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REVIEW ARTICLE

Antioxidant potential of medicinal plants

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Abstract
Medicinal plants are used for health care either directly or indirectly as they are rich source of several ingredients. Ethnomedical traditions prove that they have a great therapeutic value and are important bioresources. Phytochemicals are naturally occurring compounds having immense antioxidant potential and are of great interest in securing health benefits of consumers. Each portion of the plant has its own medicinal properties possessing different types of secondary metabolites which plays important role in treatment of different types of diseases and for manufacturing of drugs. The phytopharmaceutical preparations should be safely assessed and well established before their usage. In spite of medicinal uses, phytochemicals have also been used in cosmetics, fragrance and as food supplements. Global research is recently focusing on search of new medicines or active compounds with proven significant scientific output. This review focusses on the metabolic fingerprint and biological properties of various plants which play a major role in antioxidant activity along with their mechanisms of action.

Keywords Medicinal plants · Secondary metabolites · Phytochemicals · Antioxidant activity · Mode of action

Introduction

Importance of medicinal plants and their application in healthcare

Medicinal plants have amazing health benefits as they are natural healers and are used for healthcare in both developed and developing countries. Herbal medicine is traditionally known to be harmless and is generally used for long-standing diseases. A number of drugs of plant origin are included in modern pharmacotherapy (Welz et al. 2018). The preventive role of medicinal plants is known since prehistoric period and that information has been passed over generations within human communities (Inoue et al. 2019). Texts of Ayurveda, Sidda, homeopathy and Unani guided medical practitioners and made them experts in treating patients using medicinal herbs. Richness in bio-diversity of Indian flora was well recognized all over the world which helped in documentation of natural resources in the form of books, treaties and research papers etc. It is very interesting to know that even in 21st century, 70% of the population in villages use herbal therapy for health problems and Ayurvedic system is still proving itself to the needy people. Drug authentication is done by experts after studying each component of herbal medicine critically to raise Ayurvedic system of medicine to world standard. Tribal people were well acquainted with wild plants and their healing properties (Logesh et al. 2017). These properties were well studied by urban scholars for chronic disease treatment which reveals the invaluable knowledge of medicinal herbs. The chief criterion for any medicine is safety, quality, and effectiveness. The synergistic effects of herbal medicine contribute to greater potential in curing diseases compared to synthetic drugs (Farooq and Ngaini 2021). Herbs are easily absorbed by our body as they are natural and get assimilated quickly without any side-effects. Synthetic drug assimilation by our body is not complete and remnants of them lead to harmful interactions causing various side-effects such as allergic reactions. Plants adapt to many physical and physiological defense mechanisms by production of secondary metabolites

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such as environmental stress, stress against pathogens etc. Until the 18th century, method of treatment using therapeutic properties of many plants and their effect on the human organism was known but the active compound responsible for cure was unknown (Salmerón-Manzano and Manzano-Agugliaro 2020). Researchers recognized the importance of exact identification of medicinal plants based on morphological characters for proper diagnosis. Advances in instrumental technology helps in identification and quantification of chemical components and in easy detection of adulterants (Fitzgerald et al. 2020). Contribution of technological development in various fields of science helped in acquiring valuable knowledge for treatment of various diseases using medicinal plants to lead a healthy life. Advanced tools and analytical techniques of biotechnology and other plant sciences help in extraction of these active principles for use in modern medicine (Krishnananda et al. 2017). Secondary metabolites are much diversified low molecular weight compounds having wide range of biological properties which interact with proteins, nucleic acids and various biomembranes and are main targets of cells which were active and volatile (Wink 2015). They are metabolic intermediates of plant metabolism which are plant constituents having specific functions responsible for medicinal properties of a plant (Kabera et al. 2014). Various environment stress factors contribute for expression of these secondary metabolites and researchers are now focusing on enhancement and upregulation (Kennedy and Wightman 2011) of these pharmaceutically important compounds as the active constituents present in them are very effective and should be standardized (Raja and Sreenivasulu 2015).

Role of plants in anti-oxidant activity

Numerous medicinal plants are widely used in Ayurveda for reducing the action of aging and supplementary disorders associated with them. Rasayana is a unique branch of Ayurveda where aging procedure is optimized by homeostasis mechanism (Scartezzeni and Speroni 2000). This is possible because of the phytochemicals which are present in plants. Plants manufacture considerable amount of diverse anti-oxidants during biotic and abiotic stress conditions (Bailey et al. 2005). They include a variety of secondary metabolites which are natural antioxidants and avoid oxidative stress caused by reactive oxygen species, helping the plant in free radical scavenging activity. This shields plant cell from cell damage and cellular oxidation. In human beings, strong anti-oxidant nature of plants proved to have a positive effect when taken as diet or as medicine preventing cancer and ageing processes (Tan et al. 2018). Researchers are now focusing on natural anti-oxidants in contrast to synthetic anti-oxidants as they are more efficient than synthetic antioxidants (Rice-Evans et al. 1996; Anwar et al. 2018). India has huge diversity of plants where phytotherapy is involved in using active components of plants or plant extracts. The molecule which hampers oxidation of supplementary molecules is known as anti-oxidant. A chemical response which damages cells by chain reactions produced by free radicals is known as oxidation. Oxidative metabolism forms many byproducts called reactive oxygen intermediates. They are highly reactive and form free radicals through chain reaction. Cells are in high risk of oxidative stress caused by these free radicals causing even neurodegenerative diseases and cardiovascular diseases (Kasote et al. 2013) as they affect biomolecules such as proteins, lipids and even DNA (Kasote et al. 2015; Sharifi-Rad et al. 2020). Anti-oxidants scavenge these free radicals protecting body from oxidative stress. Human body also has capable defense machinery against free radicals but disfunction of cellular organelles lead to production of free radicles (Schrader and Fahimi 2006). Hence there is a need to maintain free radicals in the body at a minimum level by constantly taking dietary antioxidants. A wide variety of anti-oxidants naturally occur in nature which differ in composition and properties such as enzymes, vitamins, minerals etc. (Gupta and Sharma 2006). Antioxidant activity is not restricted to specific plant part or specific families. Oxidative stress is caused by low levels of antioxidants or antioxidant enzymes which damage cell structure and function thereby causing many human diseases, including cancers. Natural antioxidants present in fruits, vegetables and plants decrease the effects of ageing and promote health. A range of oxidative stress, leading cause of degenerative diseases may be prevented using these plant extracts. Innovative and effective natural antioxidants developed by researchers help in advancement of pharmaceutical industries (Atanasov et al. 2021).

