Biosciences, Biotechnology Research Asia Vol. **7**(2), 745-758 (2010)

Natural antioxidants from fruits and vegetables: An alternative to synthetic antioxidants

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(Received: September 10, 2010; Accepted: October 22, 2010)

ABSTRACT

Free radicals are highly reactive form of molecules. After their endogenic generation inside human body, they diversely affect human cells and cause various disorders. Antioxidants scavenge free radicals which cause oxidative damage of important biological molecules. Human body possesses natural antioxidant system for protection but sometimes the oxidant-antioxidant level becomes disturbed either due to depletion of immune system or due to more generation of free radicals. Plants contain various secondary metabolites like polyphenolic components which acts as antioxidants. Fruits and vegetables as dietary sources are rich in polyphenolic compounds and other secondary metabolites but many of these are not isolated and purified for their antioxidant potential. Fruits and vegetables are consumed fresh hence; there are less chances of antioxidant loss. As fruits and vegetables are part of daily human diet, it helps in improving endogenous antioxidant level by consuming them. Consumption of fruits and vegetables as source of natural antioxidants is a health beneficiary alternative to consumption of synthetic antioxidants which cause adverse health effects. In this review, antioxidant composition, characterization, positive health effects and efforts to improve the content of various food and vegetable sources has been discussed.

Key words: Antioxidants, free radical, fruits and vegetables.

INTRODUCTION

Free Radical

Highly reactive, chemical moiety of very short life span, containing unpaired electron is collectively called as a free radical. Due to their short life span, after formation, they immediately react with biomolecules like DNA, protein, carbohydrate etc. and cause structural modifications, resulting in to various disorders. Plant derived material mainly contains several types of secondary metabolites which protect body from free radical attack.

Various synthetic antioxidants like butylated hydroxyl anisole (BHA), butylated hydroxyl toluene (BHT), gallic acid esters etc. are currently available in market but their application has been restricted because of the adverse health effects. Also, synthetic antioxidants have low solubility with moderate activity[1]. In a situation like depletion of immune system, consumption of natural antioxidants as free radical scavengers is beneficial. Uptil now, various medicinal plants have been screened for their potent antiradical activity. Several bioactive components have been isolated and purified and used in the preparation of many formulations. Besides medicinal plants, fruits and vegetables also can act as a good source of natural antioxidants. Hence, recently interest has been developed for the study of natural antioxidants from vegetables and fruits. Vegetables are mainly consumed after processing and because of that, loss of antioxidant activity occur after heat application. Attempts have been made to assess fruits and vegetables antioxidants such as phenolics, flavonoids, lycopene, anthocyanin, ascorbate etc. Such bioactive compounds can be isolated, purified and used as a source of natural antioxidants. Recent studies have focused on improvement of fruit and vegetable varieties through genetic engineering

methods for enhancing antioxidant content and activity. This review presents an account on various fruits and vegetables as a source of natural antioxidants.

Types of free radicals

Free radicals which cause cell damage are grouped on the basis of their active centre molecule and life span[2]. Free radicals like oxygen centered radicals (ROS) and nitrogen centered radicals (RNS) are highly reactive. Other than these two, carbon centered, sulfur centered and phosphorous centered radicals are also formed. When oxygen molecule is reduced in a series of chain reaction by one –electron, there is formation of different types of reactive oxygen species (ROS) which includes superoxide radical, hydrogen peroxide, hydroxyl radical etc. Peroxyl radical, singlet oxygen also belongs to this group. Sometimes drug molecules get reduced in the body during their metabolism and form nitrogen derived free radicals like nitric oxide radical, nitrogen di oxide radical etc., a bioactivation effect[2].

Sources of free radical generation

There are mainly two different sources, by which free radicals are generated in the body. Exogenous sources include tobacco consumption, cigarette smoking, exposure to pollutants, radiation, pesticides etc. Endogenously free radicals arise mainly by the metabolic activity of some enzymes, autooxidation, leakage of mitochondrial electron transport chain etc.[3-5].

