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Archana Bachheti *Editors*

Non-Timber Forest Products

Food, Healthcare and Industrial Applications

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This book is dedicated to our families, institutes, universities, fellow colleagues, and students.

Preface

Forests cover 31% of the world's land surface, provide habitats for animals, livelihoods for humans, and generate household income in rural areas of developing countries. They also supply other essential amenities, for instance, they filter water, control water runoff, protect soil erosion, regulate climate, cycle, store nutrients, and facilitate countless non-timber forest products (NTFPs). The main NTFPs comprise forest-based herbs, grasses, climbers, shrubs, and trees used for food, fodder, fuel, beverages, medicine, animals, birds, and fish for food, fur, and feathers, as well as their products, for instance, honey, lac, silk, paper, and so on. At present, these products play an important role in the daily life and well-being of millions of people worldwide. Hence, forests and their products are valuable and often NTFPs are considered as the 'potential pillars of sustainable forestry'. Additionally, NTFPs' development and promotion are important to reduce the destruction of biodiversity. Income from plant and animal products gathered from forests is generated through local, national, trans-national, and international trade. In fact, NTFPs have been serving human civilization for a long time, and the items like food, herbal drugs, forage, fuel-wood, fountain, fibre, bamboo, rattans, leaves, barks, resins, and gums, have been continuously used and exploited by humans from the forests. NTFPs are known to be particularly important components of household subsistence, especially food consumption. Villagers rank wild foods such as thatch grass, edible orchids, mushrooms, and wild fruits consistently as the most important forest resources. Forest-based foods or products have higher nutritional value than domestic animal or garden foods. Wild plants and animals provide foods with greater nutrient densities than alternative foods imported through market networks in remote mountain areas. It has been noticed that wild edible foods are rich in terms of vitamins, protein, fat, sugars, and minerals, and depending upon their availability they can be used in different seasons throughout the year. Also, forest-based herbs, grasses, climbers, shrubs, and trees have been widely recognized and used as important raw materials for pharmaceutical industries. According to an estimate, globally about 1.5 billion people use or trade NTFPs at local or regional scales, and generally, these trades are invisible to researchers and policy makers. Further, numerous industries-based NTFPs are now being exported in considerable quantities by developing countries. Accordingly, an increasingly evident consequence of this development is the generation of employment opportunities in remote rural areas. So, these points, at the same time, highlight the role of NTFPs in poverty alleviation in different regions of the world.

This book provides the reader with a wide spectrum of information on NTFPs, including important references. The book consists of 18 chapters, and the vast coverage of diverse aspects of the subject reflects well from the table of contents. We hope that this compendium of chapters will be very useful as a reference book for graduate and post-graduate students and researchers in various disciplines of forestry, botany, medical botany, economic botany, ecology, agroforestry, and biology. Additionally, it is useful for scientists, experts, and consultants associated with the forestry sector.

We are highly thankful to all eminent authors who have contributed chapters and provided their valuable time and knowledge for this edited book. We also wish to say thanks to Mr. Eric Stannard, Senior Editor (Botany) at Springer, and all his associates, for their cooperation at every stage of the book production. We shall be happy to receive comments and criticism, if any, from subject experts and general readers of this book.

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Azamal Husen (BSc from Shri Murli Manohar Town Post Graduate College, Ballia, UP, MSc from Hamdard University, New Delhi, and PhD from Forest Research Institute, Dehra Dun, India) is a Foreign Delegate at Wolaita Sodo University, Wolaita, Ethiopia. He has served the University of Gondar, Ethiopia, as a Full Professor of Biology, and also worked as the Coordinator of MSc Programme and the Head, Department of Biology. He was a Visiting Faculty of the Forest Research Institute and Doon College of Agriculture and Forest at Dehra Dun, India. He has more than 20 years of experience in teaching, research, and administration. Dr. Husen specializes in biogenic nanomaterials fabrication and their application, plant response to nanomaterials, plant production and adaptation to harsh environments at physiological, biochemical, and molecular levels, herbal medicine, and clonal propagation and improvement of tree species. He has conducted several research projects sponsored by various funding agencies, including the World Bank, the Indian Council of Agriculture Research (ICAR), the Indian Council of Forest Research Education (ICFRE); and the Japan Bank for International Cooperation (JBIC), etc. He has published over 100 research papers, review articles, and book chapters, edited books of international repute, presented papers in several conferences, and produced over a dozen of manuals and monographs. Husen received four fellowships from India and a recognition award from the University of Gondar, Ethiopia, for excellent teaching, research, and community service. An active organizer of seminars/conferences and an efficient evaluator of research projects and book proposals as he is, Dr. Husen has been on the Editorial board and the panel of reviewers of several reputed journals of Elsevier, Frontiers Media SA, Taylor & Francis, Springer Nature, RSC, Oxford University Press, Sciendo, the Royal Society, CSIRO, PLOS, and John Wiley & Sons. He is included in the advisory board of Cambridge Scholars Publishing, UK. He is a Fellow of the Plantae group of American Society of Plant Biologists, a Member of International Society of Root Research, Asian Council of Science Editors, ISDS, and INPST. Also, he is Editor-in-Chief of *American Journal of Plant Physiology*; and a Series Editor of *Exploring Medicinal Plants* published by Taylor & Francis Group, USA.

Rakesh Kumar Bachheti graduated from the Hemwati Nandan Bahuguna University, Garhwal, India, in 1996. He completed his MSc in Organic Chemistry from Hemwati Nandan Bahuguna University, Garhwal, India, in 1998. He had undergone a one-year Post-Graduate Diploma in Pulp and Paper Technology from Forest Research Institute, Dehradun, in 2001. He obtained his PhD in Organic Chemistry from Kumaun University, Nainital, India, in 2007. He is presently working as an Associate Professor of Organic Chemistry in the Department of Industrial Chemistry at the Addis Ababa Science and Technology University (AASTU) of Ethiopia, where he teaches PhD, graduate, and undergraduate students. Before joining AASTU, Dr. Rakesh was working as Dean Project (Assistant) in Graphic Era University (A grade university by NACC) Dehradun, India. Dr. Rakesh also presented papers in various international (Malaysia, Thailand, and India) and national conferences. He was also a member of various important committees such as the Internal Quality Assurance Cell (IQAC), Antiaging committee. His major research interests include natural product for industrial application, biofuel and bioenergy, green synthesis of nanoparticles, their application and pulp and paper technology. He retains a fundamental love for natural products, which permeates all of his research. He has also successfully advised 30 MSc and 3 PhD students upon completion and countless undergraduates have done research in his laboratory. Dr. Bachheti has over 50 publications dealing with various aspects of natural product chemistry and has 8 book chapters published by Springer, Elsevier, and Nova Publisher. Presently, he is supervising 3 PhD students, 3 Master's students, and also working for 2 research projects funded by AASTU.

Archana (Joshi) Bachheti did her BSc in the year 1997 and MSc in 1999 from HNB Garhwal University. She received her PhD from Forest Research Institute, Dehradun, India, in 2006. She has carried out research projects and consultancy work in the areas of ecorestoration/development of wasteland, physico-chemical properties of *Jatropha curcas* seed oil and their relation with altitudinal variation and has been a Consultant Ecologist to a project funded by a government agency. Dr. Joshi is currently an Associate Professor at Graphic Era University, Dehradun, India. She has also served in many capacities in the academia within India and provided expertise internationally for more than 15 years, where she taught Ecology and Environment, Environmental Science, Freshwater Ecology, Disaster Management, and Bryophytes and Pteridophytes. Her major research interests encompass the broad, interdisciplinary field of plant ecology, with a focus on eco-restoration, green chemistry, especially the synthesis of nanomaterial and medicinal properties of plants. The breadth of her research spans from degraded land ecological amelioration, physical and chemical properties of plant's oil to plant-based nanomaterial. She guided 1 PhD student and at present supervising 3 scholars as well as guided graduate and undergraduate students for their research projects. While it was the fascination with forest biodiversity that captured her interest, it has been her love for the exploration of values of biodiversity and social upliftment through it that has maintained that passion. Dr. Joshi has published more than 40 research articles in international and national journals along with 6 book chapters. She organized several national seminars/conferences at Graphic Era University, India.

Potential Role of Forest-Based Plants in Essential Oil Production: An Approach to Cosmetic and Personal Health Care Applications

Limenew Abate, Archana Bachheti, Rakesh Kumar Bachheti, Azamal Husen, Mesfin Getachew, and D. P. Pandey

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1 Introduction

Essential oils (EOs) are a mixture of different complex molecules. They could be considered as a generic term for the liquid and highly volatile components of plants, with a strong and characteristic odor (Bayala et al. 2014). They are present in plants as secondary metabolites in their flowers, leaves, fruits, buds, seeds, rhizomes, barks, and roots (Borai and Husen 2003; Joshi et al. 2003; Shaaban et al. 2012a, 2012b). *Terpenes thyphimurium* (monoterpenes and sesquiterpenes), aromatic

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compounds (aldehyde, alcohol, phenol, methoxy derivative), and terpenoids (isoprenoids) are the main constituents of EOs (Tongnuanchan and Benjakul 2014).

Rutaceae, Rosaceae, Pinaceae, Myrtaceae, Myristicaceae, Lauraceae, Lamiaceae, Apiaceae, and Asteraceae are some of the very important families rich in EOs (Borai and Husen 2003; Joshi et al. 2003; Andres et al. 2012). Also, different plant species such as *Artemisia rehan*, *Aframomum corrorima*, *Ocimum basilicum*, *Nigella sativa, Piper nigrum*, *Foeniculum vulgare, Trigonella foenum*, *Zingibere officinale*, *Hibiscus sabdariffa* are the main sources of EO (Properzi et al. 2013). EOs from *Rosmarinus officinalis* (rosemary) are very important in cosmetic sprays; the leaf extract of the plant is reported to be used in fragrance preparations at up to 0.5%. The extract of the plant was also used in face powders at up to 0.05% (Fiume et al. 2018). The EO extracts from *Plantago lanceolata* are used in the cosmetic industry by different industries found in European countries (Grigore et al. 2015). Aqueous infusions and stabilized fresh juice from leaves of this plant species are important in cosmetics (Weryszko-Chmielewska et al. 2012). The plant leaves are also used for the manufacturer of lotion, creams, and face masks in the European industry (Grigore et al. 2015). The genus *Eucalyptus* (Myrtaceae), which is indigenous to Australia, is well known and broadly dispersed and planted genera worldwide. It contains almost 900 species; of these 300 species have EOs. The EOs of some *Eucalyptus* species like *Eucalyptus camaldulens*, *Eucalyptus gunnii*, *Eucalyptus citriodora*, and *Eucalyptus globules* are used in cosmetics (Grbović et al. 2010). Eucalyptus oils are usually used in different industrial products such as perfumes, deodorizers, lotion, creams, detergents, and soaps (Zhang et al. 2010). *Mentha* genera, which is found in Lamiaceae family such as *Mentha piperita* and *Mentha spicata*, are cultivated and grow all over the world on a large scale and used for cosmetic products and food for flavoring properties (İscan 2002). Different types of EOs isolated from different plants found in America, such as anise oil from the fruit of *Pimpinella anisum*, bitter-fennel fruit oil from *Foeniculum vulgare*, caraway oil from the fruit of *Carum carvi*, cardamom oil from the seed of *Elettaria cardamomum* cinnamon leaf oil from *Cinnamomum zeylanicum*, clove oil from flower of *Syzygium aromaticum*, coriander oil from the fruit of *Coriandrum sativum*, and lavender oil from flower of *Lavandula angustifolia*, are used as cosmetic industries (Sharifi-Rad et al. 2017).

The EOs derived from the flower of *Rosa damaseena* are used for skin cream, lotion, ointment for beautification, smoothness, and protection from sunburn also EOs is extracted from the flower of *Jasminum grandiflosum* used to prepare skin cream and lotion (Kapoor 2005). EOs such as menthone, limonene, methyl acetate, carvone, menthol, and carvacrol from *Mentha piperita* have been used to treat headaches, itching can relieve different infections of viral, fungal, and bacterial when inhaled or applied in the form of a vapor balm (Ravid et al. 1987). δ-terpineol and γ-terpinene present in EO obtained from the flower of *Origanum vulgare* are used in the nervous system, respiratory tract, and disorders of the gastrointestinal tract (Tanu and Harpreet 2016). Although the cost of EOs is high because of the number of plant material required large, the production of EO has been increasing, since EOs do not possess any side effects and are pure. The need for EO is increasing

(Hyldgaard et al. 2012). EOs are very important as a strong marketing advantage in the promotion and sale of many beauty and personal care products; however, the cost of natural EOs are always higher than those of synthetic oils (Sarkic and Stappen 2018). For instance, the market of EOs in India will be exceeding up to 790 million USD and that of France will be increased up to 8.5% by 2024 (Irshad et al. 2020).

EOs showed different applications in pharmaceutical industries, natural preservatives, and cosmetic products (Dreger and Wielgus 2013). They are used as ecological roles, as healing the plant's wounds, defense by repelling herbivorous animals and protecting against microbial growth (De-Mesquita and Luz 2018). They are also used as medicine and possess a chemopreventive action. Many chemicals, pharmacological, and medical literature suggested that they are used in the treatment of cancer of the liver, lung, skin, and stomach (Palazzolo et al. 2013). Alternatively, EO derived from flowers attract volatile compounds and pollinators, help to attract animal, birds, and bees toward themselves, and is used for ensuring the perpetuation and reproduction of plant species (De-Mesquita and Luz 2018). Insecticidal behavior of many monoterpenoids to the red flour beetle and housefly is another application of EOs (Koul et al. 2008). EOs are important as therapeutic agents in conventional, ethno, and complementary alternative medicines mostly as an antiseptic, antipruritic, anthelmintic, local anesthetic, antispasmodic, anti-inflammatory, and analgesic (Umaru et al. 2019). Generally, EOs have pharmacological, agricultural, food, and cosmetic application (Prakash et al. 2015) (Fig. 1). This chapter aims to provide an overview of the potential role of EOs that are obtained from forest-based and or elsewhere available plant species and its cosmetic and personal health care applications.

2 EOs and their Features

2.1 EOs

EOs are liquid aroma and volatile molecules derived from almost every part of the plant. They are the lifeblood of a plant. It can exist in the veins or sacs, glands, glandular hairs of a plant, tree, or grass (Alamgir 2017). The "oil" is obtained from leaves, roots, fruits, and flowers. To treat several ailments by using aromatherapy, the actual aroma which is obtained from EOs is very important (Ali et al. 2015). EOs are easily evaporated at or above room temperature. The composition of an EO varies based on the geographical location, the species of the extracted plant, extraction technique, and harvesting time (Dima and Dima 2015). The importance of EOs is depending on their sensory, physical, and chemical behavior, which is a characteristic property of oils (Gediya et al. 2011). EOs assists our body to fight against illness and develop the body's natural defenses. EOs are also capable of being antiseptic and balancing the emotion. They are also used by plants as a defense

Fig. 1 Application of essential oils

mechanism from herbivores, insects, and microorganisms (War et al. 2012). Nowadays, there is an increase in the interest of the researchers for those plants that contain anticancer bioactive compounds (Patil et al. 2009).

2.2 *Chemical Composition*

EOs usually consist of lower molecular weight molecules such as aromatic and aliphatic compounds, terpenoids, and terpenes (Gonzalez-Burgos et al. 2011). Ninety percent of the constituent of EOs are monoterpenes, and trance amount aromatic compounds also exist (Bakkali et al. 2008). Sesquiterpenes and monoterpenes have isoprene units and contain oxygenated groups such as aldehyde (sinensal and citronellal), acid, ester (γ-tepinyl acetate, cedryl acetate), phenol, alcohol (α-bisabolol, geraniol), ketones (*p*-vetivone and menthone) or lactone (De-Mesquita and Luz 2018). EOs also contain nonterpenic compounds such as cinnamaldehyde, safrole, and eugenol (Dhifi et al. 2016). The largest group of EOs are terpenoids (96%) (Mohammed et al. 2018). Regarding polarity, EOs can be a complex mixture of nonpolar and polar molecules(Masango 2005). EO provides a characteristic odor, flavor, or scent to an aromatic plant (Benchaar et al. 2008). The characteristic aroma of EOs and biological activity are usually derived from sesquiterpenes, monoterpenes, and oxygenated derivatives of them (Brusotti et al. 2014). Terpenes and terpenoids are accountable for the fragrant, culinary, and medicinal applications of medicinal and aromatic plants (Mohammed et al. 2018). Each EO is made from complex chemical make-up, but they are nearly all comprised of some combination of furocoumarins, coumarins, lactones, oxides, esters, acids, ketones, aldehydes, phenols and alcohols with general classification terpenoids, monoterpenoids, sesquiterpenes, and aromatic compounds (Sharifi-Rad et al. 2017).

2.3 EOs from Different Parts of Plants

Different aromatic or medicinal plants in their special glands or cells contain EOs (Jahan et al. 2015). Different plant species such as *Arternisia rehan*, *Aframomum corrorima*, *Ocimum basilicum*, *Nigella sativa, Piper nigrum*, *Foeniculum vulgare, Trigonella foenum*, *Zingiber officinale*, and *Hibiscus sabdariffa* are the main sources of EOs (Properzi et al. 2013). EOs derived from the flower of *Lavandula angustifolia*, *Salvia rosmarinus*, *Mimosa pudica, Syzygium aromaticum,* and *Dianthus caryophyllus* can be used as a source of Eos, and *Cymbopogon jwarancusa* and *Cymbopogon citratus* species used their leaves to obtain EO. Both stem and leaves of *Cinnamomum verum*, *Verbena bonariensis*, *Pogostemon cablin*, and *Pelargonium graveolens* important for EOs foundations. Barks of *Canella winterana* and *Cassia cinnamon,* wood of *Santalum album,* roots of *(Valeriana officinalis, Chrysopogon zizanioides, Sassafras albidum, and Angelica archangelica*), seeds of *Myristica fragrans, Anethum graveolens, Carum carvi, Coriandrum sativum, and Foeniculum vulgare*, fruits of (*Juniperus communis, Citrus limon, Citrus sinensis, and Citrus bergamia*), and rhizomes of *Curcuma longa, Acorus calamus,* and *Zingiber officinale* are also very important sources of EO (Kumar and Jnanesha 2017). EOs such as isopulegone (30.49%) and menthone (39.55%) are the main components of EOs obtained from *Mentha longifolia* (Reddy 2019). From *Cinnamomum zeylanicum* plant species, EOs like cinnamyl acetate (41.98%) are extracted from its different parts (Jayaprakasha et al. 2000). Similarly, 1,8-cineole (14.97%) and linalool (46.97%) EOs are the main components of *Ocimum basilicum* (Santoro et al. 2007), whereas eugenol (86.02%) EOs is derived from *Cinnamomum verum*. Likewise, EOs obtained from *Pogostemon cablin* have mainly a tricyclic sesquiterpene and patchouli alcohol, also named as patchoulol (32–37%) (Swamy and Sinniah 2015). Thymol (7%) and carvacrol (43%) EOs extracted from the leaves of *Plectranthus* *amboinicus* (Arumugam et al. 2016). (Amaral et al. 2017) evaluated the EOs yield of *Ocotea odorifera* and *Gaetan Vestris* in the Atlantic forest of Minas Gerais State. The result showed that EOs from fresh and dry leaves of *Ocotea odorifera* was 8.40 mL g^{-1} and *Caseariasyl vestris* was 8.7 mL g^{-1}. Some important EO-yielding plant species are illustrated in Fig. 2.

