sun, solar, and airflow drying do not yield good-quality products, and else products run the risk to be contaminated with dust, dirt, insects, birds, microorganisms, fungi able to produce aflatoxins, etc. In this regard, various drying emerging technologies have been developed to improve the quality of dried products and to reduce the time of processing. Nevertheless, it is essential to understand the main drawbacks of drying processes to really improve them. Then, a fundamental study of drying phenomena becomes essential. In this work, the mass and heat transfer phenomena during drying have been described, and the internal mass transfers were identified as the key limiting process of the whole operation. Concerning this matter, the instant controlled pressure drop technology (DIC) becomes a strategic technology for drying different types of natural functional foods. Thanks to its capacity to generate new porous structures on the food products, DIC allows surpassing the mass transfer limiting process. Hence, DIC technology could reduce the drying processing time, which leads a significant improvement in product quality. Moreover, thanks to its thermo-mechanical effect, it could also achieve perfectly bacterial decontamination of both vegetative forms and spores. DIC treatment allows to improve the availability of antioxidants, to reduce anti-nutritional, and allergic factors of foodstuffs. Finally, DIC treatment is low energy cost and friendly to the environment.

Nomenclature

A_{eff}	effective exchange surface between the product the external air (m^2)
a_w and a_{ws}	water activity for the whole material and at the surface, respectively
c_{ps}	specific heat capacity of the dried matter (J kg^{-1} K^{-1})
c_{pw}	specific heat capacity of the liquid water (J kg^{-1} K^{-1})
D_{eff}	effective Diffusivity (m^2 s^{-1})
ε_{abs}	absolute expansion (%)
φ	heat transfer (W m^{-2})
h	coefficient of convection heat transfer (W m^{-2} K^{-1})
k_p	coefficient of permeability mass transfer (m s^{-1})
K	Kelvin
λ_{eff}	thermic conductivity of the product (W m^{-1} K^{-1})
L_v	latent heat of evaporation (J kg^{-1})
M_w	molar mass of water (g mol^{-1})
P	vapor pressure surrounding the material
p_{wa}	vapor pressure of the air at a considered point (Pa)
p_{ws}	vapor pressure at the surface material (Pa)
p_{wT}	vapor pressure at the equilibrium temperature T (Pa)
dQ/dt	heat flow (W m^{-2})
dm_v/dt	vapor mass flows (kg m^{-2} s^{-1})
ρ	apparent density (kg m^{-3})
ρ_s	apparent density of dry material (kg m^{-3})
ρ_w	apparent density of water in the material (kg m^{-3})
ρ_v	density of vapor (kg m^{-3})
R	universal constant (8.314 J mol^{-1} K^{-1})
r	capillary radius (m)
t	time (s)
T	temperature
T_a	air temperature at a considered point
T_s	product temperature at the surface
v_w	absolute velocity of water flow within husks (m s^{-1})
v_s	Absolute velocity of solid porous medium (m s^{-1})
ν_v	kinematic viscosity (m^2 s^{-1})

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Edited by Vasiliki Lagouri

"Let food be thy medicine and medicine be thy food" said Hippocrates, the father of medicine approximately 2500 years ago. Is food also medicine? Are products that intend to cure diseases medicinal products and not food? Do we know the combination of foods or food components with functional properties that can help promote the well-being or reduce the risk of chronic diseases? In general terms, all foods are functional because they provide the nutrients necessary for a healthy diet. So what are the components that functional foods have beyond their nutrition value? What is the definition of functional foods? What scientific research is needed to validate health claims for functional foods? This book will provide answers to all of these questions. It is important for scientists to have the opportunities to study the relationship between a food type or a food active component and the improved state of health or reduction of diseases. The communication of health benefits to consumers is of critical importance so that they have the knowledge to make informed choices about the foods they eat and enjoy.

Published in London, UK

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ISBN 978-1-83881-151-8