Mechanisms of anti-oxidant action

Medicinal plants gained recognition in research of present times as they protect human body from damage of free radicals obtained by various oxidative stress factors (Fig. 1). Medicinal plants contain blend of chemical compounds which may operate singly or in combination to heal diseases and for improving health as they are a good source of anti-oxidants (Bhatt et al. 2013). Fruits of *Phyllanthus acidus* were found to have antibacterial, cytotoxic and anti-oxidant properties using methanol as solvent. This was due to wide range of compounds such as glycoside, tannin and resins which were pharmaceutically important (Habib et al. 2011). Leaves of *Syzygium caryophyllatum* has been evaluated for anticancer, antioxidant and antimicrobial action for its possible use in pharma industry (Annadurai et al. 2012). Anti-Inflammatory, antioxidant and antimicrobial activities of *Phyllanthus niruri, Ocimum sanctum*, and *Cadaba fruticosa* have been evaluated in methanol, ethanol and

Fig. 1 Root causes of oxidative stress (Na thalie et al. 2014)

aqueous solvents. GC–MS analysis in these plants revealed many compounds such as squalene, octadecenoic acids, farnesol, geranylgeraniol etc. which can be used for novel drug discovery (Saha et al. 2015). Lignans of *Phyllanthus niruri* were pharmacologically analyzed and were found to be a potential source of anti-hyper uricemic agents (Vikneswaran 2008). In vitro and in vivo grown plants of *Phyllanthus niruri* were analyzed for antioxidant and antimicrobial activity using various solvents. Methanolic extract of in vitro developed plants exhibited highest antioxidant and antimicrobial activity and this technology can be used for development of quality medicine (Bharat and Kothari 2011). Methanol and chloroform extracts of *Phyllanthus niruri* were used for evaluating antioxidant potential by isolating flavonoids using various assays such as DPPH free radical scavenging assay, β-carotene assay, Xanthine oxidase inhibition and Superoxide anions scavenging activity. Finally, this herb was found to be a good source of natural antioxidants, which can be used in food and pharmaceutical industries (Ahmeda et al. 2009). Phenolic content of plants was correlated with their antioxidant activity assayed by DPPH method, ABTS method, reducing power method and lipid peroxidation assays. The results proved that there is an increase in antioxidant activity with increase in phenolic compounds such as ferulic acid and caffeic acid. This was proved by Chinese herbal system of medicine (Li et al. 2009). Ten medicinal plants were compared for their phytochemical constituents, which are responsible for antioxidant activity by DPPH free radical scavenging method. These plants were used in traditional medicine and were identified as hepatoprotective plants (Vivek Kumar et al. 2011). Phytochemicals were analyzed for in vitro and in vivo antioxidant potential and the limitations of antioxidant measurements along with their applications were identified for future research on plant antioxidants. In vivo results were influenced by many factors such as metabolism, gut absorption and bioavailability thus differing in in vitro action (Kasote et al. 2015). The reaction mechanisms of medicinal plants, which act as natural antioxidants for free radical scavenging activity were evaluated by various assays, which help in expansion of novel antioxidants (Nimse and Pal 2015). Six Indian medicinal plants which are used in traditional medicine having high antioxidant potential are reviewed by Katiyar et al. (2013). Plants and animals contain large amounts of antioxidants counteracting cell damage and repairing damaged cells (Haleem et al. 2008). *P. amarus* in leaf extract revealed the presence of Fumaric acid which possess exceptional antioxidant properties and compound 1-Heptacosanol was reported to have anti-microbial, anti-oxidant and nematicidal properties in some marine algae (Sravanthi et al., 2016a, b, c, d). In-Silico Docking analysis was done *in Phyllanthus amarus* plant for recognition of antioxidant compounds viz. Fumaric acid, 1-Heptacosanol using AutoDock tools (Sravanthi et al. 2017). *Phyllanthus amarus* have powerful antioxidant property which is evident from the study in which phyllanthin evident by its low IC50 value (Sravanthi et al. 2016a, b, c, d). IC 50 value in *Phyllanthus amarus* leaf extracts are lower than stem and root extracts which indicates the high potentiality of leaf compared to root and stem in its anti-oxidant properties which may be due to the presence of phenols and flavonoids (Sravanthi et al., 2016a, b, c, d). Ethanolic leaf extra of *P. amarus* found to exhibit 3,5-di-t-butyl phenol have antioxidant properties (Sravanthi et al. 2016a, b, c, d).

