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Fundamentals of antioxidant capacity in food

Fundamentos da capacidade antioxidante em alimentos

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RESUMO

Este artigo tem como objetivo discutir os conceitos básicos da capacidade/atividade antioxidante nos alimentos e do equilíbrio oxidativo necessário à saúde. A linguagem neste artigo é mantida básica o suficiente para que o público em geral possa entender. O artigo fornece informações condensadas sobre esta área como parte de um esforço mais amplo para popularizar a ciência. O artigo começa discutindo os conceitos básicos de antioxidantes e radicais livres desde os conceitos de química geral. As reações de redução da oxidação são essenciais para a vida, mas também produzem radicais livres nocivos, é a dicotomia básica a ser discutida. O trabalho apresenta então a importância da alimentação no equilíbrio oxidativo do metabolismo humano e como esse equilíbrio é necessário para a manutenção e promoção da saúde, principalmente reduzindo o risco de doenças crônicas não transmissíveis. Por fim, o artigo discute o papel dos antioxidantes no antienvelhecimento e na proteção do DNA.

Palavras-chave: Radicais livres; AGEs; envelhecimento; vitaminas; fenólicos.

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ABSTRACT

This paper aims to discuss the basic concepts of antioxidant capacity/activity in food and the oxidative balance needed for health. The language in this paper is kept basic enough for the general public to understand. The paper provides condensed information on this area as part of a broader effort to popularize science. The paper begins by discussing the basic concepts of antioxidants and free radicals since general chemistry concepts. Oxidation-reduction reactions being essential for life, but also producing harmful free radicals is the basic dichotomy to be discussed. The paper then presents the importance of food in the oxidative balance of human metabolism and how this balance is necessary for the maintenance and promotion of health, mainly reducing the risk of non-transmissible chronic diseases. Finally, the paper discusses the role of antioxidants in anti-aging and DNA protection.

Keywords: Free radicals; AGEs; aging; vitamins; phenolics.

INTRODUCTION

Understanding the need for a healthy diet rich in fruits and vegetables necessarily involves the idea of a balance between harmful and beneficial substances present in our body. These two types of substances can come from endogenous sources (originating from internal factors) and exogenous sources (originating from external interactions). In the case of food, beneficial substances are considered exogenous and thus constitute a sort of second line of defense in our body. This desired balance between harmful and beneficial substances is measured in terms of oxidation and antioxidation (reduction) reactions and called oxidative balance (Pisoschi and Pop, 2015).

The antioxidant activity in a food can be defined quite simply as the ability that some substances present in this food have to extinguish highly oxidizing (reactive) substances called free radicals, present in our metabolism. Thus, antioxidants are able to inactivate the damage effects of these radicals on the organism in question (Branini et al., 2019).

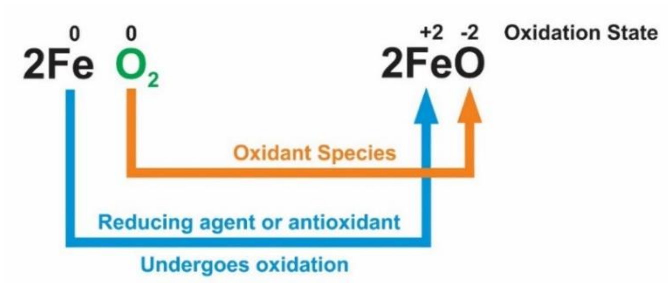
Chemical concepts

Oxidation-reduction reactions are present in many fundamental and indispensable situations for life. We live in an oxidizing atmosphere. The process of breathing itself is highly oxidizing. The nutrients present in foods undergo several oxidative reactions when they are ingested or even during their shelf life. The idea of antioxidant activity (AA) of a nutrient goes through the basic chemical concept of oxidation and reduction (antioxidation): the species called oxidizing agent or simply oxidizing, has this name because it causes oxidation, loss of electrons, in the other chemical species, being the one who is reduced (gains electrons) (Apak et al. 2016).

The electron is an electrically negative very small particle that is found around the atomic nucleus. The idea of stability for an atom can be fairly summarized in the fact that it needs to have pairs of electrons in the last layer. When this does not happen, the atom may be able to capture electrons from another atom in order to have its electronic stability achieved. This is the basic idea of the reactivity of a free radical, an oxidizing substance (Santos, 2019).

In Figure 1, the reducing species (reducing agent or antioxidant) causes the reduction (gain of electrons) in the other chemical species. By reducing this other species, the reductor loses electrons (loses negative charge, which makes it more positive), that is, it undergoes oxidation (Silvertein, 2011).

Figure 1: Example of the concept of oxidation and reduction (antioxidation) in a simple chemical reaction.



Source: Authors (2023).

The concept of an antioxidant substance can be simplified to a substance that provides electrons to another species that is an oxidant, i.e., that has the ability to capture these electrons. The antioxidant makes the oxidizing substance chemically stable. Free radicals are, therefore, unstable, oxidizing molecules where at least one atom has an odd number of electrons in its last layer; the vast majority are very reactive, existing for a short period of time because they react very easily with the medium (Klein; Braibante, 2017).

When trying to stabilize themselves, free radicals capture electrons from molecules such as proteins, nucleic acids, or even cellular structures, besides removing electrons from other molecules, generating other free radicals. They can also attack the DNA molecule, destroy part of the molecule and cause oxidation in some components, producing mutations and even cancer (Oliveira, 2016). In food systems free radicals can produce spoilage, discoloration (non-enzymatic reactions within the food itself) and rancidification (Kumar, 2011).

