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Antioxidants in Vegetarian and Non-Vegetarian Diets

Bachelor Thesis

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Declaration

I declare that the Bachelor Thesis “Antioxidants in Vegetarian and Non-Vegetarian Diets” is my own work, and all the sources cited in it are listed in the Bibliography.

Prague, 13 July 2020 Signature

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Antioxidants in Vegetarian and Non-Vegetarian Diets

Summary

Oxidative stress is a well-known criterion to cause any disorders for health in a long-term basis in the body. Free radicals are parameters of oxidative stress and triggers of oxidative balance in the body. Antioxidants, however, are thought as a defensor against free radicals, and reducing element of oxidative stress. The imbalance of oxidative stress can cause severe long-term illnesses in the body. A diet and its sources are a big influencer in the many functions of the body, such as physiological and psychological functions. The connection of the food to the gut and the brain are inseparable as they affect the development of the brain and the body. Types of diets show differences not only in macro and micronutrients but also their impact on the process of the diseases.

The aim of the thesis is to compare vegetarian and non-vegetarian diet sources with their antioxidant status and their effect on disorders in the body as long-term consequences, by reviewing scientific literatures, scientific articles, and books.

The thesis is composed of four main topics. The first topic is about oxidative stress, its component, and its impact on health. The second topic is about antioxidant and its diversity. The third topic is about diets, their comparison and their impact on health. The last topic is about diet and its overall impact on long-term illnesses on the body.

Keywords: antioxidant, phenolic compound, plant, meat

Contents

Introduction

Throughout history, food and health have always taken a part of the evolution of the human and its body. The diet humans choose and the way they consume food are some of the main factors of a lifestyle and a great influence on long-term effect in the health.

The balance of oxidative stress and antioxidant defenses in the body can cause severe diseases or prevent oxidation depending on the antioxidant amount and its defense function. A diet style is a big factor in correlating oxidative stress with its antioxidant features. A diet can play a major role in contracting many types of diseases such as obesity, type 2 diabetes, atherosclerosis, neurodegenerative or cardiovascular diseases, osteoporosis, or cancer. Hence, some varieties of diet can be associated with diseases in humans.

Antioxidants are organic compounds that can be found in some form in any type of food. They are present in fruits, vegetables, nuts, grains, legumes, herbs, spices, chocolate, coffee, beverages, and animal food sources. Therefore, antioxidants are known to be great sources for defending the body's system against disorders and diseases. They can also be used as an additive in food and beverages to prolong the shelf life of products (Shahidi and Ambigaipalan, 2015).

Two types of diets are considered to have main differences in the sources of macronutrient and micronutrient contents with the antioxidant variety and its activity in the body. These diets are vegetarian and non-vegetarian diets.

There is a link between the intake of antioxidants and the progress of disease in the body depending on the antioxidant activity.

The goal of this Bachelor thesis is to review the relationship between oxidative stress and antioxidant features of various foods and its effect on health in both vegetarian and non-vegetarian diets, with studies made in the last twenty years.

1 Oxidative Stress

Oxidative stress is an imbalance between the production of free radicals and the body's ability to neutralize their harmful effects with antioxidants. Excessive amounts of Reactive Oxygen Species (ROS) and Reactive Nitrogen Species (RNS) can react and cause free radicals in the body. They attack to biological components and tissues in the body.

However, free radicals can chemically interact with cellular components, such as genetic material DNA, proteins, or lipids, and steal their electrons to stabilize. This in turn destabilizes the molecules of the cellular components, which then search for and steal an electron from another molecule, causing a large chain of free radical reactions. And that can hurt us. With a severe number of free radicals and insufficient quantity of antioxidants cause oxidative stress in the body. The oxidative stress can lead to some chronic diseases as a long-term effect.

Excessive production of free radicals and because of oxidative stress can be in charge of some disorders in the body, like cardiovascular diseases, diabetes, cholesterol, neurodegenerative diseases, dementia, Parkinson's and Alzheimer's diseases and cancer.

1.1 Free Radicals

A free radical is a molecule or an ion that has one or more unpaired electrons and is therefore highly reactive with other molecules (Carocho & Ferreira, 2013).

Oxygen by-products are relatively non-reactive, but some of them can affect metabolism in the biological system, resulting in these highly reactive oxidants. However, not all reactive oxygen species are harmful to the body. Some of them useful in killing infected pathogens or microbes.

The very first step of the occurrence of free radicals is autoxidation. Autoxidation is an oxidation with the presence of an oxygen molecule. It is a chain reaction in which a free radical is produced.

Autoxidation occurs in three steps: Initiation, propagation and termination. The initiation step is the first phase of the forming of free radicals. This step is an endothermic reaction, which means it requires energy to break the bond of the molecule. The energy source may come from heat or UV light. After the free radicals are produced, they continue creating more free radicals, and this step is called propagation. Termination is the last step and this is the cancelling out of the free radicals. The concentration of free radicals gets lower in this step. Both propagation and termination steps are exothermic reactions. They release a large amount of energy (Shahidi and Ambigaipalan, 2015).

The formation of free radicals and the steps in the order of initiation (1), propagation (2), and termination (3) are shown down below.

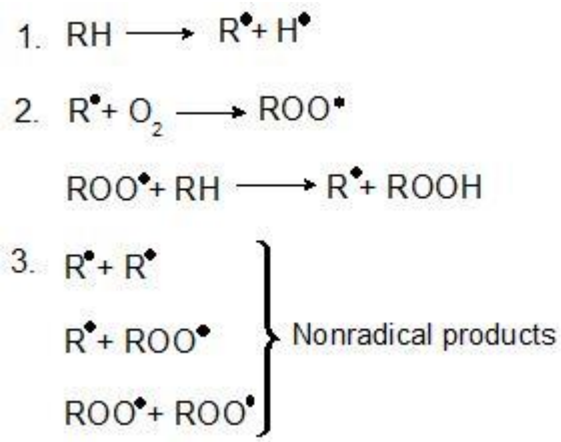


Figure 1. *Mechanism of the occurrence of free radicals*

(Shahidi and Ambigaipalan, 2015)

Free radicals can be formed from the reactions with oxygen, UV radiation in the sunlight, toxic compounds, exposure to pollutants, cigarette smoking, or air pollution. They are also formed from metabolic reactions in the body, such as energy production.

The figure down below shows the interaction between environmental parameters and its results of free radicals to cause gene expression and molecules damage. As a result of inflammation and oxidative stress, chronic diseases and additional production of reactive species can occur. To reduce this undesirable outcome, dietary and endogenous antioxidants work together to reduce oxidative stress development and damage.

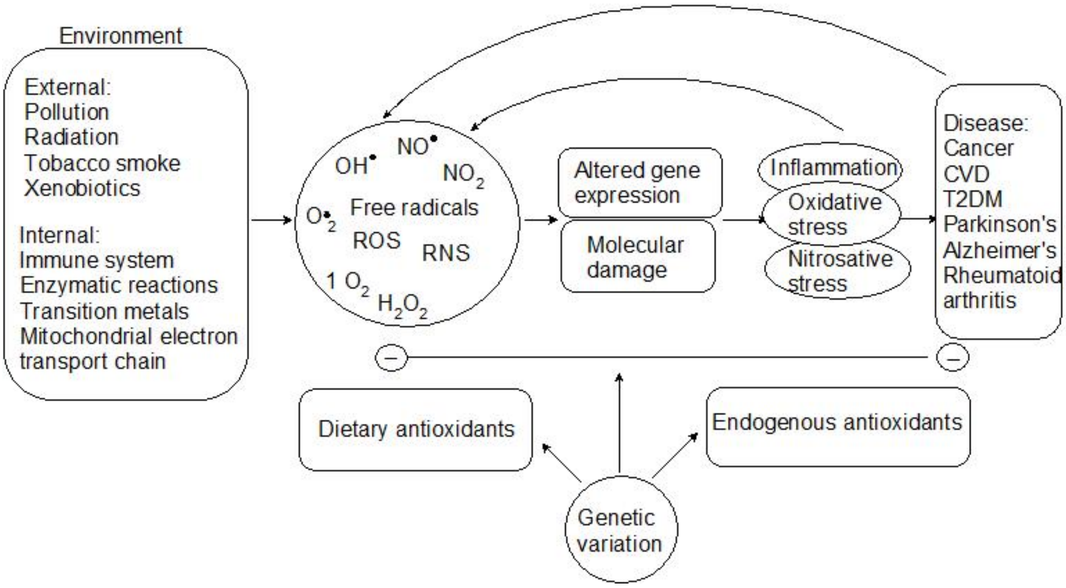


Figure 2. *Overview of the relationship between the production of reactive species, oxidative stress, disease development and the role of antioxidants and genetic variation. CVD: Cardiovascular disease; T2DM: type 2 diabetes mellitus*

(Da Costa, Badawi & El-Sohemy, 2012)

1.2 Illnesses

Oxidative stress causes not only aging, but also long-term damage to the body. It leads to many pathophysiological conditions in the body. These are, for example, obesity, type 2 diabetes, osteoporosis, inflammatory diseases, heart failure and heart attack, atherosclerosis, different types of cancers, cardiovascular diseases, various neurodegenerative diseases, such as: Parkinson’s disease, Alzheimer’s disease.