Adverse effects of free radicals on human beings

Free radicals are continuously produced inside the human body by various metabolic processes. But, body also possesses several types of molecules which interact with free radicals and reduce their adverse effects. Hence, there is equilibrium between formation of free radicals and its detoxification. Different types of disorders are developed when this equilibrium gets disturbed. Lipid components in LDL are prone to oxidation. After LDL oxidation, cytotoxic products accumulate and promote platelet aggregation and finally lead to formation of atherosclerotic plaque[6]. Neurotic plaques are found in the brain of Alzheimer's patient under severe stress condition, as intracellular antioxidant enzymes level is changed. One of the major causes of pathogenesis of arthritis is increased lipid peroxidation and increased oxidative stress[1]. The synovial fluid of arthritic patient contains fewer amounts of antioxidant enzymes as the level of diene conjugates increase. DNA base modification takes place by the continuous attack of reactive oxygen species. Damaged DNA molecules are the prime causative agent of carcinogenesis[1]. When endogenous antioxidant level decreases, protein, lipids, DNA etc. are attacked by ROS and RNS continuously and forms damaged products which are responsible for different types of disorders. Ageing process is associated with development of such damaged biomolecules by free radicals[7].

Antioxidant

Antioxidants are chemical moieties which mainly neutralizes free radicals after interaction with them. They either scavenge free radicals or stop or reduce chain reaction of oxidative process. Exogenous antioxidants include different types of nutrient derived vitamins, minerals, proteins, enzymes, phytochemicals etc. whereas endogenous antioxidants include mainly enzymes. Though antioxidants help to quench free radicals, but differ in their affinity towards various free radicals and binding site of organism.

Sources of antioxidants

Dietary and therapeutic sources of antioxidants include synthetic and natural i.e., plant derived products. Synthetic antioxidants are chemically synthesized organic compounds but, the major disadvantage is their adverse effects on human health. Natural antioxidants are mainly obtained from medicinal plants, spices, fruits and vegetables.

Types of antioxidants

According to nature and mechanism of action, antioxidants are classified into two broad groups such as enzymatic and nonenzymatic antioxidants. Enzymatic antioxidant includes endogenous enzymes like catalase, superoxide dismutase, glutathione peroxidase, glutathione reductase etc. which catalytically act to scavenge free radicals and provide primary defense to the body. Non enzymatic antioxidants include different

plant derived natural products such as vitamins, polyphenolic, flavonoids etc. Other than these, some metal binding proteins, minerals, cofactors of vitamins and organic acids also help to terminate free radical generation[8].

Vitamin E and C are chain breaking antioxidants[9]. Both these antioxidants terminate lipid peroxidation by donating one electron to the free radical intermediates. But, vitamin A mainly reacts with singlet oxygen and is a type of preventive antioxidant. Endogenous antioxidant enzymes namely superoxide dismutase, catalase etc. donate one electron to reactive free radicals and non radicals and convert them into non reactive non radicals in a series of reactions. After providing single electron, antioxidant molecule becomes antioxidant radical but has very less activity to interact with different biomolecules[10]. Plant derived chemical constituents are also important for their antioxidative property.

Positive health effect of antioxidant

Antioxidant molecule do not act singly, it requires a network of water and fat soluble antioxidants for complete removal of free radicals[11, 12]. Polyphenolic flavonoids mainly reduce or stop radical oxidation process by providing hydrogen ions and also by possessing metal chelating capability. Vitamin C, E and A found in different fruits and vegetables and consumption is helpful to quench free radicals. Hence, consumption of these fruits and vegetables is beneficial because Vitamin E helps in preventing blood coagulation in arterial wall in case of arteriosclerosis and senile formation in Alzheimer's patient. Combination of natural antioxidant and synthetic drugs in rheumatic arthritis patient also help to reduce disease severity. Decreased level of circulating Vitamin E and A promotes the increased risk of lung cancer[13]. Decreased level of these vitamins also enhances risk of colon cancer[14, 15]. Other than vitamins majority of different classes of phenolic and flavonoid compounds, found in fruits and vegetables, protect body from pathogenesis of several cancer and dangerous diseases.

Antioxidant as prooxidant

Antioxidants are beneficial to human health. But, some time it acts as prooxidant which enhances formation of free radicals instead of its elimination. Then the oxidative stress results into cell death. Antioxidants act as prooxidant in presence of transition metal ions. Administration of certain antioxidants at very high doses and other factors like route of administration and its duration etc affect their antioxidant activity[16-18].