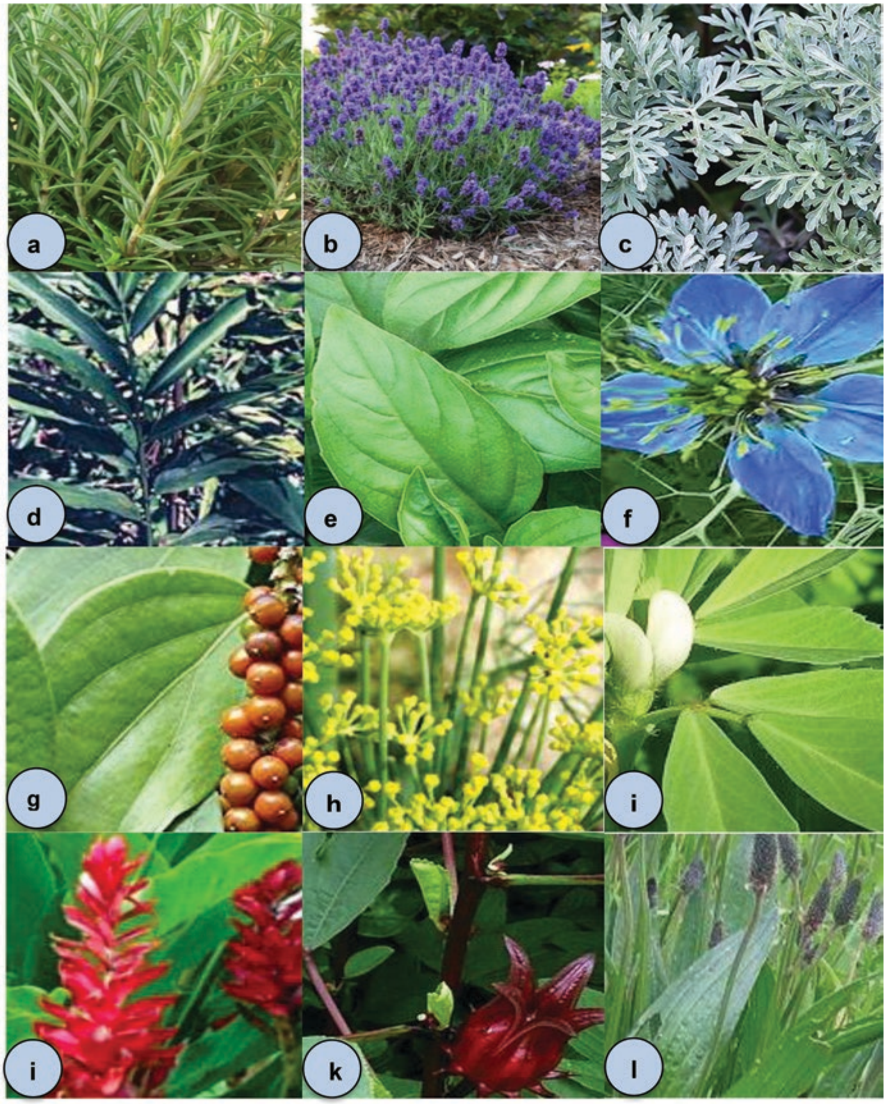

Fig. 2 Different important essential oil yield plants (**a**) *Rosmarinus officinalis*, (**b**) *Lavandula angustifolia,* (**c**) *Arternisia rehan*, (**d**) *Aframomum corrorima*, (**e**) *Ocimum basilicum*, (**f**) *Nigella sativa*, (**g**) *Piper nigrum*, (**h**) *Foeniculum vulgar,* (**i**) *Trigonella foenum*, (**j**) *Zingibere officinale*, (**k**) *Hibiscus sabdariffa,* and (**l**) *Plantago lanceolata*

3 Importance of the EOs in Cosmetics

Currently, EOs are the focus of intensive scientific research and also draw the awareness of pharmaceutical and cosmetic industries because of their possible capacity of natural preservatives or active pharmacological compounds (Dreger and Wielgus 2013). It is estimated that more than 3000 EOs are used in cosmetic and flavor industries which have commercial importance (Bakkali et al. 2008). EOs or components obtained from them are used in natural remedies, additives, food preservers, agriculture, dentistry, sanitary products, perfumes, and makeup products (Salleh et al. 2016). For instance, *d*-carvone, geranyl acetate, or *d*-limonene are utilized in soaps, creams, and perfumes and also used as natural flavoring agents, fragrances for industrial solvents, and as household cleaning products. EOs that were extracted from the flower of *Cymbopogon martini* which contains geraniol, geranyl, acetate, citronellol, and linalool have been used to prepare soap, high-grade perfume, and citronellol, geraniol, nerol, and linalool. EOs from the flower part of *Rosa damascene* is used to synthesize perfume and different cosmetic products, while cineole obtained from the flower of *Cananga odorata* is used to make shampoo soap, perfumes, and detergents (Skaria 2007). Bisabolol EOs is extracted from *Salvia runcinata*, a plant native to South Africa is used in shampoos, fine fragrances, decorative cosmetics, and other toiletries. Also, it is used in non-cosmetic products like detergents and household cleaners as well as in pharmaceutical formulations (Piochon et al. 2009). Linalool is a well-known aromatic compound isolated from aromatic plants and is used widely in perfumes for flavor, cosmetics, and soaps (Dutta et al. 2007). Geraniol (terpene alcohol) is one of the major components of EOs obtained from aromatic plants. *Monarda fistulosa* plant species are known for geraniol EOs with 95% (Chen and Viljoen 2010). It is one of the well-known compounds in the fragrance and flavor industries (Chen and Viljoen 2010). Rose oil, citronella oil, and palmarosa oil are some other examples of plants where geraniol is present naturally. Geraniol has rose-like odor and is usually used in creams, body lotions, perfumes, aftershave lotions, and hygiene products (Sarkic and Stappen 2018). Some of the important chemical compounds found in EOs that are used in cosmetics industries are presented in Fig. 3.

Limonene has an attractive lemon-like smell, which makes it a main important additive of fragrance and flavor. In cosmetics formulation, it is one of the well-known cheap and frequently used fragrances. It can exist in different types of beauty products like shower gels, hair conditioners, shampoos, perfumes, and soaps (Vieira et al. 2018). Linalool is a monoterpene, which is found naturally in more than 200 oils derived from wood, flowers, leaves, and herb (Gershenzon and Dudareva 2007). Linalool is a well-known EO and is isolated from aromatic plants and used widely in perfumes for flavor, cosmetics, and soaps (Dutta et al. 2007). Lavender EOs that are extracted from *Lavandula angustifolia* contains allyl acetate (25–47%), linalool (45%), terpinen-4-ol (8%), camphor (1.5%), limonene (1%), and 1,8-cineole (3%) (Sarkic and Stappen 2018). The oils have shown importance in the cosmetic preparation of hair shampoo and bath salt (Sabara et al. 2009). Besides eucalyptol

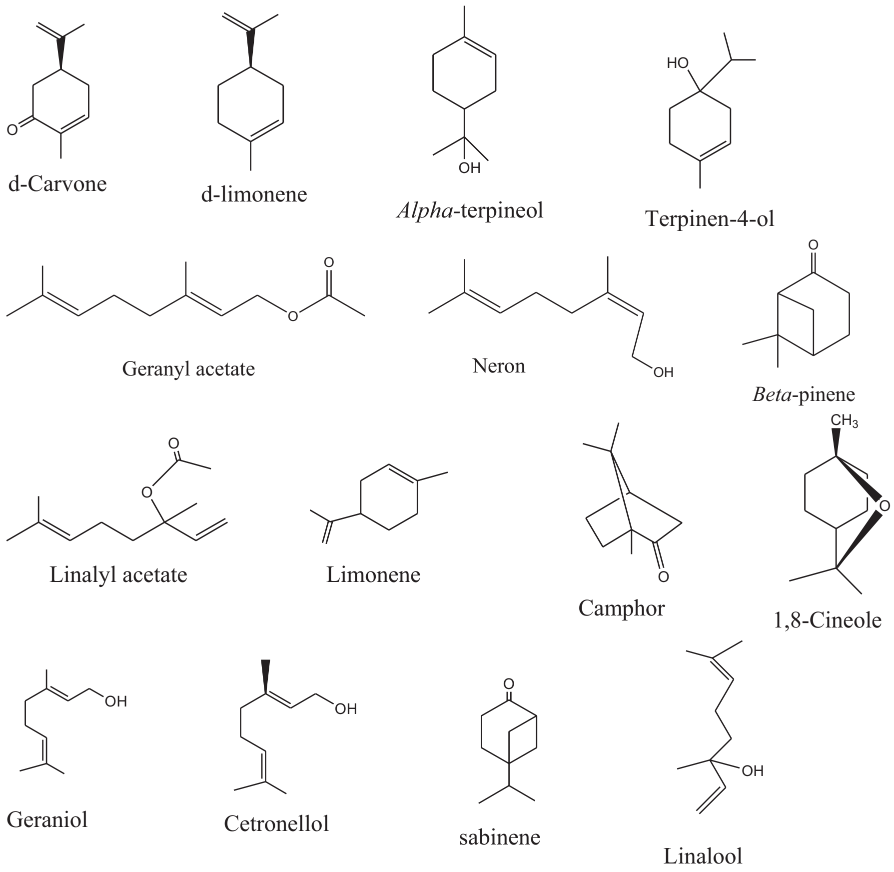

Fig. 3 Some important chemical compounds found in plants as an EOs and are frequently used in cosmetic industries

(19.4%), α-pinene (14.7%), camphor (9.5%), bornyl acetate (9.1%), camphene (6.9%), β-pinene (6.7%), β-myrcene (5.8%), limonene (5.2%), and borneol (5.0%) are the main chemical compounds in rosemary EO and used widely for hair care, as it nourishes the hair, promotes hair growth, and helps against dandruff. It is also recommended in hairloss treatment (Tomi et al. 2016; Sarkic and Stappen 2018). Cosmetic-based industries used EOs mainly because of their famous fragrance behavior. EOs are also added as a fragrance in the natural original product as ingredients. Some of the known fragrance EOs are menthol, linalool, linalool, limonene, geraniol, farnesol, eugenol, neral (citral B), geranial (citral A), carvone, and bisabolol (Sarkic et al. 2018). Overall, they are listed in Table 1.

Table 1 Example of EOs exist in the different classification of cosmetic products

Plant name	Common name	Plant part used	Main phytochemical present	Cosmetic product	References
Aloe vera	True aloe	Leaves	β-carotene, α- tocopherol, and γ-linoleic acid	Cosmetic textiles	Cheng et al. (2008)
Camellia japonica	Camellia	Flower	α-Terpineol, α-terpinolene, α-pinene, β-pinene, α-terpinyl acetate, and spathulenol	Anti-chapping and anti-wrinkling agent	Jung et al. (2007)
Camellia sinensis	Tea plant	Leaves	Terpinen-4-ol, γ-terpinene, and α-terpinene	Perfumes, deodorants, and antiperspirants	Uter et al. (2013)
Citrus aurantium	Sweet orange	Fruits	Nootkatone, α-terpineol, linalool, and limonene	Used in soap and perfume industry	Haj Ammar et al. (2012)
Citrus sinensis	Sweet orange	Fruit	Myrcene, α-pinene, linalool, octanal, and decanal	Soap	Aburjai and Natsheh (2003)
Commiphora myrrh	Myrrh	Sap from stem	α-Cubebene, α-copaene, caryophyllene, β-elemene, epi-β-santalene, δ- and γ-cadinene	Dentifrices and toothpastes	Adwan et al. (2012)
Helichrysum italicum	Immortelle	All green parts of the plant	α-Cedrene, α-curcumene, geranyl acetate, limonene, nerol, neryl acetate, and α-Pinene	Important as a fragrance in perfume, cosmetic, and soaps	Kladar et al. (2015)
Lavandula angustifolia	Lavender	Aerial parts	Linalool, linalyl acetate, geraniol, β-caryophyllene, and lavandulyl acetate	Used as a fragrance ingredient in perfumes, cosmetic and soap, and pharmaceutical	Steflitsch (2013)
Lavandula hybrida	Lavender	Flower	D-Fenchone, α-pinene, and camphor	Cosmetic textiles	Boh and Knez (2006)
Lavandula stoechas	Lavender	Flower	D-Fenchone, α-pinene, and camphor	Sunscreen cream	Lee et al. (2011)
Lavendula, angustifolia	English lavender	Flower	Linalool and geraniol	Soap	Aburjai and Natsheh (2003)

(continued)

Table 1 (continued)

Plant name	Common name	Plant part used	Main phytochemical present	Cosmetic product	References
Lavendula latifolia	Broadleaved lavender	Flower	Linalol, 1,8-cineol, camphor, citronellol, coumarin, eugenol, geraniol, limonene, and linalool	Soap	Aburjai and Natsheh (2003)
Lavendula stoechas	Spanish lavender	Leaves	Lavandulyl acetate, terpinen-4-ol, and lavandulol	Soap	Aburjai and Natsheh (2003)
Matricaria chamomilla	Chamomile	Flower head	Chamazulene and *cis*-β-farnesene	Used as additive of bath, skin oil, and skin creams, shampoos, cosmetics, decorative, toothpastes, and mouthwash-products	Sarkic and Stappen (2018)
Mentha arvensis	Corn mint	Aerial parts	Citral, *z*-citral, geranyl acetate, and *trans*-geraniol	Dentifrices and toothpastes	Adwan et al. (2012)
Mentha piperita	American mint	Leaves	Alcohol and terpene	Dentifrices and toothpastes	Adwan et al. (2012)
Mentha piperita	American mint	Leaves	Alcohol and terpene	Chewing gums, toothpastes, and mouthwashes	Sugiura et al. (2012)
Origanum majorana	Oregano	Aerial *parts*	Sesquiterpene, terpinene, terpineol alcohol, and flavonoids	Sunscreens	Lee et al. (2011)
Pelargonium graveolens	Geranium	Flower	Citronellol, geranyl acetate, limonene, phenyl ethyl alcohol, and linalool	Perfumes, deodorants, and antiperspirants	Uter et al. (2013)
Rosa x. damascene	Damask rose	Flower	Citronellol, phenyl ethanol, geraniol, nerol, farnesol, and stearpoten	Soaps, body lotions, and face creams	De Groot and Schmidt (2016)
Rosmarinus officinalis	Rosemary	Leaves	1,8-Cineole, camphor, and α-pinene	Shampoo	Aburjai and Natsheh (2003)

(continued)

Table 1 (continued)

Plant name	Common name	Plant part used	Main phytochemical present	Cosmetic product	References
Rosmarinus officinalis	Rosemary	Leaves	1,8-Cineole, camphor, and α-pinene	Helps against dandruff, promotes hair growth, nourishes the hair, fragrance in soaps, cologne water, and lavender water	Tomi et al. (2016)
Rosmarinus officinalis	Rosemary	Leaves	1,8-Cineole, camphor, and α-pinene	Repairing (anti-acneagents)	Lee et al. (2011)
Salvia officinalis	Common sage	Leaves	α-Thujone, 1,8-cineole, and camphor, β-thujone, camphene and sesquiterpenes, and α-humulene	Dentifrices and toothpastes	Adwan et al. (2012)
Salvia officinalis	Common sage	Leaves	α-Thujone, 1,8-cineole, and camphor, β-thujone, camphene sesquiterpene, and α-humulene	Cosmetic textiles	Boh and Knez (2006)
Salvia officinalis	Common sage	Flower	α-Thujone, 1,8-cineole, and camphor, β-thujone, camphene sesquiterpene, and α-humulene	Hair growth and stimulants	Aburjai and Natsheh (2003)
Salvia rosmarinus	Rosemary	Leaves	1,8-Cineole, α-pinene, and camphor	Cosmetic textiles	Voncina et al. (2009)
Syzygium aromaticum	Clove	Flower buds	Eugenol, eugenyl acetate, and β-Caryophyllene	Perfumes, deodorants, and antiperspirants	Lee et al. (2011)
Thymus vulgaris	Thyme	Flower	Linalool, borneol, geraniol, sabinene, hydrate, thymol, and carvacrol	Anti-dandruff	Aburjai and Natsheh (2003)
Trigonella foenum	Fenugreek	Seed	*b*-Pinene, 2,5-dimethylpyrazine, 6-methyl-5-hep-ten-2-one, and camphor	Softener/ smoothing (emollients)	Aburjai and Natsheh (2003)

4 Importance of the EOs in Personal Health Care Practices

EOs provide a simple way to provide comfort, promote emotional well-being, and alleviate certain physical symptoms (Allard and Katseres 2016). For over 5000 years, EOs have been used as health-promoting agents for the management of different diseases (Tavares-Dias 2018). EOs plays a key role in treating dermatological issues such as psoriasis, eczema, hives, acne, and rashes. They have an important role to play in the enhancement of immune function by controlling hormones secreted by the adrenal glands, consequently resulting in the alleviation of stress. It also stimulates the production of immune-boosting cells, supporting the lymph to remove toxins, and stimulating the immune response (Bhalla et al. 2013). Sulfur-containing EOs slow down carcinogenesis and change the metabolism of procarcinogen. These EOs can enhance detoxification by increasing the levels of phase II enzymes or by decreasing the levels of some phase I enzymes such as cytochromes P450 (Jana and Mandlekar 2009). α-Terpeniol, camphor, borneol, and 1,8-cineol EOs present rosemary can specifically induce cytochrome P450 (CYP) that can decrease the activity of carcinogens (Bhalla et al. 2013). EO extracted from *Citrus sinensis* contains limonene and perillyl alcohol that help in fighting cancer. Chemical compounds like geranyl, germacrene D, alpha-terpineol, linalyl acetate, and linalool derived from *Salvia sclarea.* EO is very efficient in controlling the level of cortisol in women along with its antimicrobial and also helps in controlling the production of sebum, regulate muscle cramps, eases tension, menstrual periods along with a seductive and aphrodisiac activity (Hanif et al. 2017). Some of the personal health care applications of EOs are listed in Table 2.

5 Conclusion

EOs are a very important part of cosmetics and personal health care. The attractive and pleasant smell of EO increases its use in cosmetic products. EOs obtained from different parts of the plants are used for cosmetic preparation such as shampoo, detergent, toothpaste, soaps, perfumery, skin creams, lotions, and hair oils. Also, they possess different personal health care like treatment of headache, insomnia, menstrual disorders; relax both mind and body, and stress-relieving properties. Terpenoids, terpenes, sesquiterpenes, and monoterpenes are the main constituent of EOs. The demands of natural EOs for different purposes have shown increment, as they are safe, effective, and cheap. Although EOs are known as nontoxic and safe, the scientific literature showed that they may possess a strong allergy potential. There are scientific studies on the application of Eos, but their toxicity and allergic response required further thorough investigation. There are many plants in forests whose EO chemical composition is not yet studied and also not used for commercial purposes. Thus, further investigation related to the identification of different forest-based oil-yielding plant species, isolation, characterization, impact of EOs on human skin, and various health needs necessitates detailed scientific investigation.

