

**ROLE OF ANTIOXIDANTS IN METABOLISM: A BRIEF REVIEW****GOPAL KRISHNA SAHU****Medical Biotechnology Division, Department of Biochemistry, Pt. J.N.M. Medical College, Raipur, India-492 001***ABSTRACT**

Reactive oxygen species (ROS) are produced as a normal product of cellular metabolism. Various environmental stresses lead to excessive production of ROS causing progressive oxidative damage and ultimately cell death. The very common ROS are hydroxyl radicals ($\cdot\text{OH}$), superoxide anion radicals ($\text{O}_2^{\cdot-}$), hydrogen peroxide (H_2O_2), singlet oxygen ($^1\text{O}_2$), hypochlorite radical (ClO^{\cdot}), nitric oxide (NO) radical and many types of lipid peroxides. These radicals have some physiological functions at lower concentrations but at higher concentrations impart very deleterious effects on biomolecules such as lipids, proteins and nucleic acids. To prevent the damaging effects of these harmful oxidants, aerobic organisms have evolved a highly structured system of compounds known as antioxidants. Some of the low molecular weight non-enzymatic antioxidants include ascorbate, alpha-tocopherol, glutathione, carotenoids and flavonoids etc. Whereas catalase, superoxide dismutase, glutathione reductase and peroxidases are the important types of enzymatic antioxidants induced in response to oxidative stress both in plants and animals. A general account of some important enzymatic and non-enzymatic antioxidants has been reviewed in this paper.

KEY WORDS: Reactive oxygen species, oxidants, antioxidants, oxidative stress***Corresponding author****GOPAL KRISHNA SAHU***Medical Biotechnology Division, Department of Biochemistry,
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INTRODUCTION

Organisms that possess aerobic mode of respiration use molecular oxygen (O_2) as the terminal acceptor of electrons. During the process of oxidative phosphorylation which forms most of the energy within a cell, O_2 accepts electrons and protons that are finally reduced to water (H_2O). This process of oxidative phosphorylation that takes place in mitochondria generates free radicals.¹ These active radicals are also produced continuously as byproducts of various metabolic pathways that take place in various compartments of the cell. Reactive oxygen species (ROS) are highly reactive oxygen-containing molecules including the free radicals. The very common ROS are hydroxyl radicals (OH), superoxide anion radicals (O_2^-), hydrogen peroxide (H_2O_2), singlet oxygen (1O_2), hypochlorite radical (ClO^-), nitric oxide (NO) radical and many types of lipid peroxides. These radicals have some physiological functions at lower concentrations but at higher concentrations impart very deleterious effects on biomolecules such as lipids, proteins and nucleic acids.² To prevent the damaging effects of these harmful oxidants, aerobic organisms have evolved a highly structured system of compounds known as antioxidants.

SOURCE OF ANTIOXIDANTS

Many antioxidant nutrients can be obtained from various food sources. Eating a wide variety of foods will

help to get the benefits of these antioxidants. Some of the food sources of antioxidants are whole grain wheat, brown rice, nuts, carrot, tomato, bean etc. The food source of antioxidant is presented in table 1.

ANTIOXIDANTS AND ITS TYPES

The chemical reaction in which electrons are transferred from one substance to another is known as oxidation. The substance that accepts the transferred electrons is the oxidizing agent or the oxidant. Molecules that could prevent the oxidation of other molecules are known as antioxidants. The chain reactions caused by the free radicals are terminated by the antioxidants by removing the free radical intermediates and thus inhibit other oxidation reactions by being oxidized themselves. A disproportion between the level of free radicals and antioxidants leads to oxidative stress that has various adverse effects in a living system. Antioxidants are of various types (Table 2). In general, these can be classified as non-enzymatic and enzymatic antioxidants. Some of the antioxidants are derived from nutrients where as others are endogenous. Nutrient-derived antioxidants include ascorbic acid (vitamin C), tocopherols and tocotrienols (vitamin E) and carotenoids. Enzymatic antioxidants are catalase (CAT), superoxide dismutase (SOD) glutathione reductase (GR), peroxidases (POXs) etc.

Table 1
Food sources of antioxidants according to American Dietetics Association.

