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11. Functional Foods and Phytochemicals

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Abstract:

Functional foods and phytochemicals are both interconnected concepts that have gained popularity among people in recent years because of the health benefits they provide when eaten in the right quantities as part of our routine diet.

Functional food is defined as natural or processed food containing biologically active substances that provide health benefits in addition to nutritional value. Phytochemicals, on the other hand, are organically occurring bioactive compounds that have a variety of biological activities, including neuroprotective, anti-diabetic, antioxidant, anti-cancer, and anti-inflammatory properties.

Phytochemicals can be found in various functional foods, such as fruits, vegetables, grains, nuts, seeds, herbs, spices, and beverages. According to a recent report of WHO noncommunicable diseases (NCDs) such as type 2 diabetes, heart disease and cancer contribute to 41 million yearly deaths, or 74% of all fatalities worldwide and the main causative factors claimed for it, is unhealthy lifestyle, especially poor eating habits.

Fruits, vegetables, Indian herbs and spices, grains, nuts, and beans are examples of plant-based foods which are rich in Vitamins, minerals, fiber, antioxidants, omega-3 fatty acids, & phenolic compounds that help the body to fight against chronic diseases including cancer, cardiovascular disease, and gastrointestinal related illness. This chapter delivers an overview of the definition, classification, sources, and health benefits of functional food and phytochemicals.

Keywords:

Functional foods, Phytochemicals, Flavonoids, Bioactive compound, Nutraceuticals.

11.1 Introduction:

Food is a term that refers to the chemicals that are needed for a variety of critical tasks, including energy production, nutritional provision, and support for numerous metabolic processes, as well as body growth and maintenance. Earlier, nutrition science was primarily concerned with avoiding vitamin deficiencies and encouraging healthy body growth. Earlier, nutritionists were primarily concerned with ensuring that individuals received adequate nutrients to support their health and growth (Doyon & Labrecque, 2008). In the past few decades, research on nutrition has expanded its focus to include both nutrients and non-nutritive compounds and their potential impact on disease prevention and risk reduction (Crowe & Francis, 2013). A direct association between foods and one's health has resulted in several scientific investigations to determine the impact of foods or dietary elements on distinct bodily processes (Kaur & Das, 2011).

Many individuals struggle to achieve the goal of eating for health and wellness due to the complicated marketplace and conflicting information from various sources. However, the desire for a healthy and pain-free lifestyle has led to the availability of functional foods that contain higher levels of bioactive compounds or physiologically active nutrients and non-nutrients which are known to have beneficial effects on health (Crowe & Francis, 2013). According to recent statistics, noncommunicable diseases (NCDs) are prevalent in India and are likely to rise in the future years. NCDs are expected to account for around 67% of the illness profile in the country by 2030 (Kanwal, 2022). In India, the proportion of mortality caused by NCDs has climbed of nearly 163% from year 1990 to 2016. The most common NCDs include cardiovascular illnesses, cancer, diabetes, and stroke. Furthermore, the use of food as medicine has been practiced for millennia and is not a new phenomenon. Although Hippocrates did not start the functional foods movement, he did state roughly 2,500 years ago that "food should be used as medicine and medicine should be used as food" (Meyer, 1998). Even though genetics have an influence in the development of some diseases, the majority of them may be avoided or decreased by living a healthy lifestyle that incorporates a suitable food, physical exercise, weight control, and a healthy environment. People can also improve their diet's health-promoting features by taking supplements or eating meals enriched with health-promoting ingredients. A nutritious diet can help avoid malnutrition as well as noncommunicable illnesses such as heart disease, obesity, and cancer. Whole grains, vegetables, fruits, and plant-based diets lower the risk of heart disease and can aid with weight loss. Individual qualities, cultural environment, and locally accessible foods all influence what constitutes a healthy diet (Baker et al., 2022; Health, 1989; world health organization, 2020). There is growing evidence from several types of research, including epidemiological, pre-clinical, and clinical investigations, suggesting there is a substantial link between food habits and quality of life. This research demonstrates that both essential and non-essential components of our meals can influence growth, development, performance, and prevention of illness (Milner, 2000). Likewise, the majority of food items possess functional properties that contribute to enhancing overall well-being. Functional components can be found in various food groups, including fruits, vegetables, grains, meat, fish, and dairy products. It is important to acknowledge the diverse array of naturally occurring compounds derived from plants and animals that contain active elements, which actively contribute to physiological functions. Therefore, these substances deserve special awareness for their efficacy in promoting and maintaining good health (Essa et al., 2023).

11.2 Definition of Functional Food:

A Japanese scholarly group proposed the concept of functional food in the early 1980s. The first functional foods regulation was introduced in the same decade under the acronym FOSHU, which stands for "Foods for Specified Health Use." Functional foods were initially characterized as foods capable of regulating biological activities and hence assisting in illness prevention (Shimizu, 2003).

The FSGs law covers certain food groups that are thought to be important for human health, especially among vulnerable populations. These food classes include processed cereal-based diets, baby food, weight reduction meal replacements, infant formula, follow-up formula, and specialized medicinal meals (D. M. Martirosyan & Singharaj, 2016). Furthermore, a functional food is both a food component or a natural food that has undergone a technical or biotechnological addition or extraction procedure. The consequences must be portrayed in quantities that are reasonably expected to be ingested as part of the food (Castillo, M., Iriondo-DeHond, A., & Martirosyan, 2018). These functional foods are intended to prevent, treat, or manage chronic illnesses or their related problems (D. Martirosyan & Miller, 2018). Definitions of functional foods given by different organizations are shown in Table 11.1.

Table 11.1: Definitions of Functional Foods Given by Different Organizations

Source	Functional food definition	References
Functional Food Center (FFC)	"Adequate & non-toxic amounts of natural or processed foods containing either identified or unidentified biologically active components that have been scientifically demonstrated to offer health benefits for the prevention, management, or treatment of chronic illnesses are recommended."	(D. Martirosyan & Miller, 2018)
International Life Sciences Institute (ILSI)	“Foods that provide health benefits beyond basic nutrition due to the presence of physiologically active dietary components.”	(Crowe & Francis, 2013)
European Food Safety Authority (EFSA)	"A functional food is a food that, in addition to providing basic nutrition, positively impacts specific functions in the body, resulting to an improved state of health and well-being or a lower risk of disease." It could be a natural food or one that has been altered through technological or biotechnological processes, such as the addition or removal of certain components. To be designated as a functional food, it must demonstrate its therapeutic effects in quantities typical of a regular diet."	(D. M. Martirosyan & Singharaj, 2016)