Table 2 Uses of different essential oils as personal health care

Plant name	Common name	Plant part used	Main phytochemical present	Uses as personal health care system	References
Anthemis nobilis	Chamomile	Flower	Myrcene, camphene, azulene, *beta* caryophyllene, pinocarveol, cineole, bisabolol, pinene, farnesol, and pinocarvone	Treatment of headache, insomnia, and menstrual disorders, relax both mind and body and brings on sleep, use before sleep for bath, stress-relieving properties ease out depression and worry	Srivastava et al. (2010) Setzer (2009), and Lawless (1995)
Cananga odorata	Ylang-ylang	Flower	Farnesene, pinene, eugenol, beta caryophyllene, methyl chavicol, geranial, benzyl acetate, farnesol, Geranyl acetate, geraniol, and linalool	Antidepressive in nature with euphoric behavior, retard the rapid breathing and heartbeat with perfect use in shock and trauma situations	Ali et al. (2015)
Carumc arvi	Caraway	Seed	Carvacrol and carvone	Carminative, flavor, and stimulant	Tanu and Harpreet (2016)
Cuminum cyminum	Cumin	Seed	β-Pinene and α-pinene	Carminative and stimulant	Tanu and Harpreet (2016)
Lavandula officinalis	Lavender	Leaves	1,8-Cineole, beta-ocimene, linalyl acetate, terpinen-4-ol, linalool, camphor	Supporting mental alertness, improving the feeling of well-being, skin massage with a depression of central nervous system and anxiety	Price (1993)
Lavendula officinalis	Lavender	Leaves	Linalool, pinene, and cineol	Aromatic, carminative, and flavor	Tanu and Harpreet (2016)
Mentha piperita	Peppermint	Leaves	Menthone, limonene, methyl acetate, carvone, menthol, and carvacrol	Treat headache, itching, can relieve different infection of viral, fungal, and bacterial and inhaled or applied in the form of a vapor balm	Ravid et al. (1987)
Menthe piperita	Peppermint	Leaves	Menthone and menthol	Anti-viral, stimulant, flavor, and antiseptic	Tanu and Harpreet (2016)

(continued)

Table 2 (continued)

Plant name	Common name	Plant part used	Main phytochemical present	Uses as personal health care system	References
Ocimum basilicum	Basil	Flower	Eugenol	Analgesic, anticancer, antibacterial, antiviral, and antidiabetic	Tanu and Harpreet (2016)
Origanum vulgare	Oregano	Flower	δ-Terpineol and γ-terpinene	Nervous system, respiratory tract, and disorders of the gastrointestinal tract	Tanu and Harpreet (2016)
Pelargonium graveolens	Geranium	Leaves	Sabinene, methone, terpineol, myrtenol, citral, citronellylformate, linalol (linalool), geraniol, citronellol, geranic, and eugenol	To rectify menopausal associated problems, blood disorder diabetes, in throat infection, nerve tonic, sedative properties, endometriosis treatment, anxiety, and stress-related problems, some fungal infections, aging skin, eczema, and used in dermatitis	Lawless (1995), Lis-Balchin (1999) and Price (1993)
Rosmarinus officinalis	Rosemary	Leaves	Bornyl acetate, camphene, pinene, cineol, borneol, myrtle, and camphor	It regularizes the blood used stimulating the nervous system to be used in paralysis and hysteria, to relieve the rheumatic pain which aggravates due to cold and retards and pressure the hardening of arteries	Svoboda and Deans (1992), Jimbo et al. (2009), and Atsumi and Tonosaki (2007)
Syzygium aromaticum	Clove	Flower buds	Eugenol	Antidiabetic, analgesic, anticancer, anti-bacterial, and antiviral	Tanu and Harpreet (2016)

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Aromatic Oils from Forest and Their Application

Sandra Gonçalves and Anabela Romano

Contents

1 Introduction

Plants are a repository of chemical molecules known as secondary metabolites that have important physiological functions mainly in the interaction between the plant and its environment. Included in these molecules, aromatic plants produce a volatile odoriferous mixture of compounds that can be extracted as an essential oil (EO). The volatile compounds are organic molecules that have a high vapor pressure or a high volatility at normal pressure and temperature (Rehman et al. 2016).

EOs have been used for centuries around the world for distinct purposes according to each culture and their value for health, beauty, and wellness. Recently, there has been a renewed interest in EOs due to their pluripotent pharmacological activities as evidenced by multiple scientific studies. EOs are already established in folk and Western medicine as remedies, are used in aromatherapy, as insect repellents, as food preservatives, in perfume and cosmetic products, and for many other applications. Since EOs are extracted from natural sources, they are generally well accepted by consumers. Furthermore, many EOs and their components received the generally

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recognized safe status (GRAS) by the United States Food and Drug Administration (FDA) highlighting their value particularly for applications in food preservation (Hyldgaard et al. 2012).

The essential oil–producing species are broadly distributed among the plant kingdom including families from Gramineae to Rosaceae (Joshi et al. 2003; Borai and Husen 2003; Öztekin and Martinov 2007). Lamiaceae, Apiaceae, Myrtaceae, Rutaceae, Verbenaceae, and Zingiberaceae are some of the most important families of aromatic plants. Among the great diversity of plants, EOs from Mediterranean species are some of the most relevant ones. Special emphasis for plants of the Lamiaceae family, consisting of about 236 genera and 7200 species (Raja 2012), which include species like oregano, sage, rosemary, and thyme, which produce some of the most commercially important EOs. Due to its unique complex of ecosystems and the remarkably high number of indigenous plants, the Mediterranean region is particularly noted for its spectacular array of plants with outstanding properties. Mediterranean aromatic plants have been traditionally used since ancient times to enhance the aroma and flavor of foods and as remedies in folk medicine. Nowadays, EOs from some of these plants have huge potential for utilization in different industries due to their powerful bioactivity (Giacometti et al. 2018).

Due to the broad range of biological activities displayed by EOs, they are extensively used for many applications including in cosmetics (perfumes and make-up products), in hygienic products (fragrances for household cleaning products), in food preservation, agricultural products (biopesticide, repellents, and herbicides), and as natural remedies in aromatherapy. The EOs industry developed into a highly active and successful market over the past decade. Thus, this chapter aims to summarize and discuss the main biological effects and industrial applications of EOs, namely, in food preservation, pharmaceutics, agricultural products, cosmetic and personal health care products, and textiles.

2 Essential Oils: Chemistry and Specificities

EOs are complex mixtures of more than 300 secondary metabolites synthesized mainly by aromatic and medicinal plants. They can be stored in epidermal cells, cavities, and secretory cells of glandular trichomes (Dhifi et al. 2016), and its production involves different enzymatic reactions and two complex natural pathways, the cytosolic enzymatic mevalonic acid pathway and the plastidic and enzymatic 1-deoxy-D-xylolose-5-phosphate pathway also called the 2-*C*-methylerythritol-4-phosphate pathway (Rehman et al. 2016). EOs can be isolated from different parts of the plant, namely, leaves, flowers, stems, roots, seeds, etc., and correspond to a small fraction of the plant composition (<5% dry matter) (Valderrama and Ruiz 2018). They are complex mixtures of many volatile compounds that exhibit a characteristic odor depending on its composition. Terpenes (e.g., pinene, myrcene, limonene, terpinene, and *p*-cymene), terpenoids (e.g., oxygen-containing hydrocarbons), and aromatic phenols (e.g., carvacrol, thymol, safrole, and eugenol) are found to

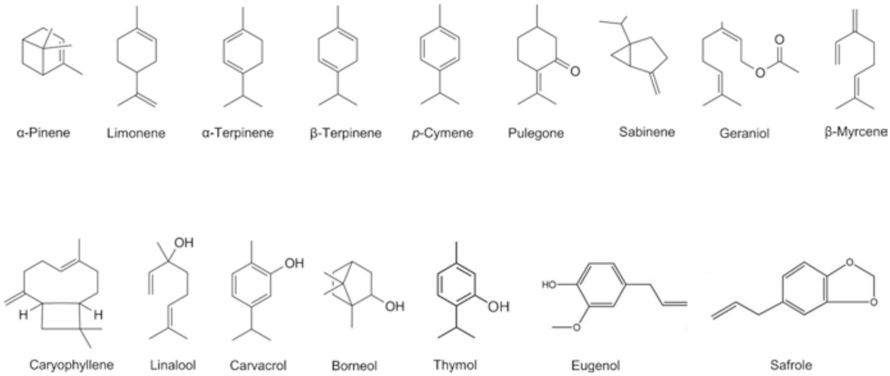

Fig. 1 Chemical structures of representative essential oils components

have major roles in the composition of various essential oils (Fig. 1) (Koul et al. 2008).

Generally, each EO is composed of 20–60 components, although it may contain more than 100, at very different concentrations. Usually, two or three are the major components present at relatively high concentrations (20–70%), whereas others are only present in trace amounts (Bilia et al. 2014). These compounds are responsible for several functions in the plant such as the attraction of beneficial insects and pollinators, protection against biotic (pests and/or microorganisms) and abiotic stresses (heat, cold, etc.), and protection against herbivores (Dhifi et al. 2016). The chemical composition of EOs is greatly variable, both qualitatively and quantitatively, depending on numerous factors, such as plant organ, harvesting seasons/time, geographical sources, plant maturity degree, etc. (Dhifi et al. 2016). Since EOs occur in plants in low amounts, the extraction process considerably affects the yield and quality of the recovered oil. Hydrodistillation and steam distillation are the traditionally used methods to extract EOs from the plant material (Dima and Dima 2015). Hydrodistillation using a Clevenger apparatus is the approach recommended by the European Pharmacopeia. Ultrasound-assisted extraction, microwave-assisted extraction, high-voltage electrical discharges, and sub- and supercritical fluid extraction are modern techniques recently used for EOs recovery.

3 Bioactivity

EOs display a broad range of biological activities such as antimicrobial, antioxidant, anti-inflammatory, neuroprotective, cardioprotective, insecticidal, etc. (Fig. 2) (Burt 2004; Calo et al. 2014; Dhifi et al. 2016; Jugreet et al. 2020). Due to these properties, many EOs are valuable as cosmetics and sanitary products (perfumes, make-up products, household cleaning products), biopesticides, repellent agents, food preservatives, aromatherapy, etc.

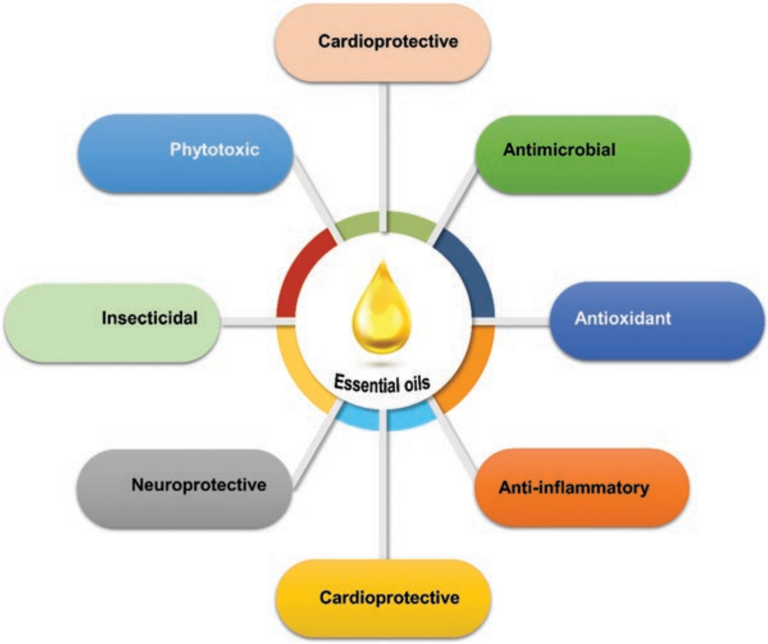

Fig. 2 Important biological properties exhibited by essential oils

Free radicals and reactive oxygen species have been associated with several diseases. Thus, antioxidants can be used in the treatment and prevention of diseases related to oxidative stress. Oxidation reactions can also occur in food products when exposed to oxygen, heat, or light. Deterioration processes of food products are related to oxidation reactions and decomposition of oxidation products. Hence, antioxidants are also important to maintain the quality of food products. Natural antioxidants have been considered valuable alternatives to synthetic antioxidants that have raised growing concerns and health security issues (skin allergies, gastrointestinal tract problems, and increased risk of cancer) (Lourenço et al. 2019). EOs are composed of different compounds containing conjugated carbon double bonds and hydroxyl groups that can donate hydrogen and, therefore, can inhibit free radicals and minimize oxidative stress effects (Zhang 2005; Hamidpour 2017). EOs and their constituents have been reported as exerting antioxidant activity by different mechanisms including prevention of chain initiation and free-radical scavenging activity (Rodriguez-Garcia et al. 2016). The composition of EOs greatly contributes to their antioxidant capacity, and compounds with conjugated double bonds usually display considerable antioxidant properties (Dhifi et al. 2016). Phenolics (e.g., thymol, eugenol, and carvacrol), acting by donating hydrogen atoms to free radicals, are the main antioxidant compounds present in EOs (De Souza et al. 2019). Compounds like certain alcohols, ethers, ketones, aldehydes, and monoterpenes also have antioxidant properties (Rodriguez-Garcia et al. 2016). EOs from

Mediterranean aromatic plant species, such as basil, oregano, lemon balm, thyme, and sage, have been recognized to be powerful sources of antioxidants (Mimica-Dukić et al. 2016). The antioxidant activity displayed by EOs makes them important for pharmaceutical and cosmetic applications as substitutes for synthetic antioxidants as well as alternative additives in the food industry.

The antioxidant activity of several EOs, as well as its components, has been evaluated using different methods, particularly in vitro chemical-based assays that are useful, low cost, and high throughput. Some methods commonly used to evaluate the radical scavenging activity of EOs are 2,2-diphenyl-1-picrylhydrazyl (DPPH), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS), and hydroxyl assays. β-carotene-linoleate model systems and thiobarbituric acid reactive substances assays have been used to study food products and organic substances with lipid contents. Additionally, to evaluate the reducing power, the most used methods are ferric antioxidant power reduction, cupric ion reducing antioxidant capacity, and phosphomolybdenum assays.

The increase in the development of antibiotic resistance among pathogenic microorganisms motivated the search for more efficient antimicrobial agents, particularly from natural sources and EOs, which have been widely investigated in the last years. The antibacterial activity of EOs has been associated with the reduction in membrane potential, interruption of proton pumps, and ATP exhaustion (Turina et al. 2006). The antibacterial, antifungal, and antimycotic activities of many EOs against a broad spectrum of pathogens have been reported (Aumeeruddy-Elalfi et al. 2016; Salehi et al., 2018; Potente et al. 2020).

The anti-inflammatory properties of EOs have also been demonstrated by different authors. Maruyama et al. (2005) showed that cutaneous application of geranium EO can suppress the inflammatory symptoms with neutrophil accumulation and edema in mice. Recently, Avola et al. (2020) observed that oregano EO reduced some parameters implicated in inflammation and accelerates wound healing in a human keratinocytes cell model. The anti-inflammatory activity of EOs may be attributed not only to their antioxidant action but also to their interaction with signaling cascades involving cytokines and regulatory transcription factors, and on the proinflammatory genes' expression.

The neuropharmacological effects of EOs have been demonstrated in animal models by displaying a significant influence in the hypothalamic–pituitary–adrenal axis, the sympathetic nervous system, and in neurotransmitter systems including serotonergic, DAergic, and GABAergic systems (Gonçalves et al. 2020; Lizarraga-Valderrama 2020). In addition, clinical studies showed that EOs applied by inhalation influenced several physiological parameters such as blood pressure, heart rate, respiratory rate, brain waves composition, and cortisol serum levels. The capacity of EOs to activate different neural pathways without the side effects usually induced by synthetic drugs makes them potential alternatives for the treatment of mental disorders, such as depression, anxiety, and dementia (Lizarraga-Valderrama 2020).

In addition to the abovementioned activities, EOs have demonstrated a vast range of other effects, such as antiviral, anticancer, antidiabetic, hepatoprotective, cardioprotective, anti-hyperpigmentation, as recently reviewed by Jugreet et al. (2020).

4 Industrial Applications

As aforementioned, EOs possess a broad spectrum of biological activities and, thus, have a great potential for many applications. This section will be dedicated to the most important industrial applications of EOs (Table 1).

4.1 Food Industry

These days, food safety is a key issue for both consumers and the food industries. There is an urgent need for safer food through the development of new and nontoxic preservative agents with antimicrobial and antioxidant properties, since synthetic chemicals used to control pathogen strains create serious preoccupations for human health (Prakash et al. 2015; Falleh et al. 2020). The sulfites commercially used as a food preservative, for instance, have been linked with antinutritional effects such as the degradation of thiamine or vitamin B1 in food (Gutiérrez-del-Río et al. 2018). The use of natural and safer preservatives in food products is particularly attractive leading to obtaining products with a natural or "green/organic" status. In this sense, particular attention has been paid to the use of EOs for food preservation applications (Burt 2004; Dhifi et al. 2016).

The utility of EOs for food preservations is mainly related to their antimicrobial activity well established since antiquity. The antimicrobial properties of EOs are not related to a single mechanism but to many targets in the microorganism cell (Calo et al. 2014). Due to their hydrophobicity/ lipophilicity, EOs are able to cross the cytoplasmic membrane and mitochondria and permeabilize the layers of fatty acids, polysaccharides, and phospholipids (Burt 2004). EOs are also able to disintegrate bacterial cell wall and cytoplasmic membrane structures by disturbing the conformation of their constituents, such as fatty acids, polysaccharides, and phospholipid layers, and increasing their permeability. The antimicrobial activities of EOs against foodborne pathogens are mainly related to phenolic compounds, such as thymol, carvacrol, or eugenol, in their composition (Dhifi et al. 2016, Ben Jemaa et al. 2017; Ben Jemaa et al. 2018a; Gutiérrez-del-Río et al. 2018). These compounds alter the permeability of the bacterial membrane leading to its death (Adelakun et al. 2016; Hyldgaard et al. 2012). Nevertheless, other EOs components including minor compounds also contribute to the antimicrobial effects of EOs probably by displaying a synergistic effect with the other components (Falleh et al. 2020). There are no specific resistances or bacterial adaptations against EOs reported in the literature which is a favorable aspect highlighting the relevance of EOs as natural preservatives.