Food sources	Antioxidant nutrients
Acorn squash, pumpkin, winter squash	Beta carotene
Apples	Catechins
Apricots, cantaloupe, peaches	Beta carotene
Beans	Catechins, vitamin E
Beets	Anthocyanins
Bell peppers	Beta carotene, vitamin C
Berries	Anthocyanins, catechins, ellagic acid (in raspberries and strawberries), resveratrol (in blueberries), vitamin C
Broccoli, greens, spinach	Beta carotene, lutein, vitamin C
Brown rice	Selenium
Carrots	Beta carotene
Chicken	Selenium
Citrus fruits	Vitamin C
Corn	Lutein
Egg	Lutein (in yolks); selenium, vitamin A
Eggplant	Anthocyanins
Garlic and onions	Selenium
Grapefruit, pink	Lycopene, vitamin C
Grapes, red wine	Anthocyanins (in red and purple grapes), resveratrol
Mango and papaya	Beta carotene, vitamin C
Milk	Vitamin A
Nuts, nut butters, oils, seeds	Vitamin E
Oatmeal	Selenium
Peanuts	Resveratrol
Prunes	Anthocyanins
Salmon, tuna, seafood	Selenium
Sweet potatoes	Beta carotene, vitamin C
Tea, black or green	Catechins
Tomatoes (canned)	Lycopene, vitamin C
Watermelon	Lycopene, vitamin C
Wheat germ, whole grains	Selenium, vitamin E

In addition to these, certain low molecular weight compounds, metal binding proteins and phytonutrients are known to possess antioxidant properties.³ Antioxidants can also be grouped as primary or natural antioxidants and secondary or synthetic antioxidants. Primary antioxidants are mainly phenolic structures that react with lipid radicals and form more stable products. These include minerals, antioxidant vitamins and phytochemicals. The secondary antioxidants are also phenolic structures that receive the free radicals and

play a role in prevention of the chain reactions.⁴ Antioxidants may be soluble in water or in lipids. The water soluble antioxidants react with the oxidants in the cell cytosol and blood plasma where as lipid soluble antioxidants prevent the cell membrane from the damaging effects of lipid peroxidation.⁵ Antioxidants are usually synthesized in the body or are obtained from various diets.⁶

Table 2
Various types of antioxidants³

Dietary Antioxidants	Endogenous antioxidants	Metal Binding Proteins
Vitamin C (L-ascorbate)	Bilirubin	Albumin (copper)
Vitamin E (α -Tocopherol)	Thiols, e.g., glutathione, lipoic acid, N-acetyl cysteine	Ceruloplasmin (copper)
B- carotene and other carotenoids and oxycarotenoids, e.g., lycopene and lutein	NADPH and NADH	Metallothionein (copper)
Polyphenols: flavonoids, flavones, flavonols, and proanthocyanidins	Ubiquinone (coenzyme Q10)	Myoglobin (iron)
	Uric acid	Transferrin (iron)
	Enzymes: superoxide dismutase, catalase, glutathione peroxidase, ascorbate peroxidase and glutathione reductase etc.	

I. NON-ENZYMATIC ANTIOXIDANTS

The common non-enzymatic antioxidants include very low molecular weight compounds such as ascorbic acid, tocopherol, carotenoids, glutathione and flavonoids etc. Among these compounds, ascorbic acid, α -tocopherol and β -carotene are the most widely studied nutritional antioxidants. The structure and function of few of these compounds have been described in the forthcoming sections.