Plant and plant derived material as natural antioxidant

Medicinal plants are rich in various types of active chemical constituents which normally help to cure human health disorders by acting additionally and synergistically. Researchers are attempting to screen plants to isolate and identify the different active principles for knowing the actual mechanisms of action. Many types of medicinal plants have already been evaluated for their antioxidant property[19, 20]. Some bioactive compounds have also been purified from various medicinal plants and have been incorporated in formulation of several drugs. Not only the medicinal plants, spices and beverages are also active in inhibition of free radical generation. Tea is a very popular stimulative beverage. It is known that, major phytoconstituents of black tea and green tea are theaflavin and epigallocatechin gallate. Antioxidant activity of red wine is due to presence of catechin and epicatechin rather than other resveratrol[21]. It is also true that, antioxidant activity is not only due to particularly one bioactive compound but due to combined effect of different antioxidants. Although a lot of information is available on antioxidants from medicinal plants, relatively less information is available on fruits and vegetables as dietary sources of antioxidants. But, a few reports are available on fruit and vegetable as source of antioxidants. This review mainly focuses on antioxidant property of some commonly edible fruits and vegetables and their principal bioactive compounds.

Fruits as source of natural antioxidants

Apart from medicinal plant and spices, fruits and vegetables are also important for their potent antioxidant activity. Table 1 and 2 enlist example of some fruits with their antioxidant principle and antioxidant properties. Consumption of polyphenolic compounds including flavonoids, anthocyanins, phenols etc. and also β-carotene, vitamin C, E, coumarins etc. is important in reducing

risk of cancer through their role in inhibition of tumor formation[22]. Commonly consumed fruits are classified as acidic and alkaline fruits. Hence, it is important to categorize which one is better with respect to the antioxidant property.

Acidic fruits

In acidic fruit category, the one of the important class is berry fruits. A lot of berry fruits are cultivated throughout World but, among them the most commonly consumed ones are mulberry, strawberry, black berry and blue berry etc. These different types of berry fruits confer high antioxidant potential since they contain high amount of anthocyanins[23-25]. Antioxidant activity of fruits is also interconnected with period and temperature of harvesting. It was observed that, at harvest, the amount of phenolics, anthocyanin and antioxidant activity in ORAC assay was almost three folds higher in highbush and lowbush blueberry than strawberry and raspberry. But, ascorbate content was found to be higher in strawberry and raspberry than others[24, 25] (Table 1). Antioxidant activity of fruits also depends upon its storage temperature, duration etc. Kalt and his research group tested all the fruit samples after storage at different temperatures to check phenolics, anthocyanins, ascorbate content and antioxidant capacity[26]. It was observed that, anthocyanin content and antioxidant capacity of strawberry and raspberry were affected after the storage at various temperatures. Antioxidant activity was increased after storing at 20^0 C than at 0^0 C for eight days. Storage at ambient temperature enhances phenolic metabolism which greatly affect their antioxidant capacity[26]. Apart from flavonol and anthocyanin, berries also contain huge amount of different classes of flavonoids and phenolic compounds which include hydroxycinnamic acid, flavan-3-ols (rich in strawberry), hydroxycinnamic acid (black currant) and more surprisingly, their contents vary from cultivar to cultivar[27, 28]. Extracts of different cultivars of berries also possess efficient scavenging activity towards chemically generated superoxide radical[29]. Xanthine oxidase activity of black currant cultivar is mainly due to their high content of anthocyanins and polyphenols[30].

Another common acidic fruit, *Lycoperiscon esculentum* (tomato) is usually consumed as a raw edible fruit in salad or after cooking in some culinary preparations. Consumption of tomato helps to reduce different types of cancer[31]. A lot of tomato cultivars are grown worldwide. As tomato is a cheap and easily available natural source, apart from the whole fruit, its peel and pulp were also examined for radical scavenging property. George *et al.* tested twelve different varieties of *Lycoperiscon esculentum* and found that peel and pulp of only 818 variety contained the greatest amount of lycopene, ascorbic acid and total phenolics on its fresh weight basis[32]. Whereas, on dry weight basis, peel of 818 variety contained highest amount of lycopene and ascorbic acid and T56 variety contained much greater phenolic content. But, pulp of DT-2, BR-124 and 5656 variety possessed maximum amount of lycopene, ascorbic acid and total phenolics respectively. It was also observed that, peel had much more lycopene, ascorbic acid and phenolic content than pulp[32]. On FRAP assay and different free radical quenching assay, extract of 818, DT-2 variety possessed maximum activity. Two local varieties of tomato commonly cultivated in India, namely S-22 and Samrudhi were checked for their antioxidant potential in two different solvent systems – methanol and aqueous. S-22 variety showed more antioxidant potential in DPPH, superoxide, hydroxyl and nitric oxide radical scavenging assay than Samrudhi[33]. It was also observed that, methanolic extract has more antioxidant activity than aqueous, mainly because of more extraction of antioxidant compounds in methanol than water. The amount of total phenolics and flavonoid was also found greater in S-22 variety than Samrudhi in both the extracts.