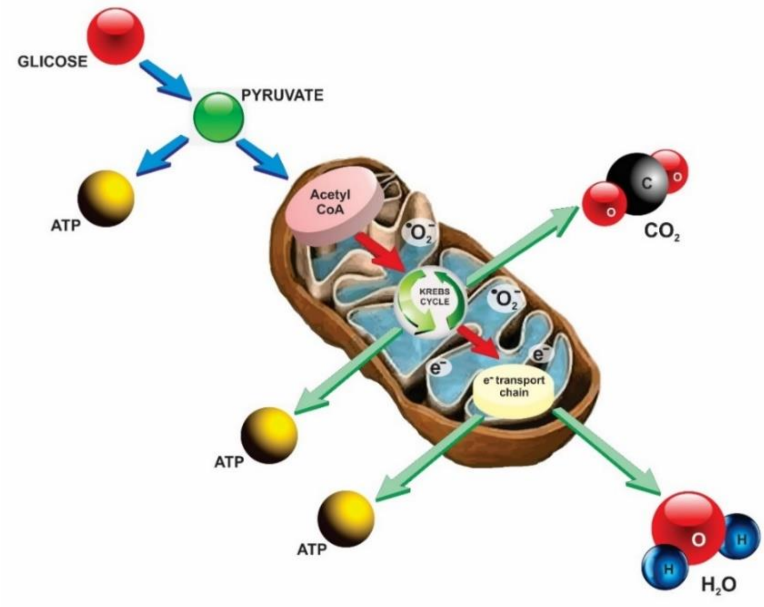
Biological Concepts

Cellular-scale respiration - Examples of some free radical formation

Mitochondria are the main producers of reactive oxygen species, which damage DNA, proteins and lipids if not quickly quenched. It is known that 2 to 5% of the oxygen from respiration generates free radicals (Barbosa et al., 2010).

In mitochondria, oxygen binds to two hydrogen atoms and forms a water molecule. However, oxygen does not always turn directly into water, because at some points in the mitochondria (Figure 2) there is a loss of electrons that are soon captured by the oxygen molecule. When it gains an electron in the mitochondrion, the oxygen turns into a superoxide radical. The superoxide is strong enough to capture another electron and turn into a hydrogen peroxide molecule that is stable. Hydrogen peroxide molecules can pass through the cell membrane and react strongly with iron, copper, or zinc atoms that they encounter along the way. Hydrogen peroxide is not a radical, but it can gain one more electron, forming the most reactive of the radicals: hydroxyl (OH-) which reacts instantly with molecules in the cell (Oliveira, 2016).

Figure 2: General schematic of mitochondrial respiration with representation of oxygen flow and electron leakage.



Source: Authors (2023).

The main free radicals are usually formed by in chain reaction. Table 1 lists some examples of free radicals: reactive Oxygen species (ROS) and reactive Nitrogen species (RNS), how they are formed and their form of action in a living organism (Peterson et al., 2012; Chen and Zweier, 2014; Deboer, 2015).

Table 1: Examples of reactive oxygen species (ROS) and reactive nitrogen species (RNS), their formation and action in metabolism.

ROS/RNS	Main formation	How it acts
$O_2^{-\bullet}$ Superoxyde	Superoxide Enzymatic process, auto-oxidation reaction, and non-enzymatic electron transfer reactions.	Reducing agent of iron complexes and oxidizing agent of ascorbic acid and of α-tocopherol.
$HO_2^{\bullet}$ Hidroperoxila	Protonation of $O_2^{-\bullet}$	Initiates the peroxidation of fatty acids.
$OH^{\bullet}$ Hydroxyl	H_2O_2 (hydrogen peroxide) generates the hydroxyl radical through reaction with a metal, especially iron.	Reacts with organic and inorganic molecules, including DNA, proteins, lipids, and carbohydrates.
$NO^{\bullet}$ Nitric oxide	Action of the enzyme nitric oxide synthase, using arginine as substrate and NADPH as source of electrons.	It is an intracellular messenger that stimulates guanylate cyclase, protein kinase, and aids in smooth muscle relaxation of blood vessels.
$NO_2^{\bullet}$ Nitrogen dioxide	Protonation of $ONOO^-$ (peroxynitrite) or homolytic fragmentation of $ONOOCO_2^-$ (also RNS).	Acts on the antioxidant mechanism by decreasing ascorbate and α-tocopherol in plasma.

Where: NADPH (nicotinamide adenine dinucleotide phosphate); $ONOOCO_2^-$ (nitrosoperoxo-carbonate anion). Source: Authors (2023).

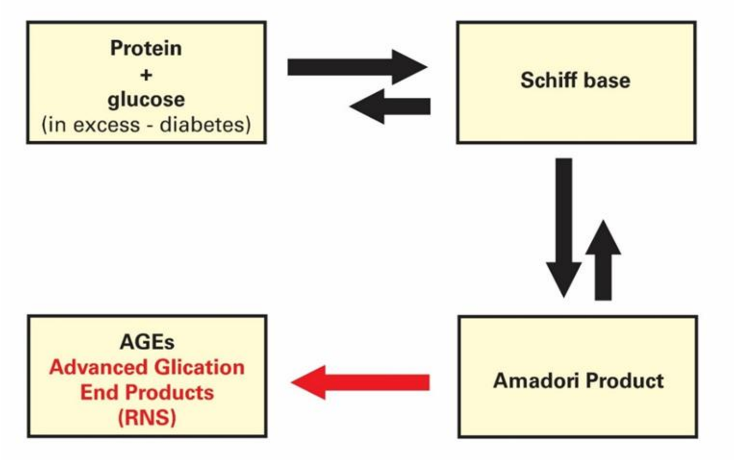
Advanced Glycation Agents (AGEs) - Specials NRS

The Maillard Reaction (MR) is the chemical reaction between an amino acid or protein and a reducing carbohydrate that gives products their caramelization and is responsible for the taste, odor and color of foods. MR is, in fact, a set of non-enzymatic reactions of reducing sugars with amine groups and occurs in vivo (Figure 3). (Henning; et al., 2011).