Source	Functional food definition	References
Institute of Food Technologists (IFT)	"Foods and food components which offer benefits to health beyond basic nutrition are products that provide essential nutrients in quantities that frequently exceed normal requirements for normal functioning, health, and development." They also include other bioactive components that are beneficial to general health."	(MacAulay, J., Petersen, B., 2005)
The European Commission Concerted Action Group on Functional Food Science in Europe (FUSOSE), The International Life Sciences Institute	"Food that qualifies as 'functional' is defined as food that has been scientifically proven to positively impact one or more bodily functions, surpassing basic nutritional requirements. Such food contributes to an enhanced state of health and well-being or lowers the risk of certain conditions."	(Blades, 2000)
Food and Nutrition Board (FNB)	"A functional food is defined as a product consist of potentially helpful ingredients, which includes "any altered food or food component that has the potential to provide a health benefit beyond the conventional nutrients it contains."	(Havel et al., 1994; Kruger & Mann, 2003)
US General Accounting Office (GAO)	Food that purports to offer additional health advantages beyond fundamental nourishment.	(Noonan, 2004)
Health Canada	Functional foods are foods that mimic traditional diets while providing physiological benefits.	(Shahidi, 2009)

Functional foods are frequently used interchangeably with nutraceuticals. The two names, however, are not equivalent. Functional foods are items that look like regular foods but have established physiological advantages. Nutraceuticals, on the other hand, are products obtained from foods that are used medicinally in the form of pills, capsules, or liquids and have exhibited physiological benefits. Functional foods are whole foods that have been transformed or enhanced to give a specific health advantage, whereas nutraceuticals are isolated components or extracts from foods that have been found to provide a specific health benefit. Additionally, Nutraceuticals are chemicals derived from whole foods that have both medicinal and nutritive properties, whereas dietary supplements are products that include one or more dietary elements such as vitamins, minerals, herbs, or other botanicals.

11.3 Types of Functional Foods:

The main types of functional foods are conventional foods and modified foods (shown in Figure 11.1) Conventional food items are in their original, unaltered form and have not underwent any modifications.

Convectional foods can be further classified as plant based conventional foods and animal based conventional foods such as vegetables, dairy, legumes, fruits, fish, as well as grains, which possess noteworthy health benefits. Conventional functional food refers to food made from natural or whole-food ingredients. They contain beneficial substances like vitamins, minerals. healthy fatty acids, and antioxidants. The traditional plant based conventional foods include dry fruits, fresh fruits, leafy green and non-leafy vegetables, legumes, seeds, nuts, herbs & spices. Such as brown rice, buckwheat, kiwi, pears, peaches, apples, cashews, chia seeds, chickpeas, oats, salmon, kimchi, cod, tempeh, kefir, turmeric, ginger, cinnamon, green tea, coffee, black tea, kale, spinach, pistachios, flaxseeds, almonds, hemp seeds, black beans, barley and many more. While animal based conventional foods are milk, eggs, fish and meat. A safe and organic diet prioritizes bioactive compounds while minimizing harmful substances such as prolonged toxins, metabolites, pesticides, and fertilizers. Opting for organic and whole food promotes a balanced lifestyle and lowers the likelihood of health issues (Arshad et al., 2021; Di Renzo et al., 2020). Modified foods, on the other hand, refer to food products that have been modified to enhance or supplement with specific nutrients to promote health benefits. In these additional nutrients, like probiotics, fiber, vitamins, and minerals are added for specific health benefits. These include fortified juices, dairy products like milk and yoghurt, fortified milk substitutes like coconut,

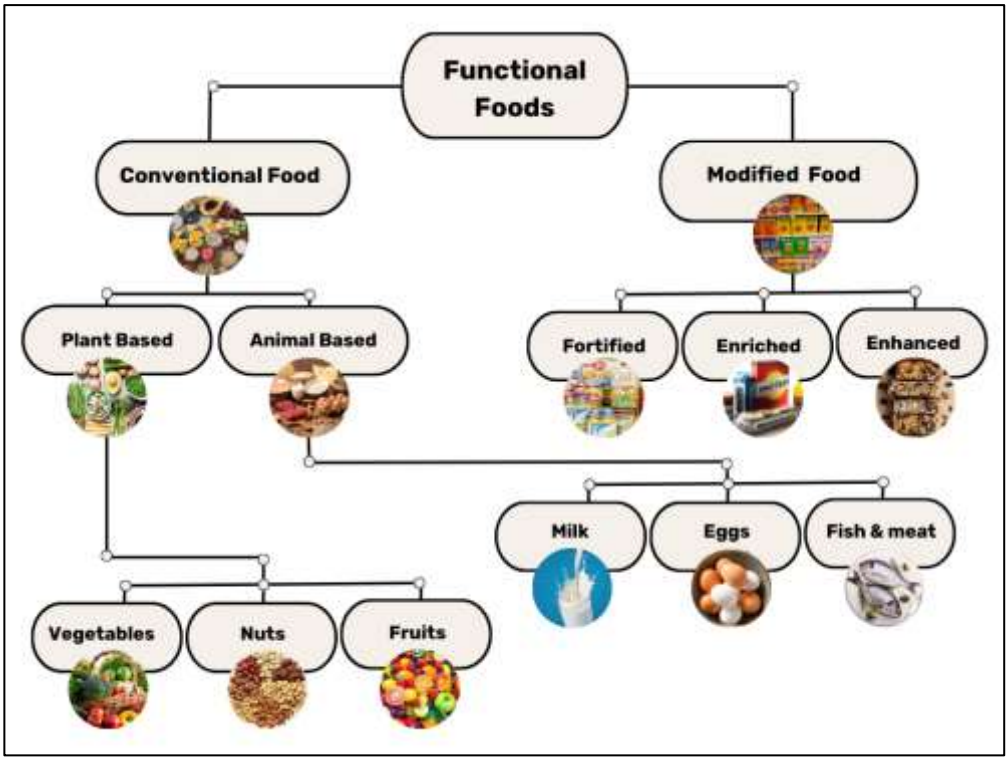

Figure 11.1: Classification of Functional Food

almond, cashew, and rice milk, fortified grains like pasta and bread, fortified granola and, cereal and fortified eggs. Modified foods can be divided into fortified, enriched & enhanced foods.

Fortification is the process of adding vitamins or nutrients that aren't typically found in that food. Fortification can be employed to fix or avoid prevalent nutrient intake deficiencies, to balance a diet's total nutrient profile, recover nutrients lost during processing, or to attract consumers who are interested in enhancing their diet. On the other hand, food enrichment is the process of reintroducing micronutrients lost while processing into a food product. Some nutrients may be lost or eliminated during food processing, especially in the case of refined grains. In order to restore or raise the levels of certain nutrients in the food to match recommended dietary standards, enrichment is used. The presence and quantity of the additional nutrients are noted on the labels of enriched foods. Foods that have been enhanced beyond their natural state in order to offer more functional or health benefits are referred to as enhanced foods (Siró et al., 2008). Incorporating bioactive chemicals, antioxidants, probiotics, or other substances that help with boosting health or enhancing particular physiological functions are just a few examples of enhancement approaches. The elimination or reduction of undesired ingredients, such as lowering the sodium or sugar content, may also be a part of enhanced foods. The phrase "enhanced foods" can be used broadly to refer to a variety of products, each with unique additions. These foods may have labels promoting certain health advantages or useful qualities.