Alkaline fruits

Among several alkaline fruits, most commonly consumable and cultivable are apple, banana, fig etc. Apple fruit shows many positive health effects and its regular consumption help to keep human healthy. Different cultivars of apple like Custard apple, Plum-Claudia apple, Apple-Granny, Smith, Apple-Renette, Apple-Red -delicious are well known for their antioxidant activity (Table 2). Antioxidant activity of apple fruits may be due to synergistic or antagonistic effects of different classes of flavonols[25]. The most common market fruit is banana and is also available year-round. Usually pulp of banana is consumed, whereas peel of this fruit is thrown off as waste. Peel of banana

Table 1: Antioxidant activity of different varieties of acidic fruits with their possible active principle

S. No	Fruits	Part	Chemical Constituents	Inhibitory action	Reference
1.	Mulberry	Leaf	Anthocyanin (+++)	lipid peroxidation (++)	23-30
	Blueberry	Whole fruit	Phenolics(+++), Flavonol & Anthocyanin(+++)	AA (+++)	
	Highbush blueberry	Whole fruit	Phenolics & anthocyanins (+++) ascorbate(+)	ORAC (+++)	
	Lowbush blueberry	"	,,	,,	
	Blackberry	"	Flavonol & Anthocyanin (+++)	AA (+++)	
	Strawberry	"	Flavonol, Phenolics & anthocyanins (+) ascorbate(+++)	ORAC (+)	
	Raspberry	"	,,	,,	
	Berry variety	"	Flavonoid & phenolics(+++)	SOD (++)	
	Black currant	"	Anthocyanin(+++), Polyphenol (+++)	Xanthine oxidase (++)	
2.	Tomato variety	Peel, Pulp	Ascorbic acid & phenolics, lycopene (+++)(F.W.)	FRAP(+++)	32,33
	818	Peel	Ascorbic acid & lycopene (+++)(D.W.)	FRAP(++)	
	T56	Peel	Phenolics (+++) (D.W.)	,,	
	DT-2	Pulp	Lycopene (+++) (D.W)	FRAP(+++)	
	BR-124	,,	Ascorbic acid(+++) (D.W.)	FRAP(++)	
	5656	,,	Phenolics (+++) (D.W.)	,,	
	S-22	Whole fruit	Phenolics & flavonoid (++)	$DPPH^{\cdot}$, $O_2^{\cdot-}$, $NO^{\cdot}$ (++)	
	Samrudhhi	,,	Phenolics & flavonoid (+)	$DPPH^{\cdot}$, $O_2^{\cdot-}$, $NO^{\cdot}$ (+)	

Note: +: low, ++: moderate, +++: high, AA: Antioxidant activity

contain higher amount of phenolics than pulp and antioxidant activity of peel was also found more in lipid autooxidation method. Both peel and pulp contain gallocatechin as principal antioxidant, but, its quantity was found in abundant in peel which can be related to its potent antioxidant capacity[34]. Hence, nutritive value of peel of banana can not be ignored and proper processing should be optimized to use it for consumption. Fig (*Ficus carica*) is more common in Mediterranean diet and is consumed in fresh or dried form. Fig is rich in several minerals, vitamins, amino acids etc. and its consumption helps to maintain human health[35, 36]. Whole fig fruit contain flavonoids and possess antioxidant potential[25]. But, antioxidant property was not checked in the skin and pulp separately. Solomon *et al*. in his restudied the anthocyanin content of six fresh fig varieties[37]. Fruit, skin and pulp of two fig varieties namely Mission and Chechik have appreciable amount of polyphenolics and anthocyanins and possess highest antioxidant potential by TEAC method followed by Brown-Turkey, Bursa and Brunswick, Kadota varieties. Brunswick, Kadota varieties does not