A substantial number of EOs have been tested in a specific food matrix to eliminate pathogen microorganisms. Many EOs and their components were approved by the European Commission (EC) and by the FDA and are classified as GRAS (Hyldgaard et al. 2012; Ben Jemaa et al. 2018b). Some EOs with the GRAS status are lavandin, menthol, rose, sage, oregano, cinnamon, basil, clove, coriander,

Table 1 Some applications of important essential oils

Common name	Scientific name	Family	Application/effects	References
Basil	*Ocimum basilicum* L.	Lamiaceae	Food preservation (fillets), delayed food spoilage	Karoui and Hassoun (2017)
Chamomile	*Matricaria chamomilla* L.	Asteraceae	Cosmetics and personal healthcare products, moisturizers, anti-aging, after sun	Carvalho et al. (2016)
Eucaliptus	*Eucalyptus* spp.	Myrtaceae	Cosmetics and health care products, dentifrices, and toothpastes	Adwan et al. (2012)
			Herbicidal	Li et al. (2020), Ibáñez and Blázquez (2019)
			Pharmacological, wound healing potential	Saporito et al. (2017)
Lavender	*Lavandula* spp.	Lamiaceae	Herbicidal	Haig et al. (2009)
Oregano	*Origanum* spp.	Lamiaceae	Food preservation (active packaging), increase the shelf life of fish fillets	Martins et al. (2020)
			Food preservation, control microbial growth in fresh celery	Davila-Rodriguez et al. (2019)
			Food preservation (active packaging), bread preservation	Passarinho et al. (2014)
			Food preservation, reduced lipid oxidation in raw pork	Boskovic et al. (2019)
			Insecticide effect, against adults of *Myzus persicae*	Digilio et al. (2008)
			Herbicidal	Frabboni et al. (2019), Grul'ová et al. (2020)
Pennyroyal	*Mentha pulegium* L.	Lamiaceae	Insecticide effect, against adults of *Aphis gossypii*	Behi et al. (2019)
Pennyroyal	*Mentha pulegium* L.	Lamiaceae	Antifeedant effect (insecticide), *Myzus persicae, Spodoptera littoralis* and *Leptinotarsa decemlineata*	Kimbaris et al. (2017)
Peppermint	*Mentha x piperita* L.	Lamiaceae	Cosmetics and health care products, dentifrices, and toothpastes	Adwan et al. (2012)
Rosemary	*Rosmarinus officinalis* L.	Lamiaceae	Food preservation (fillets), prevented lipid peroxidation	Karoui and Hassoun (2017)
			Food preservation, control microbial growth in fresh celery	Davila-Rodriguez et al. (2019)
			Postharvest, controlling decay and extending the storage life of mango fruits	Kupaei and Garmakhany (2014)

(continued)

Table 1 (continued)

Common name	Scientific name	Family	Application/effects	References
			Postharvest, controlling decay and anthracnose disease in strawberry fruits	Hosseini et al. (2020)
			Antifeedant effect (insecticide), *Myzus persicae* and *Spodoptera littoralis*	Santana et al. (2014)
			Pharmacological, wound healing potential	Saporito et al. (2017)
			Cosmetics and personal healthcare products, repairing (anti-acne agent)	Lee et al. (2011)
			Herbicidal	Alipour et al. (2019), Frabboni et al. (2019)
Sage	*Salvia officinalis* L.	Lamiaceae	Food preservation (active film), preservation of carp burgers	Ehsani et al. (2019)
			Cosmetics and personal healthcare products, dentifrices, and toothpastes	Adwan et al. (2012)
Thyme	*Thymus* spp.	Lamiaceae	Food preservation (edible coatings) increase the shelf-life of strawberries during cold storage	Martínez et al. (2018)
			Food preservation, reduced lipid oxidation in raw pork	Boskovic et al. (2019)
			Postharvest, controlling decay and extending the storage life of mango fruits	Kupaei and Garmakhany (2014)
			Textile applications, antimicrobial protection	Walentowska and Foksowicz-Flaczyk (2013), Karagonlu et al. (2018), Zaharia et al. (2020)

nutmeg, ginger, and thyme, and the compounds thymol, carvacrol, eugenol, linalool, carvone, vanillin, cinnamaldehyde, citral, and limonene. Thyme and oregano EOs are among the top 10 most popular EOs used as food preservatives (Boskovic et al. 2019).

The efficacy of an EO is dependent on its type and composition. For instance, basil EO was more efficient in delaying food spoilage due to its antimicrobial activity, whereas rosemary EO was more effective in preventing lipid oxidation related to its antioxidant properties (Karoui and Hassoun 2017). The efficacy of EOs can be altered when interacting with certain food components, such as proteins, fats, water, carbohydrates, antioxidants, and salt. Food pH is also an important factor affecting the efficacy of the EO (Smith-Palmer et al. 2001; Calo et al. 2014; Adelakun et al. 2016). Some extrinsic factors, such as packaging process, gaseous composition, temperature, microorganisms' nature and initial concentrations, can also influence the efficiency of EOs as food preservatives (Rattanachaikunsopon and Phumkhachorn 2010; Hyldgaard et al. 2012; Rodriguez-Garcia et al. 2016).

EOs and their components demonstrate antibacterial and antifungal properties against a broad range of microbial pathogens (Pandey et al. 2017; Falleh et al. 2020) The efficacy of EOs as food preservatives has been tested in several food matrices, namely, meat products, fruits and vegetables, and dairy products. EOs have been tested both in pure form and as formulations to enhance the shelf-life of food commodities in different food products and storage containers, and significant shelf-life enhancement has been observed in several cases (Tripathi and Kumar 2007; Pandey et al. 2014).

Lipid oxidation is a major cause of food deterioration that limits its shelf-life and affects its quality. Thus, the use of antioxidants is fundamental to prevent oxidation of these products and extend their shelf-life. EOs have revealed a great antioxidant potential and therefore have enormous potential in the food industry (Jugreet et al. 2020). For instance, oregano EO and its components showed a great capacity to delay lipid oxidation due to its antioxidant action (Botsoglou et al. 2003; Terenina et al. 2011).

Nanoencapsulation has been used as a strategy to protect EOs against environmental factors (e.g., oxygen, light, moisture, and pH), to prevent their volatility, improve stability and solubility, and maintain or even improve their bioactivity (Ataei et al. 2020; Jugreet et al. 2020). Studies by Hussein et al. (2017) indicated that nanoencapsulation enhanced thermal stability of rosemary EO that can be useful for various thermal processing industrial applications. Encapsulation is also a successful strategy to minimize the organoleptic effects of EOs. Encapsulation of EO from thyme significantly reduced its organoleptic impact on milk (Ben Jemaa et al. 2017).

The use of films and coatings as active packaging systems has been increased in the last years and are considered promising strategies for food preservation that involve the migration of active components from the packaging to the food products to exert their action (Jugreet et al. 2020). There are many studies reporting the effectiveness of EOs in different types of active packaging systems due to its antimicrobial and antioxidant properties (Espitia et al. 2012). For instance, Martínez et al. (2018) showed that chitosan edible coatings with thyme EO increased the shelf-life of strawberries during cold storage up to 15 days.

The literature available indicates that EOs have a vast potential for applications in the food industry due to their capacity to prevent microbial contamination and lipid peroxidation in food products, thus increasing the shelf-life of food products, preventing deterioration, and, at the same time, maintaining nutritional and sensorial properties.

4.2 Agricultural Applications

Deterioration is an essential factor affecting the storage of fruits and vegetables postharvest and is responsible for substantial financial losses. Pesticides and fungicides continue to be the main method to control the deterioration of these products. Nevertheless, in the last years, the intensive use of these products caused great concern due to environmental and human health risks. This led to the reinforcement of regulations about the maximum residue limits allowed in these products—Regulation (EU) No 528/2012. Additionally, many efforts are presently dedicated to developing different strategies to control postharvest diseases, particularly greener alternatives. Among these strategies, plant extracts and EOs containing compounds with antimicrobial properties emerged as interesting alternatives (Pino et al. 2013; Mari et al. 2016; Palou et al. 2016). The antimicrobial agents can be used in vapor or liquid systems, mixed with surfactants in immersion tanks during the packaging process or in wax formulations, to prevent postharvest diseases (Aguilar-Veloz et al. 2020). The application of natural antimicrobial agents is mainly performed in the form of edible coatings and films because these are the most appropriate strategies to mitigate environmental risks and improve food quality. Also, the use of encapsulation methods allows the controlled release and avoids undesirable structural and bioactivity changes of natural compounds.

In the last years, many investigations demonstrated the potential of EOs from several sources to control postharvest diseases as recently reviewed by Aguilar-Veloz et al. (2020). For instance, treatment with thyme and rosemary encapsulated EOs is effective in controlling decay and extending the storage life of mango fruits, maintaining fruit quality (Kupaei and Garmakhany 2014). The effect of garlic and rosemary EOs on the development of strawberry fruit decay was studied using contact and vapor assays (Hosseini et al. 2020). It was observed that, in comparison with non-treated fruits, EOs reduced the development of fruit decay and anthracnose disease incidence, and at the same time, maintained sensory attributes and quality parameters.

Agriculture is highly dependent on the application of pesticides to control crop pests and improve crop yield. However, the indiscriminate use of synthetic pesticides is associated with negative effects to both human health and the environment. Thus, efforts have been made to replace the use of synthetic products with eco-friendly alternatives, including the use of biopesticides from plant sources. Biopesticides are usually less toxic for mammals and safer for both consumers and non-target beneficial organisms than synthetic insecticides (Walia et al. 2017). Moreover, biopesticides typically possess a wide spectrum of biological activity against insects.

In this sense, EOs with powerful biological properties including insecticidal, nematicidal, ovicidal, fungicidal, and bactericidal have great potential against important agricultural pathogens and pests (Regnault-Roger et al. 2012; Pavela and Benelli 2016; Karkanis and Athanassiou 2020; Isman 2020). Also, EOs can inhibit growth, food intake, and oviposition in several agricultural pests. The different components of EOs have distinct mechanisms of action. The capacity to disrupt the cell wall and cytoplasmic membrane of bacteria and fungi, leading to cell death, is a common mechanism of EOs. Additionally, some EO components induce neurotoxicity in insects by different mechanisms such as GABA receptors, octopamine synapses, and inhibition of acetylcholinesterase enzyme.

EOs are complex mixtures of different compounds with distinct mechanisms of action and showing synergistic effects; thus, they can be effective in preventing the development of resistant organisms, which is a great advantage of EOs as biopesticides.

Many studies indicated the great potential of EOs as active ingredients in the production of plant pesticides (Pavela and Benelli 2016; Karkanis and Athanassiou 2020; Isman 2020). EOs from Mediterranean plants have a considerable insecticidal value against important pests of vegetable crops. For instance, it was recently observed that the EOs from *Mentha pulegium* (Lamiaceae) and *Pistacia lentiscus* (Anacardiaceae) induced high mortality rates in two *Citrus* aphids. The main compounds of EO from *M. pulegium* and *P. lentiscus* were pulegone (45.89%), *cis*-menthone (23.25%), α-pinene (2857%), and β-myrcene (21.03%), respectively. Previous studies indicated that EOs from several Mediterranean Lamiaceae species were particularly toxic for aphids (Digilio et al. 2008; Santana et al. 2014). EOs from Asteraceae species, such as absinthe and *Artemisia absinthium* L., also exhibited aphicidal activity by decreasing the activity of acetylcholinesterase and Na^+/K^+-ATPase (Czerniewicz et al. 2018). Additionally, EOs from Mediterranean species also showed antifeedant activity against other agricultural pests. EO from *M. pulegium* exhibited insecticidal activity against *Leptinotarsa decemlineata* (Kimbaris et al. 2017). Encapsulation of this EO proved to be a good strategy to extend the duration of insecticidal activity (Kavetsou et al. 2019). In fact, this strategy has been applied for the formulation of neem oil, a recognized biopesticide available in several countries (Pascoli et al. 2020).

Although the revised literature showed that EOs from many plants revealed good insecticidal properties, only few biopesticides based on EOs are commercially available. Pavela and Benelli (2016) indicated several reasons to this fact: many published studies but few practical results; rigorous legislation; low persistence of effects; and absence of quality and enough materials at reasonable prices.

Weed management, usually involving the use of herbicides, can be responsible for high costs in agricultural systems, and the adverse effects associated with their use have led to the development of novel biological and ecological methods. EOs from different plants showed capacity to inhibit seed germination, and/or shoot growth and development, indicating that they can be effective in weeds' control (Raveau et al. 2020). EOs from Lamiaceae family were extensively investigated for their herbicidal potential. For instance, studies by Frabboni et al. (2019) showed that the germination of different weed species was differently affected by oregano and rosemary EOs and particularly by their concentrations. Sumalan et al. (2019) also observed that oregano EO displayed herbicidal potential by inhibiting the germination of seed weeds previously fumigated with the EO, suggesting its use as bio-herbicide. From an economic point of view, the use of bio-herbicides for weed control has an advantage with respect to hand weeding.

4.3 Pharmaceutical/Medical Applications

Currently, there is a great trend to use natural compounds to produce more effective and safer medications. This was triggered by the problems revealed by synthetic drugs, such as signs of toxicity or side effects, the development of multidrug-resistant bacteria, and some chemotherapy-resistant tumor cells. Due to their broad range of pharmacological and psychological effects, EOs have been recognized as therapeutic agents since ancient times. EO exposure can occur by inhalation, ingestion, and skin applications.

EOs are unstable volatile compounds and easily degradable by oxidation, volatilization, heating, and light; therefore, their encapsulation in nanosystems is an appropriate strategy to improve their stability and bioactivity. Nanodelivery systems provide a vast range of advantages, namely, the sustained and controlled drug release, profound tissue penetration due to the nanometric size, cellular uptake and subcellular trafficking, protection of cargo therapeutics both at extracellular and at intracellular levels, widening the pharmaceutical, and biomedical applications of EOs (Jugreet et al. 2020). Consequently, several EO-loaded nanodelivery systems have been tested, such as polymer-based nanoparticles, lipid-based nanoparticles, inclusion complexes, etc.

Several studies demonstrated that the association of EOs with nanoparticles enhanced their antimicrobial activity improving their future biomedical applications (Jugreet et al. 2020). For instance, Saporito et al. (2017) demonstrated that lipid nanoparticles based on natural lipids, loaded with eucalyptus or rosemary EOs improve the wound healing process. Moreover, olive oil, which is rich in oleic acid, displayed synergism with eucalyptus EO in which concerns wound repairing and antimicrobial effect.

4.4 Cosmetic and Personal Healthcare Products

Nowadays, consumer concern about the possible risks of synthetic substances for human health results in a renewed interest in natural cosmetics. EOs have recognized properties that are valued in cosmetic industrial products, particularly in perfumes, and skin and hair care products (Carvalho et al. 2016).

If in the past cosmetic industry used EOs mostly for their fragrance properties, today many interesting properties of EOs have been explored for cosmetic products. Flower EOs, namely, rose, tuberose, narcissus, gardenia, jasmine, and lavender, are the most common aroma components used in cosmetic products (Aburjai and Natsheh 2003). EOs from rosemary, mint, and bergamot are also used to improve the odor of a product. Additionally, due to their antimicrobial properties, some EOs can also be used as preservative ingredients in cosmetics, replacing the synthetic chemicals. For instance, Yorgancioglu and Bayramoglu (2013) showed that formulations containing thyme and oregano EOs at relatively low concentrations avoid the development of pathogenic microorganisms in cosmetic products. Also, studies by Claffey (2003) showed that EO mouthwashes have a similar ability to control plaque bacteria as alcohol mouthwashes and provided further benefits, like reduce gingivitis and oral malodor. EOs can also be used in these products as cooling agents, i.e., mint and eucalyptus EOs provide a long-lasting refreshing feeling to the skin and mouth (Aburjai and Natsheh 2003).

EOs with antioxidant properties can be also included in cosmetic products to improve their shelf-life, to protect the skin against free radicals responsible for skin aging, etc. Some EOs are also used in hair care products for various purposes like provide shine and conditioning effects to the hair, improve the beauty of the scalp, control dandruff, etc. (Carvalho et al. 2016).

EOs are also used in cosmetic products for their pharmacological properties and in this case are designated as cosmeceutical products. EOs detain numerous bioactive properties desirable for the cosmetic industry. For instance, geranium EO is applied in cosmetics as cleansing for over-oily skin, acne, and eczema. Chamomile EO is used to treat skin inflammation and to prevent skin disorders due to its anti-inflammatory properties (Aburjai and Natsheh 2003). Ursolic acid from rosemary EO can promote collagen build-up and elastin synthesis, thus preventing wrinkles and improving blood circulation in the skin and scalp (Kolar et al. 2009). EOs have also been used in cosmetic products due to their anti-melanogenic (Chou et al. 2013) and anti-aging properties (Aumeeruddy-Elalfi et al. 2018).

As aforementioned for other application of EOs, microencapsulation techniques are also being used to develop cosmetic formulations of personal care products due to its ability to protect the active compounds from degradation and evaporation and to allow their controlled release (Carvalho et al. 2016). Indeed, cosmetic delivery systems are a millionaire market in expansion with great potential to be explored. Additionally, the development of innovative and differentiated products with natural and nutraceutical components is a growing market trend.

4.5 Textile Applications

Textile industry is challenged to add new functionality to its products by the consumers' expectations of high hygiene and comfort. Antimicrobial textiles obtained by the application of antimicrobial agents are particularly popular to be used in healthcare, work/uniforms, sports apparel, military, personal care products, and home textiles. Since consumers are becoming more sensible for the use of natural products, EOs with recognized antimicrobial properties emerged as good agents for textile applications. Microencapsulation of antimicrobial agents within the fiber's matrix is a technique used to provide antimicrobial properties to textile products (Jugreet et al. 2020). Microcapsules loaded with thyme EO were prepared to develop antimicrobial textile materials to be used for wound dressings and bandages (Karagonlu et al. 2018). Results showed that fabrics with different concentrations of microcapsules showed antimicrobial activity. Recently, emulsions based on thyme essential oil-beeswax matrix were applied on cotton support, and the antimicrobial activity against bacteria evaluated (Zaharia et al. 2020). It was observed that the antibacterial activity increases with thyme oil and beeswax concentrations in the emulsions. The authors recommend these emulsions with antibacterial effect as a good option for the production of textile materials.

5 Concluding Remarks

Increasing tendency toward the application of natural low-toxic compounds generate a renewed attraction in EOs for many applications. EOs are produced mainly by aromatic plants and comprise compounds from different chemical classes of volatiles, oxygenated derivatives, and non-volatile compounds, including hydrocarbons, fatty acids, sterols, carotenoids, waxes, and flavonoids. Numerous research articles investigating the chemical and biological characterization of plant EOs provided interesting results supporting the utility of many EOs in numerous fields. The biological properties (e.g., antimicrobial, antioxidant, anti-diabetic, antiviral, anticancer, cardioprotective, neuroprotective) of EOs have been scientifically validated and some mechanisms of action elucidated. EOs are complex mixtures of different components, and it is likely that their biological activities are not due to single mechanisms. Among the biological properties exhibited by EOs, their remarkable antimicrobial and antioxidant attributes have enabled their exploration for several aims, such as extend the shelf-life of food products (e.g., active packaging systems), conservation of cosmetic products, production of textiles, etc. The GRAS status attributed to EOs highlights their value for food applications. In addition, their insecticidal, repellent, antifeeding, and phytotoxic effects make them effective eco-friendly pesticides and herbicides for agricultural uses.

The high volatility, hydrophobicity, and oxidation-prone nature of EOs could be a limitation for their application; nevertheless, the use of micro- and nanotechnologies allows to overcome these problems. These emergent technologies have been applied to improve the controlled release and to protect active compounds against degradation, evaporation, oxidation, and volatility; thus, more industrial applications of EOs are to be anticipated in the future. At the same time, the potentialities of EOs can be increased through the development of suitable formulations. Owing to the growing expansion of this area and the immense potential of EOs, they continue to be promising alternatives in a variety of industries to be explored in the future.

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Role of Traditional Chewing Sticks in Oral Hygiene and Other Benefits

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Abbreviations

EO	Essential oils
MIC	Minimum inhibition concentration
PPS	Preliminary phytochemical screening
TCS	Traditional Chewing Sticks
WHO	World Health Organization
ZOI	Zone of inhibition

1 Introduction

Plant or botanical medicine is the oldest form of medicine all over the world in history. The African continent is known to be home to countries with rich therapeutic preparations (Iwu 2014; Beshah et al. 2020). As it is culturally enriched, easily accessible and affordable, and the trust of communities on medicinal value, traditional medicines play a supplementary role in the missing and inadequacy of modern healthcare. A larger proportion of the African population relied on traditional medicine for primary health care. As a result of a wide range of ecological and climatic conditions, African nations are known to have diverse flora (Husen et al. 2012). More than 50,000 distinct species are known to occur, and over 5000 plants are used for medicinal purposes in Africa. Among the health problems commonly affecting communities in African nations, oral health problems are significantly affecting day-to-day activities. Being the starting point for the digestive system and center for some of the enzymatic activities and most of the sensory practices, the oral cavity is related to different physiological activities of our body. The problems are also closely related to other health problems.