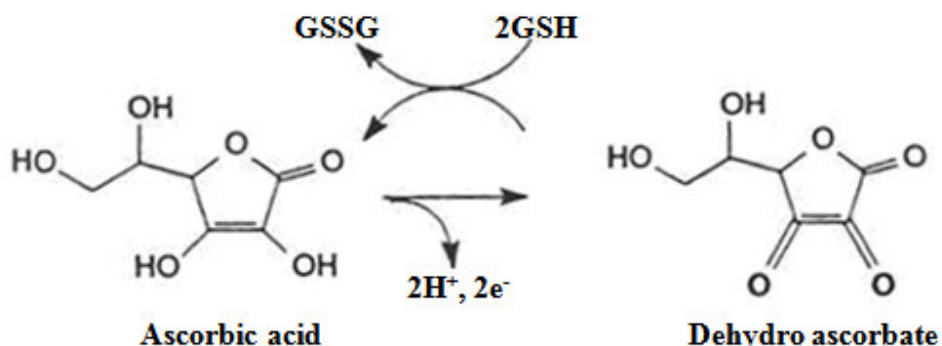
i. Ascorbic acid

The antioxidant ascorbic acid (L-ascorbate; vitamin C) is apparently a ubiquitous molecule in eukaryotes.⁷ Ascorbate is a water soluble antioxidant. It is known to be synthesized in all plant species studied so far⁸; and thus present in various foods of plant origin that provide the major source of dietary vitamin C for humans and many other vertebrates. The quantity of this compound ranges from 10-100 mg/100 g that are several folds higher than those of other vitamins.⁹ Ascorbate is synthesized by many vertebrates. However, during the course of evolution the biosynthetic pathway of ascorbate has been lost in some fishes, birds and mammals including human beings due to lack of the last enzyme L-gulonolactone oxidase in the pathway.^{10,11} Ascorbate is formed in kidney of fish, amphibians and reptiles whereas in mammals it is produced in the liver.^{12,13} The biosynthesis of ascorbate is known to be followed by different pathways in plants and animals. Yeast cells produce D-erythroascorbate an analogue of ascorbate. The start compound for the synthesis of ascorbate in animals is α -D-glucose where as in plants

and yeast it starts from D-mannose and D-arabinose respectively.¹⁴ The physiological role of ascorbate is that it donates electrons to various enzymatic and non-enzymatic reactions and thus acts as a reductant. In the reduction process, ascorbate on donation of one electron is oxidized to semidehydroascorbate that further oxidizes to dehydroascorbate on donating the second electron (Fig.1). The reduced state of ascorbate is maintained in the cells and extracellular fluid by glutathione and NADPH-dependent enzymatic mechanisms.¹⁵⁻¹⁷ Ascorbate can reduce and neutralize the effect of hydrogen peroxide.⁹ The antioxidant activity of ascorbate protects against UV-induced damage caused by free radicals.¹⁸ Ascorbate uptake has been observed in keratinocytes exposed to UVB radiation and regulate inflammatory responses in the skin.¹⁹ During the synthesis of collagen, ascorbate oxidizes proline residues to hydroxyproline. Scurvy, which results from the decline of collagen synthesis appears when the level of plasma ascorbate declines below 10 μ M. The level can be maintained through daily consumption of 10 mg ascorbate.⁹ Higher intake of ascorbate is known to lower the wrinkled appearance and is associated with better appearance of skin with aging.²⁰ The role of ascorbate in wound healing has also been reported. Damage due to free radicals generated at the site of wound may be restricted by ascorbate by promoting keratinocyte differentiation.²¹ The dose of ascorbate in those species that do not synthesize the compound may vary with physiological status, daily variations, stress, and disease.

Figure.1

Oxidation of ascorbate to dehydroascorbate. Ascorbate is first oxidized to semihydroascorbate with the loss of one electron and then further oxidized to dehydroascorbate on donating the second electron.



In plants; ascorbate is known to occur in all cell types. Dry seeds that are almost lacking the ROS scavenging activities do not possess ascorbate. However, in germinating seeds the synthesis of ascorbate has been observed after some hours of incubation.²² Ascorbate, though acts as a direct antioxidant, is also used as a reductant by ascorbate peroxidase, that plays an essential role in stress resistance in plants.²³ It is known to present in all sub-cellular compartments, including the apoplast of cell wall, chloroplasts, cytosol, vacuoles, mitochondria, and peroxisomes.²⁴⁻²⁶ Ascorbate is present at high concentrations in all parts. The concentration may reach to 20 mM in chloroplasts.⁷ Within the chloroplast, 10 to 20% of the ascorbate occurs in the thylakoid lumen.²⁷ Ascorbate has manifold functions in plants. It is a major antioxidant playing an important role in lowering of excessive ROS activity through enzymatic as well as non-enzymatic detoxification.²⁸ It also acts as a cell signaling modulator in many cellular processes including cell division, cell expansion and cell wall growth.²⁹⁻³¹ Ascorbate plays a crucial role in protection against various environmental stresses such as, drought, salinity, ozone, extreme temperature and high light