11.4 Functional Food and Phytochemicals:

As discussed earlier Functional foods are foods that offer health benefits in addition to basic nutrition. Apart from that, they often contain phytochemicals, which are naturally occurring compounds found in plants. There is a strong correlation between functional foods and phytochemicals. Many functional foods contain high levels of phytochemicals, which are believed to be responsible for their health benefits. For instance, blueberries are a functional food that contains high levels of phytochemical named anthocyanin. These substances, which give the berries their blue color have been found to have anti-inflammatory and antioxidant qualities. In the same way, the isoflavone and other compounds found in soybeans make them a functional food. Numerous health advantages of these substances have been demonstrated, including a decreased risk of heart disease and some cancers. Tomatoes are another example of functional foods that include phytochemicals. Lycopene, a phytochemical found in tomatoes, has been demonstrated to have antioxidant qualities and may lower the risk of some types of cancer. Additionally, allicin-containing garlic and catechin-containing green tea. These phytochemicals have been proven to have anti-inflammatory and anti-cancer effects.

11.5 What Are Phytochemicals?

Phytochemicals, commonly known as phytonutrients, are naturally occurring active compounds abundant in various food sources such as vegetables, fruits, nuts, seeds, tea, whole grains, legumes, and dark chocolate. While there exists a vast array of phytochemicals, only a limited selection has been discovered and characterized from plants (Cao et al., 2017; Singh & Chaudhuri, 2018). Phytochemicals found in food are diverse and plentiful, encompassing various types such as carotenoids, polyphenols, coumarins, flavonoids, isoflavones, indoles, lignans, catechins, organosulfures, phenolic acids, isothiocyanates, stilbenoids, phenylpropanoids, saponins, ginsenosides, anthraquinones (Cao et al., 2017; Zhao et al., 2018). The majority of food items, including whole grains, fruits, vegetables, and nuts, contain phytochemicals. These phytochemicals, whether

individually or in combination, have significant potential for therapeutic purposes in the treatment of various diseases. The single fruit or vegetable can contain hundreds of theses phytochemicals. The presence of phytochemicals in food provide protection against numerous diseases such as cancer, heart disease, diabetes, hypertension, inflammation, infections caused by microorganisms, viruses, parasites, mental disorders, spasms, ulcers, osteoporosis, and related conditions (Srilakshmi, 2018; Thakur et al., 2020).

11.5.1 Types of Phytochemicals:

Phytochemicals can be classified into different groups, including polyphenols, alkaloids, terpenoids, organosulfur compounds, and nitrogen-containing compounds, depending on where they are produced in plants or food source (Carrera-Quintanar et al., 2018; Lara et al., 2020; Liu, 2004). Dietary phytochemical classification with food sources are shown in Figure 23.2. Polyphenols are the most abundant category. Each type of phytochemical is further described below in depth along with food sources and therapeutic benefits.

A. Polyphenols: Polyphenols are a diverse group of compounds found in many foods derived from plants, including vegetables, fruits, nuts, seeds, and grains. They are well-known for their antioxidant properties, which aid in the protection of cells from free radical damage. Polyphenols may also play a role in regulating obesity by modulating lipogenesis and regulating inflammatory cytokines and adipokines involved in the mechanisms of this disease (Martinez et al., 2022). Polyphenols are sub categorized into 6 types phenolic acids, coumarins, stilbenes, tannins, curcumins and flavonoid.

a. ***Phenolic Acids:***Phenolic acids have two subtypes namely hydroxybenzoic acid and hydroxycinnamic acid. Fruits, including tropical fruits like blackberry, raspberry and white vegetables like potatoes and onion are good sources of hydroxybenzoic acid. Kiwi, plum, carrots, wheat, eggplant, lettuce are some natural sources of hydroxycinnamic acids (Kaseke et al., 2021). They offer several health benefits, including antioxidant and anti-inflammatory properties, which protect against oxidative stress and chronic diseases. Phenolic acids also contribute to improved cardiovascular health by positively influencing lipid profiles, blood pressure, and insulin resistance. Additionally, phenolic acids can positively impact gut health by influencing the composition of the gut microbiome. It is vital to keep in mind that the health advantages of hydroxycinnamic acids are dependent on a variety of factors, including food processing, dietary intake, bioaccessibility, and pharmacokinetics.
b. ***Coumarins:*** Coumarins can be found in citrus fruit varieties like oranges, lemons, limes, grapefruit, strawberries, cherries, carrots, and tomatoes. Some types of cinnamon contain higher amount of Coumarins. Coumarins act as antioxidants, lower cardiovascular disease risk, suppress cancer cell growth, manage diabetes and hypoglycemia, act as hepatoprotectants, reduce inflammation, and provide photoprotection. However, it's important to note that the specific health benefits depend on the type of coumarin and the plant source.
c. ***Stilbenes:*** Stilbenes are a group of polyphenolic compounds that are naturally found in various dietary sources such as grapes, berries, peanuts, almons, red wine (Tsai et al., 2017). They have intricate structures with various numbers of stilbenes and polymeric types and are distinguished by the presence of a 1,2-diphenylethylene nucleus. Stilbenes

have diverse bioactivities including anti-tumor, anti-oxidant, anti-inflammatory, anti-fungal, anti-diabetic and anti-Alzheimer's disease effects.

d. ***Curcumins:*** Curcumin is a phytochemical agent that can be extracted from the powder rhizome of the plant Curcuma longa Curcumin has been reported to possess a wide range of pharmacological properties such as antimicrobial, antioxidative, anti-inflammatory, anticancer, and lipid-lowering properties