Table 2: Antioxidant activity of different varieties of alkaline fruits and their varieties with their possible active principle

S. No.	Fruits	Part	Chemical constituents	Inhibitory action	Reference
1.	Apple variety				25
	Custard apple	Whole fruit	Flavonol (+++)	AA(++)	
	Plum-Claudia apple	,,	,,	,,	
	Apple Granny	,,	,,	,,	
	Smith apple	,,	,,	,,	
	Apple-Renette	,,	,,	,,	
	Apple red-delicious	,,	,,	,,	
	Cherry apple	,,	Flavonol (+++) Anthocyanin(+++)	AA(+++)	
2.	Banana	Peel	Phenolics & Gallocatechin(+++)	Lipid autooxidation (+++)	34
		Pulp	Phenolics & Gallocatechin(++)	Lipid autooxidation (++) TEAC (+++)	
3.	Fig variety	Fruit, skin, pulp	Polyphenolics& anthocyanin(+++)		25,37
	Mission fig	,,	Polyphenolics	,,	
	ChechikBrown-Turkey	,, ,,	& anthocyanin(++)	TEAC (++)	
	Bursa	,,	,,	,,	
	Brunswick	,,	Polyphenolics& anthocyanin(+)	TEAC (+)	
	Kadota	,,	,,	,,	
	Common fig	Whole fruit	Flavonoid (++)	AA(++)	
4.	Almond	Skin	Flavonoid(+++)	ORAC (+++)	40,41,42
		,,	Phenolic compound (++)	ORAC (++)	

Note: +: low, ++: moderate, +++: high, AA: Antioxidant activity

contain anthocyanin. Two prime anthocyanins namely cyaniding-3-glucoside, cyanidine-3-rhamnoglucoside are present in Mission vriety. It was also emphasized that, skin of figs is a potent free radical scavenger due to its high polyphenolic content than fruits and pulp[37].

Anthocyanin antioxidants of some edible fruits were also checked by several techniques. Though, vitamin C acts as an antioxidant but still this compound and sugar molecules sometime suppress the activity of polyphenols[38]. Anthocyanins can be easily extracted in aqueous fractions but its isolation is cumbersome. Einbond *et al* isolated and identified polar anthocyanin in aqueous fraction after partitioning methanolic extract with hexane and ethyl

Table 3: Antioxidant activity of different leafy vegetables with their possible active principle

S. No.	Vegetables	Part	Chemical Constituents	Inhibitory action	Reference
1.	Water spinach	Leaf,	Phenolics(+), Flavonoid (+++)	$DPPH^{\cdot}$, $NO^{\cdot}$, FTC, reducing power (+)	45,46,47
		vein	Phenolics(+++), Flavonoid (+)	$DPPH^{\cdot}$, $NO^{\cdot\cdot}$, FTC, reducing power (+++)	
2.	Coriander	Leaf	Polyphenols	linoleic peroxidation(+++)	45,47
3.	Halas	Leaf	Polyphenols	linoleic peroxidation(+++)	45,47
4.	Horseradish	Leaf Oil	Polyphenols Isothiocyanate	linoleic peroxidation(+++) β-carotene bleaching	45,47,48
5.	*Lepidium meyenii*	Edible part	Flavonol (+++), Catechin (+)	$DPPH^{\cdot}$, $OH^{\cdot}$, lipid peroxidation, peroxyl radical	49
6.	White cabbage	Edible part	Phenolics(++)	Fe-induced lipid peroxidation(++)	45
7.	Cauliflowet	Edible part	Polyphenols	TEAC (+++), $DPPH^{\cdot}$ (++)	47

Note: +: low, ++: moderate, +++: high, AA: Antioxidant activity

Table 4: Antioxidant activity of different fruit and flower vegetables with their possible active principle

S. No	Vegetables	Part	Chemical Constituents	Inhibitory action	Reference
1.	*Luffa echinata*	Edible part	-	$DPPH^{\cdot}$, $OH^{\cdot}$, lipid peroxidation	51
2.	Sponge gourd	Edible part	Polyphenolic component	AA, $NO^{\cdot}$ (+)	52
3.	Eggplant	Edible part	Phenolics(++),anthocyanin (+++), ascorbic acid (+++)	$NO^{\cdot}$ & linoleic peroxidation(+++)	47
4.	Bitter gourd	Edible part	Polyphenols (++)	$DPPH^{\cdot}$ (+)	47