Oral health is strongly associated with overall health and is defined as a prerequisite for any health policy (Glick and Meyer 2014). An overstressed and unhealthy body will compromise the immune system and so oral pathogens' damage will intensify and lower the overall disease resistance. Recent research in the area confirms that oral disease contributes to several ailments such as oral cancer development (La-Rosa et al. 2020), diabetes, heart disease, stroke, premature birth, and pneumonia (Alexander and Straub-Bruce 2013). In another study, diabetic adults are found to be vulnerable to oral hygiene problems (Al Amassi and Al Dakheel

2017). Above all, oral health is explained and noted by every part of a community from children to adults. This makes the issue more social. The most sensitive parts of the human oral cavity are our teeth and tongue. Among the possible ways of keeping oral health, mouth wash and teeth brushing are most commonly used for excavations. For this purpose, chewing sticks like tree twigs, bird feathers, and animal bones were used. The modern toothbrush was developed on the use of chewing sticks by the Babylonians (3500 BC) (Jardim et al. 2009).

In addition to its connection to other health conditions, oral health has varied impacts on the quality of daily living (Baiju et al. 2017). Generally, oral health and specifically dental health is an undetachable part of general health (Shekar et al. 2015). According to a WHO report on oral health, the cost of oral health is very high, and communities overlook oral health as an important part of their general well-being. Oral health also significantly affects physical fitness and performance (Bramantoro et al. 2020). These are among the main reasons why we need to consider oral health. The use of medicinal plants in oral health care activities has been reported in many African nations such as Ethiopia (Abate 1989; Mequanente 2009; Moges and Moges 2019), Burkina Faso (Tapsoba and Deschamps 2006), Madagascar (Ranjarisoa et al. 2016), Uganda (Namukobe et al. 2011; Ocheng et al. 2014), Cameron (Ashu Agbor and Naidoo 2015; Michele Lolit et al. 2015), Nigeria (Ajibesin et al. 2008; Adekola and Akinola 2019), Kenya (Omwenga et al. 2015; Fukuda et al. 2016). Namibia (Chinsembu 2015), Tanzania (Malik et al. 2014).

The World Health Organization (WHO) estimates that oral disease affects nearly 3.5 billion people and has also become a burden on the health care system of many countries (Fisher et al. 2018). Oral health conditions include mainly dental caries, periodontal diseases, oral cancer, bad breath, and oro-dental trauma. Oral diseases are known to be highly prevalent, and globally dental decay is the common disease with increasing prevalence in low- and middle-income countries (Peres et al. 2019). Oral disease affects highly poor and marginalized groups in society, as it is closely linked to socioeconomic status. Peres et al. (2019), recommended that different approaches are needed to tackle this global challenge. WHO strategy recommends alternative traditional medicine to combat health problems (WHO 2013). The use of herbal extracts for oral/dental disease is recommended as an alternative for synthetic antimicrobials due to lesser side effects and primary resistance to drugs (Shekar et al. 2015; Irani 2016). A study (Ayele et al. 2013) revealed that there is a strong positive relation between caries development and tooth brushing practices. For this practice to be enhanced, the use of traditional chewing sticks (TCS) will be significant because it is affordable for the lower economic status community. The use of TCS will integrate both the use of a toothbrush and toothpaste (Goyal et al. 2011). Besides the minimal cost, the side effect of TCS is also is minimal as it grows naturally. Most of the ethnobotanical studies of medicinal plants in different parts of Africa considered oral health. The greater attention given in the ethnomedicinal studies and higher prevalence of oral hygiene problems is key issues. The main aim of this chapter is to give an overview of the role of traditional chewing sticks in oral health in Africa and elsewhere, its phytochemical investigations or composition, and its pharmacological studies.

2 Preparations of TCS

2.1 Methods of Preparation and Use of TCS

Plant species used for TCS have different local names in different countries. Preparations of TCS may vary from place to place slightly across African nations. Often, TCS can be prepared from roots, twigs, or stems of selected plant species. Plants and their parts to be sued as TCS are selected according to the availability of the plant species, the cultural heritage of the local community, and the existing traditional knowledge toward keeping oral health. Sticks or roots from fresh plant materials will be cleaned and trimmed to a common length of 7–15 cm and 4–6 mm thick. The bark part will be removed from one of the ends of the trimmed stick/root and then one end of the trimmed stick will be chewed or tapered till it becomes soft and frayed into a brush-like form, which is then used to clean teeth similar to a modern toothbrush (Negusse 2007; Zakariyyah et al. 2017). For reputed usage, it will be soaked in water to replenish the softness of the end fiber. The detailed procedure for the preparation is as follows:

Step 1: Collecting the plant sticks/roots.
Step 2: Trimming and cutting into pieces.
Step 3: Removing bark or cleaning outer parts from one end.
Step 4: Chewing and frying the cleaned end.
Step 5: Soaking the sticks in clean water for later use.

Steps 1 and 2 are preparing the stick for the market, steps 3 and 4 are preparing for use of the TCS, and step 5 is for softening the fiber later use.

TCSs are considered an ancient toothbrush (Clarence et al. 2020). The use of TCS in African nations is mainly for esthetic values (Shekar et al. 2015), hygiene (Muhammad and Lawal 2010), and religious (Baiju et al. 2017) purposes. Health policies are also targeting prevention as a key (Iwu 2014) to support the use of TCS for the prevention of tooth decay. It is associated with cultural activities and religious teaching; the use of TCS is detachable from the day-to-day activities of the community. The use of TCS as an older method of keeping oral health hygiene continued to be mostly used because of its lower cost, availability, religious (Wu et al. 2001), and social (Hooda et al. 2009) reasons in many middle Eastern, African, and Asian people (Olsson 1978). The criteria for choosing the plant species are fiber quality (softness), taste, and, nowadays, pharmacological activity. TCS is also used against toothache, bad breath, and tooth decay. These medicinal plants are also used in the preparation of toothpaste, decoctions, and mouth wash for oral health problems apart from their use as TCS.

2.2 Plant Species Used/Ethnobotany

Traditionally different plant species are used to make TCS at different cultures and geographical locations. The most common and usually commercially available include those shown in Fig. 1. Africa is known for its cultural diversity, and the traditional knowledge is wider and varied. This can be reasoned out from the difference in climate (geographical location) and culture. Ethnobotanical studies done at different places of Ethiopia indicate the use of 62 plant species for making TCS and

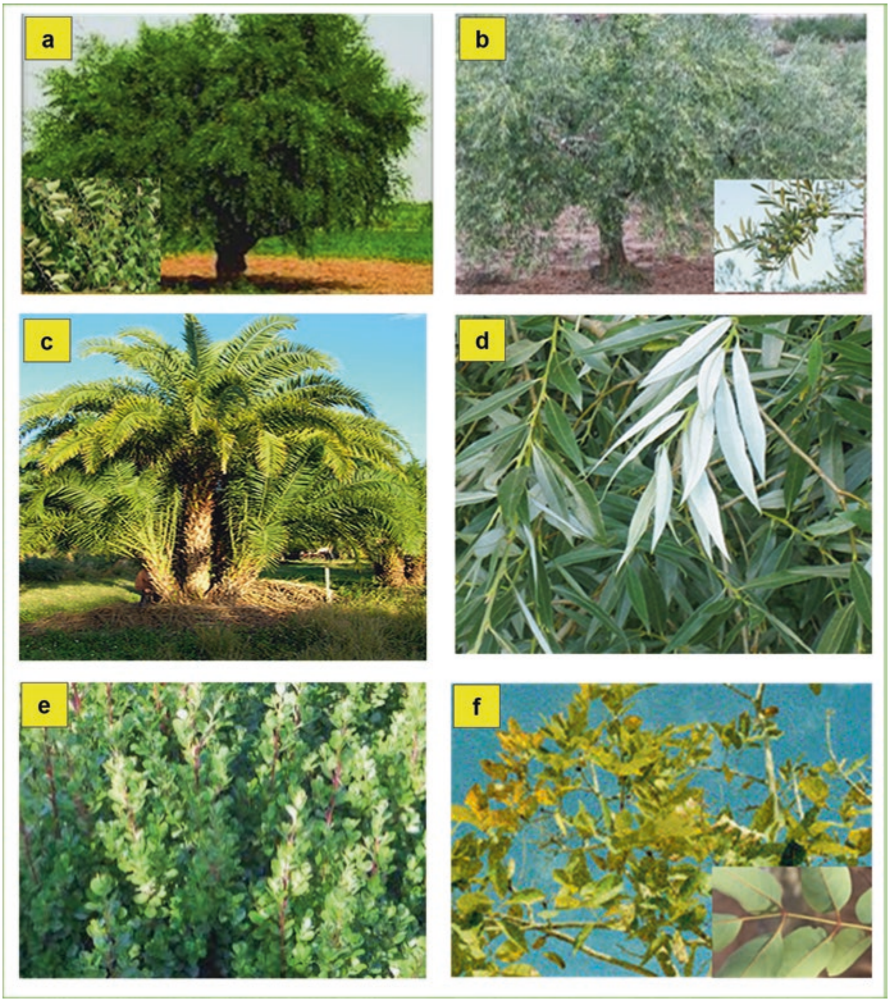

Fig. 1 Some plant species used as traditional chewing sticks (**a**) *Salvadora persica,* (**b**) *Olea europaea*, (**c**) *Phoenix reclinate,* (**d**) *Salix subserrata,* (**e**) *Myrsine Africana,* and (**f**) *Stereospermum kunthianum*

35 plant species for chew and hold a purpose for toothache and related ailments of the oral cavity. Similarly, in other African nations, a significant number of species are used for the same purpose (Table 1).

Per the result of the literature search, 62 plant species were found to be used directly as TCS in Ethiopia of which 4 (6.5%) are endemic, 3 (4.8%) are introduced, and the remaining (88.7%) are indigenous. This shows the use of TCS is based on indigenous species and knowledge. A significant number of species are also used along with maintaining oral health. Some species are prescribed by local practitioners for toothache and bad breath. Most of these are managed as chewing and holding between teeth. Plant species like *Salvadora persica*, *Vernonia amygdalina, Acacia nilotica, and Clausea anisata* are among the most commonly used species for making chewing sticks in many African nations. The plant species used to make TCS belong to more than 35 families. Species of the families Fabaceae, Malvaceae, and Oleaceae are most commonly used in making the traditional chewing sticks. These families are well known for the species used as medicinal plants with antioxidant activities (Prakash et al. 2014), anti-inflammatory activities (Alamgeer et al. 2018), and anticancer activities (Tuasha et al. 2018a). Half (50%) of the plant species are shrubs, 30% are trees of different sizes, and the rest 20 % are herbs. There is a greater alternative to use the shrubs and herbs for making TCS rather than trees, which can be mainly used for other purposes. The root of nine species is used for making TCS while twigs/stems for the others. This is also not against vegetation, as the stems or twigs can regenerate for those possible to generate.

Few examples of plant species that are frequently used as TCS, and available in Ethiopian local markets, are *Clausena anisate*, *Myrsine africana*, *Olea europaea*, *Phoenix reclinata*, *Salix subserrata*, *Salvadora persica*, and *Stereospermum kunthianum* (Seshathri and Thiyagarajan 2011). However, some others are used by the community and cultivated in home gardens in different parts of Ethiopia. Most of the TCS from the majority of plant species are not marketed. Boys are mainly engaged in preparing and marketing TCS. In some places, old religious men are also taking part. Especially, the boys are selling the semi-prepared TCS in two modes. One is the mobile mode by tying the trimmed and cleaned sticks in the form of a bundle (Fig. 2a) and looking for customers through the normal market, religious gatherings, and other crowded cities. The old men prefer mainly the second mode which is plain display of the clean and trimmed sticks (Fig. 2b). The sellers are accompanied with a small knife and pieces of wood for cutting and a base for cutting. The samples of TCS obtained from various plant species and displayed in the market places are presented in Fig. 3a–j. On the display-type market, TCSs are presented wrapped by polyethylene singly as shown in Fig. 3 c, d, e; and bulk as shown in Fig. 3g to protect from dust and keep the softness of the fiber. Some of them also have a design as shown in Fig. 3d. TCS labeled in Fig. 3c is made from the root of the citrus tree and is not suggested in ethnobotanical studies. Usually, in the local Ethiopian market, one stick costs about 2–5 Ethiopian Birr.

Table 1 List of plants used as traditional chewing sticks

Species (Family)	Habits	Parts used	References
Justica shimperina (Hochst. ex. Nees) (Acanthaceae)	Shrub	Twigs	Jansen (1981), Tamene (2000), Seshathri and Thiyagarajan (2011)
Agave sisalana Perro ex. Eng. (Agavaceae)	Robust perennial	Stem	Kassu et al. (1999)
Lannea schimperi (A. Rich). Engl (Anacardiaceae)	Tree	Twigs	Gemedo-Dalle et al. (2005)
Rhus natalensis Krauss (Anacardiaceae)	Shrub/ small tree	Twigs	Tamene (2000), Negusse (2007)
Schinus molle L. (Anacardiaceae)	Tree	Fresh stem	Regassa (2013)
Ilex mitis (L.) Radlk (Aquifoliaceae)	Tree	Twigs	Regassa (2016)
Phoenix reclinata Jacq. (Arecaceae)	Tree	Petiole	Kassu et al. (1999), Seshathri and Thiyagarajan (2011)
Artemisia abyssinica Sch. Bip.ex. Rich (Asteraceae)	Herb	Stem	Meragiaw et al. (2016)
Kleinia squarrosa Cufod. (Asteraceae)	Shrub	Stem	Belayneh and Bussa (2014)
Vernonia amygdalina Del. (Asteraceae)	Shrub	Twigs	Negusse (2007), Seshathri and Thiyagarajan (2011)
Stereospermum kunthianum Cham. (Bignoniaceae)	Shrub/ small tree	Stems	Kassu et al. (1999), Van Vuuren and Viljoen (2006), Seshathri and Thiyagarajan (2011)
Cadaba longifolia (R. Br.) DC. (Capparidaceae)	Shrub	Stem	Kassu et al. (1999)
Maerua oblongifolia Forssk. A. Rich (Capparidaceae)	Shrub	Stems	Van Vuuren and Viljoen (2006)
Juniperus procera Hochst. (Cuprassaceae)	Tree	Stem	Seshathri and Thiyagarajan (2011)
Jatropha curcas L. (Euphorbiaceae)	Shrub	Twigs	Bekele-Tesema (2007)
Acacia nilotica (Fabaceae)	Tree	Stem, twigs	Negusse (2007), Dagne (2011)
Baphia abyssinica Brummitt (Fabaceae)	Tree	Stem	Bekele-Tesema (2007)
Indigofera arrecta Hochst ex. A. Rich. (Fabaceae)	Shrub/ woody herb	Twigs	Gemedo-Dalle et al. (2005)
Indigofera oblongifolia Forssk (Fabaceae)	Shrub	Stem	Dagne (2011)
Lonchocarpus lexiflorus Guill. & Perr. (Fabaceae)	Deciduous tree	Twigs	Bekele-Tesema (2007)

(continued)

Table 1 (continued)

Species (Family)	Habits	Parts used	References
Millettia ferruginea (Hochst.) Bac. (Fabaceae)	Tree	Stem	Kassu et al. (1999)
Pterolobium stellatum Forssk. Brenan (Fabaceae)	Shrub	Twigs	Gemedo-Dalle et al. (2005)
Sesbania sesban (L.) Merr. (Fabaceae)	Shrub/ small tree	Stem	Seshathri and Thiyagarajan (2011)
Dovyalis abyssinica (A. Rich) Warb. (Flacourtiaceae)	Shrub/ small tree	Stems	Van Vuuren and Viljoen (2006)
Hypericum revolutum Vahl (Guttiferae)	Small tree	Stem	Kassu et al. (1999)
Clerodendrum myricoides (Hochst.) (Lamiaceae)	Shrub	Stem	Giday et al. (2007), Seshathri and Thiyagarajan (2011), Abebe (2013), Regassa (2013)
Premna schimperi Engl. (Lamiaceae)	Shrub	Root	Gebrehiwot (2010), Tamene (2011), Chekole et al. (2015)
Lippia adoensis Hochst. Ex. Walp. (Lythraceae)	Shrub	Twigs	Tamene (2000)
Dombeya torrida (J. F. Gmel) (Malvaceae)	Tree	Stem	Kassu et al. (1999)
Hibiscus falvifolius Uibr. (Malvaceae)	Shrub	Twigs	Gemedo-Dalle et al. (2005)
Kosteletzkya adoensis Hochst. Ex. A. Rich. (Malvaceae)	Herb	Stem	Bussmann et al. (2011)
Sida ovata Forssk. (Malvaceae)	Shrub	Twigs	Gemedo-Dalle et al. (2005)
Sida rhombifolia L. (Malvaceae)	Shruby herb	Stem	Seshathri and Thiyagarajan (2011)
Sida schimperiana Hochst. Ex A. Rich *(*Syn: *Sida cunefolia)* (Malvaceae)	Shrub	Root	Kassu et al. (1999), Tamene (2000), Van Vuuren and Viljoen (2006), Chekole et al. (2015), Alemeye et al. (2018)
Lepidotrichilia volkensii (Gurke) Leroy (Syn: Trichilia volkensii) (Meliaceae)	Tree	Twigs	Bekele-Tesema (2007)
Melia azedarach L. (Meliaceae)	Tree	Stem	Gebrehiwot (2010), Regassa (2013)
Stephania abyssinica Quart. Dill and A. Rich Walp. (Menispermaceae)	Woody climber	Root	Avigdor et al. (2014)
Myrsine Africana L. (Myrsinaceae)	Tree	Twigs	Kassu et al. (1999)

(continued)

Table 1 (continued)

Species (Family)	Habits	Parts used	References
Jasminum abyssinicum Hochst. Ex. DC. (Oleaceae)	Woody climber	Young stem	Bussmann et al. (2011), Chekole et al. (2015)
Jasminum stans Pax. (Oleaceae)	Shrub	Stem	Kassu et al. (1999)
Ligustrum vulgare L. (Oleaceae)	Shrub	Stem	Kassu et al. (1999)
Olea europaea L. (Oleaceae)	Tree	Twigs	Tamene (2000), Negusse (2007), Dagne (2011), Teklay et al. (2013), Beyene (2015), Amsalu et al. (2018), Worku (2019)
Olinia rochetiana A. Juss. (Oliniaceae)	Shrub	Stem	Kassu et al. (1999), Regassa (2016)
Phytolacca dodecandra L'Her. (Phytolaccaceae)	Shrub	Twigs	Bussmann et al. (2011)
Pittosporum abyssinicum Delile. (Pittosporaceae)	Tree	Twigs	Bussmann et al. (2011)
Pittosporum viridflorum Sims. (Pittosporaceae)	Shrub/ small tree	Stems	Kassu et al. (1999), Van Vuuren and Viljoen (2006)
Rumex nepalensis Spreng (Polygonaceae)	Herb	Root	Giday et al. (2009)
Clematis simensis Fresen. Ranuculaceae	Woody climber	Stem	Abebe (2011), Seshathri and Thiyagarajan (2011), Tuasha et al. (2018b)
Caylusea abyssinica (Fresen.) Fisch and Mey (Resedaceae)	Herb	Root	Tolasa (2007)
Rubus apetalus Poir. (Rosaceae)	Shrub	Stem	Seshathri and Thiyagarajan (2011)
Gardenia ternifolia Schumach & Thonn. (Rubiaceae)	Small tree	Twigs	Bekele-Tesema (2007)
Taverniera abyssinica Rich (Rubiaceae)	Shrub	Root	Kassu et al. (1999)
Clausena anisate Willd. Benth. (Rutaceae)	Shrub/ small tree	Stems	Kassu et al. (1999), Van Vuuren and Viljoen (2006), Haimanot Reta (2010), Seshathri and Thiyagarajan (2011), Suleman and Alemu (2012), Kefalew et al. (2015), Mekuanent et al. (2015), Alemeye et al. (2018)
Salix subserrata Willd (Salicaceae)	Bush/small tree	Twigs	Kassu et al. (1999), Negusse (2007)
Dobera glabra Forssk. (Salvadoraceae)	Shrub/ small tree	Twigs, stem	Negusse (2007), Dagne (2011), Meragiaw et al. (2016)
Salvadora persica L. (Salvadoraceae)	Tree	Root, twigs, stem	Kassu et al. (1999), Tamene (2000), Dagne (2011), Paulos (2012), Meragiaw (2016)

(continued)

Table 1 (continued)

Species (Family)	Habits	Parts used	References
Osyris quadripartita Decn. (Santalaceae)	Shrub/ small tree	Stem	Kassu et al. (1999), Van Vuuren and Viljoen (2006)
Dodonaea angustifolia L.f. (Sapindaceae)	Shrub	Twigs	Negusse (2007), Tamrat (2011), Tolossa and Megersa (2018)
Grewia bicolor Juss. (Tiliaceae)	Shrub/ small tree	Stem	Belayneh and Bussa (2014)
Celtis toka (Forssk.) Hepper & Wood (Ulmaceae)	Deciduous tree	Twigs	Bekele-Tesema (2007)
Rhoicissus tridentate R. B. Drumm. (Vitaceae)	Shrub	Fresh root	Mengistu et al. (2019)
Tribulus terrestris L. (Zygophyllaceae)	Herb	Root	Bussmann et al. (2011)

3 Phytochemical Constituents on Some Plant Species Used TCS

The amount of both primary and secondary metabolites varied depending on the habitat from where the medicinal plants are collected (Al-Ghamdi and El-Zohri 2017) and the respective collection season (Van Vuuren and Holl 2017). Phytochemical constituents are among the important aspects of discussion for the role of TCS on oral health. Only few species used in TCS preparation are phytochemically investigated. Among them, nearly half of the studies are on aerial or whole parts of the plants (Table 2).