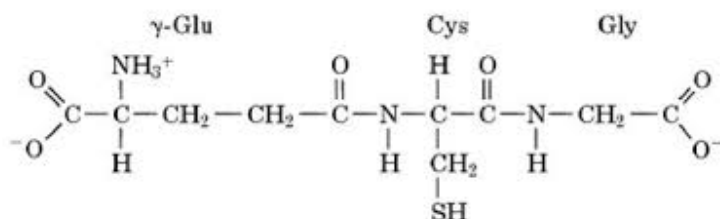
intensity.³²⁻⁴² The level of this antioxidant is known to elevate in plants subjected to environmental stress. Plants with low ascorbate biosynthesis are sensitive to various environmental stress conditions affecting their growth and development.^{43,44} The role of ascorbate in abiotic stress has been recently reviewed by Venketesh and Park.⁴⁵

ii. Glutathione

Glutathione (GSH) is the most abundant and widely distributed antioxidants in cells. It is a low molecular weight compound that consists of a tripeptide (L- γ -glutamyl-L-cysteinyl-glycine; Fig. 2). It is synthesized in all animals and is thus not an essential nutrient.⁴⁶ The antioxidant property of GSH is attributed to the presence of thiol group (-SH) in cysteine that acts as a reducing agent required in the diet. The biosynthesis of glutathione requires the participation of two enzymes. In the first step L-glutamate and cysteine produce γ -glutamylcysteine mediated by the enzyme glutamate cysteine ligase. In the second step, the amino acid glycine reacts with γ -glutamylcysteine through the enzyme glutathione synthetase.

Figure.2

Reduced glutathione (GSH): L- γ -glutamyl-L-cysteinyl-glycine



Within the cell glutathione exists both in reduced (GSH) as well as in oxidized (GSSG) state. The thiol group of the GSH donates H^+ and e^- to reactive oxygen species and thus becomes reactive. Two such reactive glutathiones now react with each other and

oxidize to form the glutathione disulphide (GSSG). The reduction of GSSG is catalysed by the enzyme GR using NAPH as the reductant. In normal healthy cells/tissues most of the glutathione exists in GSH state, the level of which is being maintained by the

enzyme glutathione reductase (GR). While the concentration of glutathione in animal tissues varies from 2-5 mM, leaf tissues contain less than 1 mM of glutathione.⁴⁷ Cells under oxidative stress possess an increased ratio of GSSG to GSH. Imbalance of GSH is observed in a wide range of pathologies, including, cancer, neurodegenerative disorders, cystic fibrosis, HIV, aging and Parkinson's disease.⁴⁸ Glutathione plays a multifunctional role in the metabolism of both plants and animals. It scavenges the free radicals and the ROS through enzymatic reactions within in the cell. The nitric oxide (NO) cycle is known to be regulated by glutathione.⁴⁹ GSH conjugates with NO to form S-nitrosoglutathione which is cleaved by the thioredoxin system to release GSH and NO.⁵⁰ Intracellular GSH is known to mediate the targeting of endogenous NO.⁵¹ Glutathione also play a role in iron metabolism. Experimentally it has been evidenced that yeast cells depleted of or containing toxic level of GSH could trigger iron starvation like response leading to impairment of extra-mitochondrial iron-sulphur cluster enzyme activity without alteration of thiol-redox maintenance.⁵² In addition, glutathione also participates in removal of formaldehyde, a carcinogen from the cell, detoxification of methylglyoxal, melanin inhibition, prostaglandin metabolism, spermatogenesis and sperm maturation, proliferation of lymphocytes and epithelial cells, activation of T-lymphocytes and cytokine production.^{48,53-55} Glutathione plays very crucial role in plants subjected to both abiotic and biotic stress. It prevents the injuries caused due to environmental stress leading to exposure of plants to oxidative stress. Glutathione participates in enzymatic processes and thus prevents the plants from oxidative stress.⁵⁶ It is one of the key components of the glutathione-ascorbate cycle (Fig. 3) that scavenges hydrogen peroxide.⁵⁷ The glutathione content of plants is being affected under stressful conditions generated by abiotic factors like radiation, air pollutants, low and high temperature.⁵⁸ Phytochelatin that are synthesized in response to heavy metal stress in plants are the oligomers of glutathione.⁵⁹ Glutathione also participates in plant defense against pathogens.⁶⁰ The enzyme glutaredoxin which is involved in flower development and plant defense signaling uses glutathione as a substrate.⁶¹ The Level of reduced

ascorbate within the cell is being maintained by glutathione. The reconversion of dehydroascorbate to ascorbate uses glutathione and NADPH. The relationship between glutathione and ascorbate has been presented in Fig. 3.