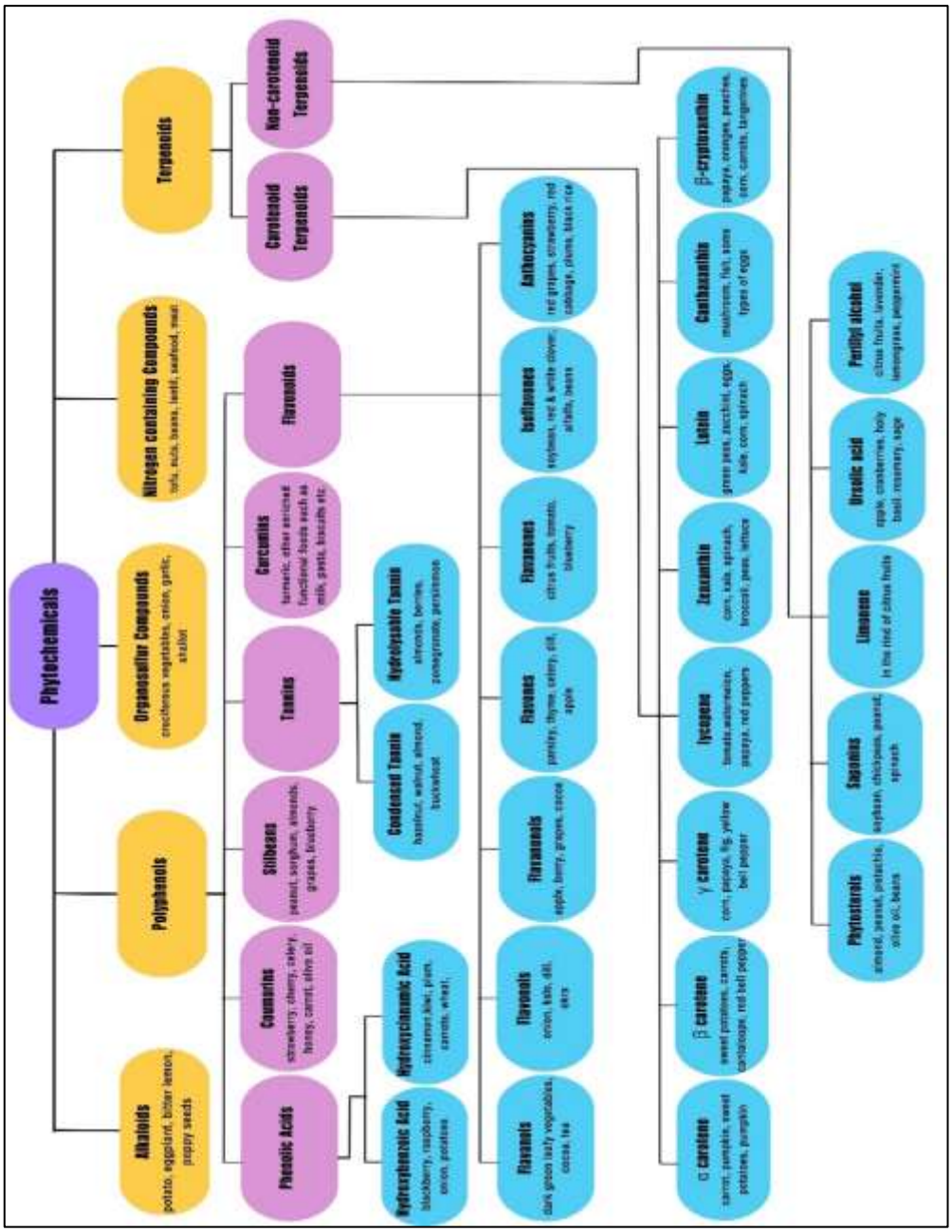

Figure 11.2: Dietary Phytochemical Classification with Food Sources

(Ba & Fá, 2019; Nosrati-Oskouie et al., 2022). Foods that may contain curcumin include mustard, cheese, and butter. However, the amount of curcumin in these foods may be relatively low, and it may be difficult to consume enough curcumin through diet alone to achieve its potential health benefits. There are curcumin fortified foods products as well such as buffalo ghee incorporated with curcumin, macaroni fortified with green tea and turmeric curcumin extract, kulfi, butter cookie and many more.

e. ***Tannins:*** Tannins are highly reactive and eco-friendly, and can be found in various foods, including green coffee beans, fruits, and dates. Tannins can also affect the bioavailability of iron in the diet by binding to it, which can reduce the bioavailability of iron (Gaffney et al., 2004). However, tannins can also have antioxidant and antibacterial properties, making them useful for wound healing applications. They are further classified into two categories. Condensed Tannin & Hydrolysable Tannin. Some foods that are rich in condensed tannins include hazelnuts, walnuts, almonds, buckwheat and buckwheat grits. Hydrolysable tannins are a type of polyphenol found in almonds, berries, soybean, pomegranate, persimmon, grapes and so on.
f. ***Flavonoids:*** Many plants, fruits, vegetables, and leaves contain phytochemical compounds called flavonoids. Flavonoids have a number of health benefits, including antiviral, anti-inflammatory, antioxidant, anticancer, cardioprotective and neuroprotective properties. The kind of flavonoid, its (potential) method of action, and its bioavailability all affect these functions within the body (Ullah et al., 2020). There are seven different types of flavonoids found in food: flavanols, flavonols, flavanonols flavones, flavanones, isoflavones, and anthocyanins (Santhiravel et al., 2022).
g. ***Flavanols:***Flavanols are a class of secondary plant metabolites that exhibit several beneficial health properties, including acting as antioxidant, anticarcinogen, cardioprotective, anti-microbial, anti-viral, and neuroprotective agents (Luo et al., 2022). Flavanols are found in many foods, including cereals, legumes, fruits, vegetables, forages, cocoa, grapes, and apples and many more.
h. ***Flavonols:*** Flavonols are a type of flavonoid, which are compounds found in many plant-based foods that have antioxidant properties. Some foods that are rich in flavonols include kale, dill, apples, broccoli, onions, and tofu. Flavonols have been studied for their potential health benefits, including reducing the risk of cancer and degenerative diseases.
i. ***Flavanonols:*** Flavanonols are a subclass of flavonoids, which are a group of plant compounds that have antioxidant properties and are associated with various health benefits. Apples are a good source of flavanonols, particularly the flavan-3-ols catechin and epicatechin. Berries, such as blueberries, raspberries, and strawberries, are rich in flavanonols, including quercetin and myricetin. Grapes and Cocoa are a good source of flavanonols, particularly catechin and epicatechin.
j. ***Flavones:*** Flavones are a type of flavonoid, which are antioxidants of plant origin with a beneficial role in the prevention of different diseases. flavones are particularly rich in green leaf herbs, such as dill, parsley, and celery leaves. The main food sources of flavonoids were found to be apples, tea infusions, onions, strawberries, and oranges.Epidemiological studies have linked dietary flavonoid consumption to lower risk of various cancers, including breast, gastric, colorectal, and prostate cancers.
k. ***Flavanones:*** Flavanones are a type of flavonoid, which are a group of plant compounds that have antioxidant and anti-inflammatory properties. There are several foods that are rich in flavanones, including citrus fruits like lemons, oranges, and grapefruits. Other

foods that are rich in flavanones include tomatoes, strawberries, and blueberries (Rodríguez-García et al., 2019). Flavanones have been shown to have potential health benefits, including conferring neuroprotection and reducing the risk of cardiovascular disease.

l. ***Isoflavones:*** Isoflavones are found in high amounts in soybeans and soy products, as well as in other legumes and some fruits and vegetables. Isoflavones have been the subject of many studies due to their potential health benefits, such as reducing the risk of certain cancers and improving bone health. They have also been investigated for their pharmacological properties, such as their ability to inhibit xanthine oxidase and cyclooxygenase-2 enzymes, which are involved in gout and inflammation.

m. ***Anthocyanins:*** Anthocyanins are a type of water-soluble pigment in the phenolic family. They are accountable for the red, purple, and blue colors found in vegetables and fruits. Anthocyanins are abundant in vegetables and fruits, with berries, grapes, and a few tropical fruits having the highest concentrations. Additionally, they can be found in cereal grains, roots, and tubers which vary in color from red to purplish blue. The health benefits of anthocyanins have been widely described, especially in the prevention of diseases associated with oxidative stress, such as cardiovascular and neurodegenerative diseases.