Nearly half of the investigations used PPS as a method for the identification of the phytochemical groups. The major phytochemicals present in TCS are flavonoids, alkaloids, essential oil, phenolics, tannins, saponins, steroids, terpenoids, quinones, and coumarins. Out of these, flavonoids, alkaloids, phenolic, and terpenoids are the most commonly reported phytochemicals. The most frequently investigated species are *Salvadora persica*, *Acacia nilotica*, and *Jatropha crucas*. It is understood that the basis for the chemical effects of TCS is the chemical constituents present in it. Some of the species that are used as chew and hold species to maintain oral health are *Justica schimeriana* (Abdela et al. 2014), *Kalanchoe petitiana* (Mekonnen et al. 2013), *E. racemose* (Chhabra et al. 1989), *Cissus quadrangularis* (Dhanasekaran 2020), *Amaranthus caudatus* (Martinez-lopez et al. 2020), *Jasminum grandiflorum* (Sadhu et al. 2007), and *Solanum incanum* (Kaunda and Zhang 2020). In addition to the organic composition, few investigations report on the inorganic or mineral and vitamin contents of *Salvadora persica* (Halawany 2012; Zakariyyah et al. 2017), *Cissus quadrangularis* (Dhanasekaran 2020), *and Amaranthus caudatus* (Martinez-lopez et al. 2020).

The ethnomedicinal studies show the existence of rich traditional knowledge toward maintaining oral health and general health. Due to the increasing tendency

Fig. 2 Traditional chewing sticks market types (**a**) bundle type for mobile market and (**b**) display type for stationary market

of drug resistance by pathogens, the need for alternative, available, and affordable antimicrobial substances is increasing (Mabona and Van Vuuren 2013; Varijakzhan et al. 2020). As one can see from Table 2, more than half of the species used for TCS are not investigated phytochemically. These plants like some of the other medicinal plants lack enough scientific data to validate the ethnobotanical use of the respective species/plants. For effective utilization of the pharmacological potentials, it is important to investigate the phytochemistry of the species/plants into consideration. Both validating the traditional knowledge from ethnobotanical studies and justification of the chemical effect of using TCS are the driving forces for further phytochemical investigations.

Fig. 3 Some of the traditional chewing sticks used in Ethiopia and neighboring countries (**a**) *Olea europaea* (twigs), (**b**) *Sida schimperiana* (Root), (**c**) *Citrus* spp. (root), (**d**) *Clausena anisate* (stem), (**e**) *Pittosporum abyssinicum* (stem) (**f**) *Phoenix reclinata* (petiole) (**g**) *Stereospermum kunthianum* (stem), (**h**) *Salvadora persica* (root) (**i**) *Salix subserrata* (stem), and (**j**) *Salvadora persica* (stem)

4 Therapeutic Effects of Some Plants as Used for TCS

The role of plant species in traditional medicine is supported by the biological activities of the respective major phytochemicals. The beneficial role of using TCS includes antioxidant (Hooda et al. 2009), antiseptic, antimicrobial, anticarcinogenic, anti-inflammatory, and analgesic effects (Khatak et al. 2010; Niazi et al. 2016). Therapeutic variation is expected along with the seasonal variations that affect the phytochemical compositions of plant species (Khatak et al. 2010). The

Table 2 Phytochemicals identified in plant species used for making traditional chewing sticks

Species (Family)	Parts investigated	Isolated/identified phytochemicals	Method used	References
Acacia nilotica (Fabaceae)	Stem and bark	Tannins, flavonoids, alkaloids, terpenes, and essential oil	PPS	Rather et al. (2015), Subhan et al. (2018)
Caylusea abyssinica (Fresen.) Fisch and Mey (Resedaceae)	Leaves	Acidic amino acids	Ion-exchange Column	Olsen and Sorensen (1980)
Clausena anisate Willd. Benth. (Rutaceae)	Stem, bark, and root	Alkaloids, peptide derivatives sitosterol, sigma sterol, flavonoides, saponines, tannins, coumarines, and quinones	CC and TLC PPS	Geyid et al. (2005), Songue et al. (2014), Alemeye et al. (2018)
Clematis simensis Fresen. (Ranuculaceae)	Aerial	Triterpenoids, saponins, alkaloids, polyphenols, and unsaturated sterols	PPS	Geyid et al. (2005)
Dodonaea angustifolia L.f. (Sapindaceae)	Aerial	Alkaloids, terpenoids, saponins, tannins, glycosides, phenols, and flavonoids	PPS	Riaz et al. (2012)
Hypericum revolutum Vahl (Guttiferae)	Leaf and stem	Flavonoids, tannins, terpenoids, saponins alkaloids, and coumarins	PPS PPS	Van Staden and Lall (2020), Rampadarath et al. (2014)
Indigofera arrecta Hochst ex. A. Rich. (Fabaceae)	Twigs	Alkaloids and flavonoids	–	Gerometta et al. (2020)
Jatropha curcas L. (Euphorbiaceae)	Stems, whole parts/root	Terpines, flavonoides, phenols, lignans, proteins Coumarins, fatty acids, and antraquinones	Various	Sabandar et al. (2012), Abdelgadir and Van Staden (2013), Cavalcante et al. (2020)
Juniperus procera Hochst. (Cupressaceae)	Stem/bark	Diterpinodes	–	Seshathri and Thiyagarajan (2011)
Justica shimperina (Hochst. ex. Nees) (Acanthaceae)	Twigs and leaves	Alkaloids, saponins, tannins, phenols, steroids, flavonoids, and terpenoids	PPS	Abdela et al. (2014)
Lannea schimperi (A. Rich). Engl (Anacardiaceae)	Roots and stems	Alkaloids, flavonoids, saponins, phenolics, and amino acids	PPS	Maroyi (2019)

(continued)

Table 2 (continued)

Species (Family)	Parts investigated	Isolated/identified phytochemicals	Method used	References
Maerua oblongifolia Forssk. A. Rich (Capparidaceae)	Stems/ aerial	Terpenoids, fatty acid derivatives, sterols	GC/MS	Abdel-Mogib (1999)
Melia azedarach L. (Meliaceae)	Fruits	Terpenoids	–	Qiu et al. (2019)
Myrsine Africana L. (Myrsinaceae)	Fruits	Triterpenoids and benzoquinone	Various	Arot Manguro et al. (2003)
Olea europaea L. (Oleaceae)	Twigs/ whole parts	Flavonoids, terpenoids, phenols, and coumarins	PPS	Msomi and Simelane (2017)
Osyris quadripartita Decn. (Santalaceae)	Stem/leaves	Alkaloids, tannins, glycosides, steroids, terpenoids, flavonoids, saponins, and anthraquinones	PPS	Abebaw et al. (2017)
Rumex nepalensis Spreng (Polygonaceae)	Root	Anthraquinones, tannins, and stilbenoids	PPS	Vasas et al. (2015)
Salix subserrata Willd. (Salicaceae)	Whole parts	Flavonoids, esters, aromatic acids, sterols, and their glycosides	Various	Hussain et al. (2011)
Salvadora persica L. (Salvadoraceae)	Root, twigs, stem	Aromatic and esters of fatty acids, essential oil, alkaloids, flavonoids, tannins, saponins, and lignin glycosides,	Various	Niazi et al. (2016), Zakariyyah et al. (2017)
Schinus molle L. (Anacardiaceae)	Fresh stem	Essential oil	–	Hosni et al. (2020)
Sida rhombifolia L. (Malvaceae)	Stem/ whole parts	Alkaloids	–	Chhabra et al. (1990)
Sida schimperiana Hochst. Ex A. Rich (*Syn: Sida cunefolia*) (Malvaceae)	Root	Alkaloids, flavonoïdes, saponines, polyphénols, tanins, coumarines, and quinones	PPS	Alemeye et al. (2018)
Stephania abyssinica Quart. Dill and A. Rich Walp. (Menispermaceae)	Root/leaves	Alkaloids	Various	(Omole et al. 2014)
Stereospermum kunthianum Cham. (Bignoniaceae)	Stems	Naphthoquinones and anthraquinones	Bioassay-guided fractionation	Onegi et al. (2002)
Taverniera abyssinica Rich (Rubiaceae)	Root	Medicarpin, 4-hydroxymedicarpin, and 3,4-dimethoxypropiophenone	–	Fullas (2001)

(continued)

Table 2 (continued)

Species (Family)	Parts investigated	Isolated/identified phytochemicals	Method used	References
Tribulus terrestris L. (Zygophyllaceae)	Root	Saponins, falvonoides, alkaloids, vitamines, tanins, lignan amides, and cinnamic acid amides	–	Ercan and El (2016), Song et al. (2016)
Vernonia amygdalina Del. (Arecaceae)	Stem/twigs	Essential oil, sesquiterpene lactones, and steroids	–	Chhabra et al. (1989), Liu et al. (2019)

PPS preliminary phytochemical screening, *CC* column chromatography, *TLC* thin layer chromatography

biological activities of the respective species can be beneficial specifically for oral health and generally for body health. As in the case of a phytochemical investigation, a limited number of studies on pharmacological activities of the respective species used in TCS have been reported.

Previously, the community assumes its effectiveness is attributed to its mechanical action to remove caries (decays) and plaque. Nowadays, in addition to the mechanical effect of cleaning using TCS, pharmacological effects are also investigated or studied (Saha et al. 2012). The chemical constituency is associated with biological activities or therapeutic effects. Ethnobotanical studies are used as a source of information on medicinal plants for their varied therapeutic effects. Both in vivo and in vitro studies (Chelli-chentouf et al. 2012) are used for the pharmacological studies toward confirmation of the therapeutic effects suggested within the traditional knowledge. Here again, a set of standard assays are used for pharmacological studies. Each phytochemical discussed in the previous section is mentioned as a responsible component for the respective effects. Significant activities of the plant species used in TCS are considered in this section.

4.1 Antioxidant Activities

As part of the physiological structure, the oral cavity can be affected by reactive species generated internally or ingested from outside as foreign. Antioxidants are useful for oral health due to the protective mechanism involving scavenging of varied reactive species such as hydroxyl radical and others. Antioxidants reduce oral pathogens by preventing the disintegration of biomolecules and cell membranes (Chinsembu 2015) and function as radical scavengers (Dhanasekaran 2020). A larger number of antioxidants occur naturally in medicinal plants being varied in composition and properties. Phenols and flavonoids are reported to be powerful antioxidants (Bhatt et al. 2013).

There exists a correlation between the total phenolic contents and the antioxidant activities (Rached et al. 2016; Noreen et al. 2017). The phytochemical

Table 3 Antioxidant-rich species used in traditional chewing sticks

Species (Family)	Parts used/ studied	Major phenolics (TPC)	References
Salvadora perisca L. (Salvadoraceae)	Root	Phenolics and polyphenolic compounds, Total phenolic content: 794.6 mg as D-catechin equiv./100 g	Ibrahim et al. (2015)
Salvadora perisca L. (Salvadoraceae)	Stem/root	Antioxidant enzymes, peroxidase, and catalase	Mohamed and Khan (2013)
Melia azendarch L. (Meliaceae)	Leaves	TPC: 16–109 μg GAE/mg	Ervina et al. (2020)
Rhus natalensis Krauss (Anacardiaceae)	Root	Total antioxidant capacity (DPPH): 83.05 μg/mL	Zacharia et al. (2020)
Olea europaea L. (Oleaceae)	Leaves	TPC: 20–34.41 mg/g fresh weight	Petridis et al. (2012), Ali et al. (2015)
Schinus mole L. (Anacardiaceae)	Leaves	Oxygenated monoterpenes	Hosni et al. (2020)
Juniperus procera Hochst. (Cupressaceae)	Aerial	Essential oil	Burits et al. (2001)
Osyris quadripartite Decn. (Santalaceae)	Leaves	TPC: 100–504 mg GAE/g extract	Rached et al. (2016)

TCP total phenolic content, *GAE* gallic acid equivalent, *DPPH* diphenyl picrylhydrazyl, IC_{50} half maximal Inhibition concentration (at 50%)

investigations show phenolics and flavonoids are major components of most medicinal plants. This indicates the potential of the medicinal plants used in TCS as antioxidants for better oral health. The total antioxidant determination is younger as most investigated in the past five years (Table 3). The lower values of antioxidant capacity as in the case of *Rhus natalensis* and *Momordica foetida* revealed the significant antioxidant activities of the species. Similarly, the greater values of the TPC in *Salvadora perisca*, *Melia azendarch*, *and Osyris quadripartite* indicate the better antioxidant capacity of the species.

4.2 Antiseptic Activities

The oral cavity is one of the active sites for potentially harmful microorganisms. To reduce or stop the growth of these harmful pathogens, antiseptics are needed. In addition to the common applications of EO as antimicrobial and insecticidal components, terpenes have antiseptic potential (Amirah et al. 2019). Examples for this include *Thymus schimperi* (Ahmad and Rajagopal 2013), *Salvadora persica* (Ahmad and Ahamed 2012; Ahmad and Rajagopal 2013; Chinsembu et al. 2015; Farag et al. 2017; Khan et al. 2020; Niazi et al. 2016; Zakariyyah et al. 2017), *Ricinus communis* (Rampadarath et al. 2014), *Mentha pulegium* (Domingues and

Santos 2019), *Datura stramonium* (Gairola et al. 2014), *Solanum incanum* (Gairola et al. 2014), and *Melia azedarach* (Farooq et al. 2019). Besides its role in oral hygiene, *Salvadora persica* is known for its antioxidant, antidiabetic, and anticancer activities (Abdul et al. 2019).

4.3 Antimicrobial Activities

Antimicrobial activities include antibacterial and antifungal activities (Varijakzhan et al. 2020). Chemical compositions rich in alkaloids, flavonoids, lignans, glycosides, tannins, organic acids, and vitamin C are known to possess significant antimicrobial activities (Ahmad and Rajagopal 2013). Terpene derivatives were found to have a potent antimicrobial activity (Amirah et al. 2019). Fabaceae is a well-known family of plant species for antimicrobial activities (Gerometta et al. 2020). Among the species used for TCS are *Acacia nilotica, Baphia abyssinica*, *Indigofera arrecta*, *Indigofera oblongifolia*, *Lonchocarpus lexiflorus, Millettia ferruginea*, *Pterolobium stellatum,* and *Sesbania sesban* that belongs to the fabaceae family. Antimicrobial screening done by Seshathri and Thiyagarajan (2011) revealed that TCS made from *Juniperus procera* offers protection against strep throat caused by *Streptococcus pyogenes*. They reported a 20 mm zone of inhibition in ethanol extract. Here both the constituencies and the therapeutic effects are shown to be different for the use of different solvents (medium). The root extract of *Sida shimperiana* shows a better antimicrobial activity (Van Vuuren and Viljoen 2006). Following this better activity, it was used in the formulation of a toothpaste and mouth wash (Alemeye et al. 2018). A threefold enhanced antimicrobial activity of *Justica shimperiana* using combined effect with cinnamon and brown honey was reported by Seshathri (2012). The combination effect is also described in terms of an advantage to multitherapeutic effects (Van Vuuren and Holl 2017).