1.2.1 Various Heart Diseases

Heart disease is the leading cause of death worldwide. The risk of heart disease is caused by several factors, such as high cholesterol, high blood pressure, cigarette smoking, and diabetes. They promote atherosclerosis. Atherosclerosis refers to the formation of a “plaque” on the walls of the arteries that disrupts blood flow to the heart and other vital organs.

The oxidation of low-density lipoproteins (LDL – a type of bad cholesterol in the blood) inside the arterial wall is thought to be a critical step in the development of atherosclerosis. Several studies point to an association between low dietary antioxidant intake and increased frequency of heart disease.

People with high levels of antioxidants in their blood have a lower risk of heart disease. For example, people who took more vitamin E regularly had a 41% lower incidence of heart disease than those who took less. A dietary increase in antioxidant vitamins can reduce the risk of heart disease by 20-30%.

1.2.2 Different Types of Cancer

Cancer also kills millions of people around the world. Diet can cause cancer in up to 35% of all human cancers. Low amounts of antioxidants in the diet may also be responsible for this disease. Low food intake from fruits and vegetables doubles the risk of most cancers.

Free radicals stimulate cell division, and these form the onset of mutagenesis and tumorigenesis. When a cell with a damaged DNA strand divides it causes disruption and deformation of the groups of cells that make up cancer.

In this case, antioxidants act as a protective effect. They reduce oxidative damage to DNA and the abnormal increase in cell division.

In addition, cigarette smoking and chronic inflammation lead to a strong generation of free radicals, which appears to be the cause of many cancers. Many studies suggest that people who smoke tend to have lower antioxidant levels than non-smokers, putting smokers at risk for cancer.

1.2.3 Lung Diseases

The respiratory system is a well-known target for free radical attack. This is based on endogenous factors, as well as exposure to pollutants and toxins, smoking, etc.

Recent studies suggest that free radicals may be involved in the development of lung disorders, such as asthma. Antioxidants appear to reduce the development of asthmatic symptoms. Vitamin C, Vitamin E, and beta-carotene supplements have been associated with improved lung function.

1.2.4 Negative Effect on the Brain and Nerves

Free radicals can also damage nerves and the brain. Nervous tissue may be particularly sensitive to oxidative damage. This is because the brain receives a disproportionate percentage of oxygen and has large amounts of polyunsaturated fatty acids, which are highly susceptible to oxidation and oxidative damage. Alzheimer's disease, Parkinson disease and dementia are the most significant neurodegenerative diseases.

1.2.5 Cataract

Cataract formation is thought to involve free radical damage to the lens protein. Cataract formation can be slowed down by regular consumption of supplemental antioxidants such as vitamin E, vitamin C, and carotenoids.

1.2.6 Other Diseases

There are other diseases such as diabetes, rheumatoid arthritis. These are also associated with low levels of antioxidants in the blood.

The balance of oxidative stress can be explained by levels of oxidants and antioxidants. High number of antioxidants can suppress oxidants, thus reduce the oxidative stress.

2 Antioxidants

Every cell that uses enzymes and oxygen to perform its function is exposed to free radical reactions. This can cause serious cell damage. Antioxidants are molecules present in cells that prevent these reactions by donating their electrons to free radicals without destabilizing themselves.

Antioxidants are organic compounds with at least one aromatic ring connected to one or more hydroxyl groups. They are formed as secondary metabolites, mostly in plants, to function as defensive features against oxidation in the body. Antioxidants are present in fruits, vegetables, beverages, and herbs with different types of varieties and amounts as dietary antioxidants. The most known important dietary antioxidants are ascorbic acid (Vitamin C), α-Tocopherol (Vitamin E), and carotenoids.

Antioxidants also show in the body and cells as anti-proliferative, anti-carcinogenic, anti-inflammatory, antiallergic, antimicrobial, and antiviral features (Chen & Xu, 2019).

2.1 Function

The main function of antioxidants is to prevent or regress oxidation. They work as a defense system of the body. Oxidation is the reaction of molecules with losing an electron, causing the creation of a free radical. Oxidation can occur in tissues, cells, and also foods.

Antioxidants function as a free radical scavenger to protect any damages that are caused by a free radical.

2.2 Mechanism

There are two ways of function of antioxidants. First one is as Hydrogen Atom Transfer (HAT). It works as transferring of hydrogen to a radical in the later step of the propagation. The energy of this reaction works with Bond Dissociation Enthalpy (BDE). The second one is as Electron Transfer (ET), and it is a redox reaction since it the transfer of the electron. Antioxidants lose one of their electrons to neutralize the free radical. In both reactions, the lower energy between the O-H in HAT or in ET, the easier the hydrogen or electron transfer of the antioxidant.

Antioxidants donate an electron to a free radical to neutralize it in the body and antioxidants become antioxidant radicals which are more stable and less readily available.

2.3 Antioxidant Defense

Antioxidant defense plays a role against any type of occurrence of free radicals in the body. It is important for the prevention of oxidative stress by detoxifying such as superoxide radical (O^{-}_2), nitric oxide (NO), hydroxyl radical ($^{\bullet}OH$), and hydrogen peroxide (H_2O_2).

There are two types of antioxidant defense systems: Exogenous antioxidant defense and endogenous antioxidant defense which also split into two types, enzymatic and non-enzymatic, which mainly take charge as intracellular reducing agents.

Exogenous antioxidants are mostly found in fruits, vegetables, and grains. These are: vitamins (Vitamin E and C), trace elements such as zinc and selenium, carotenoids such as beta-Carotene, phenolic acids such as gallic acid and caffeic acid, flovonols, flavanols, anthocyanidins, isoflavones, flavanones and flavones.

Endogenous enzymatic antioxidants are Superoxide dismutase (SOD), Catalase (CAT), and glutathione peroxidase (GPx), glutathione reductase, thioredoxin reductase and glucose-6-phosphte dehydrogenase.

Endogenous non-enzymatic antioxidants are glutathione (GSH), uric acid, lipoic acid, NADPH, coenzyme Q, albumin, and bilirubin (Bouayed & Bohn, 2010).

The balance between oxidants and antioxidants are maintained by the endogenous and exogenous antioxidants. Also, the body's ability to benefit and metabolite the antioxidants is connected to its genetics. With these parameters, oxidative stress balance can be fixed.

The sources of some exogenous dietary antioxidants in foods are shown in the table below.

Exogenous antioxidants	Dietary sources
Vitamin C (ascorbic acid)	Bell peppers, strawberries, kiwi, Brussel sprouts, broccoli
Vitamin E (tocopherols, tocotrienols)	Vegetable oil and its derivatives, nuts, and seeds
Carotenoids	Orange and red vegetables, and fruits (carrots, tomatoes, apricots, plums) and green leafy vegetables (spinach, kale)
Polyphenols (flavonols, flavanols, anthocyanins, isoflavones, phenolic acid)	Fruits (apples, berries, grapes), vegetables (celery, kale, onions), legumes (beans, soybeans), nuts, wine, tea, coffee, cocoa
Trace elements (selenium, zinc)	Seafood, meat, and whole grains

Table 1. *Some exogenous antioxidants and their dietary sources*

(Da Costa, Badawi & El-Sohemy, 2012).

3 Where we can find antioxidants

Antioxidants can be present as naturally in plants and animal cells as well as can be produced as artificially.

3.1 In plants/microbes/animals

Plants and animals produce antioxidants in their bodies. Antioxidants can be classified as endogenous and exogenous antioxidants in the body, based on their origin of produce. Endogenous antioxidants are produced in the body of organisms and can be function as enzymes in animals and plants. Exogenous antioxidants are non-enzymatic and not produced in the body of animals, therefore called exogenous. Exogenous antioxidants are originated form plants, such as ascorbic acid, tocopherol, beta-Carotene, or glutathione, and must be taken into the body via diet. Endogenous and exogenous antioxidants function as defense systems in the body (Fuchs-Tarlovsky, 2013). Thanks to the microbiota in the gut, various bacteria can also produce exogenous enzymatic antioxidants for the host.