iii) α -Tocopherol (Vitamin E)

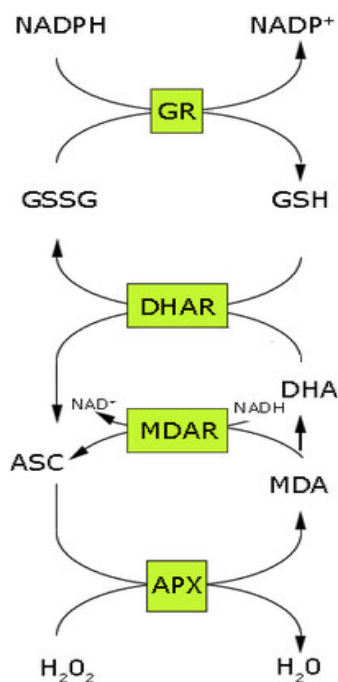
α -Tocopherol is a lipid-soluble antioxidant. It is one of the eight vitamin E forms synthesized by plants⁶²; and is the most biologically active form of vitamin E.⁶³ It remains bound to the cell membrane of animal cells and protects the membrane from lipoxy radicals generated during lipid peroxidation.⁶⁴ The so formed α -tocopheroxyl radicals produced in this process are recycled back to the active α -tocopherol through reduction of other antioxidants such as ascorbate, retinol or ubiquinol of membrane lipids.⁶⁵ It stops the production of reactive oxygen species formed from oxidation of fats and is termed a chain-breaking antioxidant because it prevents the chain reaction of lipid peroxidation.⁶⁶⁻⁶⁸ α -Tocopherol is abundantly found in wheat germ oil, sunflower, and safflower oils (Brigelius-Flohé et al., 1999; Reboul et al., 2006).^{69,70} Vitamin E is also known to trigger apoptosis of cancer cells and inhibition of free radical formations.⁷¹

iv. β -Carotene

Carotenoids are natural pigments which are synthesized by plants and are responsible for the bright colors of various fruits and vegetables. A variety of carotenoids are found in the foods that we eat. Most of these carotenoids have antioxidant activity and in association with other antioxidants can increase their activity against free radicals. Of these carotenoids, β -carotene has been best studied. β -carotene is an orange-colored, fat soluble carbon-hydrogen carotenoid, found abundantly in yellow-orange fruits and vegetables such as carrots, sweet potato, pumpkin, mango, papaya and in dark green, leafy vegetables like spinach, sweet potato leaves, kale and sweet gourd leaves.^{72,73} Among the carotenoids, β -carotene is the most widely distributed carotenoid in foods.⁷⁴

Figure.3

The glutathione-ascorbate cycle. APX: ascorbate peroxidase; ASC: L-ascorbate; MDA: monodehydroascorbate; DHA: dehydroascorbate; MDAR: monodehydroascorbate reductase; DHAR: Dehydroascorbate reductase; GR: glutathione reductase, GSSG: oxidized glutathione, GSH: reduced glutathione



Chemically, β -carotenes are terpenoids synthesized from eight isoprenes containing 40 carbons (Fig. 4). The potential biological antioxidant properties of β -carotenes may be attributed to its chemical structure and interaction with biological membranes.⁷⁵ Primarily, β -carotene has been found to react with peroxy (ROO^\cdot), hydroxyl (OH^\cdot), and superoxide ($\text{O}_2^{\cdot-}$) radicals.⁷⁶ The $^1\text{O}_2$ quenching efficiency of β -carotene is much

higher than α -tocopherol.⁷⁷ β -Carotene is a precursor to vitamin A and possesses the highest pro-vitamin activity compared to several different carotenoids that could be metabolized into vitamin A.⁷⁸ Carotenoids including beta-carotene are health promoting when taken at dietary levels. Consumption of food-based antioxidants like β -carotene seems to be useful for the prevention of macular degeneration and cataracts.⁷⁹

