Chapter 2
Plants of Indian Traditional Medicine with Antioxidant Activity

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Abstract Oxidative stress is associated with increased production of reactive oxygen species (ROS) that can pose a threat to cells by causing lipid peroxidation, protein oxidation, nucleic acid damage, enzyme inhibition and activation of cell death pathways. An uncontrollable production of ROS may lead to organ dysfunction and diseases. It has been well documented in the last few decades that antioxidant compounds are the major agents that eliminate/scavenge ROS hence inhibiting oxidative stress and hindering the onset and development of non communicable chronic diseases (NCDs). Naturally occurring antioxidant compounds in plants may contribute to their potential dietary, nutritious and curative activities against ROS-induced oxidative cellular damage and NCDs. India is endowed with a variety of natural resources and flora with antioxidant principles that can be used in traditional medicine aimed at maintaining health and curing NCDs. Indian plants are important sources of alkaloids and phenolic compounds with potential antioxidant activities. Ancient texts of *Ayurveda* and *Charaka Samhita* mention innumerable herbal formulations in the treatment of NCDs that we know are caused due to oxidative stress and free-radical damage. Scientists around the world have shown interest in the Indian system of medicine and have realized the potential of Indian plants against ROS-induced cellular damage and NCDs. Plants mentioned in the texts of Indian traditional medicine are discussed here so as to project a picture of Indian flora as potential sources of antioxidants in the prevention and management of human NCDs.

Keywords Indian plants • Medical plants • Natural antioxidants • Trees • Shrubs • Herbs

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2.1 Introduction

Free radicals are produced either as a result of cell metabolism or after exposure of biological systems to environmental factors. Many diseases of ancient and contemporary times are believed to have been mediated by free radical-induced damage to cells (Pham-Huy et al. 2008). Our body has developed several antioxidant defence systems to limit damage from reactive oxygen species (ROS) and reactive nitrogen species (RNS). Oxidative stress results when generation of ROS supersedes cellular antioxidant defences. The detrimental results include the initiation of several diseased conditions in a human body, which tend to worsen with continuous exposure in due course of time. The development and wide application of chemical antioxidants (Li et al. 2007) have been constrained due to negative side effects and escalating costs. A wide array of secondary metabolites of herbal origin such as the phenolic compounds (phenolic acids, flavonoids, coumarins, quinines and other polyphenols), nitrogen compounds (alkaloids and amines), vitamins, terpenoids and other secondary metabolites have antioxidant activities (Gul et al. 2011). Naturally occurring antioxidant compounds are gaining prominence, and their identification in plants has promoted their potential dietary, nutritious and curative applications (Brewer 2011) against ROS-induced oxidative cellular damage and non communicable chronic diseases (NCDs) (Fig. 2.1).

India is endowed with an important variety of natural resources and flora with potential antioxidant activities useful in traditional medicine to maintain health and cure diseases (Scartezzini and Speroni 2000; Katiyar et al. 2013). Ancient *Ayurveda* "science of life" and its documented practices, an integral part of Indian culture and materia medica, indicated a pivotal role of several plants (Sivarajan and Balachandra 1996) in the treatment of various health concerns (Svoboda 1998; Dev 1999; Subhose et al. 2005; Rathore et al. 2007; Ven Murthy et al. 2010; Pandey et al. 2013) including some contagious diseases (Singh and Singh 2008). Various Indian plants have been also used in treatment of male reproductive disorders and diseases such as infertility, contraception, libido, sexually transmitted infections and reproductive tract cancers (Lohiya et al. 2016). The *Ayurveda* dates back to the period of the Indus Valley Civilization, about 3000 BC. (Ven Murthy et al. 2010). Now traditional herbal medicines represent more than 60 billion US$ in the global market. Their widespread availability, ease in procurement, low cost of processing and reduced risk of side effects are the hallmarks of their success as complementary or alternative therapies against NCDs.

There is evidence from rodents studies that herbal preparations such as Brahmarasayana, Narasimharasayana, Ashwagandharasayana, Amrithaprasham, Mentat and Abana have radioprotective effects and reduced radiation-induced ROS production and cellular damage in organs and tissues of biological systems (Saini et al. 1984; Kumar et al. 1996; Jagetia et al. 2002; Jagetia and Baliga 2003). In the *Charaka Samhita* (by *Charka* in 1500 BC), *Triphala*, an Ayurvedic formulation comprising *Terminalia chebula*, *Emblica officinalis* and *Terminalia bellirica*, is described as a *tridoshic rasayan* that has balancing and revivifying effects on *vata*,

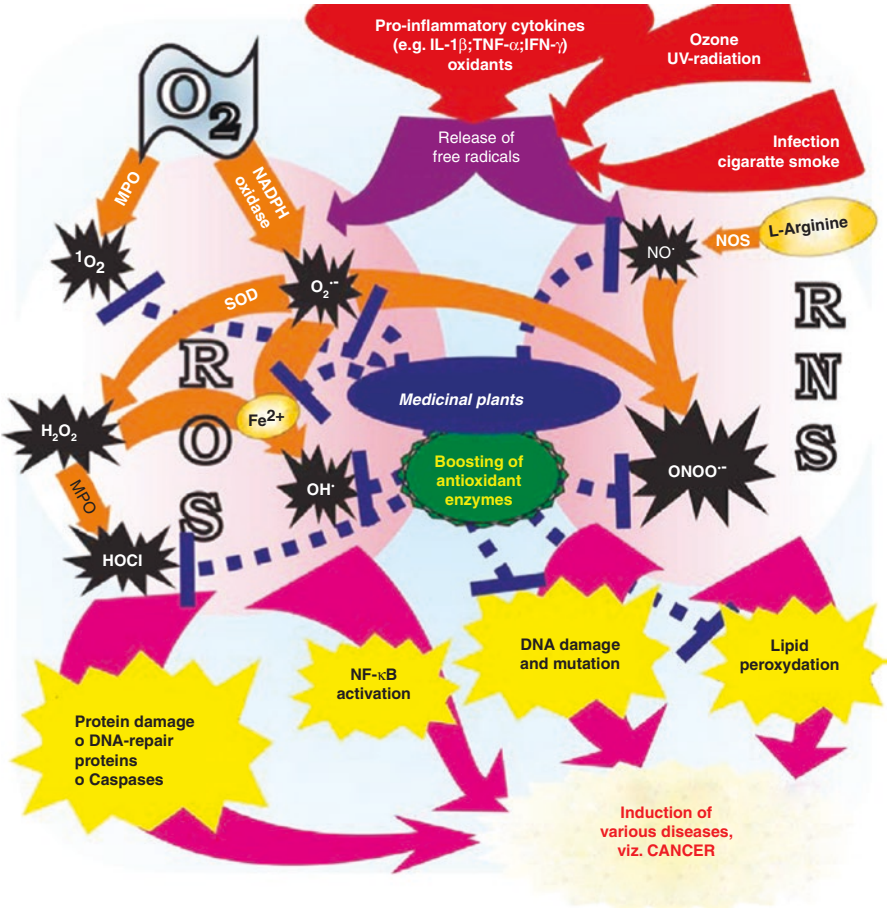


Fig. 2.1 Role of medicinal plants in prevention of diseases. Medicinal plants inhibit various diseases including iron overload, liver toxicity and cancer by reducing oxidative stress. Generation of reactive oxygen species (ROS) and reactive nitrogen species (RNS) is initiated by respiratory bursts, which is initiated by various physiological and environmental factors. An assortment of ROS and RNS from molecular oxygen and L-arginine, respectively, formed by myeloperoxidase (MPO), nicotinamide adenine dinucleotide phosphate (NADPH) oxidase, superoxide dismutase (SOD) and nitric oxide synthase (NOS) leads to lipid peroxidation, DNA damage and then followed by mutation and nuclear factor-kappa B (NF-κB) activation. These phenomena give rise to wide range of diseases. Plant extracts exert their effect by inhibiting the formation and also scavenging the free radicals and non-radical ROS. Plant products also chelate iron and thus reduce iron overload-related pathological sequences

pitta and *kapha*, the three elements that constitute human life (Sharma and Dash 1998). The plants of *Triphala* have been proven useful source of natural antioxidants and their possible use in mitigating NCDs (Hazra et al. 2010b).