3.2 Division

There is a wide selection of antioxidants in the nature. The division of antioxidants is made according to their origin, which is how they are derived and what they are used for. Two types of phenolic antioxidants are known: Synthetic and Natural Phenolics, as shown in the figure down below.

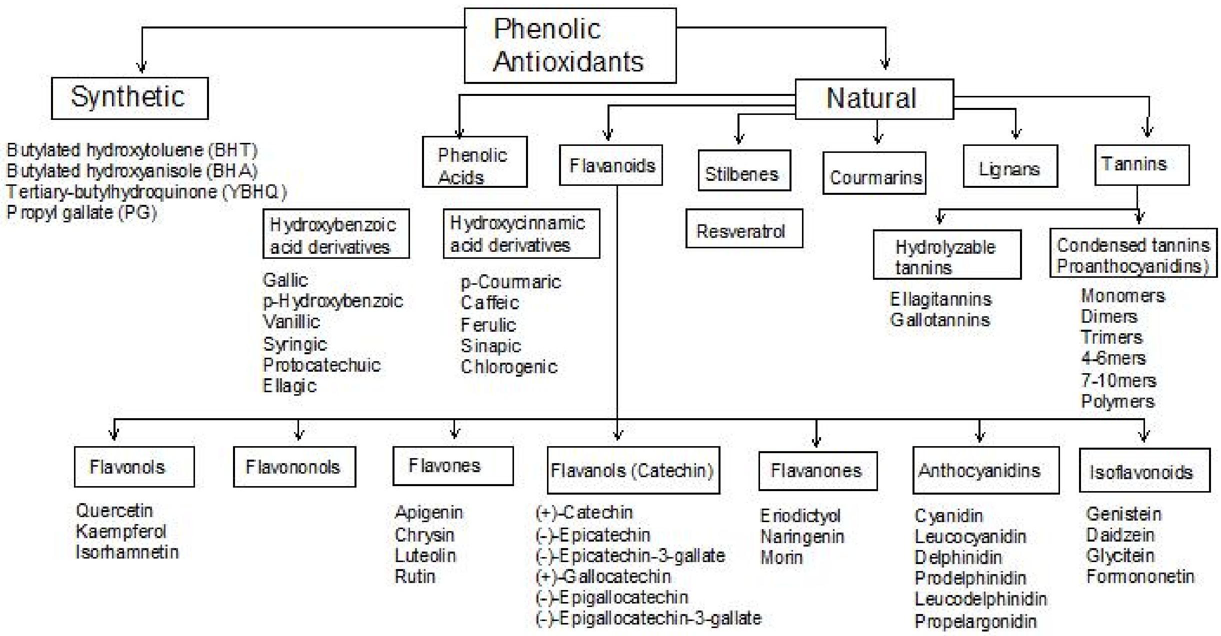


Figure 3. *Division of Phenolic Antioxidants*

(Shahidi and Ambigaipalan, 2015)

3.2.1 Synthetic phenolic antioxidants

The first group of phenolic antioxidants is synthetic phenolic antioxidants. There are four groups of synthetic phenolic antioxidants, and they are butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), tertiary-butylhydroquinone (TBHQ) and propyl gallate (PG). They are used as additives in food to prevent the oxidation of fats, oils and lipids during processing or storage. Most of them are soluble in oils and fats, but insoluble in water. They may exhibit better activity when they are used together than when used singly, such as BHT with BHA, or BHA with BHT/TBHQ/PG. (Shahidi and Ambigaipalan, 2015).

In the figure 4, chemical structures of synthetic phenolic antioxidants are shown.

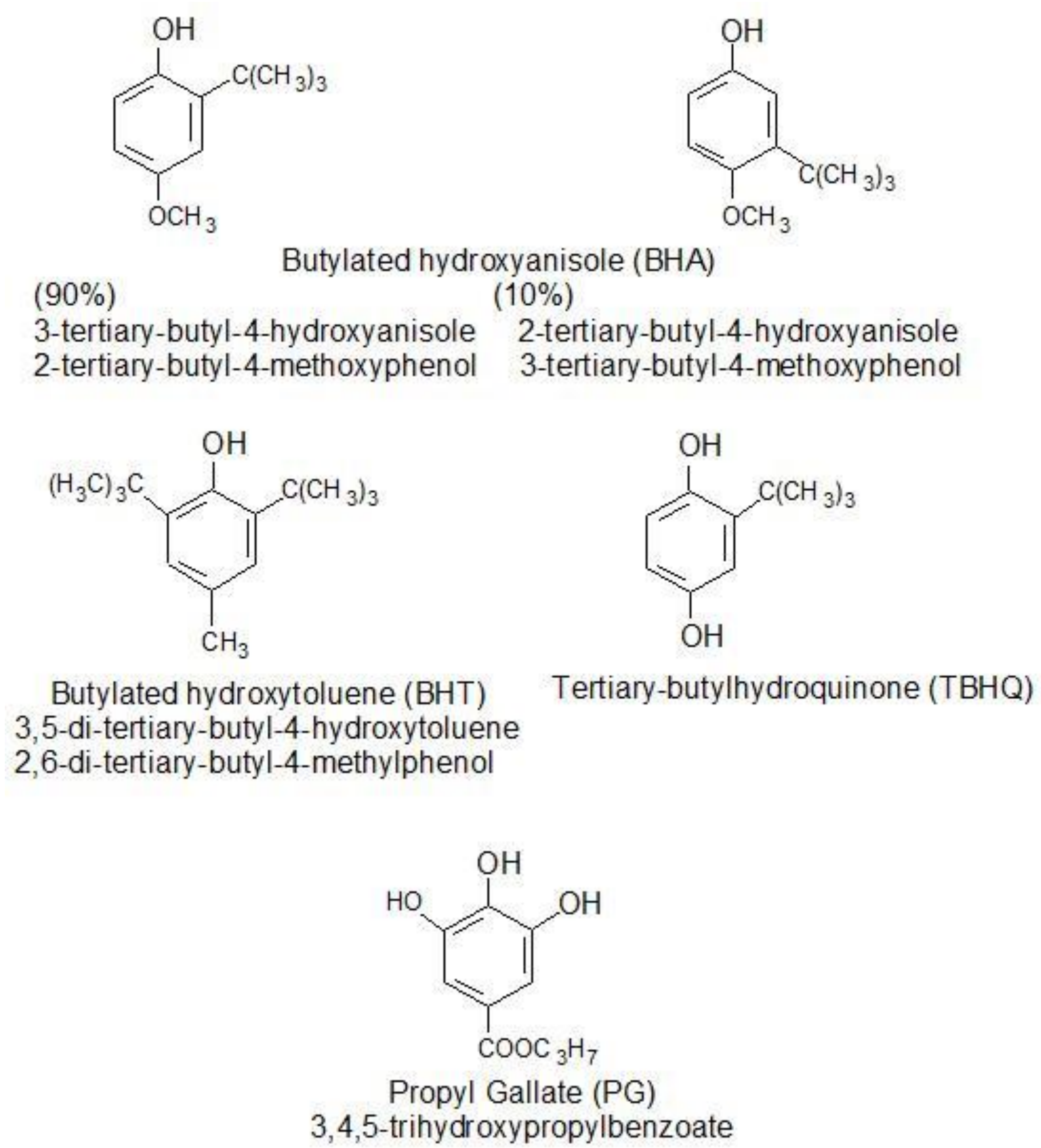


***Figure 4**. Chemical Structures of Synthetic Phenolic Antioxidants*

(Shahidi and Ambigaipalan, 2015).

According to the Joint FAO/WHO Expert Committee on Food Additives (JECFA), the daily intake of Synthetic Phenolic Antioxidants is shown in the table below.