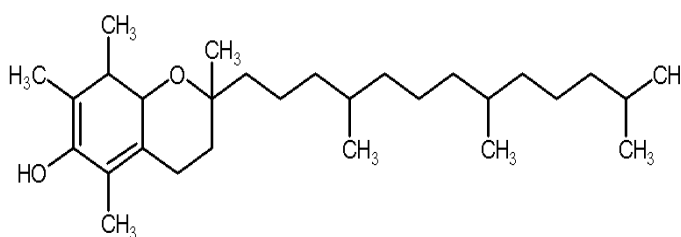


Figure. 4
 β -carotene

β -carotenes usually exist in *trans* (*E*) and *cis* (*Z*) isomerization forms.⁸⁰ The isomer (*all-E*)-form is the predominant isomer found in plant foods.⁸¹ The (*Z*)-isomers of β -carotene are present in human tissues including mainly in liver, kidney, adrenal gland and testes.⁸² However, in human serum (*all-E*)- β -carotenes constitute about 95% of the total β -carotenes.⁸³ The (*Z*)-isomers of β -carotene is also known to possess antioxidant activity *in vitro*.⁸⁴⁻⁸⁶

II. ENZYMATIC ANTIOXIDANTS

The enzymatic antioxidants are present in all sub-cellular compartments. Usually, an organelle has more than one enzyme to scavenge a single ROS.^{87,88} The characteristic features and metabolic functions of few major enzymatic antioxidants have been discussed in the following sections.

i. Catalase

The enzyme catalase (CAT; H₂O₂:H₂O₂ oxidoreductase, EC 1.11.1.6) occurs in all living organisms that possess aerobic respiration. It catalyses the conversion of H₂O₂, a byproduct of many normal metabolic processes in to H₂O and O₂.⁸⁹ CAT is one of the fastest enzymes and the rate of decomposition of H₂O₂ is extremely high. The catalytic activity of CAT is about 10⁻⁷ min⁻¹. Enzyme CAT is a heme containing porphyrin attached to four polypeptide chains and each chain consists of 500 amino acids. As the degradation of H₂O₂ by CAT does not involve the participation of cellular reducing equivalents, it provides the cell with a very energy-efficient mechanism to remove H₂O₂.⁹⁰ It has been proposed that catalase may be uniquely suited to regulate the homeostasis of H₂O₂ in the cell.⁹¹ In plants, CAT is located in peroxisomes where it converts H₂O₂ generated during β -oxidation of fatty acids and photorespiration to H₂O and O₂. CAT in plants exists as multiple isoforms (isoenzymes). Various isoforms of CAT have been observed in many plant species including maize, cotton, sunflower and tobacco.⁹²⁻⁹⁵ The presence of multiple CAT isozymes suggested multiple functions for CAT in a variety of plant tissues at various developmental stages and under constantly changed environmental conditions.⁹⁰ Though two isoforms of CAT (A, B) occur in developing and mature cotton seeds, three additional isoforms (C, D and E) have been observed to appear after germination.⁹³ The expression of CAT genes is not only influenced by genetic and developmental signals, but is also significantly influenced and responsive to various exogenous environmental signals such as temperature extremes, pathogenesis, radiation, drought, light and numerous xenobiotics etc. In maize three biochemically distinct forms of CAT (CAT-1, CAT-2, CAT-3) are being expressed by three *Cat* (*Cat* 1, *Cat* 2, *Cat* 3) genes and the expression of each gene varies under different environmental conditions.^{96,97} H₂O₂ is used as a potent antimicrobial agent when the cells are infected with a pathogen. These pathogens, such as *Mycobacterium tuberculosis*, *Legionella pneumophila*, and *Campylobacter jejuni*, inactivate the peroxide radicals mediated through CAT and, thus survive in the infected host cells.⁹⁸ Mutants of barley and maize plants deficient in catalase activity are unable to survive under photorespiratory conditions.⁹⁹ These studies indicate the significant physiological role played by CAT in plants.