Note: +: low, ++: moderate, +++: high, AA: Antioxidant activity

acetate[38]. It was found that, extract of *Blighia sapida*, *Chrysophyllum cainito*, *Eugenia uniflora*, *Gaultheria shallon*, *Mammea americana*, *Muntingia calabura* and *Myrciaria cauliflora* have less IC_{50} values which implies highest DPPH radical scavenging property. Cyaniding-3-glucoside is the principle compound in *Myrciaria cauliflora* and *Chrysophyllum cainito*, but, delphinide-3-glucoside is abundant in *Eugenia uniflora*. In this case mainly anthocyanins are responsible for free radical scavenging property.

Dry fruits also have been appreciable amount of antioxidants. Almond possesses some anticancer activity[39]. Flavonoid compounds mainly flavanones, dihydroflavonols and nonflavonoid compounds including p-hydroxybenzoic acids have been already identified from skin of *Prunus dulcis*[40, 41]. Managas *et al* have extensively studied phenolic composition of almond skin[42]. Skin of Spanish variety contained almost 2 fold and 1.5 fold higher phenolic and flavonoid content than American variety respectively, whereas amount of flavonol glycosidase was found in higher concentration in American variety than Spanish variety. In both the varieties, nonflavonoid phenolic contents were of almost same quantity but, Spanish variety showed greater antioxidant activity in ORAC assay compared to American variety. Around thirty three flavonoid were detected in almond skin from HPLC data[42]. Both the types of fruits i.e., acidic and alkaline fruits possesses various antioxidant compounds and the activity is mainly due to the presence of different classes of polyphenolic compounds which may vary in different fruit subtypes and among the cultivars. But, ascorbate is mainly found in acidic fruits which provide some extra antioxidant potential to acidic fruits over alkaline fruits.

Table 5: Antioxidant activity of different root, tube, bulb vegetables with their possible active principle

S. No	Vegetables	Part	Chemical Constituents	Inhibitory action	Reference
1.	Carrot	Edible part	Crotenoid (+++)	Lipid peroxidation (++)	45
2.	Onion variety Red onion Yellow onion	Scale ,,	Phenolics(+++) ,,	Fe-induced lipid peroxidation(+++) Fe-induced lipid peroxidation(+++)	24,45
3.	Indian lotus	Rhizome	Anthocyanin (+), Phenolic (++)	TEAC, linoleic acid peroxidation, $DPPH^{\cdot}$ (+++), $NO^{\cdot}$ (++)	47
4.	Asparagas	Edible part	Anthocyanin (+), Phenolic (+)	TEAC (++)	47
5.	Potato variety TN65 TN57	 Tuberous root ,,	 Protein ,,	 $OH^{\cdot}$ & Lipid peroxidation(+++) $OH^{\cdot}$ & Lipid peroxidation(+)	53
6.	*Allium* foods	Whole fruit	Allicin, polyphenolic components	AA	55
7.	*Coriandrum sativum*	Rhizome	Polyphenols	Lipid peroxidation	56
8.	Ginger	Edible part	diarylheptanoid	$O_2^{\cdot-}$, $DPPH^{\cdot}$	57

Note: +: low, ++: moderate, +++: high, AA: Antioxidant activity

Vegetables as source of natural antioxidants

Vegetables are also prime source of natural antioxidants. As vegetables are consumed fresh, the loss of antioxidant capacity is less because there is no problem of effects of storage, post harvest treatment etc. Vegetables are usually categorized as leafy, root, tuber, bulb, fruit, flower, fungi and podded vegetables. Several vegetables under each class have already been checked for their antioxidant potential and presence of bioactive antioxidant components. Some of them are enlisted in Table 3 to 7.