B. Alkaloids: A class of naturally found organic substances known as alkaloids primarily have basic nitrogen atoms. Caffeine, morphine, and nicotine are a few typical alkaloids. Some examples of foods containing alkaloids are: potato, eggplant, bitter lemon, poppy seeds, chocolate, tea and coffee. Some alkaloids have therapeutic properties and are used to treat various health conditions (Heinrich et al., 2021). Excessive consumption of certain alkaloids can lead to toxic effects, such as liver damage, neurological disorders, and even death (Kamarul Zaman & Mohamad Azzeme, 2018).

C. Organosulfur Compounds: Organosulfur compounds are found in many different dietary sources, but two main sources are alliaceous and cruciferous vegetables. Alliaceous vegetables include garlic, onions, and shallots, while cruciferous vegetables include broccoli, kale, and cauliflower. Studies have shown that the consumption of these vegetables is beneficial for heart diseases, tumors and other chronic diseases (Mi ekus et al., 2020; Verma et al., 2023). Organosulfur compounds have anti-inflammatory properties and play a significant role in preventing various human pathological progressions, including chronic inflammation, by decreasing inflammatory mediators.

D. Nitrogen-Containing Compounds: Nitrogen is present in variety of foods in the form of proteins, nucleotides, choline, free amino acids, and creatine. Foods rich in nitrogen-containing compounds are broccoli, spinach, kale, beet, nuts, tofu, seafood and meat. Furthermore, black soya bean, edible mushrooms, sorghum grain and black chia seeds are rich in nitrogen-containing compounds. Nitrogen-containing compounds have been shown to have potential health benefits, including antioxidant, anti-inflammatory, anti-proliferative, anti-diabetic, and anti-atherogenic activities.

E. Terpenoids: Terpenoids are biologically active compounds with a wide range of pharmacological effects, involving anticancer activity. Terpenoids have anti-tumor, anti-inflammatory, anti-bacterial, anti-viral, and anti-malarial properties, as well as the ability to

favor transdermal absorption, prevent and manage cardiovascular disease, and have hypoglycemic properties. They are classified into two types: carotenoid terpenoids and non-carotenoid terpenoids. Carotenoid terpenoids have been linked to a variety of health benefits, including a lower risk of neurodegenerative diseases, cardiovascular disease, type 2 diabetes, obesity, and few types of cancer. Carotenoids have bioactive properties like antioxidant, anti-inflammatory, and autophagy-modulatory activities, which contribute to their protective function and have been associated with the treatment and prevention of various diseases. α carotene, β carotene, γ carotene, lycopene, Zeaxanthin, Lutein, Canthaxanthin and β-cryptoxanthin are the subcategories of carotenoid terpenoids (Santhiravel et al., 2022).

a. ***α carotene:*** Alpha-carotene is a provitamin A compound, meaning it can be transformed into vitamin A in the body. Foods that are rich in alpha-carotene include various fruits and vegetables, like carrots, pumpkins, sweet potato, and dark leafy greens like spinach and kale. These foods are often orange or yellow in color due to their high carotenoid content. dietary intake and tissue levels of carotenoids, including alpha-carotene, have been associated with a reduced risk of several chronic diseases such as cardiovascular diseases, type 2 diabetes, obesity, brain-related diseases, and some types of cancer.
b. ***β carotene:*** It is a vitamin A precursor that can be converted in the body to retinol, the active form of vitamin A. Beta-carotene is abundant in vegetables and fruits, particularly those with yellow, red, and orange colors. Carrots, sweet potatoes, pumpkins, mangoes, apricots, spinach, kale, and red peppers are a few of the best sources. Beta-carotene is a powerful antioxidant that can defend cells from oxidative stress involved in several diseases. It can also help to prevent chronic diseases like type 2 diabetes, heart disease, obesity, and other metabolic syndrome. Beta-carotene is associated with decreasing adipocyte and body adipose tissue size, lower proinflammatory markers such as LDL-c and VLDL-c, and increase HDL-c. It can also improve insulin resistance and preserve insulin receptors, which can control oxidative stress involved in these diseases.
c. ***γ carotene:*** Gamma-carotene is a pigment found in corn, papaya, fig, yellow bell pepper. It belongs to the same family as beta-carotene, which is a well-known carotenoid with antioxidant properties. Gamma-carotene is less well-studied than other carotenoids, so its specific health benefits and effects on the body are less well-known.
d. ***Lycopene:*** Lycopene is a non-provitamin A carotenoid and it is currently unknown whether the beneficial effects are from the native structure of lycopene or its metabolic derivatives: lycopenals, lycopenols, and lycopenoic acids (Arballo et al., 2021). Lycopene is found in various foods, including red raw tomatoes, tomato juice, watermelon, pink and red grapefruits, red peppers, ketchup, etc. It is better absorbed when consumed with fats. Lycopene can have positive effects on many stages of atherosclerosis and can affect serum lipid levels, endothelial dysfunction, inflammation, blood pressure, and antioxidative potential.
e. ***Zeaxanthin:*** Zeaxanthin is a carotenoid that is yellow in color and is a member of the xanthophyll family of plant pigments. Zeaxanthin is found in kale, spinach, egg yolks, broccoli, savoy cabbage, peas corn, and parsley (Mrowicka et al., 2022). It offers benefits such as blue light filtering and antioxidant activities, which promote eye health. Additionally, it has been associated with reducing symptoms of colds and influenza in

older adults and may contribute to cardiovascular health by lowering the risk of cardiovascular disease.

f. ***Lutein:*** Lutein is one of the few carotenoids found in high concentration in the macula of the human retina. It is an organic pigment with nutritional benefits that can be found in parsley, kale, egg yolks, spinach, and foods fortified with lutein. Corn, zucchini, green peas, and other foods also contain lutein. Numerous positive health effects of lutein include antioxidant, anti-hypertensive, anti-inflammatory, anti-atherogenic, anti-cancer, anti-ulcer, and anti-diabetic properties (Kim & Park, 2016). Furthermore, it is used to prevent eye diseases including age-related macular degeneration (AMD), cataract, and retinitis pigmentosa.

g. ***Canthaxanthin:*** Canthaxanthin is a reddish-orange xanthophyll with strong antioxidant activity and higher bioavailability than carotenes (Naz et al., 2021). Some types of eggs, mushroom, seafood, red papers are few food sources having canthaxanthin. Canthaxanthin offers several potential health benefits, including antioxidant properties that help scavenge free radicals and protect cholesterol from oxidation. It can also reduce oxidative stress in the body. Additionally, canthaxanthin exhibits immunomodulatory activity, increasing the growth and performance of immune competent cells. Furthermore, it plays a role in gap junction communication. While it is generally considered safe in small amounts, consuming large amounts of canthaxanthin can cause a condition known as canthaxanthin retinopathy, which can affect vision.