Synthetic Phenolic Antioxidants	The Acceptable Daily Intake
Butylated hydroxyanisole (BHA)	0-0.5 mg/kg body weight
Butylated hydroxytoluene (BHT)	0-0.3 mg/kg body weight
Tertiary-butylhydroquinone (TBHQ)	0-0.2 mg/kg body weight
Propyl Gallate (PG)	0-0.25 mg/kg body weight

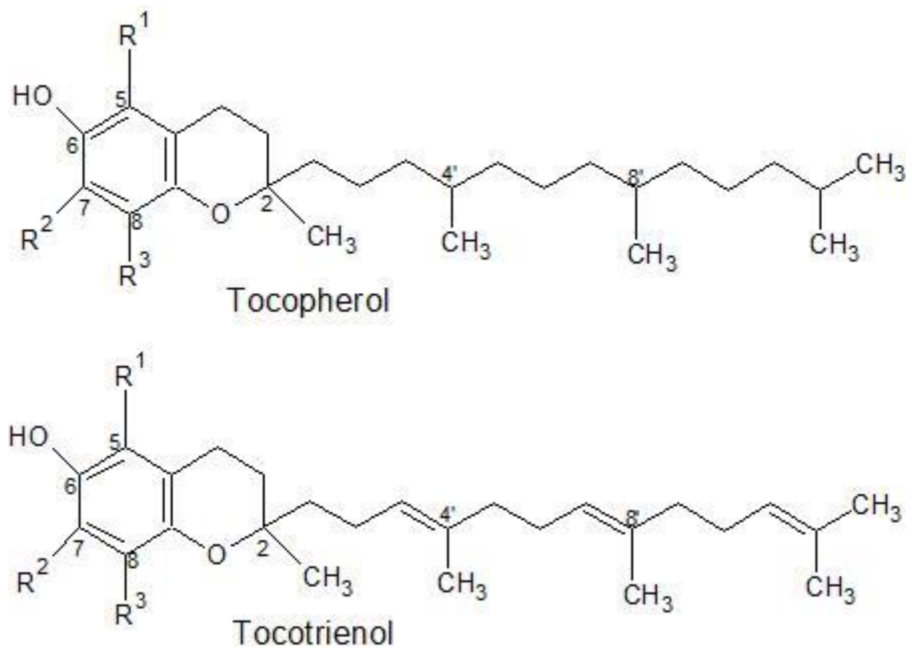
Table 2. *Acceptable daily intake of Synthetic Phenolic Antioxidants in food*

3.2.2 Natural phenolic antioxidants

The second group of phenolic antioxidants is natural phenolic antioxidants. They are divided into six groups, and even more types between each other. Natural phenolic antioxidants are phenolic acids, flavanoids, stilbenes, courmarins, lignans, and tannins. They are present in fruits, vegetables, nuts, seeds, oil, tea, coffee, beverages, herbs, and spices.

Tocopherols and tocotrienols are formed from a chromane ring (benzodihydropyrane), which is a heterocyclic compound, and a long carbon chain attached to the ring. The difference between tocopherols and tocotrienols is the saturated/unsaturated form of the chain. They are present as the form of vitamin E in the food. They can vary in the types of methyl groups in the chromane ring. Oilseeds, green leaves, and green parts of higher plants are rich in tocopherols. Especially α-Tocopherol is present mainly in the chloroplast organelle in plant cells. Tocotrienols are present in oil crops, such as palm oil, olive oil, sunflower oil, or soybean.

The chemical structures of tocopherols and tocotrienols are in the figure below.



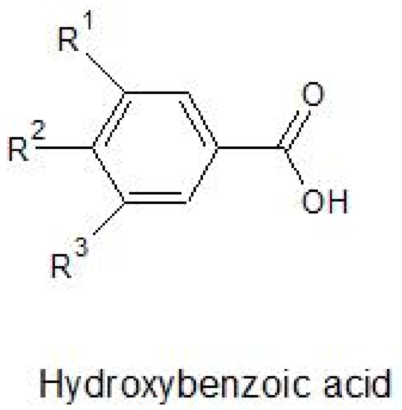
Compound	R_1	R_2	R_3
5,7,8-Trimethyl tocopherol (α-tocopherol) *5,7,8-Trimethyl tocotrienol* (α-tocotrienol)	CH_3	CH_3	CH_3
7,8-Dimethyl tocopherol (β-tocopherol) *7,8-Dimethyl tocotrienol* (β-tocotrienol)	*H*	CH_3	CH_3
5,8-Dimethyl tocopherol (γ-tocopherol) *5,8-Dimethyl tocotrienol* (γ-tocotrienol)	CH_3	*H*	CH_3
8-Methyl tocopherol (δ-tocopherol) *8-Methyl tocotrienol* (δ-tocotrienol)	*H*	*H*	CH_3

Figure 5. *Chemical structures of Tocopherols and Tocotrienols*

(Shahidi and Ambigaipalan, 2015).

Phenolic acids are another biggest group of natural antioxidants. The recommended daily intake of phenolic compounds is estimated as 1-g per day (Shahidi and Ambigaipalan, 2015).

Varieties of phenolic acids and their structures are in the figure below.



Acid	R_1	R_2	R_3
p-Hydroxybenzoic	H	OH	H
Protocatechuic	OH	OH	H
Vanillic	OCH_3	OH	H
Syringic	OCH_3	OH	OCH_3
Gallic	OH	OH	H

Acid	R_1	R_2	R_3
p-Courmaric	H	OH	H
Caffeic	OH	OH	H
Ferulic	OCH_3	OH	H
Sinapic	OCH_3	OH	OCH_3

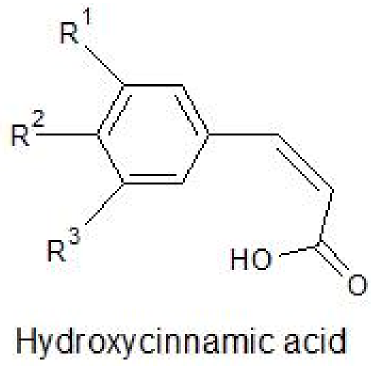


Figure 6. *Chemical structures of Phenolic Acids*

(Shahidi and Ambigaipalan, 2015)

Flavonoids have the most variety group of natural antioxidants. They extend to a large sub-group in each other, such as quercetin, kaempferol, (+)-catechin, (-)-epicacatechin, (+)-gallocatechin, (-)-epicagallocatechin, naringenin, genistein, daidzein. Their chemical structure is consisted of a phenyl group connected to a heterocyclic ring and their bond to another phenyl ring. The antioxidant activity of these groups has direct relationships with the number of the bonded hydroxyl groups They are present mostly in citrus fruits, berries, broccoli, leek, and tea (Shahidi and Ambigaipalan, 2015).

The figure of chemical structures of flavonoids is shown in the figure 7 down below.