Leafy vegetables

Ipomoea aquatica (water spinach) is a common edible vegetable and is also used for the treatment of liver disorders and constipation[43, 44]. This leafy vegetable was evaluated by different research groups for its antioxidant property. When leaf and vein of this vegetable were examined separately it was observed that, ethanolic extract of leaf and vein of this plant contained highest phenolic and flavonoid content as compared to water extract. Ethanolic fraction of vein possessed high phenolic content and less flavonoid content. But, exact opposite condition was found in case of leaf. Antioxidant activity of ethanolic extract of vein was found higher than leaf in DPPH, NO radical scavenging assay, FTC method and also in ferric to ferrous reducing power assay. The antioxidant activity of water spinach is due to its polyphenolic compounds[45-47]. Apart from water spinach, other leafy vegetables such as coriander, halas, horseradish leaves also contain natural antioxidants and help to reduce oxidative damage due to linoleic peroxidation[45, 47] (Table 3). Horseradish oil has appreciable antioxidant activity on β-carotene bleaching method and is higher than some reference compounds. The principle component present in horseradish oil is isothiocyanate and may be this bioactive constituent helps to quench singlet oxygen and possess antioxidant potential[48].

Lepidium meyenii is very comon cruciferous vegetable and is also used as fertility enhancer and also help to improves energy levels. Water extract of *Lepidium meyenii* act as hydroxyl, DPPH, peroxyl radical scavenger[49]. Flavonols are the main constituent in aqueous extract of this vegetable. Other than this catechin is also present

Table 6: Antioxidant activity of different fungi vegetables with their possible active principle

S. No.	Vegetables	Part	Chemical Constituents	Inhibitory action	Reference
1.	Shiitake mushroom	Fruit body	Polyphenolic compounds	DPPH·, NO·, β-carotene bleaching, linoleic peroxidation, AAPH induced hemolysis (+++)	47,58
	Straw mushroom	,,	,,	,,	
	Winter mushroom	,,	,,	DPPH· ,TEAC(++)	

Note: +: low, ++: moderate, +++: high, AA: Antioxidant activity

Table 7: Antioxidant activity of different podded vegetables with their possible active principle

S. No.	Vegetables	Part	Chemical Constituents	Inhibitory action	Reference
1.	Mungbean	Seedling	-	TEAC (++)	47
2.	Pea	Sprout	Phenol (+++)	TEAC (+), NO (+++)	47

Note: +: low, ++: moderate, +++: high, AA: Antioxidant activity

but in very less amount[49]. White cabbage and cauliflower also fall under leafy vegetable. While cabbage variety from Yemen has moderate antioxidant activity and contained phenolic compounds. But, the antioxidant activity was not linearly related with its phenolic contents[45]. Whereas cauliflower was found active in Trolox equivalent antioxidant capacity (TEAC) assay than in DPPH radical quenching and in lipid peroxidation inhibition assay[45]. It is also true that, antioxidant activity sometimes depends upon typical structure of phenolic compound rather than its quantity[50].

Fruit and flower vegetables

Luffa echinata fruits have some therapeutic properties. Alcoholic extract has capacity to inhibit hydroxyl and DPPH radical generation and it acts as an inhibitor of lipid peroxidation *in vitro* models[51]. *Luffa cylindrical* commonly called as sponge gourd is a daily consumed vegetable. Ethanolic extract of this fruit contain p-Coumaric acid, 1-o-feruloyl-β-D-glucose, 1-o-p-coumaroyl- β-D-glucose, 1-o-caffeoyl-β-D-glucose, 1-o-(4-hydroxybenzoyl) glucose, diosmetin-7-o- β-D-glucuronide methyl ester, apigenin 7-o- β-D-glucuronide methyl ester and luteolin 7-o-β-D-glucuronide methyl ester. Hydroxyl group at 3 and 4 positions is responsible for radical scavenging property. Sponge gourd is rich in polyphenolic compounds and its consumption helps in maintaining normal health[52]. Another most commonly consumable vegetable under this class is eggplant and it was observed that, DPPH, NO radical scavenging activity of this vegetable is due to its high phenolic content, ascorbic acid and anthocyanin content (Table 4). Water extract of eggplant vegetable inhibit almost 80% of NO radical generation stimulated by LPS, and less DPPH radical scavenging activity was found in bitter gourd extract[47] .