2.2 Reactive Oxygen Species

ROS are implicated in receptor-mediated signalling pathways (Knebel et al. 1996) as well as in transcriptional activation (Schreck et al. 1991). Oxidative stress is associated with increased production of ROS that can pose a threat to cells by causing lipid peroxidation, protein oxidation, nucleic acids damage, enzyme inhibition and activation of cell death pathways. Potentially harmful ROS include hydroxyl radical ($HO^{\bullet}$), superoxide radical ($^{\bullet}O_2^-$), peroxyl radical ($RO_2^{\bullet}$), hydrogen peroxide (H_2O_2), hypochlorous acid (HOCl) and singlet oxygen ($^1O_2$). $HO^{\bullet}$ is produced from the decomposition of hydroperoxides (ROOH), radiation of atomic O_2, UV-light dissociation of H_2O_2 and likely during Fenton chemistry where trace amounts of reduced transition metals catalyse peroxide-mediated oxidations of organic compounds. $HO^{\bullet}$ has a very short in vivo half-life of a few seconds, even though it is extremely reactive (Sies 1993) by causing damage to virtually all types of macromolecules, including carbohydrates, nucleic acids, lipids and amino acids. High levels of H_2O_2 can attack several cellular energy-producing systems through $HO^{\bullet}$ in the presence of transition metal ions. Even though not a radical, HOCl is considered a potent chlorinating and oxidizing agent. The formation of cholesterol chlorohydrins could further disrupt cell membranes and lead to cell lysis and death (Carr et al. 1996). HOCl attacks primary amines and sulfhydryl groups in proteins and chlorinates purine bases in DNA (Dennis et al. 1979). Similarly, $^1O_2$ is not a true radical either but is believed to be an important ROS in reactions involving UV exposure. Its toxicity is increased by photosensitization with molecular oxygen. The presence of metals such as iron increases the production of $^1O_2$, as well as $^{\bullet}O_2^-$, thus accelerating the oxidation of unsaturated lipids. $^1O_2$ thus induces hyperoxidation and oxygen toxicity within cells (Kochevar and Redmond 2000).

2.3 Reactive Nitrogen Species

Common RNS include nitric oxide ($NO^{\bullet}$) and peroxynitrite ($ONOO^-$). Nitric oxide is produced by a number of cell types, and sustained levels of production of this radical contribute to the vascular collapse associated with septic shock, whereas chronic production of $NO^{\bullet}$ is associated with various carcinomas and inflammatory conditions including diabetes, multiple sclerosis, arthritis and ulcerative colitis (Tylor et al. 1997). The toxicity of $NO^{\bullet}$ increases greatly when it reacts with $^{\bullet}O_2^-$, forming highly reactive $ONOO^-$ (Huie and Padmaja 1993). The relatively stable $ONOO^-$ and its protonated form, peroxynitrous acid (ONOOH), are highly reactive, cross biological membranes and undergo significant interactions with most cellular biomolecules (Pryor and Squadrito 1995). $ONOO^-$ can damage DNA by introducing oxidative modifications in both nucleobases and the sugar-phosphate backbone (Butler et al. 1998) and can also alter protein structure and function by reacting with

various amino acids in the peptide chain. The free radical $ONOO^-$ reacts with iron-sulphur clusters and inactivates enzymes implicated in critical metabolic processes (Castro et al. 1994) and triggering lipid peroxidation in cell membranes, liposomes and lipoproteins by removing a hydrogen atom from polyunsaturated fatty acids. These reactions contribute to the mechanisms of $ONOO^-$ cytotoxicity (Radi et al. 1991).

2.4 Medicinal Plants for Prevention of Chronic Diseases

Oxidative stress is involved in the pathogenesis of NCDs such as cancer, heart disease, diabetes mellitus, cataract formation and several neurodegenerative disorders (Qian et al. 2008). The burden of chronic diseases, like coronary heart disease (CHD), cancers, diabetes and obesity was found to contribute in 59% of the 56.5 million deaths worldwide in 2001, according to a World Health Organization (WHO) report (Mahady 2009). CHD comprises diseases of the circulatory system especially acute myocardial infarction, ischemic heart disease, valvular heart disease, peripheral vascular disease, arrhythmias and stroke (Mahady 2009). Medicinal sources from artichoke (*Cynara scolymus*), ginkgo (*Ginkgo biloba*), hawthorn (*Crataegus* spp.), garlic (*Allium sativum*), guggul (*Commiphora mukul*), red wine (*Vitis vinifera*), tea (*Camellia sinensis*) and saffron (*Crocus sativus*) are found to be promising dietary supplements in the prevention and treatment of CHD (Mahady 2009). Free radicals generated in our body have the tendency to manipulate a plethora of biomolecules causing these chronic health conditions. Functional plant foods/neutraceuticals are sources of antioxidants that can be consumed as beneficial diets in reducing the risk of chronic disorders such as obesity. It has been shown that *Nelumbo nucifera* extracts counteract obesity by inhibiting pancreatic lipase (Velusami et al. 2013) and also fastens healing in piles (Kalita et al. 2005).

Indian traditional practitioners of folk medicine have been using medicinal plants for treating acute and chronic diseases, since ages. Aerial parts of *Oxalis corniculata* Linn. and whole plant extract of *Leucas aspera* Spreng. are used for the treatment of diabetes (Kalita et al. 2005), whereas epilepsy is managed with the leaf extracts of *Lawsonia inermis* Linn. supplemented by cow milk (Kalita et al. 2005). Plants like *Oroxylum indicum* Vent., *Prunella vulgaris* Linn., *Sapindus mukorossi* Gaertn., *Syzygium cumini* (L.) Skeels., *Albizia chinensis* (Osb.) Merr., *Perilla frutescens* (L.) Britton and *Lasia spinosa* (L.) Thw. are used as folk remedies against impotency, skin problems, epilepsy, diabetes, snake bites, body swelling and helminthic infections, respectively (Jamir et al. 2012). *Aegle marmelos* Correa ex Roxb. extracts have been used for the treatment of abscess, heart disease and fever.

2.5 Indian Traditional Medicinal Plants and Antioxidants

Since the dawn of civilization, Indian plants (trees, shrubs and herbs) have been used as traditional medicines to cure various ailments as documented in ancient scripts of *Ayurveda*. Many plants possess compounds having large amounts of antioxidants with free radical scavenging activities. The types and parts of medicinal plants used are shown in Fig. 2.2. Plant roots, stems, barks, leaves, flowers, fruits and seeds have the potential for the treatment of several organ disorders and complications. The following is a summary of the experimental evidence for the free radical scavenging activities of medicinal plants and their health benefits.

The aim of this chapter is to scientifically establish the underlying principles of traditional Indian medicinal system, the *Ayurveda*, which regularly employs the practice of ingesting plant materials alone or as a mixture of plant materials in a form of a pill or powder. Sometimes, a solution (especially water and/or alcohol) of plant product or mixture of plant products is also used as a remedy in *Ayurveda*. It was evident that most of the plant-derived antioxidant compounds are either phenolics or flavonoids responsible for the bioactivity (Arabshahi-Delouee and Urooj 2007; Sultana et al. 2009; Sarkar et al. 2009a, b, 2014; Chaudhuri et al. 2016a, b).