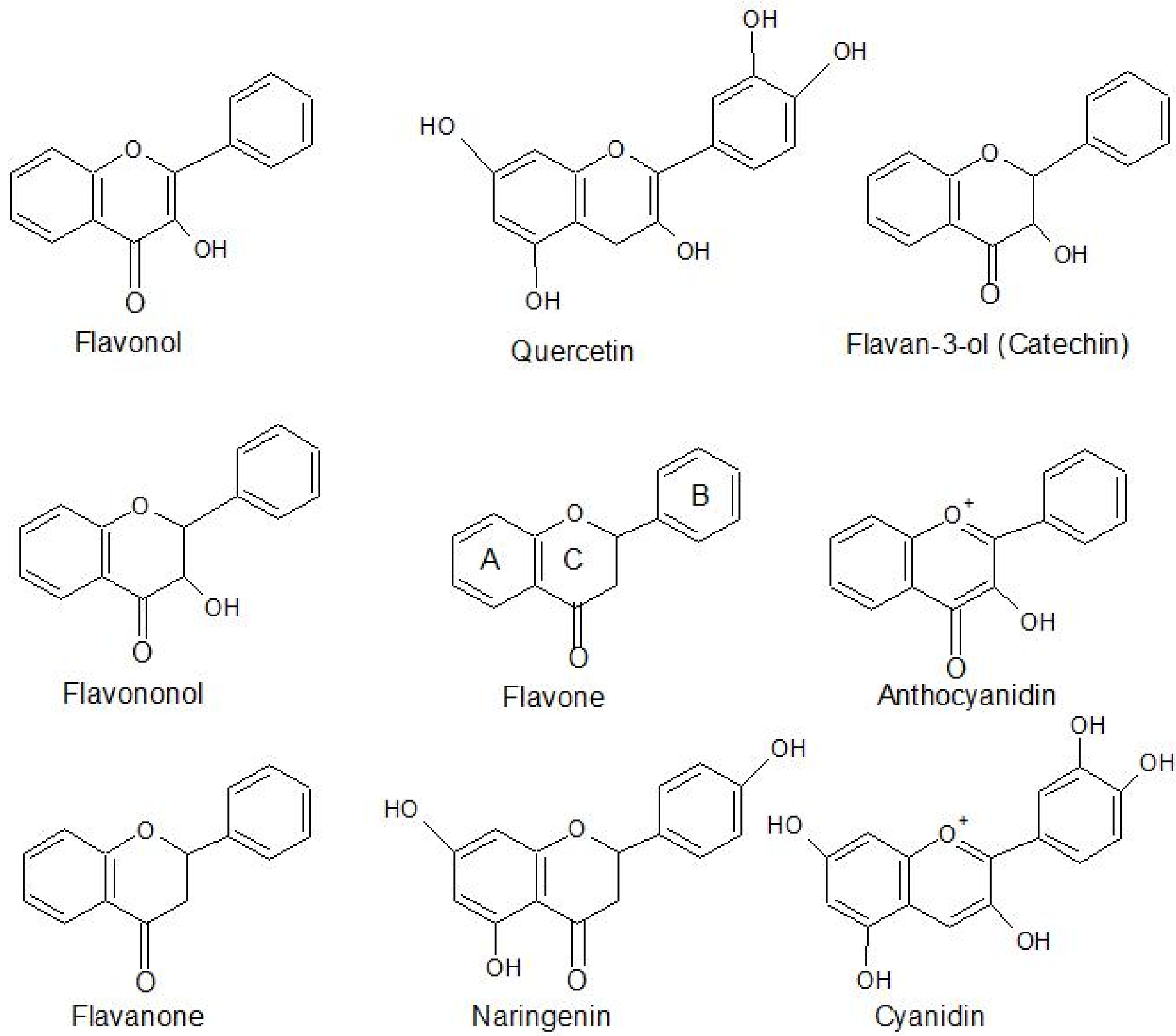


Figure 7. *Chemical structures of some flavonoid classes*

(Shahidi and Ambigaipalan, 2015)

4 Diets

There are two popular diets in the world which are considered to have a different distributions of food source and differences in sources of macronutrients as well as micronutrients with antioxidant content in foods and antioxidant activity with their function in the body.

These are vegetarian and non-vegetarian diets, which have different main protein and energy sources and different distribution of intake of antioxidants. Availability of vitamin and mineral and their amounts and capability of absorption are also different in these two diets.

A diet with a high number of serving sizes of fruits, vegetables, healthy polyunsaturated fats and oils, grains, seeds, nuts, and fibers, which is rich in vitamins and antioxidants can affect the antioxidant and oxidant balance in the body. Vegetarian and Non-vegetarian diet have differences in main intake of protein, fat, vitamin, and mineral sources. Vitamin E, and C, and selenium, zinc, manganese, carotenoids, phenolic acids are some of the ubiquitous components of naturally occurring antioxidants and available in wide varieties of plants and plant-based products.

Diet types	Differences in the diet
Vegetarian Diet	Excludes animal meat products, focuses on dairy and egg products or not.
Non-vegetarian Diet	Mostly focuses on the animal products for protein sources.

Table 3. *Diet types with their main differences*

4.1 Vegetarian Diet

A vegetarian diet excludes any animal meat such as white and red meat, or sea animals, and animal by-products and only includes some animal products such as dairy, eggs and honey. A vegetarian diet mainly focuses on plant-based foods, fruits, vegetables, nuts, seeds, and whole grains. Most of the protein and energy sources come from legumes, nuts, and whole grains, and some animal sources depending on the diet. Subsets of vegetarian diets such as ovo-lacto vegetarianism, ovo vegetarianism, lacto vegetarianism, and veganism are shown in the table 2, including the animal food options they have. The difference between them is the consumption of different types of animal products.

Recently, more adolescents and young adults have chosen a vegetarian or vegan diet. Fruits, a wide variety of vegetables, whole grains, nuts, and legumes are consumed in a vegetarian diet. This diet is also rich in antioxidants in addition to different groups of nutrients than a non-vegetarian diet which is thought to be healthy with high in polyunsaturated fats, low in saturated fats, and high in fiber.

Even though the intake of legumes, fruits, vegetables, nuts, and grains is higher in a vegetarian diet, there can be low amount and absorption of mineral and vitamins. Since the intake and availability of some important minerals and vitamins are low in vegetarian and vegan diet than the non-vegetarian diet. In animal products and meat, these minerals and vitamins are readily available to absorption thanks to their production in the body. But, for vegetarians and vegans these micronutrients are not easy to reach to the recommended daily intake. They may have deficiencies of minerals and vitamins in their blood. These micronutrients are mostly B_{12} and D vitamins, selenium, iron, zinc, magnesium, calcium, and ω-3 fatty acids. Therefore, they take daily mineral and vitamin supplements, especially for B12, D vitamins and iron, calcium, zinc, or they consume fortified foods with these minerals and vitamins.

Subsets of Vegetarianism	Consumption of Animal Products
Ovo-Lacto Vegetarianism	Include dairy and eggs
Ovo Vegetarianism	Include only eggs
Lacto Vegetarianism	Includes only dairy
Veganism	Excludes any type of animal source

Table 4. *Distribution of Vegetarian Diets*

(Benzie and Wachtel-Galor, 2010)

4.1.1 Ovo-Lacto Vegetarianism

Ovo-Lacto Vegetarianism is one of the vegetarian diet types that includes both dairy and egg products. They exclude animal meat, such as pork, beef, poultry, fish, and seafood.

This diet is the most least restrictive diet in all the vegetarian type diets.

4.1.2 Ovo Vegetarianism

Ovo Vegetarianism is a vegetarian diet type that includes consumption of only eggs in the diet. They do not consume dairy products, white and red meat, as well as fish and seafood.

4.1.3 Lacto Vegetarianism

Lacto Vegetarianism does not consume beef, pork, poultry, fish, and seafood and animal products such as eggs. However, they consume dairy products such as milk, butter, cheese, yoghurt, and kefir.

4.1.4 Veganism

Veganism is the only type of vegetarian diet that excludes any type of usage and consumption of animal sources, animal products, meat, or processed foods as well as honey, eggs, and dairy products. This philosophy comes from different aspects. The most 4 popular ideas are formed from ethical, environmental, religious, and health reasons. They do not use any animal by-product ingredients in products such as gelatin and beeswax. They also avoid using leather, silk, and wool.

This diet contains healthy food sources that are high in fiber, polyunsaturated fats, and low in saturated fats. Therefore, it is thought to be a healthy diet if it is kept maintained in a long term.

4.2 Non-Vegetarian Diet

In the history of human evolution with primate ancestors, animal food consumption was the biggest part of the diet. Meat and milk were used for food, and skins were used for clothing and creating tools. The biggest change happened when the lifestyle of humans became agricultural, with the domestication of plants from a hunting-gathering lifestyle. Therefore, the consumption of animal sources made a big difference throughout the period of the evolution, with diet patterns in metabolic and physiologic ways, from energy use to intestine and gut structure, and tooth size (Mann, 2018).

A non-vegetarian diet includes all types of food sources, including animal source foods. The intake of protein and major energy comes from these animal-based foods, mostly meat, eggs, and dairy products. Therefore, a non-vegetarian diet has richer and more diverse food sources with high intake of protein than a vegetarian diet. A non-vegetarian diet does not only have a high content of fat and easy intake of protein but also easily available and absorbed minerals and vitamins such as zinc, iron, vitamin A, and B.

Meat and animal products are not easily digestible and are high in saturated fatty acids, cholesterol, and salt, therefore non-vegetarian diet is considered with a high possibility of cardiovascular diseases, obesity, type-2 diabetes, and cancer as a long-term effect.

4.3 Vitamins and Dietary Minerals

Vitamins and dietary minerals are essential micronutrients that the body needs in small amounts and do not synthesize in the body, therefore they are supplied from the diet. They participate as coenzymes in biochemical function in the body, maintaining growth, development and improving the skin of the body.

Vitamins are organic molecules, found in fruits, vegetables, seeds, grains, and animal-based products. They cannot be synthesized in the body unless it is a provitamin. Therefore, they are obtained from diet. For example, provitamin A which is known as beta-carotene can be converted into vitamin A. Provitamin D_3 can be converted into vitamin D in the skin. Bacteria in the gut can synthesize vitamin K, and vitamin B_{12} can be synthesized in the gut by bacteria in ruminants.

There are 13 vitamins that are necessary for human body to function properly. These vitamins can be categorized as water and fat soluble. Fat soluble vitamins are vitamin A, D, E, and K. Water soluble vitamins are vitamin C and B groups. From these vitamins, vitamin E and C can also function as antioxidants in the body.

Dietary minerals are required to maintain the body's proper function. These can be categorized into two groups: Major and trace dietary minerals depending on their necessary intake amount. Major dietary minerals are calcium, chloride, magnesium, phosphorus, potassium, sodium, and sulfur. Trace dietary minerals are chromium, copper, fluoride, iodine, iron, manganese, molybdenum, selenium, and zinc. Minerals are mostly available in plants as minerals are present in soil. With the food chain, animals and humans satisfy the need of minerals. In any deficiencies because of not enough nutrition, they show abnormalities in the body. Therefore, if the intake is inadequate, they are taken with supplements.