ii. Superoxide dismutase

Superoxide dismutase (SOD; E.C.1.15.1.1) causes the dismutation of O₂⁻ and generates H₂O₂. The enzyme is ubiquitous and is found in all oxygen consuming organisms, in facultative and in some obligate anaerobes.¹⁰⁰ The enzyme was first of all isolated from mammalian blood and liver tissues as a copper protein, cupreins.¹⁰¹ Later on the role of erythro-cuprein in the inhibition of cytochrome c by O₂⁻ was identified and led to identify catalytic role of SOD in O₂⁻ dismutation.¹⁰² There are three major families of SODs known to occur

in different organisms and all are metallozymes containing metal cofactors in their active site. The Cu/Zn type (Cu/ZnSOD) binds both Copper and Zinc; Fe (FeSOD) and Mn (MnSOD) types bind either iron or manganese. Fe and Mn types are used by prokaryotes, protists, mitochondria and chloroplasts.¹⁰³ The cytosol of all eukaryotic cells contains Cu/Zn SOD and has been purified from many sources such as chicken liver, erythrocytes, spinach, *Neurospora crassa*, rice, maize and tomato etc.¹⁰⁴⁻¹⁰⁷ SODs in plants act as antioxidants and protect cellular components and different biomolecules from the damaging effects of ROS that result from drought, injury, herbicides, pesticides, ozone, plant metabolic activity, nutrient deficiencies, photoinhibition, extreme temperature, toxic metals, and UV or gamma rays.¹⁰⁸ In human beings, three forms of superoxide dismutase are present. These are named as SOD1, SOD2 and SOD3. The isoenzyme SOD1, a dimer is located in the cytoplasm where as tetrameric SOD2 and SOD3 are mitochondrial and extracellular respectively. SOD1 and SOD3 contain copper and zinc, whereas SOD2 has manganese in its catalytic centre.¹⁰⁹ SOD has anti-inflammatory properties. Treatment with SOD decreases reactive oxygen species generation and oxidative stress and may be important new therapies for the treatment of inflammatory bowel disease.¹¹⁰

iii. Ascorbate peroxidase

The enzyme ascorbate peroxidase (APX; EC 1.11.1.11) that is found in higher plants, chlorophytes, red algae, and members of the protist kingdom.¹¹¹⁻¹¹⁴ It is a heme containing peroxidase and plays a key role in ascorbate-glutathione cycle that detoxifies H₂O₂ in plant cells.²³ APX catalyses the conversion of H₂O₂ into H₂O using ascorbate as the electron donor. In plants, APX exhibits different isoforms in different sub cellular compartments such as chloroplast stroma (sAPX) and thylakoids (tAPX), mitochondria (miAPX), cytosol (cAPX) peroxisomes and glyoxysomes (mAPX). Like CAT and SOD, the expression of APX encoding genes is also modulated in response to various abiotic environmental stress as drought, salt stress, high light, high and low temperatures and heavy metals.¹¹⁵⁻¹²² Under these stressful conditions, various plants including the crop plants such as rice, tomato, barley etc are subjected to generate oxidative stress leading to over expression of APX and thus induces tolerance to various stresses.¹²³

iv. Glutathione peroxidase

Glutathione peroxidase (GPx; EC 1.11.1.9) is the enzyme family with peroxidase activity. The role of GPx is protection of the organisms from damage caused due to oxidative stress. It can use both lipid hydroperoxide and H₂O₂ as the substrates reducing into corresponding alcohols and water respectively.¹²⁴ Reduced glutathione (GSH) is the donor for these kinds of catalyzations. Many isoenzymes are known to exist in different cellular compartments. In humans, eight isoforms of GPx have been identified. The isoform

GPx1 occurs abundantly in cytoplasm of mammalian tissues and is ubiquitously expressed in many tissues, where it protects cells from oxidative stress.¹²⁵ Gpx 2 is an intestinal and extracellular enzyme, while GPx3 is abundant in plasma.¹²⁶ Most of the Gpxs found in animal cells are well characterized selenium-containing enzymes.¹²⁷

CONCLUSION

The ROS and other free radicals that are produced during the normal metabolism and physiological stress are deleterious to various biomolecules in aerobic organisms. To cope up with the damaging effect of these radicals, these organisms have developed

antioxidant machinery as an adaption strategy. Antioxidants also play a significant role in pathogenesis for prevention and control of various diseases. Plants cells are known to employ an elaborate antioxidant defense system protect themselves against ROS induced oxidative stress. Extensive researches in the field of oxidative stress have revealed the significance of antioxidants in protections against ROS. Enhancing the ROS scavenging capacity of the cells through antioxidant mediated reactions might play a major role in survival of organisms under extreme environmental conditions. Screening of various plants for the presence of antioxidants would reveal many other antioxidant enriched foods and nutrients.

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