The initial product of this reaction is an unstable compound called a Schiff base. This molecule undergoes a rearrangement, producing a stable ketoamine, called Amadori's product. Through oxidation reactions, the Amadori products are degraded into compounds with carbonyl radical, producing chain reactions with amino groups of proteins and irreversibly originating insoluble compounds with heterogeneous molecules capable of modifying the chemical and functional properties of the most diverse biological structures. These substances are called Advanced Glycation End-products (AGEs) (Bem and Kunde, 2006).

In diabetes, advanced glycation products result from the high availability of glucose with the reactions balance shifted to the products. AGEs are then RNS responsible for the side complications of the diabetes disease (Teodorowicz et al., 2018).

Figure 3: Stages of protein glycation due to diabetes and formation of AGEs.



Source: Authors (2023).

Increased inflammatory response

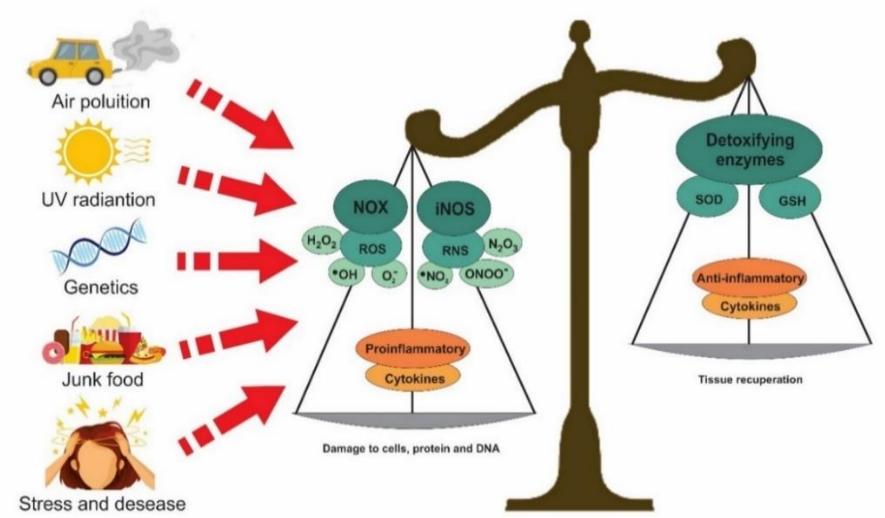
The oxidative imbalance and consequent increase in ROS/RNS triggers the production of pro-inflammatory cytokines in tissues. Figure 4 shows a schematic of an oxidative balance endogenous to metabolism without considering external (exogenous) factors. The term NOX represents the action of the enzyme NADPH oxidase and analogues, responsible for the production of ROS; whereas iNOS represents the enzyme inducible nitric oxide synthase, responsible for the formation of RNS that induce pro-inflammatory response in the form of cytokines and chemokines. On the anti-inflammatory side of the oxidative balance, we have the action of enzymes such as superoxide dismutase (SOD) and Glutathione (GSH) (Krause, 2007; Fischer and Maier, 2015).

Cytokines are small proteins secreted and released by cells, which have a specific effect on the interactions and communications between them. They are mediators necessary to drive the inflammatory response to sites of infection and injury, favoring proper healing. There are pro-inflammatory cytokines and anti-inflammatory cytokines.

Cytokine is a general term that includes lymphokines, monokines, chemokines, and interleukins (Palomino and Marti, 2015).

The exaggerated production of pro-inflammatory cytokines from a tissue injury can manifest with metabolic disturbances. After severe injury or infection, the exacerbated and persistent pro-inflammatory cytokine response, for example, can contribute to target organ damage, leading to multiple organ failure and death (Krause, 2007).

Figure 4: General scheme of an endogenous oxidative balance.



Where: NOX = process responsible for the formation of reactive oxygen species (ROS) and iNOS = process responsible for reactive nitrogen species; SOD = Superoxide desmutase enzyme and GSH = Glutathione. Source: Authors (2023).

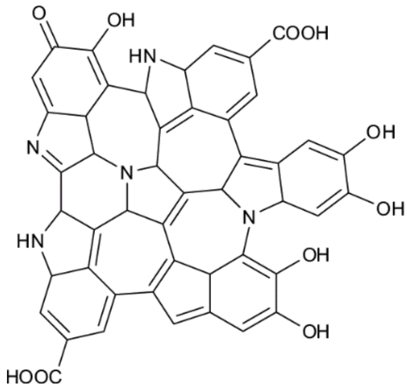
The concept of aging

Aging is a multifactorial and complex biological process. Free radicals can cause various damage to biological macromolecules such as nucleic acids, proteins, and lipids. ROS/RNS can also turn off genetic information and can even generate cancer or non-transmissible chronic diseases (NTCD) (Hatice, 2018).

Lipid Peroxidation It is the main process in aging, in which ROS assaults the polyunsaturated fatty acids of phospholipids in cell membranes, allowing these species to enter intracellular structures. ROS also reacts with low-density lipids or bad cholesterol, which become deposited in the blood vessels of arteries (Barja, 2004).

When it comes to free radicals, the term aging goes far beyond the skin state, but there is a common sense about darker skin and younger appearance. This idea can be explained by melanin chemical structure, a heteropolymer formed by monomeric units of the amino acid tyrosine that undergoes enzymatic oxidation (Figure 5). This chemical structure is plenty of double bonds and nitrogen atoms for electron supply; therefore, the common sense is correct a dark skin with more melanin tends to age less (Herrling et al., 2008 Schlessinger et al., 2022).

Figure 5: Melanin (eumelanin) most acceptable structure.



Source: Authors (2023).

Electron paramagnetic resonance (EPR) and electrochemical measure of antioxidant capacity

The importance of reactive species for health is direct measure by a technique that looks directly for reactive oxygen species, reactive nitrogen species, and reative chlorine species on their most obvious property: the unpaired electrons. Electron paramagnetic resonance is a non-destructive characterization technique that is very similar to nuclear magnetic resonance. EPR is based on the detection of unpaired electron transitions when a magnetic field is applied. This is the most sensitive technique used to detect and characterize free radicals (Silva et al., 2008; Pilawa; et al., 2017).