Scientists are using different techniques to extract the active phenolics from the plant materials taking into account their chemistry and uneven distribution in the plant matrix. Among the different techniques, polarity-based solvent extraction is used most frequently. However, the antioxidant potential of a plant material mostly relies on the solvent used for extraction as the chemical properties and polarities vary for the different antioxidant compounds. So, it is important to check the extracts obtained from solvents of different polarities rather than solely depending on the most polar solvents only (Peschel et al. 2006). However, the results from different studies suggest that the aqueous mixtures containing ethanol, methanol, acetone and ethyl acetate extracts harbour most of the antioxidant compounds from the plants (Abdille et al. 2005; Rehman 2006; Li et al. 2006; Bonoli et al. 2004; Chatha et al. 2006; Siddhuraju and Becker 2003). These results eventually correlate the solvents used for extraction with their respective bioactivities as phenolics and flavonoids are

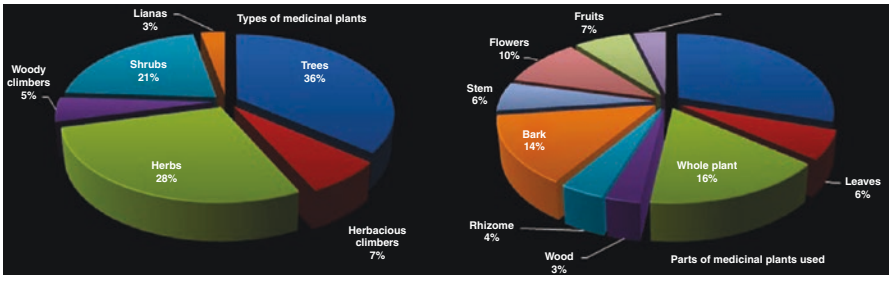


Fig. 2.2 Types and parts of Indian medicinal plants. About 70% of Indian medicinal plants grow in tropical and subtropical forests, and <30% are found in temperate and high-altitude forests. These medicinal plants belong to a wide range of plant types, including trees, herbs, lianas, woody climbers and twiners. In India, more than 90% of the plant species for industrial use are collected from the wild, and over 70% of this collection involves harvesting different parts of the plants

mostly extracted in ample amounts in high polar solvents such as aqueous methanol/ethanol as compared with absolute methanol/ethanol (Siddhuraju and Becker 2003; Anwar et al. 2006; Sultana et al. 2007). Therefore, the solvent(s) used plays an important role in determining the optimal medium of extraction of plant materials in a study of antioxidants and/or free radical scavenging properties.

2.5.1 Tree Antioxidant Activities

Two factors that differentiate trees from shrubs are (1) growing into a larger structure and (2) having a single well-defined main stem; however, the distinction between a small tree and a large shrub is not always clear (Lawrence and Hawthorne 2006). Trees are able to accumulate large quantities of carbon in their tissues by removing excess atmospheric carbon dioxide, reduce erosion, improve the climate, serve as a habitat for a diverse flora and fauna and provide food and timber and many other services to the biota. In addition, they are also a large reservoir of drugs as first described in early writings of traditional medicine. Parts of trees, including roots, barks, leaves, flowers, fruits and seeds, have been used by traditional practitioners and, recently, for identifying medicines against various diseases (Kumar et al. 2011a, b; Sharma et al. 2013). Findings of antioxidant and free radical activities from various tree parts are summarized in Table 2.1.

2.5.2 Shrub Antioxidant Activities

Shrubs are woody in nature (same as trees) but refrained in growth as they usually are under 6 m in height. Plants of several species can grow either into trees or shrubs, depending on their growing conditions including climatic and geographical restrictions. Shrubs in many parts of the world, including India, have antioxidant activities and are used in traditional medicine against many ailments (Argoti et al. 2013; Soysa et al. 2014; Anyanwu et al. 2015; Jarić et al. 2015). Much work has been done globally on shrubs used in Indian traditional medicine, some of which are mentioned in Table 2.2 according to the part of the plant used.

2.5.3 Herb Antioxidant Activities

Herbal plants are the shortest of the three forms of flora. Herbs are known for their beautiful foliage, aromatic traits, ornamental importance and numerous culinary purposes. Apart from being an important ingredient in human nutrition, herbs of Indian origin have therapeutic properties attributed to its natural phytochemical compounds and remain an integral part of the Indian traditional medicine for various biomedical applications (Sah et al. 2005; Gupta et al. 2011a, b, c; Mishra et al. 2011; Di Fabio et al. 2015; Ahmmed et al. 2016). Some of the findings related to their antioxidant activities are summarized in Table 2.3.

Table 2.1 Examples of antioxidant activities from different parts of trees

Name of the tree	Part of tree used	Solvent used for extraction	In vitro antioxidant and radical scavenging assays/in vivo experiments	References
Prunus nepalensis Ser. (Steud)	Fruits	70% methanol	$ABTS^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $NO^{\bullet}$, $ONOO^-$, HOCL, iron chelation, SOD, CAT, GST, GSH, lipid peroxidation	Chaudhuri et al. (2015)
Ficus bengalensis L. (Indian banyan tree)	Arial roots	Methanol, 70% acetone	DPPH, $ABTS^{\bullet+}$, $^{\bullet}OH$, anti-haemolytic, iron chelation, reducing power	Manian et al. (2008)
Erythrina indica	Roots	Methanol	Ferric reducing antioxidant power, DPPH, $NO^{\bullet}$, $^{\bullet}O_2^-$	Sre et al. (2012)
Pandanus odoratissimus L.	Roots	Methanol, water	DPPH, reducing power	Sasikumar et al. (2009)
Azadirachta indica A. Juss Var., Meliaceae	Root bark	80% Ethanol	DPPH, Total antioxidant	Kiranmai et al. (2011)
	Flower	Water, methanol, ethanol	DPPH	Nahak and Sahu (2011)
	Seed oil	Nil		
Vitex trifoliate	Roots	Chloroform, methanol	$^{\bullet}O_2^-$, DPPH, lipid peroxidation	Sreedhar et al. (2010)
Aporosa lindleyana Baill	Roots	Petroleum ether (40–60 °C), chloroform, ethyl acetate, methanol, 50% methanol, water	DPPH, $NO^{\bullet}$, CAT, SOD, lipid peroxidation	Badami et al. (2005)
Mesua ferrea Linn.	Roots	*n*-Hexane, dichloromethane, ethyl acetate, methanol	DPPH	Teh et al. (2013)
	Stem bark	Chloroform, ethanol	Total antioxidant, DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, anti-haemolytic, DNA protection	Rajesh et al. (2013)
	Flowers	Petroleum ether (60–80 °C), chloroform, methanol	Total antioxidant, DPPH, $^{\bullet}O_2^-$, H_2O_2	Sahu et al. (2013)
	Seed oil	Petroleum ether	DPPH, $ABTS^{\bullet+}$, $NO^{\bullet}$	Chahar et al. (2012)

Bombax ceiba Linn	Roots	Methanol	DPPH radicals, total antioxidant status, reducing power	Jain et al. (2011)
	Stem bark	95% Ethanol, water	Total antioxidant, DPPH, $^{\bullet}O_2^-$, NO$^{\bullet}$, $ABTS^{\bullet+}$, SOD, lipid peroxidation, reducing power	Gandhare et al. (2010)
	Flowers	50% ethanol, 80% acetone	DPPH, total antioxidant, reducing power	Yu et al. (2011)
Pistacia integerrima Stewart	Galls	Ethanol, *n*-hexane, chloroform, ethyl acetate, methanol	DPPH	Rauf et al. (2014)
	Leaves			
	Stem bark			
	Roots			
	Fruits	70% methanol	DPPH	Ilahi et al. (2013)
Bauhinia variegata	Stem bark	95% ethanol, water	$^{\bullet}O_2^-$, H_2O_2, DPPH, NO$^{\bullet}$, Reducing power	Rajani and Ashok (2009)
	Roots			
Acacia catechu (L.f.) wild	Heartwood	70% methanol	$ABTS^{\bullet+}$, DPPH, $^{\bullet}OH$,$^{\bullet}O_2^-$, NO$^{\bullet}$, $ONOO^-$, H_2O_2, HOCl, lipid peroxidation, DNA protection, iron chelation	Hazra et al. (2010a)
Spondias pinnata	Stem bark	70% methanol	$ABTS^{\bullet+}$,$^{\bullet}O_2^-$,$^1O_2$, NO$^{\bullet}$, $^{\bullet}OH$, $ONOO^-$, H_2O_2, HOCl, lipid peroxidation, iron chelation, reducing power	Hazra et al. (2008)
Ficus racemosa L.	Stem bark	Methanol, 70% acetone	DPPH, $ABTS^{\bullet+}$, $^{\bullet}OH$, anti-haemolytic, iron chelation, reducing power	Manian et al. (2008)
Caesalpinia sappan	Heartwood	Petroleum ether (40–60 °C), chloroform, ethyl acetate, methanol, 50% methanol, water	DPPH, levels of CAT, SOD, lipid peroxidation	Badami et al. (2003a)