In the tables below, the daily recommended intake of vitamins for adult male and female with animal and plant origin products and some dietary mineral sources are shown.

Vitamins	Recommended Dietary Allowances (RDA) for man/female	Sources in animal origin products	Sources in plant origin products
Retinol (Vitamin A) and Beta-carotene (Provitamin A)	900 mc / 700 mcg	For retinol: Beef liver, milk, butter, egg, cheese, seafood	For Beta-carotene: sweet potato, carrot, pumpkin, squash, spinach
Thiamin (Vitamin B_1)	1.2 mg / 1.1 mg	Pork,	Brown rice, soymilk, watermelons
Riboflavin (Vitamin B_2)	1.3 mg / 1.1 mg	Milk, egg, cheese, yoghurt, meat, liver, kidney	Green leaves, whole grains, legume, mushrooms, almond
Niacin (Vitamin B_3)	16 mg / 14 mg	Meat, poultry, fish	Whole grains, mushrooms, potato, peanut butter
Pantothenic acid (Vitamin B_5)	5 mg / 5 mg	Chicken, egg yolk,	Whole grains, broccoli, mushrooms, avocado, tomato
Pyridoxine (Vitamin B_6)	31 – 50 years old: 1.3 mg / 1.7 mg 50+ years old: 1.7 mg / 1.5 mg	Meat, fish, poultry, dairy, and egg	Legumes, soy products, potatoes, noncitrus fruits
Cobalamin (Vitamin B_{12})	2.4 mg / 2.4 mg	Meat, poultry, fish, milk, cheese, egg,	Fortified cereals, fortified soymilk
Biotin (Vitamin B_7 or B_8)	30 mg / 30 mg	Meat, fish, egg yolk	Whole grains
Ascorbic acid (Vitamin C)	90 mg / 75 mg	Chicken liver (even though amount decreases after frying)	Citrus fruits, potato, broccoli, bell pepper, spinach, tomato, strawberries

Calciferol (Vitamin D)	31–70 years old: 15 mcg 71+: 20 mcg	Fatty fish	Fortified milk, and cereals
α-Tocopherol (Vitamin E)	15 mg / 15 mg		Vegetable oils, green leaves, nuts, whole grains
Folic acid (Vitamin B_9)	400 mg / 400 mg		Asparagus, spinach, okra, broccoli, chickpea, black-eyed peas, orange/tomato juice
Vitamin K	120 mg / 90 mg	Liver, egg, milk,	Cabbage, spinach, broccoli, kale, green leaves

Table 5. *Vitamins and their daily recommended dietary allowances with their sources in animal and plant origin foods for intake* (Publishing, 2020)

Dietary Minerals	Sources in animal products	Sources in plant products
Calcium	Yoghurt, cheese, milk, fish	Tofu, broccoli, green leaves
Magnesium		Spinach, broccoli, nuts, seeds, peanut butter, whole grains
Potassium	Dairy products, seafood	Potato, sweet potato, bananas, tomato
Phosphorus	Red meat, dairy products, fish, poultry	Grains
Iron	Red meat, turkey	Beans, lentils, pumpkin seed
Zinc	Red meat, poultry, dairy products	Nuts and whole grains

Table 6. *Dietary minerals with sources of animal and plant products (Publishing, 2020)*

4.4 Bioavailability

Bioavailability is explained by the absorption of a substance after digestion and its easily participation to the physiological function of the body. Bioavailability of antioxidants is lower in vegetarian diets due to bioavailability is less in plant-based food than in animal-based food. Not only antioxidants, but also availability of some vitamins and minerals can show differences in different sources of food.

Antioxidant bioavailability influence biomarkers in plasma. These biomarkers can decrease or increase depending on the effect to the body. Gut microbiota also plays a role in this antioxidant bioavailability. Antioxidant molecules can be broken down to smaller molecules or can be released as the same molecule. The new consisted molecules can also affect the biomarkers variety and quantity in the plasma (Williamson & Manach, 2005).

Bioavailability and the synthesis of minerals and vitamins are also lower in a vegetarian diet than in a non-vegetarian diet. With the elimination of animal-based products, intake of zinc, iron, and copper is decreased in a vegetarian diet. Because, these minerals are present in different forms, for example, iron is available in animal-based products as heme-iron form, whereas, in plant products it is available as nonheme-iron form. Even though the absorption of the non-heme iron is increased with vitamin C and carotene sources, there are other factors to decrease the absorption, which is the intake of polyphenols and soy protein, and these intakes are different in diets (Benzie & Wachtel-Galor, 2009).

Different diets have a diverse food source content, therefore different bioavailability differs among diets because of the micro and macronutrients they contain.

5 Antioxidants + Health impact (Prooxidant)

Red berries such as fresh and frozen blueberries, cranberries, beets pomegranate, are rich in antioxidants. Sweet potato and carrot are full of carotenoids which give the orange color to the root part of the plant. Pumpkin seeds, chia seeds, and flax seeds are not only full of good fat and fiber but also health-promoting antioxidants. Herbs and spices such as turmeric, cinnamon, oregano, thyme, basil, rosemary, and clove are added to the meal to give extra flavor, but also because of their antioxidant features.

However, antioxidants may also feature as a prooxidant depending on situations such as in high doses, and available metal ions, they interact with reactive oxygen species and therefore, stimulate oxidative stress (Guardado, Molina, Joo & Uriarte, 2012).

From the best-known antioxidants, vitamin C and E are linked together for their antioxidant mechanisms. In high doses or reactions with free radicals, they show a prooxidant features. Vitamin E becomes a free radical, tocopheroxyl radical. In the presence of vitamin C, Vitamin E is regenerated by it (Carocho & Ferreira, 2013).

6 Vegetarian / Non-vegetarian Diets and Health Concerns

As a long-term effect of diets related to the health status, there are many aspects between vegetarian and non-vegetarian diets and their consequences. The diet type and consumption of some specific food in the diet affect the health status of the human body related to longevity. Health problems can cause long-term adverse effects on human health.

These health problems are obesity and type 2 diabetes, which occur because of the measure of Body Mass Index (BMI) of the body, cardiovascular diseases, osteoporosis, and cancer. The Body Mass Index (BMI) is calculated from the ratio of the weight and the square of the body height. It is expressed as kg/m^2. This index can also be explained by the internal and external factors such as genetics, physical activity and use of tobacco or alcohol. The Body Mass Index (BMI) is higher in non-vegetarians than vegetarians. Fat content of the body from the high-fat diet can cause to have a higher body mass index in the human body. A high body mass index is a risk for atherosclerosis, cholesterol, obesity, and type 2 diabetes.

Improved glycemic control, decreased blood pressure, and insulin resistance in the blood are seen as one of the most significant effects of a vegetarian diet due to a lower intake of saturated fat and higher intake of fiber because of more frequent intake of legumes, grains, fruits, and nuts than non-vegetarian diet. Therefore, it causes less formation of disorders in the body, especially Low-Density Lipoprotein (LDL) cholesterol level, obesity, and type 2 diabetes (Craig, 2010).

Regular and high consumption of fruits and vegetables has shown an inverse effect of any occurrence of cancer types considering these foods are rich in antioxidants which can function as anti-cancer. Also, high fiber in grains, legumes, and vegetables are easily digestable and associated with lower body weight, blood pressure, cholesterol, and overall a long healthy life.

Non-vegetarian diet is rich in protein content and high in calories as well as trans and saturated fatty acids. Even though, non-vegetarians have no problem with mineral and vitamin deficiencies, high content of fat can cause a higher blood pressure, an increase in Low-Density Lipoproteins (LDL) cholesterol level. A high consumption of red meat and processed meat can make certain types of cancers possible, especially when it's fried or barbequed, they contain carcinogenic heterocyclic amines (Benzie and Wachtel-Galor, 2010).

A properly maintained vegetarian diet with adequate intake of mineral and vitamin supplements are linked with a healthier status of the body. It can contribute of preventing any certain chronic diseases. Selection of the food to the body can also affect the composition of the gut structure. Since gut has a specific pH range and microorganism variety, and this can change by the nutrient content of the food. Depending upon the pH range of the gut, different types of bacteria can live favorably. Therefore, the gut has a different microbiota environment between vegetarian and non-vegetarian diets.

6.1 Biomarkers of oxidative stress and antioxidant status

Biomarkers or biological markers are a measurable indicator of biological processes, pathogenic processes, and pharmacologic processes in cell, tissue, and body. They indicate the presence of any change in nutritional deficiency, oxidant/antioxidant balance, body status, and any abnormal presence of disease states such as vitamin deficiency, or any available molecules which are found in plasma (Benzie & Wachtel-Galor, 2009).