Antioxidant substances

Enzymes and proteins - as Endogenous sources

Glutathione and the enzymes that are part of the catalytic cycle of this peptide act to decrease oxidative stress. It is a tripeptide (g-L-glutamyl-L-cysteinyl-glycine), which exists in the body in its reduced (GSH) and oxidized (GSSG) forms, acting directly or indirectly in many important biological processes, including protein synthesis, metabolism, and cell protection (Rover Júnior et al., 2001).

The enzyme activity of glutathione peroxidase (GSH-Px), on the other hand, is one of the means by which the body controls the levels of hydrogen peroxide and hydroperoxides in the attack of radical species. The enzyme glutathione peroxidase has an important feature in its structure, featuring a cysteine residue containing selenium covalently linked to the rest of the enzyme. Selenium has been characterized as an essential component of this complex molecule. Another enzyme that acts together with glutathione peroxidase is the enzyme glutathione reductase (GR). This enzyme does not act directly in the removal of radical species, but is responsible for the regeneration of glutathione to its reduced form (GSH) and prevents the stalling of the glutathione metabolic cycle (kang and kang, 2013).

Coenzyme Q10 (CoQ10) is an example of a fat-soluble antioxidant that prevents lipid peroxidation in cell membranes and plasma lipoproteins. CoQ10 is reduced to ubiquinol in blood plasma. Its levels have been inversely associated with cholesterol oxidation. Besides being widely known for its AA, CoQ10 is also an essential component of the electron transport chain for the production of ATP in cells. For this reason, CoQ10 supplementation has been associated with the improvement of many mitochondrial dysfunctions, even benefiting muscle capacity (Sánchez-Cuesta et al., 2020).

Different antioxidant enzymes have different antioxidant mechanisms. For example, peroxyredoxins are enzymes of the peroxidases family with a thiol group that can remove H_2O_2 by oxidizing cysteine residues. Peroxidase enzymes (POD) catalyze the oxidation of hydrogen peroxide to water, while oxidizing a number of other substrates (for example, phenolic compounds as seen earlier). Superoxydodesmutase (SOD), on the other hand, are metalloenzymes coordinated by Cu^{2+} or Mn^{2+} and can effectively eliminate superoxide anion. In the case of catalase (CAT), which is also a peroxidase, it uses heme iron or manganese as cofactors to convert H_2O_2 into H_2O and O_2 (Alici and Arabaci, 2016; Piasecki et al., 2019).

Proteins are considered the main target of oxidants due to their abundance in biological systems. However, there is also evidence about significant AA of proteins such as, for example, albumin that is now considered the main antioxidant in plasma with direct or indirect elimination of ROS/RNS species. Some of these properties depend on the molecular structure of this protein, such as its binding with bilirubin in plasma that acts as a co-antioxidant with α-tocopherol to inhibit lipid peroxidation; the SH group of albumin derived from cysteine that represents an important antioxidant pool to eliminate the hydroxyl radical and peroxynitrite; the oxidation of methionine residues in albumin that functions mainly as a metal chelator, are some examples of different sites of antioxidant activity in the albumin molecule (Medina-Navarro et al., 2010).

Exogenous antioxidant substances

Free radical production is not only associated with the normal metabolic processes of the human body (endogenous sources), but can also be due to environmental factors (exogenous sources) such as stress, ozone radiation, pollution, pesticide and industrial chemicals. When there is increased production of ROS/RNS compared to their removal by biological systems (antioxidant defenses), this imbalance is termed oxidative stress. Endogenous antioxidants can protect cells through various mechanisms, however, the intake of exogenous antioxidants, such as ascorbic acid (Vitamin C), α-tocopherol (Vitamin E), carotenoids and polyphenols, among others (Figure 6) that can be found in fruits, vegetables, beverages, cereals, and other food products, can complement the action of defense (endogenous) antioxidants (Alici and Arabaci, 2016; Amarowicz and Pegg, 2019).

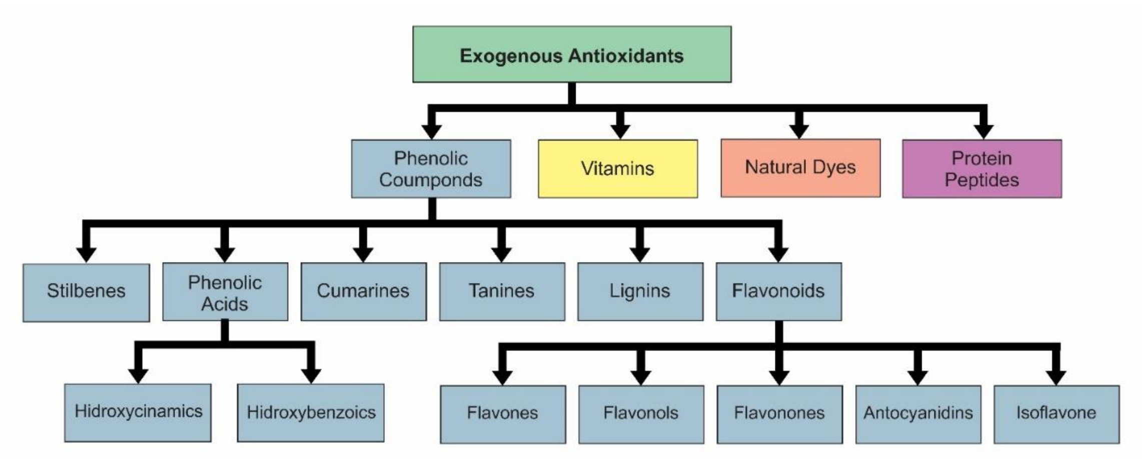
One of the advantages of exogenous antioxidants may be the regulation of redox homeostasis by elimination or even generation of reactive oxygen species, (ROS), which are required at specific low concentrations for normal cell function. Many secondary plant metabolites act as antioxidants and pro-oxidants and can affect ROS concentrations depending on reaction conditions and the presence of other more antioxidant species. In aromatic compounds such as flavonoids, antioxidant activities depend on the redox properties of the phenolic hydroxyl groups in the medium. Flavonoids, for example, have a dual action regarding ROS homeostasis: they act as antioxidants under normal conditions and are potent pro-oxidants in cancer cells, triggering apoptotic (cell death) pathways (Baldim et al., 2017; Kopustinskiene et al., 2020).