(continued)

Table 2.1 (continued)

Name of the tree	Part of tree used	Solvent used for extraction	In vitro antioxidant and radical scavenging assays/in vivo experiments	References
Cassia fistula L.	Flowers	90% methanol	$^{\bullet}O_2^-$, DPPH, liposome peroxidation, reducing power	Siddhuraju et al. (2002)
		Hydroalcohol	DPPH, reducing power	Bhalodia et al. (2011)
	Fruit pulp	90% methanol	$^{\bullet}O_2^-$, liposome peroxidation, reducing power	Siddhuraju et al. (2002)
		Hexane, methanol	DPPH, $^{\bullet}OH$, FRAP total antioxidant, reducing power	Irshad et al. (2012)
	Leaves	90% ethanol	$^{\bullet}O_2^-$, DPPH, liposome peroxidation, reducing power	Siddhuraju et al. (2002)
	Stem bark	Petroleum ether (60–80 °C), methanol	DPPH, $NO^{\bullet}$	Jagtap and Pal (2010)
		90% methanol	$^{\bullet}O_2^-$, DPPH, liposome peroxidation, reducing power	Siddhuraju et al. (2002)
	Seeds	Hexane, methanol	DPPH, $^{\bullet}OH$, FRAP total antioxidant, reducing power	Irshad et al. (2012)
Ficus microcarpa	Stem bark	Ethyl acetate	DPPH, $ABTS^{\bullet+}$, $^{\bullet}O_2^-$	Ao et al. (2008)
	Leaves			
	Fruits			
Polyalthia longifolia Benth. and Hook	Stem bark	Ethanol	DPPH, lipid peroxidation, reducing power	Manjula et al. (2010)
Prunus cerasoides D. Don	Stem bark	80% ethanol	DPPH, FRAP total antioxidant	Guleria et al. (2013a)
Abies spectabilis (D. Don) Spach.	Stem bark	Methanol, chloroform	DPPH, $ABTS^{\bullet+}$, iron chelation	Dall'Acqua et al. (2012)
	Leaves	70% ethanol	DPPH, H_2O_2, $^{\bullet}OH$, $NO^{\bullet}$, reducing power	Tote et al. (2009)

Albizia lebbeck (L.) Benth	Stem bark	Methanol	DPPH, reducing power	Suruse et al. (2013)
	Pods	80% methanol	Anti-haemolytic, $ABTS^{\bullet+}$, FRAP and TRAP total antioxidant	Zia-ul-Haq et al. (2013)
	Seeds			
Aesculus hippocastanum L.	Stem bark	Ethanol	DPPH, lipid peroxidation	Celep et al. (2012)
	Leaves			
	Flowers			
	Seeds			
Anogeissus latifolia	Stem bark	50% ethanol	DPPH, $^{\bullet}O_2^-$, H_2O_2, $NO^{\bullet}$, lipid peroxidation	Govindarajan et al. (2004)
Crataeva nurvala Buch. Ham.	Stem bark	Chloroform, ethyl acetate, acetone, methanol	DPPH	Raut and Gaikwad (2014)
Shorea roxburghii	Stem bark	Acetone, methanol	DPPH, H_2O_2, $^{\bullet}OH$, $ABTS^{\bullet+}$, reducing power	Subramanian et al. (2013)
Shorea robusta Gaertn	Stem bark	Water	DPPH	Guerrero et al. (2004)
Aphanamixis polystachya	Stem bark	Ethanol	DPPH	
Semecarpus anacardium L.	Stem bark	Hexane, chloroform, ethyl acetate, methanol	DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, $NO^{\bullet}$, lipid peroxidation	Sahoo et al. (2008)
	Leaves	Acetone, chloroform, ethanol, water	$ABTS^{\bullet+}$, DPPH, iron chelation	Barman et al. (2013)
	Nuts			
	Seeds	Ethanol	DPPH	Guerrero et al. (2004)
Bauhinia purpurea L.	Leaves	Hexane, ethyl acetate, methanol	DPPH, $NO^{\bullet}$	Urmi et al. (2013)
	Stem bark			
Saraca asoca (Roxb.) De Wild	Stem bark	60% ethanol, 90% ethanol, acetone	DPPH	Panchawat and Sisodia (2010)
	Leaves	Petroleum ether (60–80 °C), chloroform, methanol	DPPH	Kumar et al. (2012)

(continued)

Table 2.1 (continued)

Name of the tree	Part of tree used	Solvent used for extraction	In vitro antioxidant and radical scavenging assays/in vivo experiments	References
Saraca indica	Stem bark	Hexane, chloroform, ethyl acetate, ethanol, water	FRAP total antioxidant, DPPH, $ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $^{\bullet}OH$, $NO^{\bullet}$, lipid peroxidation	Gayathri and Jeyanthi (2013)
	Leaves	Petroleum ether (60–80 °C), chloroform, methanol	DPPH, $^{\bullet}O_2^-$, H_2O_2, $^{\bullet}OH$, $NO^{\bullet}$, lipid peroxidation, anti-haemolytic	Sen et al. (2014)
Pongamia pinnata (L) Pierre	Leaves	70% methanol	$ABTS^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, $NO^{\bullet}$, $ONOO^-$, $^1O_2$, HOCl, lipid peroxidation, iron chelation, reducing power	Hazra et al. (2011)
	Flowers			
	Seeds			
Moringa oleifera Lam.	Leaves	70% ethanol, 80% methanol, water	DPPH, $^{\bullet}O_2^-$, lipid peroxidation, reducing power	Siddhuraju and Becker (2003)
	Leaves	80% ethanol	FRAP total antioxidant, DPPH, levels of SOD, CAT, GSH, MDA	Fakurazi et al. (2012)
	Stems			
	Pods			
	Flowers			
	Seeds			
Momordica dioica Roxb.	Leaves	95% ethanol, water	DPPH, levels of SOD, CAT, GSH, MDA	Jain et al. (2008)
Mangifera indica L.	Leaves	98% methanol	DPPH, FTC, TBA, total antioxidant	Aqil et al. (2006)
Lawsonia inermis L.				
Sesbania grandiflora L. Pers	Leaves	Tris HCl buffer (pH 7.0)	DPPH, $^{\bullet}OH$, lipid peroxidation, iron chelation, reducing power	Padmaja et al. (2011)
Aegle marmelos L. Correa ex Roxb.	Leaves	80% methanol	FRAP total antioxidant, DPPH	Guleria et al. (2013a)
Cinnamomum camphora L. T. Nees and C. H. Eberm.				
Taxus baccata L.				