There were reports that anti-proliferative activity is always coupled with antioxidant activity (Sravanthi and Giri 2021a, b). Phytol, which is a diterpene compound, is

reported to have antioxidant and anticancer properties in ethanolic leaf extract of *Cyperus rotundus* (Sravanthi and Giri 2021a, b). An Isoprenoid compound named Squalene and 5-Hydroxymethyl furfural were found to exhibit antioxidant and anticancer properties in methanolic leaf extract of *Eupatorium triplinerve* (Sravanthi and Giri 2021a, b). Tetradecanoic acid, which is a myristic acid, is found to have antioxidant and anticancer properties in ethanol extract of bark of *Hugonia mystax* and in ethanolic leaf extracts of *Hyptis lanceolata* Poir. (Sravanthi and Giri 2021a, b). The presence of polyphenolics, genistein and other phytoestrogens were regarded as promising source of bioactive antioxidant compounds, which have been demonstrated for in vitro UV-radiation-induced oxidative damage to DNA in *Trifolium pretense* for therapeutic purposes (Anil Kumar et al., 2017). Most of the flavonoids were found to exhibit antioxidant, anti-inflammatory and antitumor activities (Sravanthi and Giri 2021a, b). Chloroform extracts of *Monochaetia kansensis,* a fungus reported presence of Hexadecane, a compound with proven anti-oxidant and antibacterial activities (Yogeswari et al. 2012).

Dietary anti-oxidants are important for maintenance of good health by removal of free radicals (Fig. 2). This is possible by various mechanisms such as (Lu et al. 2010):

- Chelation of metal ions.
- Inhibition of free radical generating enzymes.
- Activation of internal anti-oxidant enzymes.
- Prevention of lipid peroxidation by maintaining structure and function of cell membranes.
- Prevention of DNA damage.
- Prevention of protein modification.

Antioxidant defense system in plants

Plants deal with oxidative stress with an endogenous defense mechanism. Various enzymes viz. superoxide dismutase, catalase, glutathione reductase, ascorbate peroxidase, glutathione S transferase and many more are involved in the process. Nonenzymatic antioxidants are Ascorbic acid, Glutathione, phenolics, alkaloids, flavonoids, carotenoids and non-protein amino acids.

Nonenzymatic antioxidants

Ascorbate plays a significant role in AsA-GSH (Asada—Halliwell) cycle, the major antioxidant defense pathway to detoxify H_2O_2. It scavenges ROS by its capacity to donate electrons and remain stable due to electron delocalization. GSH, plays a significant role in the regulation of AsA-GSH cycle towards scavenging cellular ROS and maintaining redox homeostasis. Carotenoids scavenge harmful free radicals, and protect light-harvesting complex proteins and are also responsible for thylakoid membrane stability. Flavonoids, flavones and flavanols scavenge free radicals and reduce cell damage from lipid peroxidation. Phenolic

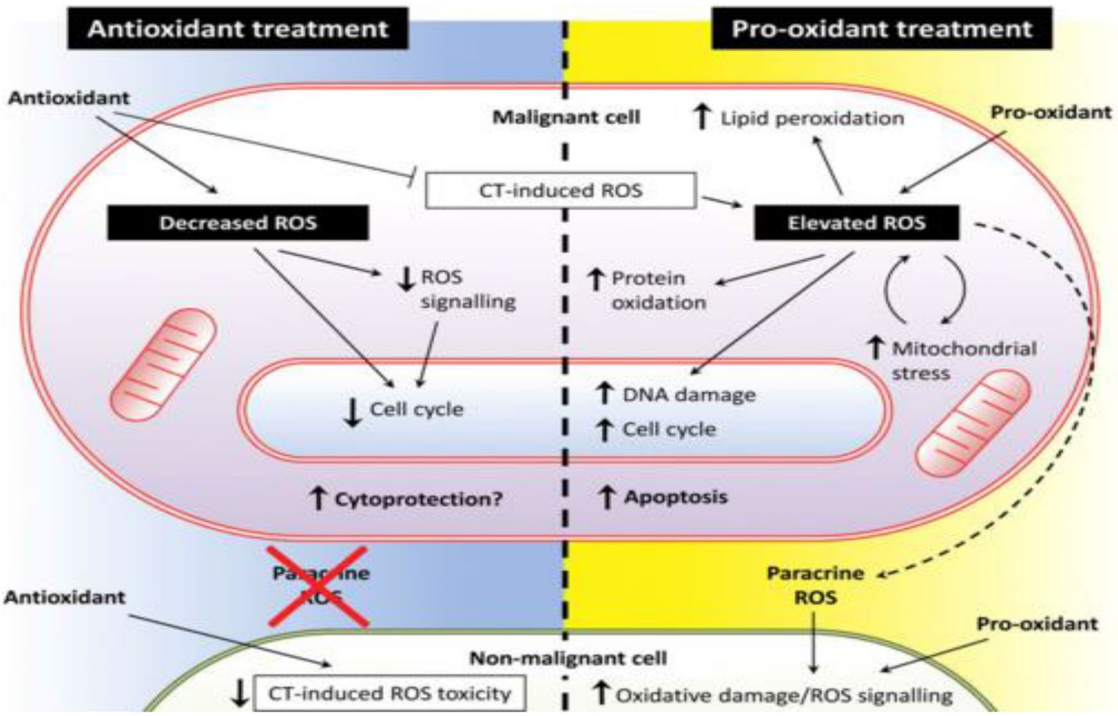

Fig. 2 Diagrammatic representation of a cell before and after anti-oxidant treatment (Paul spencer Hole et al. 2011)

compounds viz. hydroxybenzoic and hydroxycinnamic acids, act as chelators and scavengers of free radicals. Alkaloids are free radical scavengers and inhibitors of H_2O_2-induced oxidation (Hasanuzzaman et al. 2019, 2020).