However, it is not only in the human body that oxidation damage can occur. Oxidation reactions also occur in many food products when exposed to air (oxygen) and/or heat or light, and antioxidants also play an important role in maintaining the overall quality of these products. One of the most common spoilage processes is lipid peroxidation, which occurs for example in margarine, mayonnaise, and frying oils. This produces undesirable chemical compounds, such as aldehydes, ketones, and organic acids, leading to decreased shelf life, undesired modification of flavor (off flavors), and nutritional value of lipid-containing products in general (Chang and Kim, 2018).

Synthetic phenolic antioxidants, such as propylgallate (PG), tertiary butylhydroquinone (TBHQ), butylated hydroxyanisole (BHA), and butylated hydroxytoluene (BHT), among others, effectively inhibit oxidation. Similarly, chelating agents, such as EDTA, can bind to metals, slowing down the oxidation process. However, the search for effective methods to slow down the oxidation process in meats and meat products leads to the search for natural antioxidants. These preservatives include phenols from vegetables as natural antioxidants, such as vitamins (ascorbic acid and α-tocopherol), herbs and spices (rosemary, thyme, oregano, sage, basil, pepper, clove, cinnamon, and nutmeg), and plant extracts (tea, coffee, and grape seed) that contain antioxidant components, conferring longer shelf life and palatability to the food (Kebede and Admassu, 2019).

Another problem related to oxidation in foods is color change. Oxidative deterioration of lipids can cause bleaching in foods due to the reaction with pigments, especially carotenoids. Enzymatic browning is another oxidative phenomenon in post-harvest processing and storage of food products. It involves the enzymatic oxidation of phenolic compounds, leading to the formation of dark pigments. Phenolic compounds act as substrates for the activities of oxidoreductases (polyphenoloxidases and peroxidases) in the presence of oxygen. These enzymes are major contributors to changes in the color and eventually the final quality of many fruits and vegetable vegetables (Belluzzzo, 2008; Kebede and Admassu, 2019; Lourenço et al., 2019).

Figure 6: Major classes of naturally occurring exogenous antioxidants found in foods.

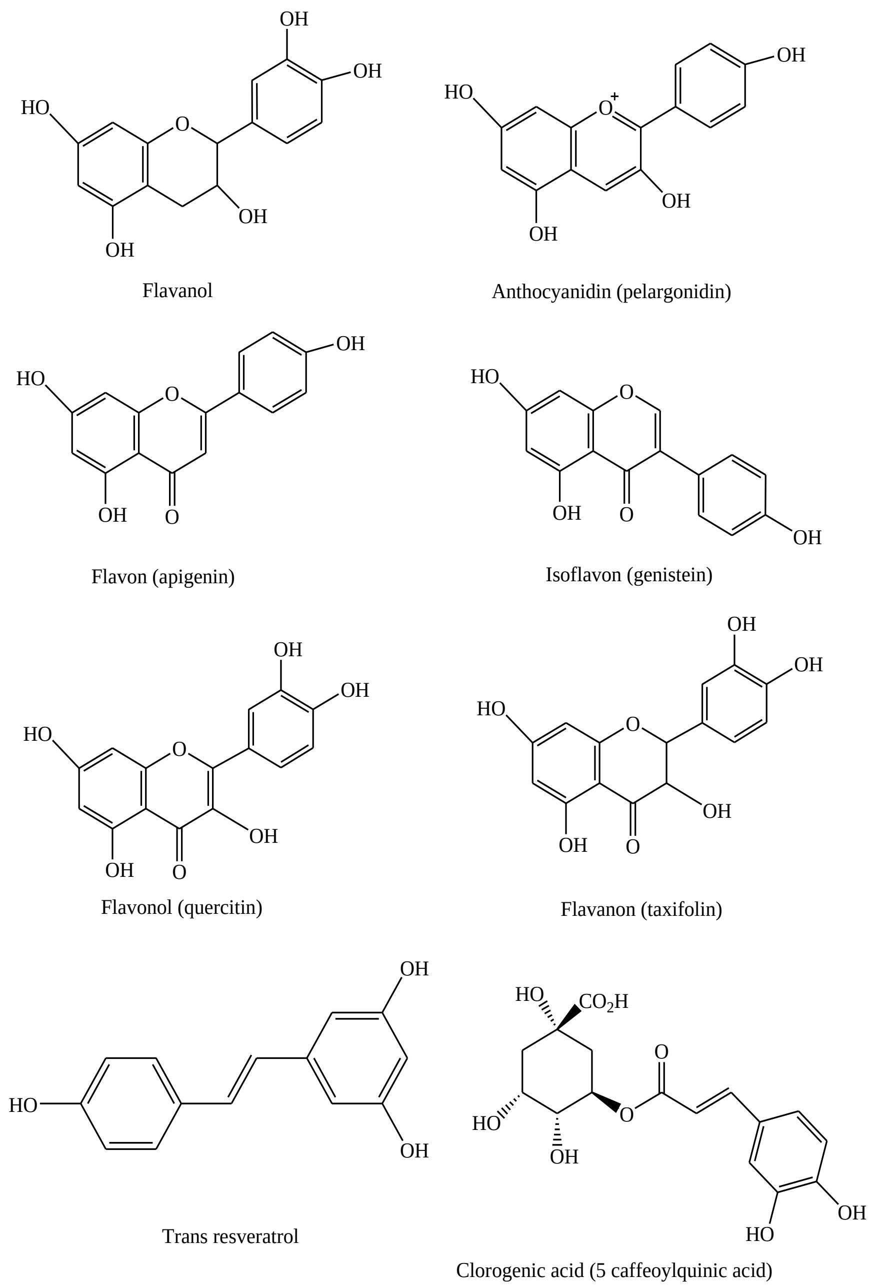


Source: Authors (2023).