Abies pindrow Royle	Leaves	Dichloromethane, methanol, acetone	$ABTS^{\bullet+}$, DPPH, FRAP total antioxidant, $^{\bullet}O_2^-$, iron chelation, reducing power	Gupta et al. (2011a)
Acacia arabica	Leaves	Methanol, 100% methanol, water	DPPH, H_2O_2	Aadil et al. (2012)
	Seeds	Acetone	DPPH, $^{\bullet}O_2^-$, $NO^{\bullet}$	Parmar et al. (2010)
Acacia pennata	Leaves	Methanol	DPPH	Nanasombat and Teckchuen (2009)
Ailanthus excels (Roxb.)	Leaves	70% methanol	DPPH, FRAP total antioxidant	Said et al. (2010)
Albizia procera	Leaves	Methanol, petroleum ether, dichloromethane, carbon tetrachloride, ethyl acetate, water	DPPH, phosphomolybdate assay, reducing power	Khatoon et al. (2013)
Anacardium occidentale	Leaves	Hexane, 95% ethanol, water	DPPH	Ifesan et al. (2013)
Carica papaya				
Commiphora caudate	Leaves	Ethanol	DPPH, $^{\bullet}O_2^-$, $NO^{\bullet}$, lipid peroxidation, reducing power	Deepa et al. (2009)
Commiphora var pubescens				
Zanthoxylum alatum Roxb.	Leaves	Essential oil, chloroform, ethyl acetate, acetone, methanol	DPPH, iron chelation, reducing power	Guleria et al. (2013b)
	Fruits	95% ethanol	DPPH, $^{\bullet}OH$, iron chelation, phosphomolybdenum reduction assay	Batool et al. (2010)
Butea monosperma Lam.	Leaves	Petroleum ether, chloroform	DPPH, $NO^{\bullet}$	Borkar et al. (2008)
	Flowers	Ethyl acetate, *n*-butanol, methanol, water	DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, $NO^{\bullet}$, anti-haemolytic	Lavhale and Mishra (2007)
Randia dumetorum	Leaves	70% ethanol	DPPH, $^{\bullet}O_2^-$, iron chelation, phosphomolybdenum reduction assay, reducing power	Gandhimathi and Bai (2013)
Delonix regia Gamble.	Flowers	98% methanol	DPPH, FTC, TBA, total antioxidant	Aqil et al. (2006)
Peltophorum ferrugineum	Flowers	Hexane, ethyl acetate, acetone, methanol	DPPH, phosphomolybdenum reduction assay, reducing power	Pavagadhi et al. (2012)

(continued)

Table 2.1 (continued)

Name of the tree	Part of tree used	Solvent used for extraction	In vitro antioxidant and radical scavenging assays/in vivo experiments	References
Lagerstroemia speciosa	Flowers	Methanol	DPPH, reducing power	Pavithra et al. (2013)
Wendlandia thyrsoidea				
Bombax malabaricum				
Olea dioica				
Wrightia tinctoria (Roxb.)	Flowers	95% ethanol	DPPH, H_2O_2, iron chelation, phosphomolybdenum reduction assay, reducing power	Ramalakhsmi et al. (2012)
Punica granatum L.	Flowers	1% HCl in methanol	DPPH, $ABTS^{\bullet+}$	Zhang et al. (2011)
	Fruit rind	98% methanol	DPPH, FTC, TBA, total antioxidant	Aqil et al. (2006)
Populus nigra	Flowers buds	Ethanol, hexane, ethyl acetate, chloroform, water	DPPH, $ABTS^{\bullet+}$, H_2O_2, $^{\bullet}OH$, $NO^{\bullet}$, HOCl, lipid peroxidation	Debbache et al. (2014)
Michelia champaca	Flowers	Hexane, ethyl acetate	DPPH	Parimi and Kolli (2012)
Litchi chinensis	Flowers	Hexane, ethyl acetate, *n*-butanol, acetone	DPPH	Yang et al. (2012)
Nerium oleander	Flowers	Petroleum ether, chloroform, ethyl acetate, methanol, water	DPPH, $ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $^{\bullet}OH$, iron chelation	Singhal and Gupta (2012)
Butea frondosa	Flowers	95% ethanol, methanol, water	DPPH, lipid peroxidation	Lal and Mantri (2011)
Castanea sativa	Leaves	Water	DPPH, β-carotene bleaching, anti-haemolytic, lipid peroxidation, reducing power	Barreira et al. (2008)
	Fruits			
	Flowers			

Terminalia chebula Retz.	Fruits	70% methanol	$ABTS^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, $NO^{\bullet}$, H_2O_2, $ONOO^-$, $^1O_2$, HOCl, lipid peroxidation; levels of SOD, CAT, GSH, GST, reducing power	Hazra et al. (2010b)
Terminalia belerica Roxb.				
Emblica officinalis Gaertn.				
Tamarindus indica	Coat	Petroleum ether, 70% acetone, methanol	$ABTS^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, FRAP total antioxidant	Siddhuraju (2007)
Areca catechu L.	Seed nuts	Petroleum ether, ethyl acetate, methanol, water, 50% methanol	H_2O_2, reducing power	Hannan et al. (2012)
Artocarpous heterolphyllus Lam	Seeds	50% dichloromethane in methanol, acetone	DPPH, $ABTS^{\bullet+}$, FRAP total antioxidant, iron chelation	Gupta et al. (2011b)
Hydnocarpus wightiana Blume.	Seed hulls	Petroleum ether, chloroform, acetone	DPPH, $ABTS^{\bullet+}$, α-glucosidase inhibitory	Reddy et al. (2005)
Alstonia scholaris Linn.	Leaves	Methanol	DPPH, $^{\bullet}O_2^-$, iron chelation, reducing power	Ganjewala and Gupta (2013)
	Follicles			
	Flowers	Hexane, benzene, methanol, water	DPPH, β-carotene bleaching	James et al. (2011)
	Fruits			
Zanthoxylum armatum DC	Stem bark	Ethanol	DPPH	Sati et al. (2011)

Table 2.2 Examples of antioxidant activities from different parts of shrubs

Name of the shrub	Shrub part used	Solvent used for extraction	In vitro antioxidant and radical scavenging assays/in vivo experiments	References
Elaeagnus latifolia Linn.	Fruits	70% methanol	ABTS$^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$	Panja et al. (2014)
Withania somnifera L. Dunal	Roots	70% methanol	ABTS$^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $^1O_2$, NO$^{\bullet}$, $^{\bullet}OH$, $ONOO^-$, HOCl, lipid peroxidation, reducing power	Chaudhuri et al. (2012)
Plumbago zeylanica L	Roots	97% methanol	DPPH, FTC, TBA, total antioxidant	Zahin et al. (2009)
	Stem Bark	Methanol	DPPH, FRAP total antioxidant	Suman et al. (2013)
Caesalpinia digyna	Roots	Petroleum ether (60–80 °C), methanol, water	ABTS$^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, H_2O_2, $^{\bullet}OH$, NO$^{\bullet}$, lipid peroxidation, levels of SOD, CAT, MDA	Srinivasan et al. (2007)
Coccinia grandis	Roots	70% methanol	DPPH, H_2O_2, NO$^{\bullet}$, reducing power	Bhadauria et al. (2012)
Asparagus racemosus Willd.	Roots	70% methanol, ethyl acetate, *n*-butanol, methanol, water	DPPH, levels of SOD, CAT, GSH, MDA	Acharya et al. (2012)
Abutilon indicum Linn.	Roots	Petroleum ether (60–80 °C), ethanol	DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, NO$^{\bullet}$, reducing power	Adikay et al. (2013)
	Stems	50% methanol water	DPPH	Chakraborthy and Ghorpade (2010)
	Flowers	70% ethanol	$^{\bullet}O_2^-$, $^{\bullet}OH$, reducing power	Revansiddaya et al. (2011)
Pothos scandens L.	Leaves	Petroleum ether, benzene, chloroform, ethyl acetate, acetone, methanol, ethanol	ABTS$^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, H_2O_2, NO$^{\bullet}$, phosphomolybdenum assay, FRAP total antioxidant, iron chelation	Sajeesh et al. (2011)
	Stem			
	Roots			
Althaea officinalis L.	Roots	50% ethanol, 70% ethanol, 90% ethanol, water	ABTS$^{\bullet+}$, HOCl, lipid peroxidation	Benbassat et al. (2014)
	Flowers	Ethanol	$^{\bullet}O_2^-$	Elmastas et al. (2003)