Antioxidant enzymes

Superoxide dismutase (SOD) a leading antioxidant enzyme exerts its activity by dismutating free oxygen radical into H_2O_2 and reducing the possibility of hydroxyl ion formation (Gill et al. 2015). Catalase converts H_2O_2 molecules into H_2O. Peroxidase oxidizes Phenoxyl hydroxide for producing phenoxyl radical. The peroxiredoxins are thiol-dependent enzymes (GSH or any other thiol), play a vital role in ROS regulation owing to their capability to reduce various organic and inorganic peroxides. Various types of reactive oxygen species were represented in Fig. 3.

The antioxidant defense system and ROS accumulation in plant cells holds a steady state balance. An optimum ROS level maintenance in cells leads to crucial redox biology reactions and regulation of plant growth and developmental process. This homeostasis is maintained by the ROS production and scavenging balance. During stress conditions high levels of ROS production demolishes the equilibrium and causes programmed cell death. ROS also plays a crucial role as a signaling molecule responsible for signal transport to the nucleus by MAPK (mitogen-activated protein kinase) pathway through redox reaction (transfer of electrons between donor and acceptor) during abiotic stress conditions.

Redox homeostasis keeps a balance with the help of antioxidant enzymes and nonenzymatic antioxidants. Redox signaling is an equilibrium between low levels of ROS (which functions as a signal to activate signaling cascade to maintain normal plant functions and high level of ROS (that causes oxidative cellular damage). A stable balance between ROS generation and scavenging is synchronized by cellular redox sensitive compounds. Antioxidants are responsible for scavenging ROS or control its production. This system consists of non-enzymatic antioxidants and oxidant enzymes. Both work in a harmonized manner to control overproduction of ROS (Decros et al. 2019; Hasanuzzaman et al. 2020).

Excellent anti-oxidant activity has been exhibited by compounds namely amariin, phyllanthusiin D and repandusinic acid belonging to ellagitannins group isolated from *P. amarus* (Meena et al. 2017). Aqueous extract of *P. amarus* has been evaluated for its anti-oxidant, anti-hyperglycemic and hypolipidemic activities using diabetic rats induced by streptozotocin. The activities of anti-oxidant enzymes viz. glutathione reductase, glutathione peroxidase and glutathione-S-transferase were increased in normal rats treated with plant extracts helping in scavenging of reactive oxygen species. It was reported that this plant is used for herbal treatment for curing diabetes and renal oxidative stress (Karuna et al. 2011). When ethanolic leaf extracts of *P. amarus* were injected to mice, the defensive capacity was proven to be increased as the chemical constituents of this plant have antioxidant properties (Akporowhe and Onyesom 2016). When whole plant of *P. amarus* was estimated for total phenolic content and antioxidant activity using various solvents, it was found that methanolic plant extract exhibited

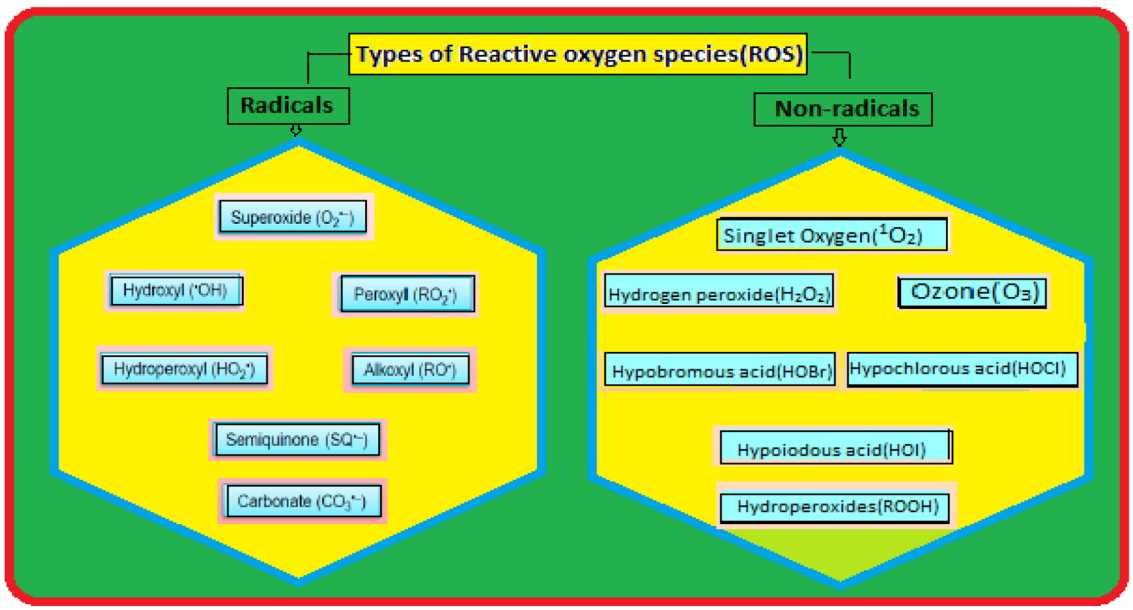

Fig. 3 Types of reactive oxygen species

good antioxidant activity due to high phenolic content (Sen and Batra 2013).