As shown in Table 4, the most commonly used experimental methods to determine antimicrobial activity were ZOI (Zone of Inhibition) assay and MIC (Minimum Inhibition Concentration) assay. MIC values are considered noteworthy (Van Vuuren and Holl 2017) when compared to other methods. Plant extracts with MIC less than 100 mg/mL using a microplate dilution method can be considered to have a good antimicrobial potency level (Rosas-pinon et al. 2012). A recent investigation shows that MIC less than 1 mg/mL is considered to have a better activity (Thibane et al. 2018). Antimicrobial phytochemicals can be classified as simple phenols, quinones, flavonoids, alkaloids, tannins, coumarins, terpenoids, and antimicrobial peptides (Allaker and Douglas 2009). Sulfur and amides (aromatic, benzylic, and aliphatic) are also considered antimicrobials (Ahmad and Rajagopal 2013). Desta (1993) investigated the antimicrobial activities of *Thalictrum rhynchocarpum* (root), *Sida ovata* (root), *Rubus apetalus* (root), *Ramanuclus multifidus* (whole plant), and *Asparagus africans* (root), tested for antimicrobial activities with other species/ parts, and found better inhibition in aqueous extracts. Antimicrobial activity of miswak (*Salvadora persica*) was found to be affected negatively by alcoholic

Table 4 Plant species used for traditional chewing sticks, their antimicrobial activity, and methods used

Species	Parts used	Activity	Method used	References
Acacia nilotica (Fabaceae)	Stem and bark	– 4–33 µg/mL	MIC MIC	Shekar et al. (2015), Rather et al. (2015)
Clausena anisate Willd. Benth. (Rutaceae)	Root	1–8 mg/mL	MIC assay	Van Vuuren and Viljoen (2006), Alemeye et al. (2018)
Clerodendrum myricoides (Hochst.) (Lamiaceae)	Stem/ whole plant	5–10 mg/ mL	MIC assay	Sileshi et al. (2007)
Dodonaea angustifolia L.f. (Sapindaceae)	Twigs	14–26 mm	ZOI	Jyoti et al. (2017)
Dovyalis abyssinicus (A. rich) Warb. (Flacourtiaceae)	Stems	0.5–8 mg/ mL	MIC assay	Van Vuuren and Viljoen (2006)
Indigofera arrecta Hochst ex. A. Rich. (Fabacae)	Root and leaves/ twigs	6.25–12.5 mg/mL	MIC	Gerometta et al. (2020)
Jatropha curcas L. (Euphorbiaceae)	Root	0.75 µg/mL 3.75–100 µg/L	MIC MIC	Abdelgadir and Van Staden (2013), Rampadarath et al. (2016)
Juniperus procera Hochst. (Cupressaceae)	Stem/ bark	20 mm 25 mg/mL	ZOI assay MIC assay	Seshathri and Thiyagarajan (2011)
Maerua oblongifolia Forssk. A. Rich (Capparidaceae)	Stems/ aerial	1.5–8 mg/ mL	MIC assay	Van Vuuren and Viljoen (2006)
Melia azedarach L. (Meliaceae)	Stem bark	–	–	Khalid et al. (2017)
Olea europaea L. (Oleaceae)	Twigs/ whole parts	14–15 mm 25 mg/mL	ZOI MIC	Seshathri and Thiyagarajan (2011), Seshathri (2012)
Osyris quadripartita Decn. (Santalaceae)	Stem/ leaves	0.2–6 mg/ mL	MIC assay	Van Vuuren and Viljoen (2006)
Pittosporum viridflorum Sims. (Pittosporaceae)	Stems	1–8 mg/mL	MIC assay	(Van Vuuren and Viljoen 2006)
Salix subserrata Willd. (Salicaceae)	Leaves and bark	–	ZOI	Hussain et al. (2011)
Salvadora persica L. (Salvadoraceae)	Root, twigs, stem	10–40 mm Broad comparable Effective	ZOI Comparison with clove oil	Hesham and Alrumman (2016), Yasmin et al. (2019), Abhary and Al-Hazmi (2018), Khan et al. (2020)
Schinus molle L. (Anacardiaceae)	Fresh stem	9–40 mm	ZOI	Hosni et al. (2020)

(continued)

Table 4 (continued)

Species	Parts used	Activity	Method used	References
Sida schimperiana Hochst. Ex A. rich (Syn: *Sida cunefolia*) (Malvaceae)	Root	0.4–6 mg/mL	MIC assay	Van Vuuren and Viljoen (2006), Alemeye et al. (2018)
Stereospermum kunthianum Cham. (Bignoniaceae)	Stems	0.4–4 mg/mL 25 mg/mL	MIC assay MIC assay	Van Vuuren and Viljoen (2006), Alemeye et al. (2018), Onegi et al. (2002), Seshathri and Thiyagarajan (2011)
Tribulus terrestris L. (Zygophyllaceae)	Root	0.31–5 mg/mL	MIC	Al-Bayati and Al-Mola (2008)
Vernonia amygdalina Del. (Arecaceae)	Stem/twigs	28 mm	ZOI	Adeoti et al. (2020)

MIC minimum inhibition concentration, *ZOI* Zone of inhibition

preservation/extraction (Abdel-Kader et al. 2019). The reason given for this loss of activity is that the reaction between hydroxyl ion from the solvents with the active compounds such as benzyl isocyanate will lead to the formation of inactive chemical species like benzyl cyanide and others. Among the chew and hold species, antimicrobial studies have been reported for *Amaranthus caudatus* (Mohanty et al. 2018), *Verbascum sinaiticum* (Tadeg 2004), *Kalanchoe petitiana* (Tadeg 2004), *Solanum incanum* (Taye et al. 2011), *Brucera antidysenterica* (Taye et al. 2011), *Thymus schimperi* (Hussain et al. 2011), *Capparis tomentosa* (Chhabra et al. 1989), *Mentha pulegium* (Domingues and Santos 2019), and *Ricinus communis* (Rampadarath et al. 2014).

4.4 Anticariogenic Activities

Anticarcinogens prevent cancer by enhancing natural defense against cancer or deactivating or blocking the action of carcinogens. Anticarcinogenic activity may arise from terpenoids (Kumar et al. 2020) and flavonoids (Dhanasekaran 2020). Among the possible sources of these phytochemicals and having similar effects, some examples reported include *Dovalyis abysisinica* and *Sesbania sesban* (Dagne 2011).

4.5 Analgesic Effects

Toothache and sore throat are among the frequent problems in the human oral cavity. Fresh root, stems, and leaves of some medicinal plants are prescribed by traditional practitioners for pin reliving by the chew and hold method. Alkaloids and essential oils are considered to be responsible for analgesic effects (Shekar et al. 2015). The species used in TCS namely *Clematis simensis* (Tadele 2017), *Jasminum abyssinicum* (Tadiwos et al. 2017), *Jatropha curcas* (Abdelgadir and Van Staden 2013; Cavalcante et al. 2020), *Olea europaea* (Ali et al. 2015)*, Salvadora persica* (Ahmad and Rajagopal 2013; Niazi et al. 2016; Zakariyyah et al. 2017; Khan et al. 2020)*, Schinus molle* (Hosni et al. 2020)*, Stephania* spp. (Kumar et al. 2010)*,* and *Tribulus terrestris* (Vadakkan et al. 2018) reported analgesic effect. Plant species used in the chew and hold method for relieving pains are also known for the same effect. Examples include *Acmella caultirhiza* (Crouch et al. 2005)*, Parthenium hysterophorus* (Issa 2015)*, Capparis tomentosa* (Hintsa et al. 2020)*, Rumex abyssinicus* (Vasas et al. 2015; Tadele 2017), *Pentas lanceolate* (Sweelam et al. 2018)*,* and *Cissus quadrangularis* (Mongalo and Makhafola 2018).

4.6 Anti-Inflammatory Activities

Inflammations or swellings following toothache and sore throat are also major problems in our oral cavity. Nonsteroidal anti-inflammatory drugs are used to help reduce this inflammation in modern medicinal practice. Larger groups of natural products exert potent anti-inflammatory activity. Various terpenoids, phenolics, and polyphenolics are the major groups of compounds to show anti-inflammatory properties (Azab et al. 2016). Many African medicinal plant species are known to possess anti-inflammatory activity in vitro (Elgorashi and Mcgaw 2019). Of those that are used for oral health in Ethiopia are *Jasminum abyssinicum* (Tadiwos et al. 2017), *Osyris quadrip artita* (Rached et al. 2016), *Hypericum revolutum* (Van Staden and Lall 2020), and *Rumex nepalensis* (Zacharia et al. 2020).

4.7 Cytotoxicity

Cytotoxicity studies are an important first step in determining the potential toxicity of plant extracts (McGaw et al. 2014). When compared to the number of species existing in Ethiopia/Africa, only a few studies on toxicological effects were reported. Based on LD_{50} (lethal dose 50%) values, the extent of toxicity of an extract can be decided (Teke and Kuete 2014). The cytotoxic studies reported on the species used for TCS and chew and hold purposes are listed in Table 5. Among the studied species for cytotoxicity using different models, most show less toxicity and even some

Table 5 Cytotoxicity of spices used for traditional chewing sticks

Plant species/family	Parted studied	LD_{50} (g/kg of body weight) IC_{50} (µg/mL)	References
Acacia nilotica (Fabaceae)		Less toxic to 3T3 mouse fibroblast cells with IC_{50} = 65.2 µg/mL	Koko et al. (2009)
Clausena anisate Willd. Benth. (Rutaceae)	Aerial/ leaves	Low-level cytotoxicity for leukemia cells	Nibret and Wink (2011)
Clerodendrum myricoides (Hochst) (Verbenaceae)	Root bark	Low cytotoxicity to L6 cells with IC_{50} > 90 (µg/mL)	Irungu et al. (2007)
Dovyalis abyssinica (A. rich) Warb. (Flacourtiaceae)	Leaves	IC_{50} = 1.4–2.9 µg/mL can be potent candidate for the treatment of trypanosomiasis	Nibret and Wink (2011)
Jatropha curcas L. (Euphorbiaceae)	Twigs	Cytotoxic toward melanoma cells, nasopharynx human carcinoma Lignans responsible for cytotoxicity Low toxicity of ethyl acetate and methanol extracts of leaves/stem bark	Sabandar et al. (2012), Abdelgadir and Van Staden (2013), Abiodun et al. (2012)
Melia azedarach L. (Meliaceae)	Leaves	Bio-selective hormonal cytotoxicity t	Ervina et al. (2020)
Olea europaea L. (Oleaceae)	Leaves	Cytotoxic at higher dose	Ali et al. (2015)
Osyris quadripartita Decn. (Santalaceae)	Leaves	Highest cytotoxicity against human tumor cells	Rached et al. (2016)
Rumex nepalensis Spreng (Polygonaceae)	Root	Substituted phenols – Weak toxicity 35.24 ± 3.5 µg/mL dose dependent Low cytotoxicity for leukemia cells HL-60 cells	Zacharia et al. (2020), Nibret and Wink (2011)
Salvadora persica L. (Salvadoraceae)	Leaves/ stem	Toxic to mice at doses up to 1200 mg/kg Low-level toxicity Cytotoxic on gingival and other periodontal structures	Albabtain et al. (2017), Niazi et al. (2016), Zakariyyah et al. (2017), Khatak et al. (2010)
Sida rhombifolia (Malvaceae)	Whole plant	Toxic at higher dose to albino Wistar rats	Assam et al. 2010
Vernonia amygdalina Del. (Arecaceae)	Aerial/ leaves	CH_2Cl_2 extract is potent for the treatment of leukemia IC_{50} = 22.4 µg/mL	Nibret and Wink (2011)

belong to the class of wild edible plants, for instance, *Acacia nilotica*, *Salvadora persica* (Meragiaw 2016); *Amaranthus caudatus*, *Dovyalis abyssinica*, *Momordica foetida*, *Rumex abyssinicus*, *and Vernonia amygdalina* (Regassa 2016; Kassa et al. 2020). The species used for the chew and hold purpose are already reported to be used ethnobotanically. Few cases of dose-dependent toxicity include *Rumex* *nataleasis* (Zacharia et al. 2020), *Salvadora persica* (Albabtain et al. 2017), *Olea europaea* (Ali et al. 2015), *Sida rhombifolia* (Assam et al. 2010), and *Verbascum sinaiticum*(Tadeg 2004). Cytotoxicity tests toward the normal cells and specifically for certain pathogenic microorganisms lack complete cytotoxicity data. As mentioned before, this is important for the complete exploration to gain the advantages toward oral health.

5 Mechanical and Others Effects of TCS

In addition to the organic phytochemicals, the major components of toothpaste and mouthwash include abrasives and fluorides. *Salvadora persica* is the most investigated for these components. Similar investigations are expected for the other species to establish possible alternatives for oral health. Abrasives are one of the components of the commercially available toothpaste (Muhammad and Lawal 2010) to help remove plaque, stains, and polishing the teeth (Joiner 2007). In addition to the chemical composition, the presence of abrasives like silica and sodium bicarbonate is mentioned as identified from *Salvadora persica* (Ahmad and Rajagopal 2013; Sukkarwalla et al. 2013; Chinsembu 2015; Varijakzhan et al. 2020). These abrasives had the mechanical advantage of cleaning teeth. In another study by Halib et al. (2017), crystals of varied shapes and sizes are expected to affect the whitening of stained teeth identified for stem bark of *Salvadora persica*. This natural abrasive agent was found to constitute O, C, S, Ca, Na, and K and affects the whitening of stained teeth in the preliminary assessment. Both the yellow and the white sulfur and sodium bicarbonate were used as a component of traditional healing for a toothache (Ashu Agbor and Naidoo 2015). As in the case of silica, sulfur is also identified from the root and stem extracts of *Salvadora persica.* It has been identified as sulfur crystal (Abdel-Kader et al. 2019) and as sulfur compounds (Wassel and Khattab 2017). The amount (%) of elemental sulfur was found to increase with temperature (Moawed 2013). The role of sulfur in keeping oral hygiene was explained from its bactericidal property (Ajmal 1981), (Sukkarwalla et al. 2013), (Abhary and Al-Hazmi 2018), (Halib et al. 2017). Vitamins are among the essential nutrients found in food for body health and are used in a small amount. Vitamin C helps in tissue healing and repairing (Ajmal 1981; Dahiya et al. 2012; Ahmad and Rajagopal 2013; Hesham and Alrumman 2016) in the oral cavity which in turn contributes to the betterment of oral health. The presence of vitamins is identified from *Amaranthus caudatus* (Mohanty et al. 2018), from aerial part of *Solanum incanum* L. (Kaunda and Zhang 2020), fromm root of *Jatropha curcas* (Oskoueian et al. 2011), from *Salvadora persica* (Hattab 1997; Chelli-chentouf et al. 2012), and from the aerial part of *Cissus quadrangularis* (L). Fluoride and chloride identified from *Salvadora persica* (Hattab 1997) were reported having enamel remineralization (Dahiya et al. 2012; Abhary and Al-Hazmi 2018) and demineralization (Bairwa et al. 2012) properties. Some Nigerian chewing sticks even have larger composition of minerals like fluoride than *Salvadora persica* (Adekola and Akinola 2019).

Investigations for abrasives, sulfur, vitamins, and fluorides lack for most species used in making TCS and should be given attention.

6 Commercial Products Associated with TCS

Extracts from the plants used in making TCS are also used in the manufacture of commercial products for oral health. Some of the common products are Sarkan toothpaste (UK), Epident toothpaste (Egypt), Flourowak miswak (Pakistan), Quali miswak toothpaste (Switzerland), and Denta care miswak plus (Saudi Arabia). In these commercial products, extract from *Salvadora perisca* is mainly used (Khatak et al. 2010) (Fig. 4).

7 Advantages, Disadvantages, and Challenges Associated with TCS

7.1 Advantages

The therapeutic and other related advantages of using TCS are discussed in the previous section. The use of traditional medicine in general is less costly and easily accessible. This is true also for TCS. As varied species are used in different parts of Africa, this broadens the alternatives and increases the accessibility for everyday use. Mostly, as TCS can be made at home from home gardens, this also contributes to higher accessibility. The side effects of using TCS is less than the use of synthesized chemical for oral hygiene (Bairwa et al. 2012). Multiple therapeutic effects like antimicrobial, jaw exercise, and contribution to general health are also advantages for using TCS (Hooda et al. 2009). TCS from *Salvadora persica* helps in maintaining the pH or buffering capacity of the oral cavity (Sukkarwalla et al. 2013) and the flow of saliva (Hesham and Alrumman 2016). *Tribulus terrestris* chewing sticks are used traditionally as a solution for male erectile dysfunction (Barkatullah et al. 2015) and as an anti-obesity and antidiabetic (Song et al. 2016). Some are also used as nutraceuticals as mentioned in the above section. The TCS from *Salvadora persica* L. has been compared to the modern toothbrush as an effective and comparable aid toward oral hygiene (Dahiya et al. 2012). The antimicrobial activity of TCS made from *Salvadora perisca* was compared to modern toothbrushes and toothpaste and found to be significantly better (Hooda et al. 2009). Comparative effectiveness of TCS with modern toothbrush toward the removal of the dental plaque was also reported (Malik et al. 2014). The use of chewing sticks revealed parallel and greater mechanical and chemical cleaning effects in a long time compared to a toothbrush.

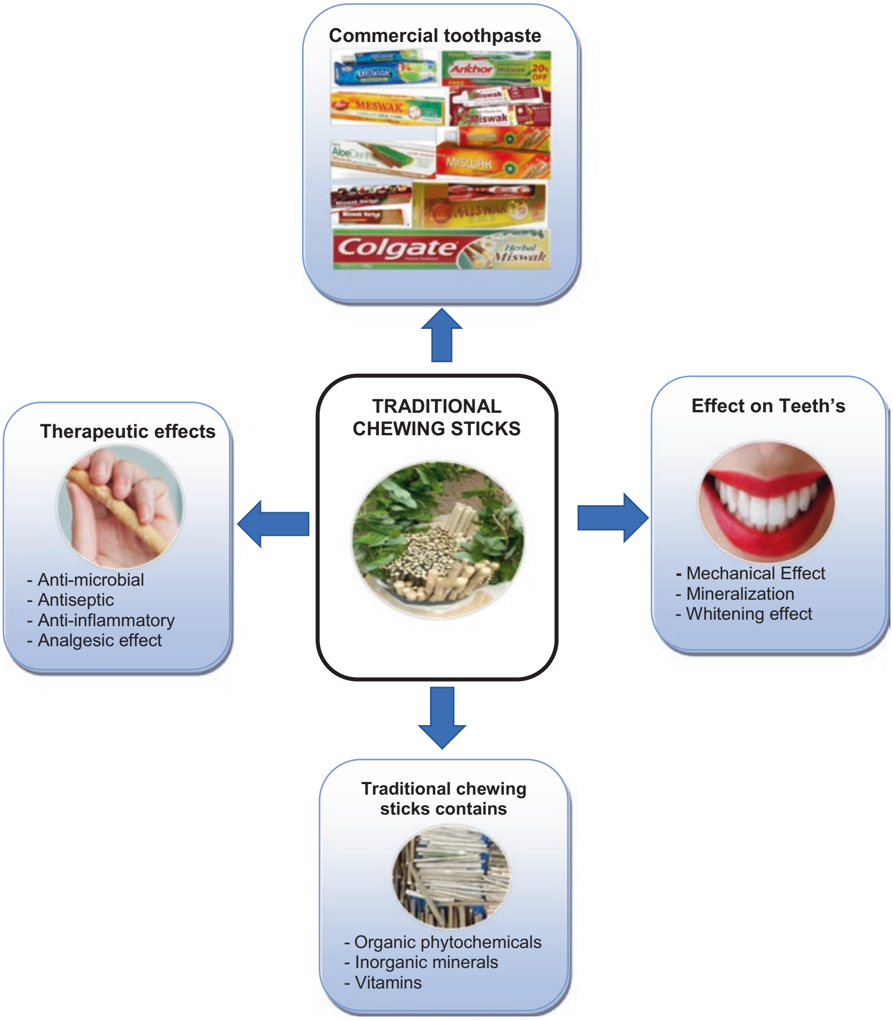

Fig. 4 Significance and various application of traditional chewing sticks

In a report from Nigeria, an insignificant difference in oral hygiene status between toothbrush users and chewing stick users was indicated (Aderinokun et al. 1999). This is against the cost of using a modern toothbrush. The use of TCS after a meal is common practice in Ethiopia and scientifically sounds to remove food remnants left in between the teeth (Seshathri 2012). *Ricinus communis*, *Acacia nilotica*, *Dodonaea viscosa* (syn: *Dodonaea angusitifolia*), and *Melia azedarach* are among the most frequently used species for multiple medicinal purposes (Rampadarath et al. 2014) including their use for making TCS.

7.2 Disadvantages

Knowing the adverse effect is important equally to know the advantages as feedback for the better use of TCS. In addition to the lack of adequate knowledge of adverse effects on herbal preparations and usage, there are some adverse effects mentioned by scholars. Abrasive fibers can lead to damage to hard and soft tissues of the teeth (Michele Lolit et al. 2015). Loss of effectiveness on long-term usage as the time for use is not restricted to the traditional use (Tadeg 2004) is expected. Teeth discoloring and rough fibers may scratch the teeth enamel and worse the gum bleeding and immoderate usage (Negusse 2007). Different levels and varieties of toxicity (Subhan et al. 2018), toxicity to normal cells for some species (Zakariyyah et al. 2017), and some species being poisonous to humans are reported (Teklay et al. 2013). Examples include antifertility effect by *Salvadora persica* (Khatak et al. 2010), *Cucumis ficicfolius, Justica shimeriana, Vernonia amygdalina* Del. is not allowed for pregnant woman and babies (Megersa 2010; Limenih et al. 2015), some constituents of *Stereospermum kunthianum* are toxic to mammalian cells (Onegi et al. 2002). Some allergic reactions may appear (Irani 2016). Diarrhea, vomiting, and headache were reported as side effects of *Cucumis ficicfolius, Justica shimeriana, and Vernonia amygdalina* Del. (Limenih et al. 2015).