Phenolic compounds or polyphenols

Phenolic compounds (Figure 7) are bioactive substances and the most abundant antioxidants in the diet. Their total dietary intake is about 10 times higher than that of vitamin C and 100 times higher than that of vitamin E and carotenoids. The main classes include: hydroxycinnamic acids, of which chlorogenic acid in coffee is a part; tannins; coumarins; lignins and the large group of flavonoids (Angelo and Jorge, 2007).

Figure 7: Examples of some chemical structures of phenolic compounds.



Source: Authors (2023).

The antioxidant capacity of polyphenols is attributed to the reducing power of the aromatic hydroxyl group that reduces various ROS and RNS. The antioxidant efficacy of polyphenols in vivo depends on their bioavailability. Flavonoids are the largest and most studied group among the polyphenols. Consisting of over 5000 identified compounds, flavonoids are also grouped into six subclasses depending on the level of hydrogenation, hydroxylation, methylation, and sulfonation of the molecules: flavonols, flavones, isoflavones, flavanones, flavanols, and anthocyanidins (Chobot and Hadacek, 2011). As examples of polyphenol groups with complex chemical structures, one can mention:

a) Melanoidins - these are brown colored polymers with undefined chemical structure that are the end products of the Maillard reaction. Several studies prove the antioxidant capacity of melanoidins that is associated with the incorporation of phenolic compounds directly to the polymer, such as chlorogenic acid, melanoidins are present in roasted coffe, (Patrignani and González-Forte, 2021).

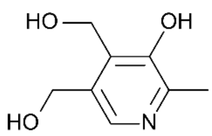
b) Pycnogenol (PYC) - is the trade name for a French maritime pine bark extract. It is a standardized extract composed of a mixture of flavonoids, mainly procyanins and phenolic acids. Studies indicate that the components of PYC are highly bioavailable. In particular, the extract exhibits greater biological effects as a mixture than its purified components, indicating that the components interact synergistically. PYC possesses strong free radical scavenging activity against reactive oxygen and nitrogen species. It also has the ability to regenerate the ascorbyl radical, protect endogenous vitamin E and glutathione from oxidative stress. Today, PYC is considered an oral photo protector (Cretu et al., 2013; Pastoriza, et al., 2014; Simpson et al., 2019).

c) Resveratrol - is a stilbene (phytoalexin) present in peanuts, red wine, and grapes. It is a secondary metabolite associated with grapevine resistance to fungi. The trans isomer are the predominant, more stable and bioactive form. In human medicine, the pro metabolites of resveratrol have been shown to possess anti-inflammatory, antiplatelet, anticancer, antifungal, and antibacterial activities, i.e., known antioxidants. However, resveratrol is also associated with the activation of sirtuin 1 deacetylase (SIRT1). This protein is related to human life extension under caloric restriction and delaying the onset of age-related diseases (Gertz et al., 2012; Li and Wang, 2017; Springer and Moco, 2019).

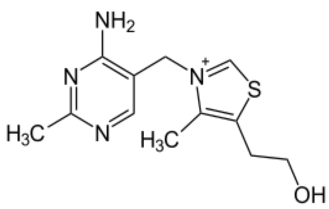
Vitamins

Vitamins are so named because these substances essential to life were believed to be amines, vital amines. In fact, vitamins are groups of heterogeneous substances that are constituents of food, and their activity is measured in terms of the remission of an injury that was caused by their absence in metabolism. Every vitamin has its characteristic activity, but not every vitamin functions as an antioxidant. The B vitamins, for example, are weak antioxidants, practically only exerting vitamin activity. On the other hand, fat-soluble vitamins D and K (mainly K2 - MK7 with seven isoprene residues) have moderate antioxidant effect (Figure 8) (Bavaresco, 2014; Higashi-Okai et al., 2006; Rosa et al., 2007).

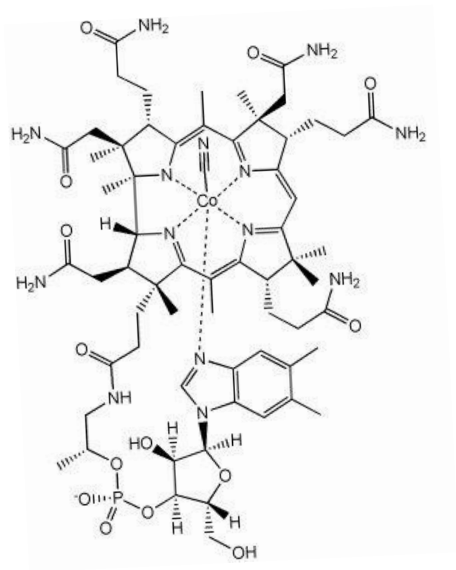
Figure 8: Some vitamins with low to moderate antioxidant activity.