There was a report on antioxidant activity of leaf extracts of *Pimpinella tirupatiensis* which were evaluated by DPPH (1, 1-diphenyl-2-picryl-hydrazyl), FRAP (Ferric Reducing Ability of Plasma), Nitric oxide scavenging, and Reducing power assays where there was a correlation of phenol and flavonoid content with antioxidant activity (Ranjit et al. 2016). Similar type of studies have been reported in *Torilis leptophylla*, where cytoprotective activity has been studied in vitro and in vivo to find novel antioxidants for development of food and pharmaceutical industries (Saeed et al. 2012). Veeru et al., (2009), screened various medicinal plants for their antioxidant activity using ascorbic acid as standard for knowing their beneficial effects in drug formulation.

P. amarus was found to be resistant against Ultra violet–B radiations as there was an increase in anti-oxidant levels on exposure to UV-B radiation. But the growth and biochemical effects were found to be decreased due to the damage that is caused by UV-B radiation. This oxidative injury was overcome by induction of anti-oxidant enzymes and UV-B absorbing compounds which help in recovery of seedlings of *P. amarus* from growth and developmental defects (Indrajith and Ravindran 2009). Aqueous extract of *P. amarus* was analyzed for antioxidant potential in rats. Rats which consumed this aqueous extract exhibited decrease in plasma lipid peroxidation, increase in plasma glutathione and increase in anti-oxidant enzymes such as catalase and superoxide dismutase, which reduces the risk of oxidative stress (Karuna et al. 2009). *P. amarus* extracts decrease muscle damage by decreasing the oxidative stress caused by high intensity exercises, which helps in reducing muscle pain and this phenomenon, helps sportsmen in keeping their body fit (Roengrit et al. 2014).

Flavonoids in plants are found to protect DNA from damage by chelation of metal ions such as copper or iron and carotenoid compounds of plants are found to protect cell membranes by prevention of lipid peroxidation (Nimse and Pal 2015). Secondary metabolites such as flavonoids and lignans proved to exhibit exogenous antioxidant activity which increases endogenous defense mechanisms of the body (Kasote et al. 2015). In vitro methods for estimation of antioxidant potential does not give predictable therapeutic effects under in in vivo conditions as antioxidants are dependent on numerous physiological metabolisms such as absorption, storage and excretion before they exhibit therapeutic effect. Hence more strategies should be developed for setting up in vitro and in vivo conditions before antioxidants are attributed to specific therapeutic effect. Most extensively used techniques for in vitro anti-oxidant evaluation are by DPPH (2, 2-Diphenyl-1-picrylhydrazyl) and NOS (nitric oxide scavenging) methods. Research is in continuous progress to identify potential anti-oxidant compounds with little side-effects. Medicinal plants contain compounds like phenols, flavonoids, and tannins which act as natural antioxidants and help in disease protection. As there is a thirst for novel natural anti-oxidants of plant origin, presence of high level of anti-oxidants in medicinal plants provide enormous scope for their application as pharmaceuticals products. Medicinal plants possessing anti-microbial, antioxidant, and anti-cancer properties are listed in Table 1.

Antioxidant potential of medicinal plant in food industry

Fruits and vegetables provide a rich source of antioxidants. Extraction of natural antioxidants from natural resources is vital for good health. Hence efficient technologies with less processing time and production cost which require less material consumption such as green technologies have emerged for efficient extraction of antioxidants from fruits and vegetables. Enzymatic cocktails or pulsed electric field usage in technology are showing prominent results for sustainable development in recent days as they are potential in extraction of antioxidants not only from edible parts but also from non-edible parts of fruits and vegetables which is a favorable aspect for inclusion in diet thereby contributing good health globally (Arias et al. 2022).

Tool and technics used for antioxidant extraction from medicinal plants and their use in pharmaceutical industry

Plant extracts are treasured sources of bioactive compounds which are used as functional products in food and pharma industries for prevention and treatment of various diseases**.** Presence of high content of tannins, phenolic acids, flavonoids, different types of phenolic compounds contribute to their high antioxidant potential for promoting human health and can be used for development of novel food-pharma ingredients for improving bio-valorization and environment (Manyou et al. 2021). Raw material movement of bioactive compounds from producer to consumer is shown in Fig. 4.

Extraction of bioactive compounds is very crucial step as inappropriate extraction method selection could change or damage the bioactive compound. Conventional extraction process involves collection of material, washing, drying and grinding. Solvent extraction involves maceration, soxhlet, and hydrodistillation (Zhang et al. 2018).

Aqueous-extraction methods are favorable as water is a cheap source. Compound extraction is high when heated but bioactive compounds are generally sensitive to heat (Lee et al. 2019). Hence extraction at low temperature under pressurized extraction mechanisms help to increase extraction efficiency (Masota et al. 2020).