Glycyrrhiza glabra	Roots	Ethanol, water	$ABTS^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $NO^{\bullet}$, $^{\bullet}OH$, iron chelation, reducing power	Visavadiya et al. (2009)
Plumbago indica	Roots	Acetone, methanol	DPPH, $^{\bullet}OH$, phosphomolybdenum assay, reducing power	Eldhose et al. (2013)
Dioscorea alata L.	Modified stem	70% methanol	$ABTS^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $^1O_2$, $NO^{\bullet}$, $ONOO^-$, $^{\bullet}OH$, HOCl, lipid peroxidation, iron chelation, reducing power	Das et al. (2012)
	Leaves	70% methanol, water		Das et al. (2014)
Tinospora cordifolia	Stems	70% methanol	$ABTS^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $^1O_2$, $NO^{\bullet}$, $ONOO^-$, $^{\bullet}OH$, HOCl, lipid peroxidation, iron chelation, DNA protection	Ghate et al. (2013)
Hemidesmus indicus R. Br.	Stems	97% methanol	DPPH, FTC, TBA, total antioxidant assay	Zahin et al. (2009)
	Roots	70% methanol	$ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $^1O_2$, $NO^{\bullet}$, $ONOO^-$, $^{\bullet}OH$, HOCl, lipid peroxidation, iron chelation, reducing power	Mandal et al. (2009)
Dioscorea pentaphylla L. Ver.	Tubers	Petroleum ether, benzene, ethyl acetate, methanol, ethanol	DPPH, $ABTS^{\bullet+}$, $^{\bullet}OH$, reducing power	Paulpriya and Mohan (2013)
Fagonia schweinfurthii (Hadidi)	Whole plants	Ethanol	DPPH, $ABTS^{\bullet+}$, H_2O_2	Pareek et al. (2013)
Caesalpinia crista Linn.	Leaves	70% methanol	$ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $^1O_2$, $NO^{\bullet}$, $ONOO^-$, $^{\bullet}OH$, HOCl, iron chelation, reducing power	Mandal et al. (2011)
Cajanus cajan (L.) Millsp.	Leaves	70% methanol	$ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $^1O_2$, $NO^{\bullet}$, $^{\bullet}OH$, $ONOO^-$, HOCl, iron chelation, lipid peroxidation, reducing power	Sarkar et al. (2009a)

(continued)

Table 2.2 (continued)

Name of the shrub	Shrub part used	Solvent used for extraction	In vitro antioxidant and radical scavenging assays/in vivo experiments	References
Clerodendrum colebrookianum Walp.	Leaves	70% methanol, water	$ABTS^{\bullet+}$, DPPH, $^{\bullet}O_2^-$, $^1O_2$, $NO^{\bullet}$, $ONOO^-$, $^{\bullet}OH$, HOCl, lipid peroxidation, reducing power	Das et al. (2013)
Rauwolfia serpentina L. Benth. ex. Kurz	Leaves	Petroleum ether (20–80 °C), 80% acetone	$ABTS^{\bullet+}$, DPPH	Harisaranraj et al. (2009)
Indigofera tinctoria L.	Leaves	Petroleum ether, benzene, chloroform, ethyl acetate	DPPH, $ABTS^{\bullet+}$, $NO^{\bullet}$, $^{\bullet}OH$, iron chelation	Anusuya and Manian (2013)
Adhatoda vasica Nees	Leaves	Tris HCl buffer (pH 7.0)	DPPH, $^{\bullet}OH$, lipid peroxidation, iron chelation, reducing power	Padmaja et al. (2011)
Abroma augusta Linn.	Leaves	Methanol	DPPH	Bhuiya et al. (2013)
Abrus precatorius	Leaves	Hexane, ethyl acetate, ethanol, water	DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, $NO^{\bullet}$, H_2O_2, phosphomolybdenum assay, FRAP total antioxidant assay, lipid peroxidation	Gul et al. (2013)
	Seeds	Ethanol	H_2O_2, $^{\bullet}OH$, reducing power	Pal et al. (2009)
Sambucus nigra L.	Leaves	80% ethanol	DPPH, β-carotene antioxidant assay	Dawidowicz et al. (2006)
	Flowers			
	Fruits			
Artemisia vulgaris Linn.	Leaves, essential oil	Steam distillation	DPPH, iron chelation, FTC, total antioxidant assay, reducing power	Bhatt et al. (2007)
	Leaves	Methanol	DPPH, $ABTS^{\bullet+}$, $^{\bullet}OH$, H_2O_2	Sharmila and Padma (2013)
Musa paradicicus L.	Flowers	80% methanol	DPPH, $ABTS^{\bullet+}$, $^{\bullet}OH$, TBA, total antioxidant assay, lipid peroxidation, reducing power	China et al. (2011)
Embelia ribes	Flowers	Ethanol, water	$NO^{\bullet}$, FTC, total antioxidant assay, reducing power	Basavaraj and Ashok (2012)

Hibiscus rosa-sinensis L.	Flowers	Ethanol, water	DPPH, FRAP total antioxidant assay	Mak et al. (2013)
Senna bicapsularis				
Cassia auriculata	Flowers	Ethanol, methanol	DPPH, $ABTS^{\bullet+}$	Kumaran and Karunakaran (2007)
Dolichos biflorus Linn.	Seeds	70% methanol	$ABTS^{\bullet+}$, $^{\bullet}OH$, $^{\bullet}O_2^-$, $NO^{\bullet}$, HOCl, lipid peroxidation, reducing power	Hazra et al. (2009)
Hygrophila schulli (Buch.-Ham.)	Seeds	Ethanol	DPPH, $ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $NO^{\bullet}$, FRAP total antioxidant assay, phosphomolybdenum assay, reducing power	Lobo et al. (2010)
Solanum muricatum Aiton	Fruits	Ethyl acetate	DPPH, $ABTS^{\bullet+}$, $^{\bullet}OH$, phosphomolybdenum assay, iron chelation, FRAP total antioxidant assay, reducing power	Sudha et al. (2011)
Berberis asiatica	Fruits	Methanol	DPPH, $ABTS^{\bullet+}$, iron chelation, phosphomolybdenum assay, FRAP total antioxidant assay, reducing power	Pal et al. (2013)
Pyracantha crenulata				
Papaver somniferum L.		95% ethanol	DPPH	Baroš et al. (2012)
Carum copticum L.	Fruits	Methanol	DPPH, phosphomolybdenum assay	Zahin et al. (2010)
Foeniculum vulgare	Seeds	Ethanol, water	$^{\bullet}O_2^-$, H_2O_2, iron chelation, reducing power	Oktay et al. (2003)

Table 2.3 Examples of antioxidant activities from different parts of herbs

Name of the herb	Herb part used	Solvent used for extraction	In vitro antioxidant and radical scavenging assays/in vivo experiments	References
Cichorium intybus L.	Roots	98% methanol	DPPH, FTC, TBA, total antioxidant	Aqil et al. (2006)
Hypochaeris radicata L.	Leaves	Petroleum ether, chloroform, ethyl acetate, methanol, water	DPPH, $ABTS^{\bullet+}$, iron chelation, reducing power	Jamuna et al. (2012)
	Roots			
Curcuma longa L.	Rhizomes	80% methanol	DPPH, FRAP total antioxidant	Guleria et al. (2013a)
Acorus calamus L.	Roots			
Acalypha indica Linn.	Leaves	Methanol	DPPH	Shanmugapriya et al. (2011)
	Roots			
Aconitum heterophyllum Wall	Roots	Ethanol	DPPH, H_2O_2, $NO^{\bullet}$, $^{\bullet}OH$, phosphomolybdate assay	Prasad et al. (2012)
Actaea spicata	Roots	Ethyl acetate, methanol	DPPH	Madaan et al. (2011)
Achyranthes aspera L.	Roots	Hexane, dichloromethane, ethyl acetate, methanol	DPPH, phosphomolybdate assay, reducing power	Rama et al. (2013)
Alpinia galanga L.	Rhizomes	Ethanol, acetone	$^{\bullet}O_2^-$, $^{\bullet}OH$, DPPH, phosphomolybdate assay	Divakaran et al. (2013)
Anacyclus pyrethrum	Roots	Ethanol	DPPH, H_2O_2, $NO^{\bullet}$, $^{\bullet}OH$, lipid peroxidation, reducing power	Sujith et al. (2011)
Argyreia speciosa (Burm.f) Boj.	Roots	Ethyl acetate, ethanol	DPPH, $^{\bullet}OH$, lipid peroxidation	Habbu et al. (2010)
	Leaves	Petroleum ether (60–80 °C), chloroform, methanol	DPPH, H_2O_2,$^{\bullet}O_2^-$, phosphomolybdate assay	Sahu et al. (2013)