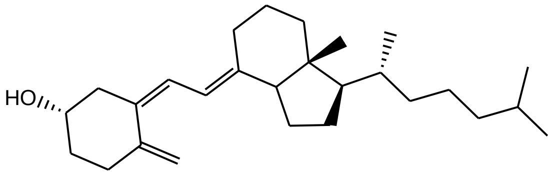
Pyridoxin – vitamin B6



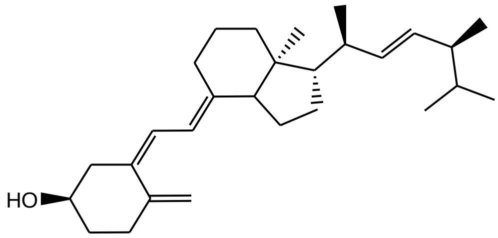
Thiamine – vitamin B1



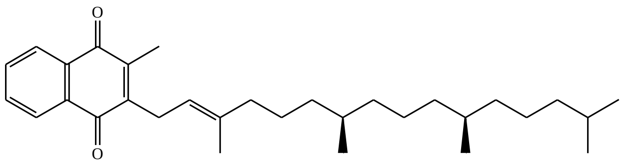
Cyanocoballamine – vitamin B12



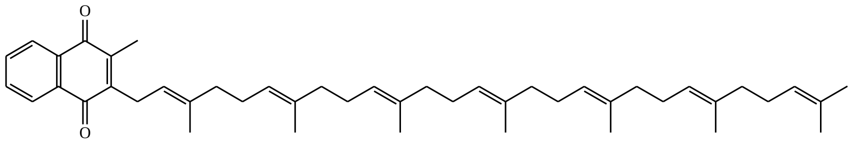
Cholecalciferol - vitamin D_3



Ergocalciferol - vitamin D_2



Vitamin K1



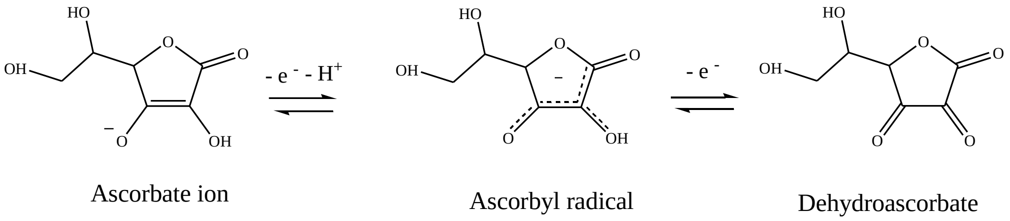
Menaquinone 7 - vitamin K2 MK7

Source: Authors (2023).

Vitamin C

The Antioxidant Activity (AA) of vitamin C occurs through the ascorbate radical (Figure 9) that reacts with ferril species and amino acid radicals, inhibiting oxidative lesions induced by H_2O_2, sequesters O_2^-, HO^-, and RNS-derived species. Ascorbic acid is also the nutrient most affected in fruit and vegetable processing, so its retention is often used as an indicator of nutritional quality and even food preservation (Barbosa et al., 2006; Rosa et al., 2007).

Figure 9: Structures involved in the AA of vitamin C.



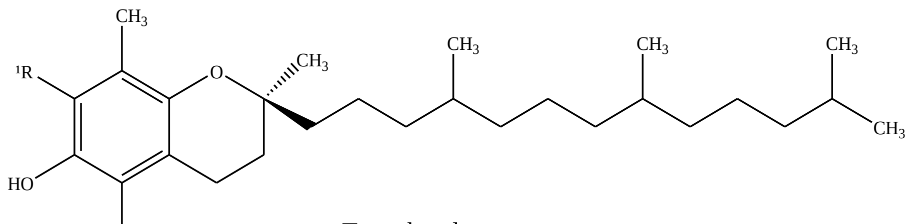
Source: Authors (2023).

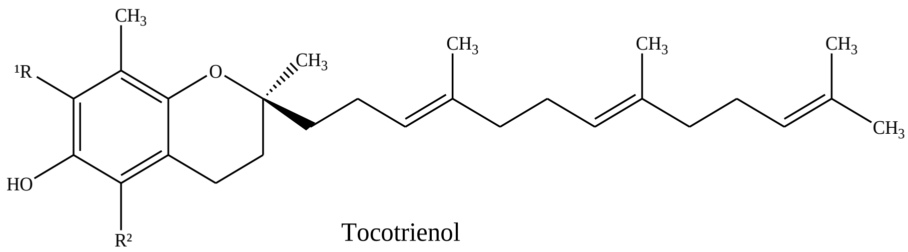
Vitamin E

Vitamin E is the term used for a group of tocopherols (α, β, γ, δ) and tocotrienols (α, β, γ, δ), illustrated in Figure 10A and 10B. Of these ones, the α-tocopherol and γ-tocotrienol show the greatest biological and antioxidant activity and are also the most abundant in the tissues. Vitamin E efficiently inhibits lipid peroxidation in vivo, especially of low-density lipoproteins (LDL), by yielding hydrogen atoms to radicals, interrupting the radical chain reaction. When α-tocopherol (α-TH) reduces a peroxyl radical (ROO-), for example, it generates the α-tocopherolyl radical (αT-), which is much less efficient at attacking fatty acid side chains than the peroxyl radical. The resulting αT- radical can be broken down or can be reduced by a more potent reducing agent, such as ascorbic acid (Figure 10C) (Traber and Atkinson, 2007; Rizvi et al., 2014).

Figure 10: **A)** Chemical structures of tocopherol and tocotrienol. **B)** Tocopherol and tocotrienol respective isomers, according R1 and R2 groups. **C)** Tocopherol's oxidation reaction.

A)





B)

Tocopherol/tocotrienol	$\mathbf{R^1}$	$\mathbf{R^2}$
α-	CH_3	CH_3
β-	H	CH_3
γ-	CH_3	H
δ-	H	H