Table 1 List of medicinal plants possessing anti-oxidant properties

S.No	Name of the plant	Family	Phytochemicals	Anti-oxidant	References
1	*Abelmoschus moschatus*	Malvaceae	Phenols and flavonoids	DPPH, hydrogen peroxide scavenging activity and ferrous reducing antioxidant property (FRAP) method	Gul et al. (2011)
2	*Acacia pennivenia*	Mimosaceae	Saponins and tannins	DPPH radical scavenging assay	Mothana et al. (2009)
3	*Acanthospermum hispidum*	Asteraceae	Sesquiterpene lactones	DPPH radical scavenging assay	Mothana et al. (2009)
4	*Acridocarpus socotranus*	Malpighiaceae	Flavonoids, terpenoids	DPPH radical scavenging assay	Mothana et al. (2009)
5	*Aloe perryi*	Aloaceae	Anthraquinones, flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
6	*Anthemis palestina*	Asteraceae	Phenols and flavonoids α-terpinene, β-terpinene, β-terpinolene, 1,8-cineole, menthone, isomenthone, and citronellal, 1,8-cineole and terpinen-4-ol, thymol and carvacrol, eugenol	DPPH, ferric-reducing antioxidant power and hydroxyl radical scavenging activity	Bardaweel et al. (2014)
7	*Ballochia atro-virgata*	Acanthaceae	Terpenoids	DPPH radical scavenging assay	Mothana et al. (2009)
8	*Bergenia ciliata*	Saxifragaceae	Tannins, alkaloids, saponins, carbohydrates, flavonoids, steroids, phlobatannins, terpenoids, cardiac glycosides tannins, alkaloids, saponins, carbohydrates, flavonoids, steroids, phlobatannins, terpenoids, cardiac glycosides Tannins, alkaloids, saponins, carbohydrates, flavonoids, steroids, phlobatannins, terpenoids and cardiac glycosides	DPPH radical scavenging assay	Ahmed et al. (2016)
9	*Blepharis spiculifolia*	Acanthaceae	Phenolic compounds and terpenoids	DPPH radical scavenging assay	Mothana et al. (2009)
10	*Boswellia dioscoridis*	Burseraceae	Volatile oil, terpenoids and flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
11	*Boswellia socotrana*	Burseraceae	Volatile oil, terpenoids and flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
12	*Capparis cartilaginea*	Capparaceae	Glucosinolates and flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
13	*Cassia siamea*	Fabaceae	Chromone (anhydrobarakol), Chromone alkaloids (barakol, cassiarin A-B), anthraquinones (chrysophanol, emodin), bianthraquinones (cassiamin A-B), flavonoids and phenolics	DPPH radical scavenging assay	Kamagate et al. (2014)
14	*Commiphora ornifolia*	Burseraceae	Volatile oil, terpenoids and flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
15	*Corchorus erodioides*	Tiliaceae	Flavonoids and phenolic compounds	DPPH radical scavenging assay	Mothana et al. (2009)
16	*Crataegus monogyna L*	Rosaceae	Phenols and flavonoids	Reducing power (RP), Ferric-reducing antioxidant power (FRAP) and DPPH radical scavenging activity	Nunesa et al. (2016)
17	*Croton socotranus*	Euphorbiaceae	Flavonoids, terpenoids and tannins	DPPH radical scavenging assay	Mothana et al. (2009)

Table 1 (continued)

S.No	Name of the plant	Family	Phytochemicals	Anti-oxidant	References
18	*Equisetum telmateia L*	Equisetaceae	Phenols and flavonoids	Reducing power (RP), Ferric-reducing antioxidant power (FRAP) and DPPH radical scavenging activity	Nunesa et al. (2016)
19	*Euclea divinorum*	Ebenaceae	Phenolic acids and tannins	DPPH radical scavenging assay	Mothana et al. (2009)
20	*Euphorbia socotrana*	Euphorbiaceae	Terpenoids, flavonoids, steroids and tannins	DPPH radical scavenging assay	Mothana et al. (2009)
21	*Eureiandra balfourii*	Cucurbitaceae	Terpenoids and flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
22	*Ficus cordata*	Moraceae	Tannins and terpenoids	DPPH radical scavenging assay	Mothana et al. (2009)
23	*Ficus deltoidea*	Moraceae	Phenol and 2, 4-bis (dimethylbenzyl)-6-t-butylphenol	DPPH radical scavenging assay	Lee et al., (2011a, b, c)
24	*Garcinia cowa*	*Clusiaceae*	flavonoids, phloroglucinols,Xanthones and triterpene	Potassium, ferricyanide reduction method	Ritthiwigrom et al. (2013)
25	*Geranium purpureum Vil*	Geraniaceae	Phenols and flavonoids Phenols and flavonoids	Reducing power (RP), Ferric-reducing antioxidant power (FRAP) and DPPH radical scavenging activity	Nunesa et al. (2016)
26	*Glossonema revoili*	Asclepiadaceae	Steroids and flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
27	*Helicteres isora*	Sterculiaceae	49-O-b -D-glucopyranosyl rosmarinic acid, 4,49-O-di-b -D-glucopyranosyl rosmarinic acid and 2R-O-(49-O-b -D-glucopyranosyl caffeoyl)-3-(4-hydroxyphenyl), lactic acid named as 49-O-b –D gluco pyranosyl isorinic acid and Rosmarinic acid	DPPH, hydrogen peroxide and nitric oxide radical scavenging assays	Bhakya et al. (2016) and Kumar (2014)
28	*Hibiscus noli-tangere*	Malvaceae	Tannins and lignans	DPPH radical scavenging assay	Mothana et al. (2009)
29	*Hypoestes pubescens*	Acanthaceae	Alkaloids and terpenoids	DPPH radical scavenging assay	Mothana et al. (2009)
30	*Lannea transulta*	Anacardiaceae	Tannins and flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
31	*Lavandula stoechas L. spp. luisieri*	Lamiaceae	Phenols and flavonoids	Reducing power (RP), Ferric-reducing antioxidant power (FRAP) and DPPH radical scavenging activity	Nunesa et al. (2016)
32	*Leucas samhaensis*	Labiatae	Volatile oil, terpenoids and flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
33	*Leucas virgata*	Labiatae	Volatile oil, terpenoids and flavonoids	DPPH radical scavenging assay	Mothana et al. (2009)
34	*Limnophila aromatica*	Scrophulariaceae	Eugenol, γ-terpinene	DPPH radical scavenging assay	Gorai et al. (2014)
35	*Lycium socotranum*	Solanaceae	Alkaloids	DPPH radical scavenging assay	Mothana et al. (2009)
36	*Maerua angolensis*	Capparaceae	Glucosinolates and tannins	DPPH radical scavenging assay	Mothana et al. (2009)
37	*Melissa officinalis*	Lamiaceae	Phenols	DPPH and hydroxyl radical scavenging activities	Brunet et al. (2008)