A biomarker can be a precursor of any available disorder in the body status. It can be measured by plasma content and amount in the cell.

7 Microbiota

From the infant to adult phase of human life, the gut microbiota changes related to many internal and external factors, such as type of birth, genetics, geography, health status, age, metabolism, immunity, dietary habits, and nutrition (Cani, 2017). The gut microbiota is sterile at birth, and by the time, it starts to build its composition. There are an estimated 10^{14} microorganisms living in the adult human gut, and almost 97% of the microbiota is formed by anaerobic bacterial species (Bedani, Isay Saad & Sivieri, 2016). The gut microbiota is in a mutualistic and symbiotic relationship with the live microorganism inside and the host.

The content of the gut microbiota can play a role in activating of enzymes and synthesizing vitamins, the shape of bacterial diversity in intestines, affecting the immune system, digesting different types of molecules, or production of metabolites.

Synthesis of vitamin K_2 is produced by the anerobic bacteria in the gut even though vitamins are available and abundance in fruits and vegetables normally. Vitamin K_2 is also available mostly in animal products such as liver, meat, and cheese. In addition, it is available in fermented plant products.

The gut microbiota is consisted of the bacterial phyla of Firmicutes, Bacteroidetes, Proteobacteria, Actinobacteria, Fusobacteria, and Verrucomicrobia. Firmicutes and Bacteroidetes constitute the majority (Tan & O'Toole, 2015). Most of the bacterial composition in the gut microbiota can differ depending on the diet type. A moderation in the diet can modify the diversity of the bacterial ecosystem. In a high animal-based diet can increase the *Firmicutes* phylum, in a long term, this will cause a bile tolerant *Bacteroides* genus and decrease the amount of *Roseburia sp*., *Eubacterium rectale*, and *Ruminococcus bromii* plant polysaccharide metabolizing bacteria, whereas in a high plant-based diet, *Bacteriodete* phylum is the abundant in the gut (Chaluvadi, Hotchkiss & Yam, 2016). This *Firmicutes/Bacteroidetes* ratio can be a clue to understand the overall status of the microbiota (Bedani, Isay Saad & Sivieri, 2016).

Diet types and intake of different macronutrients affect the biodiversity of the gut microbiota. Such as high-fat diet, low in fiber or starch, low content in protein, western style diet of high intake of animal-based food, native diet in rural areas can regulate the bacteria variety and colonization of bacteria in the gut (Tan & O'Toole, 2015).

Diet type not only affects the diversity of bacteria in the gut but also associated functional genes in the microbiome. Thanks to the gut microbiota, the human body can be able to synthesize many molecules, vitamins B and K, especially K_2.

The gut microbiota not only can be changed by a diet, but also can be regulated and kept under control by a diet. 1-day change of diet change can affect the microbiota and keep it for 7 days (Turnbaugh et al., 2009).

However, the composition of the gut microbiota may remain stable after age 2. In an elder human gut, it is not stable and has less bacterial diversity. This causes a less durable environment to external factors. Use of antibiotics, aging, and a decrease in immune system function causes a change in bacterial composition. Therefore, the metabolic activity of the changed microbiota is linked with related diseases (Bedani, Isay Saad & Sivieri, 2016). Modifications in microbiota from the diet can occur and cause some alterations from immunity of the body to bacteria varieties in the gut. Depending on the presence of specific bacteria in the gut, some disorders can be formed, such gastrointestinal diseases, cancer, especially colon cancer (Tan & O'Toole, 2015).

In the figure below, the relationship between diet type and diversity of bacteria colonization related to the production of some microbial metabolites and their effect on health status on the host is shown.

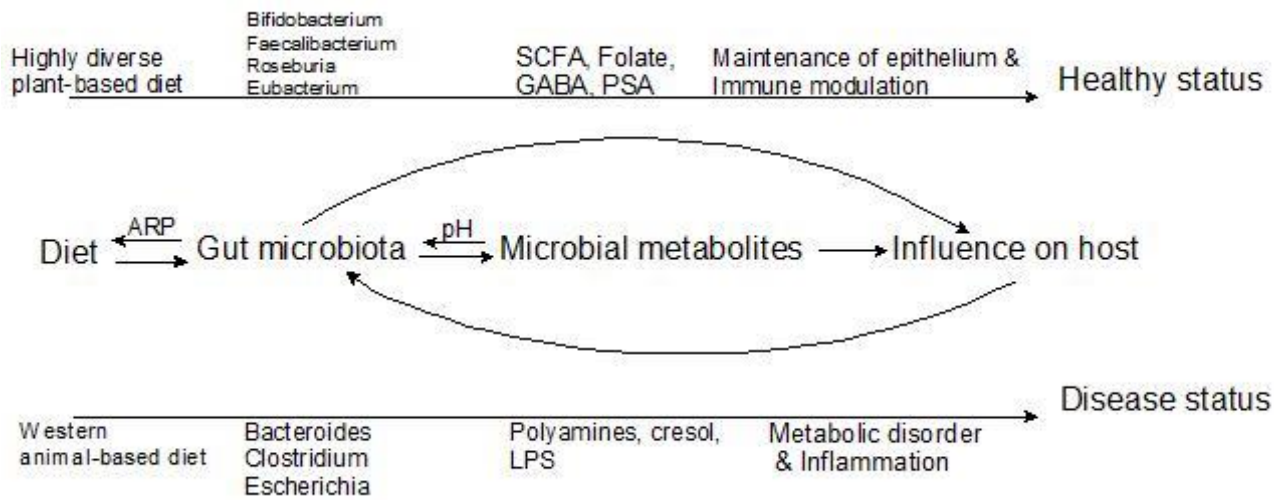


Figure 8. *Interactions between diet, gut microbiota, microbial metabolites, and host. Different habitual diet may result in different health status by manipulating gut microbiota and their metabolites. ARP: appetite-regulating peptides; SCFA: short chain fatty acid; GABA: γ-aminobutyric acid; PSA: polysaccharide A; LPS: lipopolysaccharide*

(Tan & O'Toole, 2015)

The relationship of microbiota with neuro-related diseases can be explained by its connection with the brain.

7.1 Gut-Brain Axis

The gut microbiota and the brain are connected by a bidirectional relationship. The bidirectional connection connects the brain to the gut microbiota and the gut microbiota to the brain. This connection is called as gut-brain axis. These connections include Enteric Nervous System (ENS), and Central Nervous System (CNS). The communication of the gut-brain axis is provided by neural, endocrine, and immunity. The structure of the gut microbiota and its connection to the brain influence the brain function and the behavior. Moreover, the metabolites that are produced in the gut can have an influence on the brain via the gut-brain axis and therefore, neurodegenerative diseases can occur depending on the abnormal function of the gut-brain axis, the type of the production of the bacterial metabolites and their release to the blood.

The connection of the brain and the gut microbiota is shown in the figure below.

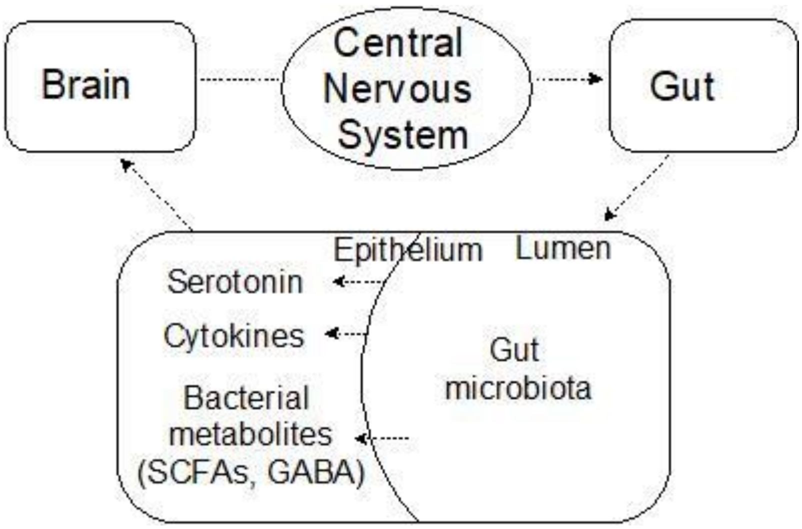


Figure 9. *The gut-brain axis. GABA: γ-aminobutyric acid; SCFA: short chain fatty acid*

(Cerniglia, 2018)

As a result of the bacterial metabolism in the gut, some neuroactive metabolites are produced. These metabolites influence the host's health positively or negatively. For example, these metabolites are Short Chain Fatty Acids (SCFAs), γ-aminobutyric acid (GABA), serotonin, and cytokines (Cerniglia, 2018).