Root, tuber and bulb vegetables

Though carrot is rich in carotenoids but, still it has moderate power to inhibit lipid peroxidation when compared with onion varieties[45]. Two different types of onion namely red and yellow variety have high phenolic content and antioxidant activity as their scales were screened in iron induced lipid peroxidation assay[24, 25] (Table 5). Bor *et al*. studied the antioxidant activity of 25 various vegetables from local market of Taichung[47]. It was found that, linoleic acid peroxidation system and in DPPH radical scavenging assay, Indian lotus (rhizome) possessed significant activity. But, in Trolox equivalent antioxidant capacity (TEAC) method, highest potential was found in Indian lotus, followed by asparagus. The coefficient of correlation between TEAC and linoleic peroxidation, TEAC and DPPH radical scavenging assay was poor. On nitric oxide radical scavenging assay model, Indian lotus showed highest activity above 40%[47]. Hou *et al* have purified trypsin inhibitor from tuberous root of two potato cultivars by enzyme specific column chromatography and checked their potential for scavenging different free radicals. It was observed that, the purified protein from TN 65 potato cultivar possessed about three fold and ten fold greater activities to protect human lipid peroxidaion and hydroxyl radical induced DNA damage respectively than TN57 trypsin inhibitor[53].

Earlier it was reported that, allicin was the major component, responsible for antioxidant activity of *Allium* foods[54]. But, according to Yin *et al*, the antioxidant activity of *Allium* member is due to combination of allicin and other compounds[55]. Antioxidant activity of these *Allium* members was because of certain bioactive compounds and sometimes it shows prooxidant action mainly after certain adverse treatment like heating, acidic pH etc.

Coriandrum sativum is used for the treatment of vomiting, dysentery, diarrhea, rheumatism etc. Polyphenolic compounds in different solvent fraction from the rhizome was extracted by Hashim *et al* and after extraction, lymphocytes cells were incubated with this isolated polyphenol to check activity of antioxidant enzymes. From this assay it was found that, polyphenol from *Coriandrum sativum* could reduce rate of lipid peroxidation[56].

Khan *et al* have isolated and purified one novel diarylheptanoid from ginger. Isolated compound was purified and it was predicted that the new isolated diarylheptanoid compound is 3,5-diacetoxy-7-(3,5-dihydroxy phenyl)-1-(3,4-dihydroxy phenyl) heptane. This isolated component was also checked for antioxidant capacity[57]. Isolated antioxidant compound scavenges superoxide and DPPH radical generation.

Fungi vegetables

Fruiting bodies of mushrooms mainly *Lentinus edodes* and *Volvariella volvacea* is also a good source of antioxidants[58] (Table 6). Aqueous extracts of both mushroom varieties have more free radical scavenging potential by β-carotene bleaching method and DPPH method than methanol extract. The same result was also found in AAPH induced hemolysis method. Also fruit body of mushroom showed more activity in inhibition of peroxidation rather than DPPH radical quenching assay[47].

Podded vegetables

Different types of podded vegetables are usually consumed either freshly after sprouting or after proper culinary preparations. In Trolox equivalent antioxidant capacity (TEAC) method, it was found that seedling of mungbean was superior over pea sprouts. But, pea sprout had a greater scavenging effect on NO radical generation stimulated by LPS than mungbean seedling[47] (Table 7).

Various fruits and vegetables possess antioxidant activity to some extent and hence, it is advisable to consume more amount of this natural food to maintain normal health and protect body from attack of free radicals.

CONCLUSION

In this era of the pollution, exposure to free radicals is ever increasing these free radicals adversely affect cell physiology and metabolism leading to cell death. Majority of medicinal plants have been screened for their antioxidant property at molecular level. Hence, information on principal antioxidants present in several medicinal plants is available and many bioactive components have also been isolated. Isolated components are being used for formulation of medicines. Though fruits and vegetables are rich source of several bioactive molecules isolation of principle antioxidants and their study is still a less studied area. Usually peel of fruits are thrown away as a waste product, but it was observed that, in some of the fruits there is more amount of antioxidants in peel than pulp. Hence, it is suggestible to use peel of fruit as a rich source of natural antioxidants or to consume it after proper processing. Green leafy vegetables and fleshy fruits are rich in secondary metabolites responsible for free radical scavenging activity. If these can be consumed without loss of antioxidant activity, it would be a very good natural source of antioxidants rather than consuming synthetic antioxidants with adverse side effects. This would also lead to reducing ageing process, increasing immunity, reducing disease occurrence. So, fruits and commonly consumed vegetables being rich in antioxidant compound can be good source of nutraceuticals.

Future prospect

To replace the synthetic antioxidants with toxic side effects, the isolation of principle bioactive components from different fruit and vegetable varieties is required and then it will be possible to use natural bioactive components as harmless dietary supplement and as therapeutic agent.

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