Table 1 (continued)

S.No	Name of the plant	Family	Phytochemicals	Anti-oxidant	References
38	*Mentha suaveolens Ehrh*	Lamiaceae	Phenols and Flavonoids	Reducing power (RP), Ferric-reducing antioxidant power (FRAP) and DPPH radical scavenging activity	Nunesa et al. (2016)
39	*Michelia champaca*	Magnoliaceae	Alkaloids, saponins, tannins, sterols, flavonoids and triterpenoids	DPPH radical scavenging assay	Lee et al. (2011a, b, c)
40	*Peperomia pellucida*	Piperaceae	Phytol, 2-Naphtalenol, decahydro, Hexadecanoic acid, methyl ester,9,12-Octadecadienoic acid(Z,Z)- and Methyl ester	DPPH radical scavenging assay	Lee et al. (2011a, b, c)
41	*Polygonum odoratum*	*Asparagaceae*	homoisoflavanones, isoflavones, flavone glycoside, triterpenoid aglycon, steroidal sapogenins, steroidal saponins, lignanoids and fatty acids	DPPH radical scavenging assay	Nanasombat and Teckchuen (2009) and Ling-Tong et al. (2015)
42	*Psidium guajava*	Myrtaceae	Tannins, flavonoids (myricetin, quercetin, luteolin and kaempferol), essential oils (caryophyllene, nerolidol, β-bisabolene, aromadendrene, p-selinene, α-pinene and 1,8-cineol), triterpenoids (oleanic acid, ursolic acid, catecolic acid, guayavolic acid, maslinic acid, ellagic acid) and β-sitosterol	DPPH radical scavenging assay	Braga et al. (2014)
43	*Rhus thyrsiflora*	Anacardiaceae	Flavonoids, terpenoids and tannins	DPPH radical scavenging assay	Mothana et al. (2009)
44	*Ruta graveolens*	Rutaceae	Furanocoumarins, carotenoids, furanoquionolones	DPPH radical scavenging assay	Pushpa et al. (2015)
45	*Strychnos lucida*	Loganiaceae	Brucine, brucine N-Oxide, loganic acid, loganin, ligustrinoside, chlorogenic acid, 3,4-di-O-caffeoylquinic acid, β-D-glucoside, syringaresinol 4-O-βpicconioside I, sylvestroside I, vanillic acid 4-O- adenosine and 4-O-(3,5-dimethoxy-4-hydroxybenzoyl) quinic acid	DPPH and superoxide dismutase (SOD) assays	Sarmento et al. (2015)
46	*Swertia chirata*	Gentianaceae	Phenols and Flavonoids	DPPH radical scavenging assay	Naqvi et al. (2013)

Table 1 (continued)