Short Chain Fatty Acids (SCFAs) are formed from 2- to 5-carbon fatty acids by the fermentation of oligosaccharides, or resistant starch in the colon. These 2-, 5- carbon fatty acids are mostly, acetate, propionate, and butyrate (Tan & O'Toole, 2015).

γ -Aminobutyric acid is a chemical neuroactive compound and plays an active role in the central nervous system as an inhibitor neurotransmitter. The γ -Aminobutyric acid which is produced by the *Lactobacillus brevis* and *Bifidobacterium dentium* bacteria, and is an important factor in decreasing anxiety, fatigue, and depression in the development of the brain in mammals.

The formation of these metabolites can adjust the pH range of the human gut. In a favorable environment of the gut, beneficial bacteria can live, whereas pathogenic bacteria cannot. These beneficial bacteria are called as probiotics and they are great helper for human gut.

7.2 Probiotics

Probiotics are live microorganisms (yeast and lactic acid bacteria) in the gut flora. They can survive in different gut environments such as in acid and bile salts. They influence the function and composition of the gut microbiota, affect the habitat they exist, directly and indirectly. With an intake of regularly and adequate amount, they can increase the diversity of microbiota, reduce digestion problems, ease the existing lactose intolerance, improve immunity, and provide health benefits for the host. They also help normalizing the gut microbiota when it is disturbed by antibiotics or stress factors. They are highly present in fermented dairy products such as yogurt, kefir and buttermilk, other fermented foods such as sauerkraut, pao cai and kimchi, kombucha tea and probiotic-fortified foods. They can be added to products to give more nutritious. To keep the probiotic's benefit, it is important to protect its activity under food processing, during storage and transit from the stomach to the small intestine.

Nonetheless, to benefit as healthy, probiotics also should be nonpathogenic, nonallergic, nontoxic, and noncarcinogenic. These microorganisms stabilize the human body in a homeostatic state.

Most of the probiotics contain bacterial strains of members of the lactic acid bacteria, Lactobacilli (*Lactobacillus acidophilus, L. casei, L. plantarum, L. reuteri, L. rhamnosus, L.*

salivarius); bifidobacteria (*Bifidobacterium breve, B. longum, B. lactis*), Bacillus (*B. subtilis, B. cereus var. toyoi*), Enterococcus (*E. faecium*), and as yeast, *Saccharomyces boulardii* (*Probiotics, Prebiotics, and Synbiotics*, 2015).

The list of the bacterial component of some probiotic food is shown in the table 3.

Fermented Food Product	Component of Probiotics
Sauerkraut	*Leuconostoc mesenteroides, Lactobacillus plantarum, Pediococcus pentosaceus, Lactobacillus brevis, Leuconostoc citreum, Leuconostoc argentinum, Lactobacillus paraplantarum, Lactobacillus coryniformis, and Weissella spp.*
Kimchi	*Leuconostoc spp., Weissella spp., and Lactobacillus spp.*
Pao Cai	*L. pentosus, L. plantarum, Leuconostoc mesenteroides, L. brevis, L. lactis, and L. fermentum.*
Kefir	*Lactobacillus acidophilus, Bifidobacterium bifidum, Streptococcus thermophilus, Lactobacillus delbrueckii subsp. bulgaricus, Lactobacillus helveticus, Lactobacillus kefiranofaciens, Lactococcus lactis, and Leuconostoc species*
Buttermilk	*Lactococcus lactis or L. bulgaricus.*

Table 7. *The names of some probiotic food and their bacterial components*

These foods are consumed not only for their probiotic functions but also, they contain vitamins, minerals, and dietary fibers.

Kimchi is considered as antimutagenic, anti-cancer, antioxidative, and antiaging. Not only bacterial content but also it contains radish, cabbage, garlic, ginger, red pepper, dietary fiber. Because of these ingredients it shows antioxidant, antimicrobial, anti-obesity, lipid-lowering features (Park & Jeong, 2016).

The composition, and diversity of the gut microbiota can cause some alterations in the body. For example, gastrointestinal diseases, high blood pressure, inflammatory bowel disease.

Mainly gastrointestinal diseases are linked with the change of the gut microbiota depending on the probiotic variety and the human health. Additionally, neurodegenerative diseases can occur due to the connection of the gut to the brain.

8 Longevity of the Vegetarian Diet

When it is considered, the vegetarian diet with an active lifestyle, less consumption of alcohol and tobacco, it shows a longer lifetime and reduced incidence of chronic illnesses or metabolic syndromes such as low BMI, low blood pressure, and cholesterol than a less active lifestyle or high consumption of alcohol and tobacco. The long-term positive effects of the vegetarian diets show up when it is maintained for years.

Decrease of chronic illnesses such as cancer and obesity in the vegetarian diet is explained by high consumption of fruits, vegetables and less or no intake of animal-based products. As a long-term effect, vegetarians have lower risk of metabolic related disorders than non-vegetarians therefore it provides a longevity for vegetarians (Tantamango-Bartley, Jaceldo-Siegl, Fan & Fraser, 2012).

To benefit of this vegetarian diet, it is important to not only eat plant-based but also to have good and healthy lifestyle habits. The health-related results are also considered with external factors.

9 Conclusion

Free radicals are a product of reactions of molecules with oxygen, and formed from smoking, being exposed to UV light and pollutants, excessive exercising, and metabolic reactions in the body. The excessive quantity of free radicals is responsible to generate an imbalance between oxidants and antioxidants which is called as oxidative stress. Oxidative stress triggers the cells, molecules, and tissues in the body. Increased oxidative stress causes chronic disorders to damage the health.

Antioxidants are organic compounds present in various plants naturally and be synthesized artificially as additives to prolong shelf life of the food and prevent the food breakdown. Fruits, vegetables, beverages, legumes, nuts, and seeds are rich in different varieties of antioxidants. Antioxidants are a part of the defense system of the body. They prevent any damages causing from free radicals by donating their electrons or hydrogens.

Food is necessary for an organism to maintain its vitality. Food has different contents depending on its sources. The diet type plays a big role in providing different nutrition when it is either a plant-based or an animal-based. The content of the diet can cause disorders in the body because micro and macronutrients affect the growth, development, and health status of the body. Vegetarian and non-vegetarian diets have different intake of polyunsaturated fatty acids, saturated fatty acids, antioxidants, vitamins, minerals, fibers, and sugar, which affect the body functionality such as body mass index, glycemic control, blood pressure, insulin resistance, low-density lipoprotein level.

Moreover, the food regulates the gut microbiota and ensures different bacteria species live. The gut microbiota is also connected to the brain via the gut-brain axis which is a bidirectional relationship of the brain and the gut. The microbiota composition has an impact on the metabolite production which affect the brain development or cause a disorder via the bloodstream.

As consequences of oxidative stress imbalance, available antioxidant variety, quantity of saturated or polyunsaturated fatty acids, content of sugar, fat, fiber, vitamins, and minerals can cause long-term diseases, such as atherosclerosis , obesity, type-2 diabetes, stroke, cardiovascular and neurodegenerative diseases, and cancer. These diseases can occur, accelerate, or be prevented by the diet, and its content.

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11 List of Abbreviations

ROS – Reactive Oxygen Species

RNS – Reactive Nitrogen Species

CVD – Cardiovascular Disease

T2DM – Type 2 Diabetes Mellitus

LDL – Low-Density Lipoproteins

DNA – Deoxyribonucleic Acid

HAT – Hydrogen Atom Transfer

BDE – Bond Dissociation Enthalpy

ET – Electron Transfer

SOD - Superoxide Dismutase

CAT – Catalase

GPx - Glutathione Peroxidase

GSH - Glutathione

NADPH - Nicotinamide Adenine Dinucleotide Phosphate

BHT – Butylated Hydroxytoluene

BHA – Butylated Hydroxyanisole

TBHQ – Tertiary-butylhydroquinone

PG - Propyl Gallate

FAO – Food and Agriculture Organization

WHO – World Health Organization

JECFA – Joint FAO/WHO Expert Committee on Food Additives

RDA – Recommended Dietary Allowances

BMI – Body Mass Index

ARP – appetite-regulating peptides

SCFA – short chain fatty acid

GABA – γ -Aminobutyric acid

PSA – polysaccharide A

LPS – lipopolysaccharide

ENS – Enteric Nervous System

CNS - Central Nervous System

12 List of Figures and Tables