h. ***β-cryptoxanthin:*** β-Cryptoxanthin is a carotenoid that offers health benefits, including reduced cardiovascular disease risk and decreased osteoporosis and hip fracture risk. β-Cryptoxanthin may regulate cellular functions, but it's important to note that carotenoids can act as free-radical scavengers and may behave as pro-oxidants in high oxygen concentrations. It is present in many vegetables and fruits, particularly those that are orange or red in color. For example, β-cryptoxanthin is found in high concentrations in sweet red peppers, persimmons, carrots, peaches, oranges, and papayas.

i. ***Non-Carotenoid Terpenoids:*** Non-carotenoid terpenoids are a diverse group of organic compounds that belong to the larger class of terpenoids. There are 5 subtypes of it namely Phytosterols, Saponins, Limonene, Ursolic acid and Perillyl alcohol.

j. ***Phytosterols:*** Phytosterols are plant-based compounds with various health benefits. They can reduce cholesterol absorption, lower total cholesterol levels, reduce the risk of cardiovascular diseases and have other pharmacological properties. They also have potential benefits for cancer prevention and possess anti-inflammatory and antioxidant properties. Other health-promoting effects of phytosterols include anti-obesity, anti-diabetic, anti-microbial, and immunomodulatory effects. Phytosterols can be found in nuts, seeds, vegetable oils (especially olive oil), whole grains, legumes, and fruits & vegetables (like avocados & broccoli). Fortified foods like margarine, orange juice, and yogurt may also contain phytosterols. However, it's important to consume them in moderation to avoid interfering with the absorption of fat-soluble vitamins and nutrients.

k. ***Saponins:*** Saponins are widely distributed in many foods and raw food materials, but occur primarily in peanut and spinach, legumes such as soybean, chickpea. Saponins have a range of medicinal properties, such as anti-inflammatory, immune stimulating, hypo-cholesterolemic, hypoglycemic, antifungal, and cytotoxic effects.

l. ***Limonene:*** Limonene is a monoterpene that possesses multiple biological properties including antioxidant, anticancer, antinociceptive, anti-inflammatory, &

gastroprotective characteristics. Limonene also demonstrates neuroprotective potential by mitigating oxidative stress, inflammation, and regulation of apoptotic cell death. It shows promise in treating neurodegenerative disorders like Alzheimer's disease, multiple sclerosis, epilepsy, anxiety, and stroke (Eddin et al., 2021). It is a volatile compound present in various fruits specially in the rind of fruits like berries, grapefruit, lemon, and cashew nuts.

m. ***Ursolic acid:*** Natural substance known as ursolic acid has a variety of medicinal benefits, such as antioxidant, anti-inflammatory, anti-apoptotic, & anti-carcinogenic effects. It has shown potential in treating various diseases such as metabolic disorders, heart conditions, cancer, and neurological disorders. Ursolic acid also has antimicrobial properties against bacteria, HIV, HCV viruses, and the malaria-causing plasmodium protozoa. It acts on different tissues and organs by suppressing cancer cell signaling, improving insulin signaling in adipose tissues, reducing cardiac damage, decreasing brain inflammation, increasing antioxidant levels in the brain, reducing liver damage, and enhancing skeletal muscle function. Ursolic acid is present in apple peel, cranberry juice, grape skin, holy basil, rosemary, thyme, oregano, sage, and other herbs.(Chan et al., 2019)

n. ***Perillyl alcohol:*** Perillyl alcohol is a monoterpene that is found naturally in cherries, mint, and lavender, in the essential oils of citrus fruits, such as oranges and lemon. Perillyl alcohol has antidiabetic potential and can reduce and normalize blood glucose levels in high-fat diet and low-dose streptozotocin induced diabetic rats. It exhibits antifungal properties and is linked to opioids. It also has increased antiproliferative activity in lung cancer, melanoma, and fibrosarcoma cells, with no significant adverse health effects.

Majority of the phytochemicals have a very low bioavailability in the human body in comparison to micro- and macronutrients because of their convoluted chemical makeup and ability to be broken down. It is significant to note that a variety of factors, such as pH, light, temperature, water activity (aw), and conditions of storage impact the stability of bioactive compounds and that certain processing methods can cause these substances to degrade. To increase the bioavailability of a specific compound, it must be consumed in a specific manner or after processing or with other supporting foods that enhance the absorption, digestion, and distribution of specific phytochemicals and this requires knowledge. Anything in excess or consuming them exclusively while ignoring other foods can be dangerous to one’s health.

11.6 Conclusion:

Functional foods are natural or processed food having a quality of enhancement of health and disease prevention. They are mainly of two types conventional foods and modified foods. Majority of functional foods which have medicinal health benefits contain phytochemicals. Phytochemicals are the reason for medicinal properties of functional foods majority of the times. Phytochemicals are non-essential, nonnutritive chemical compounds found in plants as their secondary metabolites as defense system. In this chapter detailed phytochemical classification with food sources are given. Phytochemicals gives many health benefits to human body such as reducing risk of chronic diseases, reducing the risk of chronic non-communicable diseases (NCDs), improving gut health, providing antioxidant, anti-inflammatory benefits, improving immune system function, protection

against cell and DNA damage, reducing inflammation, slowing down growth rate of some cancer cells, regulation of hormones. Although these phytochemicals and the foods that are having it have medicinal health benefits, it should not be considered as ultimate magical chemical or treatment. All foods and phytochemicals are best effective when taken in moderation and with balanced nutritious diets.