S.No	Name of the plant	Family	Phytochemicals	Anti-oxidant	References
47	*Syzygium caryophyllatum (l)*	Myrtaceae	Flavonoids, phenolic compounds, alkaloids and saponins	DPPH radical scavenging assay	Annadurai et al. (2012) and Raj et al. (2016)
48	*Teucrium socotranum*	Labiatae	Volatile oil and terpenoids	DPPH radical scavenging assay	Mothana et al. (2009)
49	*Tiliacora acuminata*	Menispermaceae	Phenols and Flavonoids alpha.-Tocopherol-beta.-D-mannoside, n-Hexatriacontane and Neophytadiene	DPPH radical scavenging activity, Hydrogen peroxide scavenging activity	Madhuvanthi et al. (2014)
50	*Polycarpaea aurea*	Caryophyllaceae	Phenols and Flavonoids	DPPH and Nitric-Oxide (NO) radical scavenging activity and FRAP assays	Raj and Giri (2021)
51	*Sphagneticola calendulacea* (L.)	Asteraceae	Phenols and flavonoids	Copper ion reducing assay (CUPRAC), DPPH, Nitric-Oxide (NO) ABTS free radical scavenging assay and FRAP assays	Md. Bari et al. (2021)
52	*Globularia alypum* L	Plantaginaceae	Phenols and Flavonoids	DPPH, ABTS and FRAP assays	Asraoui et al. (2021)
53	Elaeagnus umbellata Thunb. (autumn olive)	Elaeagnaceae	Essential oils	DPPH and ABTS radicals	Nazir et al. (2021)
54	*Salvia officinalis*	Lamiaceae	Phenolic acids, flavonoids, Rosmarinic acid	ABTS, DPPH, FRAP assays	Manyou et al. (2021)
55	*Olea europaea*	Oleaceae	Phenylethanoids, especially oleuropein	ABTS, DPPH, FRAP assays	Manyou et al. (2021)
56	*Punica granatum*	Punicaceae	Phenolic acid, flavonoids, tannins particularly ellagitannins, amino acids, alkaloids, phenolic glycosides	ABTS, DPPH, FRAP assays	Manyou et al. (2021)
57	*Mentha piperita*	Lamiaceae	Flavanones, especially eriodictyol glycosides, rutin	ABTS, DPPH, FRAP assays	Manyou et al. (2021)
58	*Petroselinum crispum*	Apiaceae	Apigenin-7-O-apiosylglucoside also called apiin and epicatechin	ABTS, DPPH, FRAP assays	Manyou et al. (2021)
59	*Ruta graveolens*	Rutaceae	Chlorogenic acid, neochlorogenic acid, coumaric acid, Rutin, psoralen, limonene and pinene	ABTS, DPPH, FRAP assays	Manyou et al. (2021)
60	*Rosmarinus officinalis*	Lamiaceae	Tannins, Tyrosol, rosmarinic acid	ABTS, DPPH, FRAP assays	Manyou et al. (2021)
61	*Maesa lanceolata*	Primulaceae	Phenols and Flavonoids	DPPH, FRAP, phosphomolybdenum assays	Ismael et al. (2021)

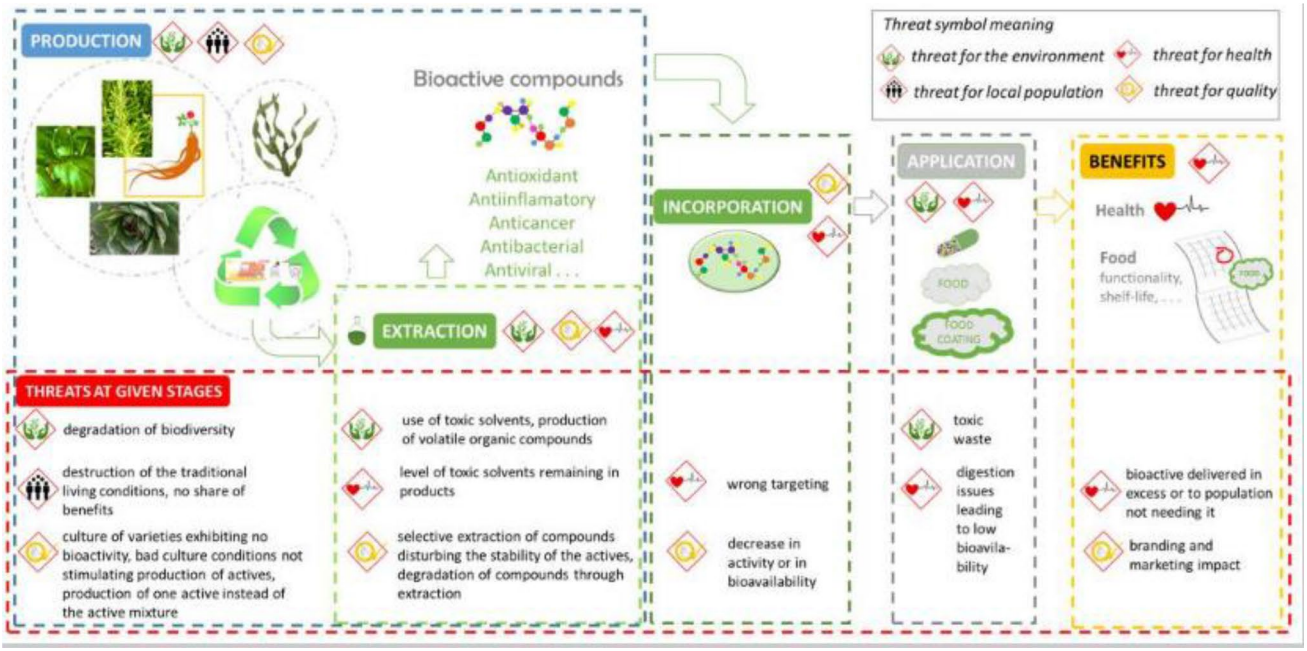

Fig. 4 Flow chart of raw material movement from producer to consumer (Kurek et al. 2022)

Bioactive compounds have a high demand and so various technologies that help in extraction for further encapsulation and delivery for evaluation of product need to be standardized to match ground reality of consumers.

Conclusions

Imbalance and oxidative damage of Reactive oxygen species are the causes for chronic diseases leading to death and disability. Antioxidant phytochemicals are the potential agents to control overproduction of oxidants. These antioxidant phytochemicals should be identified, separated and their molecular mechanisms along with their modes of action that are responsible for pharmacological activity should be further analyzed for understanding their potential in health care or adverse effects if any. Substantial contributions for identifying the novel chemical structures guided by ethnopharmacological knowledge for Natural product research is highly essential for their role in pharmaceutical or food industry.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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