Clitoria ternatea L.	Leaves	Methanol	DPPH, FRAP total antioxidant, iron chelation, reducing power	Jadhav et al. (2013)
	Stems			
	Roots			
	Flowers	95% ethanol, water	DPPH	Kamkaen and Wilkinson (2009)
	Seeds	Methanol	$^{\bullet}O_2^-$,$^{\bullet}OH$, DPPH, lipid peroxidation, reducing power	Jacob and Latha (2013)
Cissampelos parieta	Roots	50% ethanol	DPPH, $^{\bullet}O_2^-$, H_2O_2, $^{\bullet}OH$, $NO^{\bullet}$, levels of CAT, SOD, GST, GSH, lipid peroxidation, reducing power	Amresh et al. (2007)
Coscinium fenestratum	Leaves	Methanol	DPPH, $ABTS^{\bullet+}$	Goveas and Abraham (2013)
	Stems			
	Stems	Methanol	DPPH, $ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $NO^{\bullet}$, iron chelation, lipid peroxidation	Shirwaikar et al. (2007)
	Roots	Ethanol, water	DPPH, $NO^{\bullet}$, FRAP total antioxidant, reducing power	Basavaraj and Ashok (2012)
Medicago sativa L.	Roots	Methanol	DPPH, $ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $NO^{\bullet}$, iron chelation, lipid peroxidation	Rana et al. (2010)
Desmodium gangeticum	Roots	Ethyl acetate	DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, $NO^{\bullet}$, lipid peroxidation	Kurian et al. (2010)
Sida cordifolia Linn.	Whole plant	90% ethanol, water	$ABTS^{\bullet+}$, lipid peroxidation	Auddy et al. (2003)
Evolvulus alsinoides Linn.				
Maranta arundinacea L.	Tuberous rhizomes	Petroleum ether, ethyl acetate, ethanol	DPPH, $ABTS^{\bullet+}$, H_2O_2, $NO^{\bullet}$, FRAP total antioxidant, reducing power	Nishaa et al. (2012)
Striga Orobanchioides Benth.	Whole plant	Ethanol	DPPH, $NO^{\bullet}$ levels of CAT, SOD, lipid peroxidation	Badami et al. (2003b)

(continued)

Table 2.3 (continued)

Name of the herb	Herb part used	Solvent used for extraction	In vitro antioxidant and radical scavenging assays/in vivo experiments	References
Phyllanthus simplex	Whole plant	Petroleum ether (60–80 °C), ethanol	DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, phosphomolybdate assay	Chouhan and Singh (2011)
Coleous vettiveroides (Jacob)	Whole plant	Methanol	DPPH, NO$^{\bullet}$, phosphomolybdate assay	Gopalakrishnan et al. (2011)
Coccinia indica	Stem bark	Methanol	DPPH	Ajithabai et al. (2011)
Bacopa monnieri L.	Whole plant	80% methanol	DPPH, FRAP total antioxidant	Guleria et al. (2013a)
Boerhavia diffusa L.				
Acanthospermum hispidum DC	Whole plant	Petroleum ether (60–80 °C), chloroform, acetone, ethanol, water	H_2O_2, NO$^{\bullet}$, phosphomolybdate assay, reducing power	Gomathi et al. (2013)
Adiantum lunulatum	Whole plant	50% ethanol	DPPH, H_2O_2, NO$^{\bullet}$, $^{\bullet}OH$, reducing power	Sawant et al. (2009)
Allium cepa	Bulbs	Water	DPPH, $^{\bullet}O_2^-$,$^{\bullet}OH$	Kumar et al. (2013)
		Hexane, ethyl acetate, ethanol	DPPH, $ABTS^{\bullet+}$	Fidrianny et al. (2013)
Allium sativum	Bulbs	Hexane, ethyl acetate, ethanol	DPPH, $ABTS^{\bullet+}$	Fidrianny et al. (2013)
Amorphophallus campanulatus (Roxb.) Blume. ex Decne	Tubers	Methanol, water	DPPH, NO$^{\bullet}$, reducing power	Sahu et al. (2009)
Anethum sowa	Whole plant	Water	DPPH, NO$^{\bullet}$	Kumar et al. (2011a, b)
Pentanema vestitum L.	Whole plant	70% methanol	DPPH	Ilahi et al. (2013)
Eclipta alba	Whole plant	Ethanol	DPPH, $ABTS^{\bullet+}$, NO$^{\bullet}$, phosphomolybdate assay	Baldi et al. (2011)

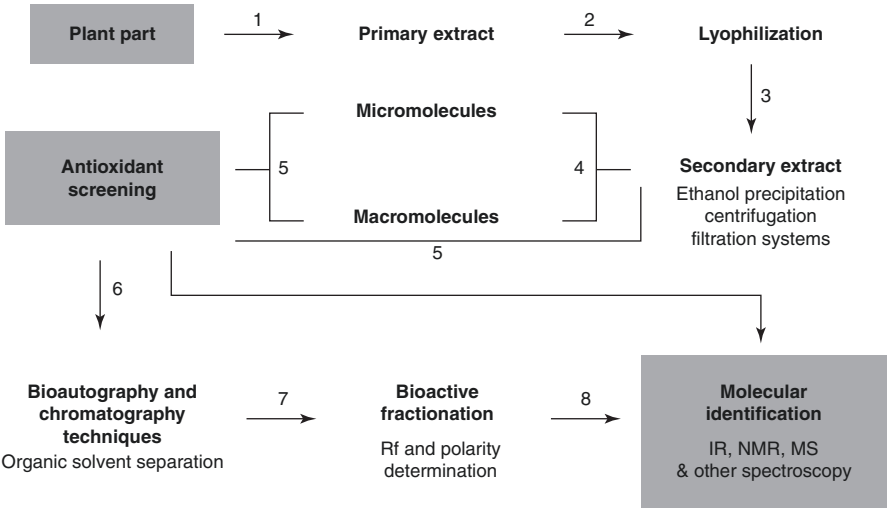
Diplazium esculentum (Koenig ex Retz.) Sw.	Young fronds	70% methanol	$ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $^1O_2$, H_2O_2, $^{\bullet}OH$, $NO^{\bullet}$, $ONOO^-$, HOCl, lipid peroxidation, iron chelation, reducing power	Roy et al. (2013)
Gymnema sylvestre R.	Leaves	70% methanol	$ABTS^{\bullet+}$, DPPH,$^{\bullet}O_2^-$, $^1O_2$, $^{\bullet}OH$, $NO^{\bullet}$, $ONOO^-$, HOCl, lipid peroxidation, iron chelation, DNA protection	Sarkar et al. (2009b)
Ocimum sanctum L.	Leaves	98% methanol	DPPH, FTC, TBA, total antioxidant	Aqil et al. (2006)
Centella asiatica	Leaves	Methanol	DPPH, $NO^{\bullet}$, reducing power	Chippada and Vangalapati (2011)
Aloe vera (L.) Burm f.	Leaves	80% methanol	DPPH, FRAP total antioxidant	Guleria et al. (2013a)
Acanthus ilicifolius	Leaves	70% ethanol	$^{\bullet}O_2^-$, $^{\bullet}OH$, $NO^{\bullet}$, lipid peroxidation	Babu et al. (2001)
	Flowers	Acetone, methanol, 70% acetone, 80% methanol, water	DPPH	Firdaus et al. (2013)
Adiantum philippense L.	Leaves	Methanol	DPPH, reducing power	Ali et al. (2013)
Andrographis paniculata	Leaves	Petroleum ether, ethyl acetate, ethanol, hydroalcohol	DPPH, $^{\bullet}O_2^-$, $^{\bullet}OH$, $NO^{\bullet}$, reducing power	Saranya et al. (2010)
Apium graveolens L.	Leaves	Ethyl acetate, methanol, butanol, water	DPPH, β-carotene-linoleate antioxidant assay	Jung et al. (2011)
Trichosanthes dioica Roxb.	Arial part (leaves, stem)	Petroleum ether, ethyl acetate, methanol, water	$NO^{\bullet}$, phosphomolybdate assay	Akter et al. (2011)
	Fruits	Water	DPPH, H_2O_2, $NO^{\bullet}$, reducing power	Shivhare et al. (2009)
Rubia cordifolia	Leaves	Hexane, chloroform, methanol	DPPH,$^{\bullet}O_2^-$, $NO^{\bullet}$	Prajapati and Parmar (2011)