11.7 References:

1. Arballo, J., Amengual, J., & Erdman, J. W. (2021). Lycopene: A Critical Review of Digestion, Absorption, Metabolism, and Excretion. *Antioxidants*, *10*(3), 1–16. https://doi.org/10.3390/ANTIOX10030342
2. Arshad, M. S., Khalid, W., Ahmad, R. S., Khan, M. K., Ahmad, M. H., Safdar, S., Kousar, S., Munir, H., Shabbir, U., Zafarullah, M., Nadeem, M., Asghar, Z., Suleria, H. A. R., Arshad, M. S., Khalid, W., Ahmad, R. S., Khan, M. K., Ahmad, M. H., Safdar, S., … Suleria, H. A. R. (2021). Functional Foods and Human Health: An Overview. *Functional Foods - Phytochemicals and Health Promoting Potential*. https://doi.org/10.5772/INTECHOPEN.99000
3. Ba, P., & Fá, B. (2019). Curcumin: Phytochemical Therapy in the Treatment of Hyperlipidemia. *Glasnik Hemicara i Tehnologa Bosne i Hercegovine*, *52*. https://doi.org/10.35666/GHTBH.2019.52.02
4. Baker, M. T., Lu, P., Parrella, J. A., & Leggette, H. R. (2022). Consumer Acceptance toward Functional Foods: A Scoping Review. *International Journal of Environmental Research and Public Health 2022, Vol. 19, Page 1217*, *19*(3), 1217. https://doi.org/10.3390/IJERPH19031217
5. Blades, M. (2000). Functional foods or nutraceuticals. *Nutrition & Food Science*, *30*(2), 73–76. https://doi.org/10.1108/00346650010314313/FULL/PDF
6. Cao, H., Chai, T. T., Wang, X., Morais-Braga, M. F. B., Yang, J. H., Wong, F. C., Wang, R., Yao, H., Cao, J., Cornara, L., Burlando, B., Wang, Y., Xiao, J., & Coutinho, H. D. M. (2017). Phytochemicals from fern species: potential for medicine applications. *Phytochemistry Reviews 2017 16:3*, *16*(3), 379–440. https://doi.org/10.1007/S11101-016-9488-7
7. Carrera-Quintanar, L., Roa, R. I. L., Quintero-Fabián, S., Sánchez-Sánchez, M. A., Vizmanos, B., & Ortuño-Sahagún, D. (2018). Phytochemicals That Influence Gut Microbiota as Prophylactics and for the Treatment of Obesity and Inflammatory Diseases. *Mediators of Inflammation*, *2018*. https://doi.org/10.1155/2018/9734845
8. Castillo, M., Iriondo-DeHond, A., & Martirosyan, D. M. (2018). Are functional foods essential for sustainable health?. *Annals of Nutrition & Food Science*.
9. Chan, E. W. C., Soon, C. Y., Tan, J. B. L., Wong, S. K., & Hui, Y. W. (2019). Ursolic acid: An overview on its cytotoxic activities against breast and colorectal cancer cells. *Journal of Integrative Medicine*, *17*(3), 155–160. https://doi.org/10.1016/J.JOIM.2019.03.003
10. Crowe, K. M., & Francis, C. (2013). Position of the academy of nutrition and dietetics: functional foods. *Journal of the Academy of Nutrition and Dietetics*, *113*(8), 1096–1103. https://doi.org/10.1016/J.JAND.2013.06.002
11. Di Renzo, L., De Lorenzo, A., Merra, G., & Gualtieri, P. (2020). Comment on: "A Systematic Review of Organic Versus Conventional Food Consumption: Is There a Measurable Benefit on Human Health? Nutrients 2020, 12, 7." *Nutrients 2020, Vol. 12, Page 696*, *12*(3), 696. https://doi.org/10.3390/NU12030696

12. Doyon, M., & Labrecque, J. A. (2008). Functional foods: A conceptual definition. *British Food Journal*, *110*(11), 1133–1149. https://doi.org/10.1108/00070700810918036
13. Eddin, L. B., Jha, N. K., Meeran, M. F. N., Kesari, K. K., Beiram, R., & Ojha, S. (2021). Neuroprotective Potential of Limonene and Limonene Containing Natural Products. *Molecules*, *26*(15). https://doi.org/10.3390/MOLECULES26154535
14. Essa, M. M., Bishir, M., Bhat, A., Chidambaram, S. B., Al-Balushi, B., Hamdan, H., Govindarajan, N., Freidland, R. P., & Qoronfleh, M. W. (2023). Functional foods and their impact on health. *Journal of Food Science and Technology*, *60*(3), 820–834. https://doi.org/10.1007/S13197-021-05193-3
15. Gaffney, S., Williams, V., Flynn, P., Carlino, R., Mowry, C., Dierenfeld, E., Babb, C., Fan, J., & Tramontano, W. A. (2004). Research Article: Tannin/Polyphenol effects on iron solubilization in vitro. *Https://Doi.Org/10.1893/0005-3155(2004)75<43:PEOISI>2.0.CO;2*, *75*(2), 43–52. https://doi.org/10.1893/0005-3155(2004)75
16. Havel, R. J., Erdman, J. W., Garza, C., Goodridge, A. G., King, J. C., Clydesdale, F. M., Cousins, R. J., Drewnowski, A., Harlander, S. K., Kolonel, L. N., Leveille, G. A., Constatine-Paton, M., Pi-Sunyer, F. X., Quandt, S. A., Rizvi, S. S. H., Rosenberg, I. H., Ross, A. C., St. Jeor, S. T., & Stunkard, A. J. (1994). Opportunities in the nutrition and food sciences: Research challenges and the next generation of investigators. *Journal of Nutrition*, *124*(6), 763–769. https://doi.org/10.1093/JN/124.6.763
17. Health, N. R. C. (US) C. on D. and. (1989). *Genetics and Nutrition*. https://www.ncbi.nlm.nih.gov/books/NBK218767/
18. Heinrich, M., Mah, J., & Amirkia, V. (2021). Alkaloids Used as Medicines: Structural Phytochemistry Meets Biodiversity—An Update and Forward Look. *Molecules*, *26*(7). https://doi.org/10.3390/MOLECULES26071836
19. Kamarul Zaman, M. A., & Mohamad Azzeme, A. (2018). Plant toxins: alkaloids and their toxicities. *GSC Biological and Pharmaceutical Sciences*, *6*(2), 021–029. https://doi.org/10.30574/GSCBPS.2019.6.2.0003
20. Kanwal, S. (2022). *Breakdown of disease present in population in India 1990-2030*.
21. Kaseke, T., Fawole, O. A., & Opara, U. L. (2021). Chemistry and Functionality of Cold-Pressed Macadamia Nut Oil. *Processes*, *10*(1). https://doi.org/10.3390/PR10010056
22. Kaur, S., & Das, M. (2011). Functional foods: An overview. *Food Science and Biotechnology*, *20*(4), 861–875. https://doi.org/10.1007/S10068-011-0121-7/METRICS
23. Kim, J. K., & Park, S. U. (2016). Current results on the potential health benefits of lutein. *EXCLI Journal*, *15*, 308. https://doi.org/10.17179/EXCLI2016-278
24. Kruger, C. L., & Mann, S. W. (2003). Safety evaluation of functional ingredients. *Food and Chemical Toxicology*, *41*(6), 793–805. https://doi.org/10.1016/S0278-6915(03)00018-8
25. Lara, M. V., Bonghi, C., Famiani, F., Vizzotto, G., Walker, R. P., & Drincovich, M. F. (2020). Stone Fruit as Biofactories of Phytochemicals With Potential Roles in Human Nutrition and Health. *Frontiers in Plant Science*, *11*, 1323. https://doi.org/10.3389/FPLS.2020.562252/BIBTEX
26. Liu, R. H. (2004). Potential Synergy of Phytochemicals in Cancer Prevention: Mechanism of Action. *The Journal of Nutrition*, *134*(12), 3479S-3485S. https://doi.org/10.1093/JN/134.12.3479S