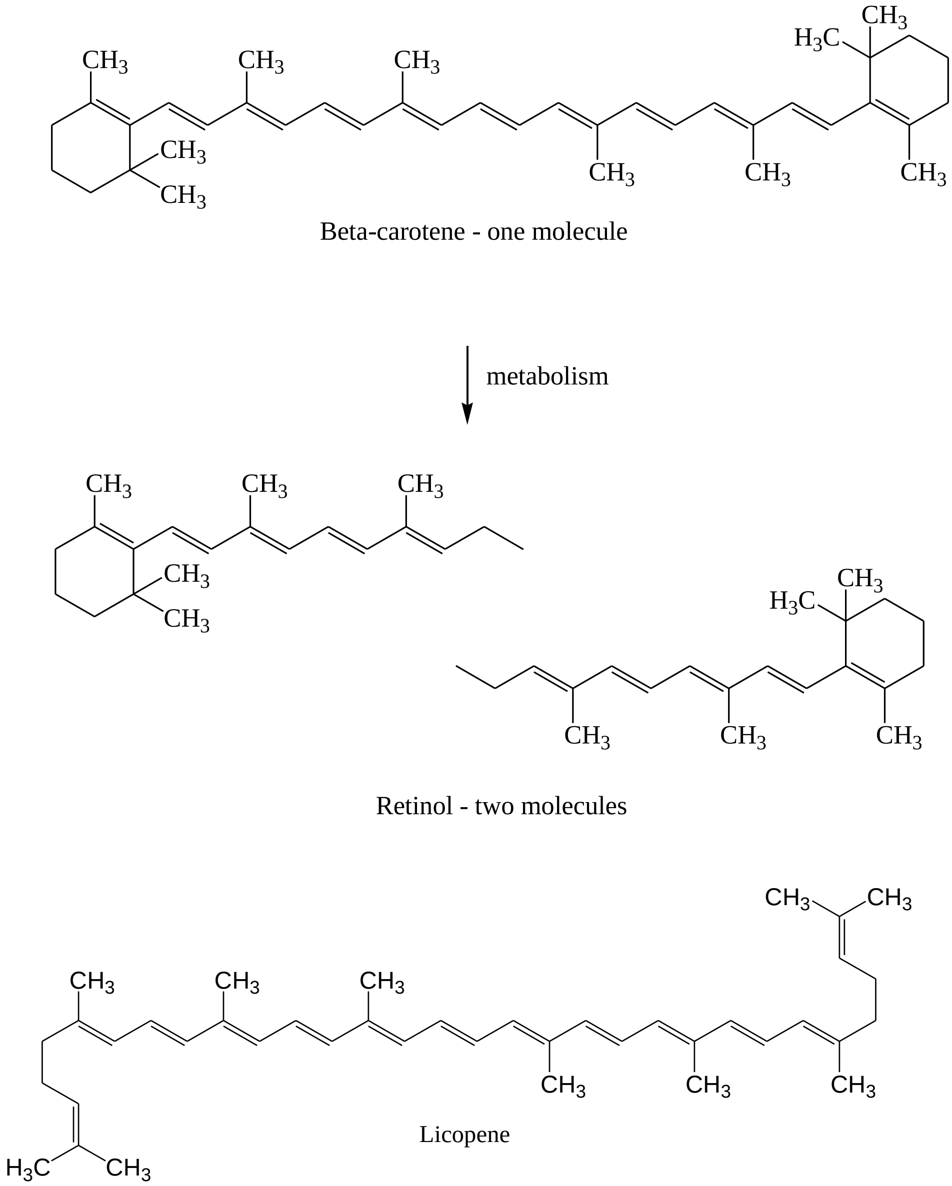
C) α-TH + ROO• → α-T• + ROOH

Source: Authors (2023).

Natural colorants (carotenoids)

The antioxidant properties of these compounds depend on their chemical structure, mainly on the system of conjugated double bonds of the polyene chain that make possible the capture of free radicals. The antioxidant activity increases with the increase in the number of conjugated double bonds, ketone groups, and the presence of cyclopentane rings in their structure. Figure 11 shows the structure of lycopene and beta carotene, the latter of which in the body is transformed into two molecules of vitamin A (retinol). There are several other molecules with similar structure that can be defined as natural colorants (DINIZ, 2015).

Figure 11: Chemical structures beta-carotene, retinol (vitamin A) and lycopene.



Source: Authors (2023).

About epigenetics and food

The term epigenetics refers to all reversible and heritable changes in the functional genome and how environmental factors can change the way genes are expressed without altering the DNA nucleotide sequence. One of the breakthroughs in epigenetics was the discovery of the direct relationship between telomere shortening and decreased longevity. Telomeres can be defined as repetitive DNA sequences located at the ends of our chromosomes. With age, telomeres undergo a shortening process. Telomere shortening is influenced by various biological mechanisms, including our lifestyle habits, dietary choices, inflammatory processes and daily stress (Niciura et al., 2015; Guillaumet-Adkins, et al., 2017).

The methylation of genomic DNA is one of the main mechanisms of epigenetic regulation in organisms. The phenomenon of DNA methylation consists of the process of replacing a hydrogen atom with a methyl group of cytosine. The reaction is catalyzed by various types of methyltransferases. If the methylation pattern is altered by an environmental agent, a new methylation pattern will be installed, activating different genes that should have been silenced, generating effects on that individual's life and health (Araújo, 2017).

Reducing oxidative stress and improving the functioning of DNA methylation pathways can extend telomere length by slowing down the biological clock. Some specific nutrients promote this maintenance of DNA health by increasing life expectancy. The methylation pathway is essential for DNA integrity and to prevent telomere shortening. Methyl group donor foods and nutrients are necessary to prevent genetic mutations that can result in various diseases including cancer (Silva, 2017).

FINAL CONSIDERATIONS

The science of oxidative stress and antioxidants is the basis for investigating the origin of various chronic and degenerative diseases, as well as strategies to cure them. Research in this area plays an important role in detecting serious diseases in the early stages and even in choosing therapy and evaluating its effectiveness. The monitoring of the oxidant/antioxidant status is a tool for the development of various areas of science and technology: medicine, sports, food, pharmaceuticals, and cosmetics, among others.

It is also important to note that not all-natural supplementation is necessarily safe and large doses of vitamin or antioxidant supplements, or a combination of these over time, may generate adverse effects and even liver damage to a patient (Navarro et al., 2017), besides the cost of a very complete supplementation that is relatively high.

The exogenous antioxidant comes easily from fruits and vegetables with the possibility of synergistic and/or protective effects (including DNA methylation) among the several classes of these substances in a food matrix. The FAO/WHO (2021) recommendation for fruits and vegetables intake is very clear, as the oxidative balance for health is considered.

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