(continued)

Table 2.3 (continued)

Name of the herb	Herb part used	Solvent used for extraction	In vitro antioxidant and radical scavenging assays/in vivo experiments	References
Paederia foetida	Leaves	70% ethanol	DPPH, $NO^{\bullet}$, H_2O_2, phosphomolybdate assay, reducing power	Uddin et al. (2014)
Tagetes patula L.	Flowers	Methanol	DPPH, $ABTS^{\bullet+}$, $^{\bullet}OH$, lipid peroxidation, reducing power	Bhattacharyya et al. (2010)
Blepharis molluginifolia	Flowers	Petroleum ether, benzene, chloroform, acetone, water, ethanol, methanol	DPPH, $ABTS^{\bullet+}$, H_2O_2	Deepika and Rajagopal (2014)
Tropaeolum majus L.	Leaves and flowers	Water, ethanol	DPPH, $^{\bullet}O_2^-$, H_2O_2	Bazylko et al. (2014)
Opuntia ficus indica f. *inermis*	Flowers	50% methanol	DPPH, FRAP total antioxidant, linoleic acid peroxidation, levels of CAT, SOD, lipid peroxidation	Alimi et al. (2011)
Tagetes erecta L.	Flowers	1% HCL in methanol	DPPH, FRAP total antioxidant	Siriamornpun et al. (2012)
Alpinia zerumbet (Pers.) B. L. Burtt. and R. M. Sm.	Flowers	Ethyl acetate	DPPH, β-carotene antioxidant assay	Elzaawely et al. (2007)
	Seeds			
Melastoma malabathricum L.	Flowers	Hexane, ethyl acetate, methanol	DPPH	Susanti et al. (2007)
Nelumbo nucifera	Seeds	50% ethanol	DPPH, $NO^{\bullet}$, levels of CAT, SOD, lipid peroxidation	Rai et al. (2006)
Macrotyloma uniflorum (Lam.) Verdc	Seeds	Methanol, 70% acetone	DPPH, $ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $^{\bullet}OH$, FRAP total antioxidant, linoleic acid antioxidant assay	Siddhuraju and Manian (2007)

Vigna unguiculata (L.) Walp.	Seeds	70% acetone	DPPH, $ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $^{\bullet}OH$, FRAP total antioxidant, β-carotene/linoleic acid antioxidant assay	Siddhuraju and Becker (2007)
Vigna aconitifolia (Jacq.)	Seeds	70% acetone	DPPH, $ABTS^{\bullet+}$, $^{\bullet}O_2^-$, $^{\bullet}OH$, FRAP total antioxidant, linoleic acid antioxidant assay, iron chelation	Siddhuraju (2006)
Piper cubeba L.	Seeds	98% methanol	DPPH, FTC, TBA, total antioxidant	Aqil et al. (2006)
Coriandrum sativum L.	Fruits	80% methanol	DPPH, FRAP total antioxidant	Guleria et al. (2013a)
	Leaves	95% ethanol	Reducing power	Sharma and Shrivastava (2013)
Celastrus paniculatus Willd.	Seeds	80% methanol	DPPH, FRAP total antioxidant	Guleria et al. (2013a)
		Petroleum ether, ethyl acetate, methanol, water	DPPH, $NO^{\bullet}$, phosphomolybdate assay, cupric reducing antioxidant capacity, reducing power	Zohera et al. (2010)
Ammi visnaga	Fruits	Ethanol, water	DPPH, iron chelation	Hilmi et al. (2014)
Nigella sativa	Seeds	Hexane, chloroform, ethyl acetate, methanol, water	DPPH, $^{\bullet}OH$, iron chelation, β-carotene antioxidant assay	Meziti et al. (2012)
		Ethanol, water	DPPH, iron chelation	Hilmi et al. (2014)
Citrullus lanatus	Seeds	Hexane, chloroform, ethanol	DPPH, $NO^{\bullet}$, H_2O_2, reducing power	Rahman et al. (2013)
Tribulus terrestris	Fruits	Hexane, water	DPPH, $^{\bullet}O_2^-$, $NO^{\bullet}$, FRAP total antioxidant, iron chelation	Bhat et al. (2012)
Citrullus colocynthis (L) Schrad.	Fruits	Methanol	DPPH, $^{\bullet}O_2^-$, H_2O_2, $^{\bullet}OH$, $NO^{\bullet}$	Kumar et al. (2008)



2.6 Conclusions

The Indian subcontinent is one of the richest ecosystems in the world with a great variety of plant species with antioxidant compounds of known and unknown nature. There has been growing interest in medicines derived from plants because of their minimal or no toxicity, negligible side-effects, ease of incorporation in the health system due to their biological origins, ease of procurement and low manufacturing and trading costs. Despite enormous interest in the therapeutic uses of medicinal plants, scientists face obstacles related to their identification, medical effectiveness, therapeutic dosage, toxicity, standardization and regulation.

The urge to discover novel plant compounds with antioxidant activity for healthcare and disease prevention is now an essential ingredient of contemporary pharmaceutical research. With rapidly growing demand for medicinal plants, a reasoned and sustainable exploitation of the flora in nature is more than important to apply. Indeed, the rapid loss of forests and restricted opportunities in botany and medicinal chemistry in university curricula will be limiting factors in the search for plant-based therapeutics that can offer promise for prevention and treatment of chronic diseases. A thorough characterization of bioactive plant compounds is essential for their acceptance into mainstream medicinal practice. Identification of phytocompounds (Fig. 2.3) provides unlimited opportunities for alternative and new preventive healthcare and therapeutic strategies against NCDs.

Fig. 2.3 Standardization flowchart from extraction to identification of bioactive phytocompounds. (*1*) Plants are chosen either randomly based on literature reports or after consultation with local healers and then followed by botanical identification. (*2*) Collected plant material is ground to optimize the solvent contact during the extraction process. Weight standardization is necessary (i.e. 100 g of plant material to 1000 ml of solvent). The primary extraction methods are variable, but the goal is to investigate reports of popular use and apply similar extraction methods. (*3*) After extraction, the volume is concentrated by lyophilization or using another concentration technique before screening. Lyophilization produces ground powder which is then resuspended in water for initial screening to confirm bioactivity, if present. (*4*) Due to the complex composition of the extract, primary separation can be used to facilitate the identification process. Micromolecules can be separated from macromolecules (proteins and carbohydrates) from the supernatant and precipitate phases obtained (*5*). The antioxidant screening by evaluation of free radical scavenging activities is the most efficient and inexpensive assay to identify initial bioactivity. (*6*) Bio-guided chromatography techniques such as bioautography preceded by solvent separation are essential to initiate the bioactive phytocompound identification process; fraction collection with high-performance liquid chromatography (HPLC) or fast protein liquid chromatography (FPLC) assays and preparative thin-layer chromatography (TLC) are also valid techniques. Bio-guided fraction and purification confirm previous results and lead to isolation of a bioactive phytocompound. (*7*) By using TLC assays, retention factor (Rf) values can be determined and the polarity or even chemical groups (by using specific dyes) elucidated. (*8*) Nuclear magnetic resonance (NMR), HPLC/mass spectrometry (MS) and gas chromatography/mass spectrometry (GC/MS) are used to identify bioactive phytocompounds

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