27. Luo, Y., Jian, Y., Liu, Y., Jiang, S., Muhammad, D., & Wang, W. (2022). Flavanols from Nature: A Phytochemistry and Biological Activity Review. *Molecules*, *27*(3). https://doi.org/10.3390/MOLECULES27030719
28. MacAulay, J., Petersen, B., S. F. (2005). Functional foods: Opportunities and challenges. *Institute of Food Technologists (IFT) Expert Report. Institute of Food Technologists.*
29. Martinez, R. M., Almeida, C. de O. R. P. de, Lima, T. P. B., Figueiredo, M. S., & Teodoro, A. J. (2022). Obesity mechanisms and importance of bioactive compounds from fruits in its regulation – a narrative review. *Research, Society and Development*, *11*(4), e11411427153. https://doi.org/10.33448/rsd-v11i4.27153
30. Martirosyan, D. M., & Singharaj, B. (2016). Health Claims and Functional Food: The Future of Functional Foods under FDA and EFSA Regulation. *Functional Foods for Chronic Diseases; Food Science Publisher: Dallas, TX, USA*, 410–424.
31. Martirosyan, D., & Miller, E. (2018). Bioactive compounds: The key to functional foods. *Bioactive Compounds in Health and Disease*, *1*(3), 36–39. https://doi.org/10.31989/BCHD.V1I3.539
32. Meyer, A. (1998). No Title. *Food Process*, *58*(8), 32–40.
33. Mi ekus, N., Marszałek, K., Podlacha, M., Iqbal, A., Puchalski, C., & Swiergiel, A. H. (2020). Health Benefits of Plant-Derived Sulfur Compounds, Glucosinolates, and Organosulfur Compounds. *Molecules*, *25*(17). https://doi.org/10.3390/MOLECULES25173804
34. Milner, J. A. (2000). Functional foods: the US perspective. *The American Journal of Clinical Nutrition*, *71*(6 Suppl). https://doi.org/10.1093/AJCN/71.6.1654S
35. Mrowicka, M., Mrowicki, J., Kucharska, E., & Majsterek, I. (2022). Lutein and Zeaxanthin and Their Roles in Age-Related Macular Degeneration—Neurodegenerative Disease. *Nutrients*, *14*(4). https://doi.org/10.3390/NU14040827
36. Naz, T., Yang, J., Nosheen, S., Sun, C., Nazir, Y., Mohamed, H., Fazili, A. B. A., Ullah, S., Li, S., Yang, W., Garre, V., & Song, Y. (2021). Genetic Modification of Mucor circinelloides for Canthaxanthin Production by Heterologous Expression of β-carotene Ketolase Gene. *Frontiers in Nutrition*, *8*. https://doi.org/10.3389/FNUT.2021.756218/FULL
37. Noonan, C. (2004). Legal requirements for "functional food" claims The effects of a melatonin-based drink on sleep patterns of healthy adults View project. *Article in Toxicology Letters*. https://doi.org/10.1016/j.toxlet.2003.05.002
38. Nosrati-Oskouie, M., Aghili-Moghaddam, N. S., Tavakoli-Rouzbehani, O. M., Jamialahmadi, T., Johnston, T. P., & Sahebkar, A. (2022). Curcumin: A dietary phytochemical for boosting exercise performance and recovery. *Food Science & Nutrition*, *10*(11), 3531. https://doi.org/10.1002/FSN3.2983
39. Rodríguez-García, C., Sánchez-Quesada, C., Gaforio, J. J., & Gaforio, J. J. (2019). Dietary Flavonoids as Cancer Chemopreventive Agents: An Updated Review of Human Studies. *Antioxidants*, *8*(5). https://doi.org/10.3390/ANTIOX8050137
40. Santhiravel, S., Bekhit, A. E. D. A., Mendis, E., Jacobs, J. L., Dunshea, F. R., Rajapakse, N., & Ponnampalam, E. N. (2022). The Impact of Plant Phytochemicals on the Gut Microbiota of Humans for a Balanced Life. In *International Journal of Molecular Sciences* (Vol. 23, Issue 15, p. 8124). Multidisciplinary Digital Publishing Institute. https://doi.org/10.3390/ijms23158124
41. Shahidi, F. (2009). Nutraceuticals and functional foods: Whole versus processed foods. *Trends in Food Science & Technology*, *20*(9), 376–387.

https://doi.org/10.1016/J.TIFS.2008.08.004
42. Shimizu, T. (2003). Health claims on functional foods: the Japanese regulations and an international comparison. *Nutrition Research Reviews*, *16*(2), 241–252. https://doi.org/10.1079/NRR200363
43. Singh, D., & Chaudhuri, P. K. (2018). A review on phytochemical and pharmacological properties of Holy basil (Ocimum sanctum L.). *Industrial Crops and Products*, *118*, 367–382. https://doi.org/10.1016/J.INDCROP.2018.03.048
44. Siró, I., Kápolna, E., Kápolna, B., & Lugasi, A. (2008). Functional food. Product development, marketing and consumer acceptance-A review. In *Appetite* (Vol. 51, Issue 3, pp. 456–467). Academic Press. https://doi.org/10.1016/j.appet.2008.05.060
45. Srilakshmi, B. (2018). *Food Science , New Age International(P) Ltd,.Publishers*.
46. Thakur, M., Singh, K., & Khedkar, R. (2020). Phytochemicals: Extraction process, safety assessment, toxicological evaluations, and regulatory issues. *Functional and Preservative Properties of Phytochemicals*, 341–361. https://doi.org/10.1016/B978-0-12-818593-3.00011-7
47. Tsai, H. Y., Ho, C. T., & Chen, Y. K. (2017). Biological actions and molecular effects of resveratrol, pterostilbene, and 3′-hydroxypterostilbene. *Journal of Food and Drug Analysis*, *25*(1), 134. https://doi.org/10.1016/J.JFDA.2016.07.004
48. Ullah, A., Munir, S., Badshah, S. L., Khan, N., Ghani, L., Poulson, B. G., Emwas, A. H., & Jaremko, M. (2020). Important Flavonoids and Their Role as a Therapeutic Agent. *Molecules*, *25*(22). https://doi.org/10.3390/MOLECULES25225243
49. Verma, T., Aggarwal, A., Dey, P., Chauhan, A. K., Rashid, S., Chen, K. T., & Sharma, R. (2023). Medicinal and therapeutic properties of garlic, garlic essential oil, and garlic-based snack food: An updated review. *Frontiers in Nutrition*, *10*. https://doi.org/10.3389/FNUT.2023.1120377
50. world health organization. (2020). *Healthy diet*.
51. Zhao, C., Yang, C., Liu, B., Lin, L., Sarker, S. D., Nahar, L., Yu, H., Cao, H., & Xiao, J. (2018). Bioactive compounds from marine macroalgae and their hypoglycemic benefits. *Trends in Food Science & Technology*, *72*, 1–12. https://doi.org/10.1016/J.TIFS.2017.12.001