7.3 Challenges

Ethnobotanical studies are challenged by the issue of intellectual property rights and access and benefit-sharing (ABS) (Tuasha et al. 2018a). This brings significant challenges in the development and implementation of regulations for the use of traditional practices (Paulos 2012). In another study, the loss of biodiversity and low regard for indigenous knowledge are indicated as the challenge of ethnobotany (Hishe 2019). In support of this indication, *Taverniera abyssinica* is reported as an endangered species (Luis et al. 2006). There is a resistance from the young generation toward searching and using the traditional knowledge (Kidane et al. 2018), as a consequence of the migration of youth to urban areas (Khatak et al. 2010). There is a need for planned advocacy for the use of TCS (Malik et al. 2014) for contributing to fill the challenging gap.

8 Conclusion

Oral health is an important component of human health. In this concern, the easy accessibility and affordability make TCS a good alternative for the modern toothbrush and toothpaste. The use of TCS in the African continent and neighboring countries is very common. Additionally, there are cultural and religious values toward the use of chewing sticks. The major roles of TCS in oral health include therapeutic effects such as antimicrobial, antioxidant, anti-inflammatory, analgesic, and antiseptic effects to fight against oral pathogenies and also the mechanical effect to remove plaques and other associated problems. The phytochemicals responsible for these effects are flavonoids, alkaloids, phenolic, and terpenoids. Other minor components of TCS like vitamins, fluorides, carbonates, and silica are also significant. For complete therapeutic advantages with lesser side effects, extensive toxicological investigations are demanding. The number of studies on pharmacological investigations are almost double when compared to the chemical constituency. As phytochemical investigations lack a significant number of species, this gap should be filled with a detailed investigation for those investigated and for those ignored. A lot should be done on the technique of using TCS and frequency of usage to maximize the benefits. In addition to this, there are also species used in the form of chew and hold for problems in oral cavity. These species can be promising candidates for making chewing sticks following their therapeutic values for better prevention of oral health problems. Additionally, these minor products generate income at local level in Ethiopia and other neighboring countries.

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Plant-Based Sweeteners and Their Applications in Modern Lifestyle

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Abbreviations

CAGR	Compound annual growth rate
CSDs	Carbonated soft drinks
FOS	Fructooligosaccharides
GRAS	Generally recognized as safe
HFCS	High fructose corn syrup
HSH	Hydrogenated starch hydrolysates
IMO	Isomalto-oligosaccharide
JECFA	Joint FAO/WHO Expert Committee on Food Additives
LCS	Low-calorie sweeteners
USFDA	United States Food and Drug Administration

1 Introduction

The history of sugar is relatively new (500 BC) as it was discovered that grass with bamboo-like stem contains a sweet juice (Eggleston 2019). This grass (sugarcane) was soon cultivated around the world in warm damp climates. Its juice was initially used in concentrated form and later (about 1400 AD) used in refined form (brown sugar) throughout Europe (Kinghorn et al. 1986). Later in the 1800s, a new source of sugar was discovered (sugar beet) with root tubers containing more sucrose per kilogram than sugar. This new source gradually replaced sugarcane in Europe. In the 1950s, sugar syrup from corn starch was discovered (now known as high fructose corn syrup), which gradually replaced sucrose in the United States (Bode et al. 2014).

The market size of natural sweeteners also exceeded by 9.2 million dollars USD in 2019 and expecting an estimated growth of 4.3% compound annual growth rate (CAGR) between 2020 and 2026. Increased consumer awareness of eating natural ingredients will further help this market grow.

The classification of sweeteners is incredibly vivid such as natural versus artificial sweeteners, nutritive versus non-nutritive sweeteners, caloric versus low-caloric or zero-caloric sweeteners, and carbohydrate vs non-carbohydrate sweeteners. Here classifying sweeteners alone is not the main objective of discussion but also to present a picture of sweeteners from natural sources, especially from plants with their general introduction.

2 Carbohydrate and Non-carbohydrate Sweeteners

Starting with the carbohydrates such as sugars, starches and fibers are naturally occurring organic substances with varying sweetness. They are found in healthy as well as unhealthy foods. The most common and important sugar is sucrose found in various fruits and vegetables. It is also found in some grasses such as *Saccharum officinarum*. Sugar is produced in plants due to photosynthesis and stored in different parts such as stalk (*Saccharum officinarum*) or root (*Beta vulgaris*). A country like Brazil uses most of its sugarcane to produce alcohol through fermentation. It is further converted as alcohol fuel to run vehicles. Worldwide approximately 179.66 million metric tons of sugar were produced in 2018–2019. The consumption was 172.6 million metric tons which are further expected to increase to about 177.8 million metric tons by 2020–2021. The other sources of sucrose (sugar maple and carob) are not very significant in terms of their commercial value. Due to its universal availability and versatility, sucrose production is growing in the developing world and gained prominence in the food.

Moving toward the non-sucrose carbohydrates, honey is one of the oldest known mixtures of such monosaccharides or disaccharides. The US Food and Drug Administration described honey as the assimilated nectar and saccharide exudate of plants modified (inversion) and stored by the honeybees (*Apis mellifera* and *Apis dorsata*) (Food and Drug Administration 2014). The color, composition, and flavor of honey depend upon the nectar-yielding flower. It also exhibits a similar result of the chemical test as for other carbohydrate sweeteners (Hasam et al. 2020). Honey has wide applications in baked goods, confectionery, and dairy products. Another natural sweetener is maple syrup (the first man-made sweeteners in America) obtained from the sugar maple tree *Acer saccharum*. It is costlier than sucrose and other starch-based sweeteners. Consequently, adulteration in maple syrup and related products is commonly seen in the marketplace (Paradkar et al. 2003). The physical properties of maple syrup are also similar to sucrose syrups which make it a perfect fit for confectionery and baking. The concentrated juice of sugar cane or sugar beet, called molasses, is generally used as animal feed and to produce alcohol through fermentation. Now with the help of technological advancements, molasses is also being transformed into food products. Cane syrup is another sweetener used in baked goods and candy products. This product is made at sugar cane plants or refineries and is well known in the United States. The composition of some popular sweeteners is given in Table 1.

Table 1 Chemical composition of sweeteners

	Honey	Maple syrup	Cane molasses
Component	Average (weight %)		
Calcium		0.07	
Citric acid	0.010		
Fructose	38.5		5–12
Fumaric acid		0.004	
Glucose	31.0		4–9
Hexoses		0.0–7.9	
Insoluble ash		0.08–0.67	
Malic acid		0.093	
Maltose	7.2		
Manganese		0.005	
Nitrogenous compounds			2.5–4.5
Proteins	0.3		0.5–1.5
Silica		0.02	
Sodium		0.003	
Soluble ash		0.30–0.81	
Succinic acid		0.008	
Sucrose	1.5	58.2–65.5	30–40
Vitamins	0.2[a]		
Water	17.1	34.0	

[a]Along with minerals

3 The Quest for an Ideal Sweetener

From the foregoing note, it is clear that sugar or caloric sweeteners are the most popular among consumers because of its properties. Sugar has become an indispensable part of our food diet, and thus progressively its overconsumption has been linked to various health issues (Lustig et al. 2012; Willett and Ludwig 2013). There is another category of sweeteners called intense sweeteners that are very diverse, from "amino acid" to "halogenated sugars." The sweetness of these compounds ranges from 30 (e.g., cyclamate) to 2000 (e.g., alitame) times than sucrose. Most of the intense sweeteners are discovered accidentally such as saccharin. Sweetness is subjective to and dependent on several factors, including temperature, pH, the medium used, the concentration of the sweetener, and the taster's sensitivity. Sucrose is the typical standard and is assigned a sweetness of "1." According to scientists, the ideal sweetener does not exist. It is said that an ideal sweetener should be as sweet as sucrose, it should be colorless, odorless, non-cariogenic, pleasant in taste, and economically viable. Further, the applications of such sweeteners should also be very versatile. On a common note, the different type of sweeteners are compiled in Fig. 1.

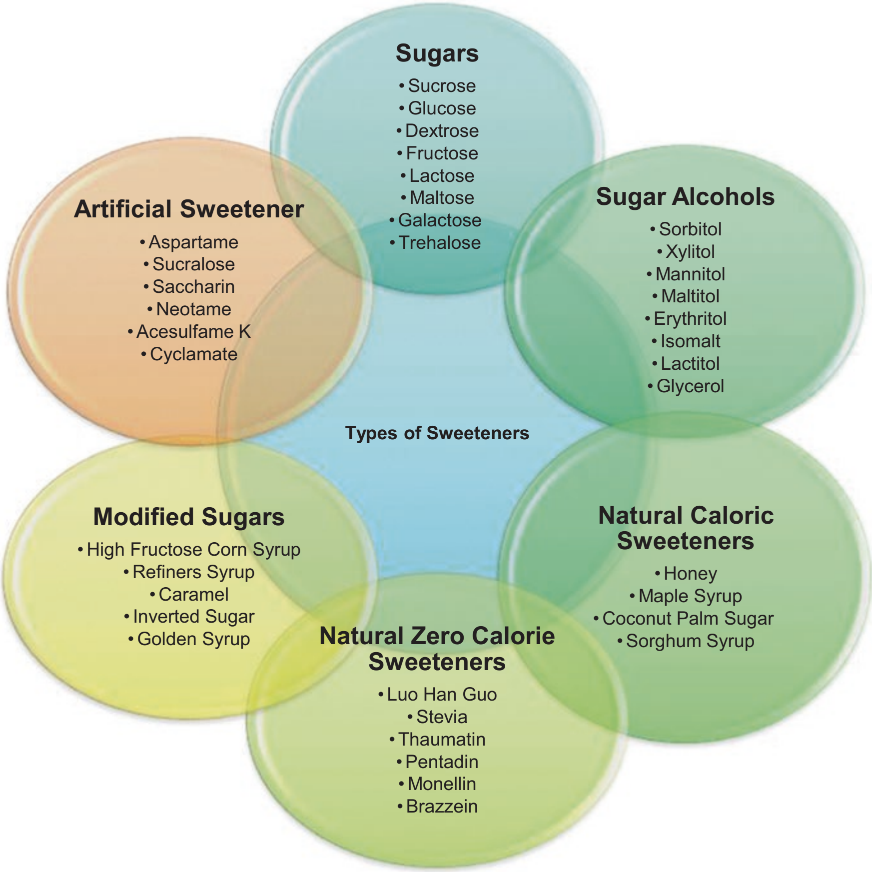


Fig. 1 Types of sweeteners

The search for ideal sweeteners led to the discovery of artificial sweeteners (Chattopadhyay et al. 2014). There are many low-calorie, or no-calorie popularly called zero-calorie, sweeteners available on the market as sugar substitutes (de Samaniego-Vaesken et al. 2020). Saccharin was the first discovered no-calorie or low-calorie sweetener. After that, many sweeteners were synthesized in laboratories and isolated from natural sources. Majority of these sweet compounds are organic and superior over saccharine. Aspartame and saccharine are called “high-intensity” or “intense” sweeteners. However, more term further proposed for such sweeteners was artificial sweeteners and natural sweeteners. However, due to the inappropriateness of these terms, the sweeteners are now termed nutritive and or non-nutritive sweeteners. The commercial viability of the non-nutritive sweeteners depends upon the factors as follows:

3.1 Taste Quality

The consumers do not readily accept the new sweeteners with changes in taste quality despite having other advantages such as low-calorie content. Beverages and carbonated soft drinks (CSDs) were the food products sweetened with the non-nutritive sweeteners. Several efforts were made to improve the taste quality of these sweeteners. The taste quality largely depends upon the type of food product in which the sweeteners are being used. However, its best measure of taste quality depends only on the consumer study.

3.2 Safety

Natural sweeteners are seeming to have no toxicity unless studies regarding their adverse effects on human health were undertaken. The research regarding the adversity of natural sweeteners led to the formulation of legislation over the use of these sweeteners and other additives. Except a few sweeteners, not all the sweeteners are listed in generally recognized as safe (GRAS) list.

3.3 Solubility and Stability

Solubility of sweeteners is the prime requirement in many manufacturing processes. The sweeteners with high solubility and dissolution rates are preferred for general utility. The second parameter is the stability of sweeteners under intended conditions of use. The stability ensures long-term usage of stored food products and their sweetening property.

3.4 Cost

Compared to sucrose, which is one of the most cost-effective sweeteners, the other alternatives must be either low cost or should have sufficient advantages to match their costs. The sweetening potency (P) generally expressed on a weight basis (Pw) is not constant for different sweeteners. Pw for a sweetener changes according to the reference sucrose concentration. For example, Pw for aspartame [Pw (0.34) = 400] is about 0.34% sucrose reference, while at 10% sucrose reference it is Pw (10) = 100. The sweetening potency P also gets affected by food system and temperature.

4 Plant-Derived Sweeteners

There has been an increased demand of low-calorie or no-calorie sweeteners in the market. Many alternatives are available to the consumers. But there is always a question in their minds that which one of the alternative sweeteners is good for health. Therefore, the demand for natural sweeteners has profoundly increased over artificial sweeteners (Tandel 2011). Plant-based sweeteners are natural and, apparently, have no side effects (Kinghorn et al. 1986). Among the many plant-based sweeteners, the difference is in their flavor profile (Philippe et al. 2014). The search for plant-based natural sweeteners also geared up in the last decades (Grembecka 2015). Despite being natural, the plant-derived sweeteners also need to be researched for their effect on human health and safety. The chemical/ molecular structure of different plant-derived sweeteners is compiled in Fig. 2. Following is a discussion on natural plant-derived sweeteners.

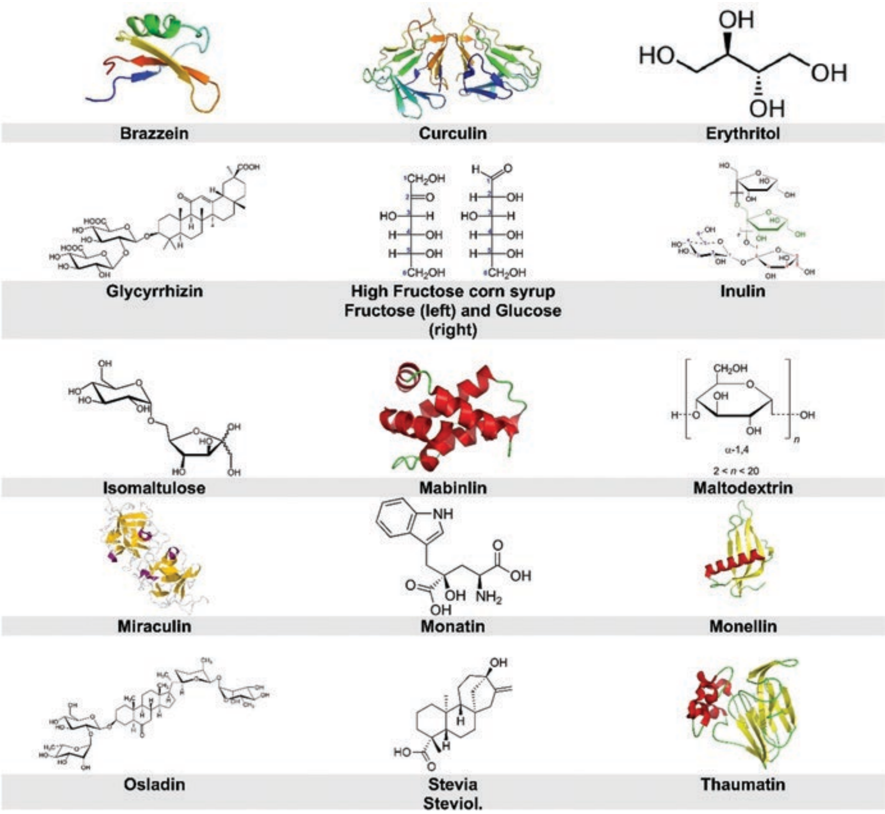


Fig. 2 Chemical and molecular structure of plant-derived sweeteners

4.1 Brazzein

Brazzein is a protein with sweet taste obtain from Oubli (*Pentadiplandra brazzeana* Baillon) which is an evergreen shrub that belongs to the family Pentadiplandraceae. For the protein brazzein, there is a taste receptor protein (TAS1R3) found in primates (Nishi et al. 2016). Wild animals usually get attracted toward this plant's sweet berries and help disperse its seeds. The plant parts, namely, leaves, roots, tubers, and berries are used in traditional culture in many ways. The roots hung are used to repel snakes, while root bark powder is used as an ingredient in African whiskey. Root is also used as vegetable, and its syrup is also marketed throughout the Congo basin (Ming and Hellekant 1994).

This plant is a monoecious shrub of 5 m (as a shrub) to 20 m (in the form of liana high in the trees) (Ming and Hellekant 1994; Bayer and Appel 2003). This plant is found in West Africa and is known to produce red berries with this sweet protein brazzein. Despite its sweetening property, this sugar alternative is not yet approved as a food additive in the United States and European Union.

Due to expensiveness of berries, the newer biofermentation technology is being used to produce brazzein from the food-grade bacteria (Berlec et al. 2008). The process is very cost-effective and more standardized compared to the traditional farming methods.

4.2 Curculin

Curculin is also a sweet protein obtained from the fruits of *Curculigo latifolia* (belongs to the family Hypoxidaceae) found in Malaysia. Curculin is a taste modifier, makes water, and sour solution taste sweet after its consumption. The protein curculin is a heterodimer consisting of two monomeric units (12.5 kDa and 12.7 kDa) connected through disulfide bridge (Yamashita et al. 1995).

Curculin is a high-intensity sweetener that is 430–2070 times sweeter than sucrose. Its taste-modifying property gets affected in the presence of divalent cations (Suzuki et al. 2004). Like most other proteins, it is also susceptive to heat and loses its sweetening and taste-modifying property at 50 °C. Because of its heat sensitivity, it is not a good candidate for hot or processed food (Yamashita et al. 1995).

Curcumin is not readily available from its natural source; therefore, alternative methods for its manufacture are being studied. The recombinant curculin protein initially produced in *E. coli* and yeast was lacking the sweet-tasting property. Later in 2004, the efforts yielded the recombinant curculin from *E. coli* with its distinct sweetening property (Suzuki et al. 2004). The challenges related to regulatory and legal issues in commercializing the recombinant curculin also need to be resolved before marketing it as a sweetener.

4.3 Erythritol

John Stenhouse a Scottish chemist discovered erythritol in 1848, and it was first isolated in 1852. Erythritol is naturally found in some fruits and fermented food (Jeya et al. 2009). At the industrial level, it is produced by fermenting glucose with yeast (Moon et al. 2010). Erythritol has been used in many food and drink products as a sweetener and flavor enhancer with approval in more than 60 countries.

Erythritol readily gets absorbed in the blood and attains peak within two hours followed by its extraction in the urine with almost 90% unchanged form (Rakicka-Pustułka et al. 2020). The scientist found some mild gastrointestinal upset with abdominal bloating and stool frequency associated with different doses of erythritol (Munro et al. 1998). The European Food Safety Authority came up with the recommended doses as 0.6 gm per kg body weight.

The caloric amount of erythritol is 0.2 kilocalories per gram which is 95% less than sugar and other carbohydrates. Erythritol is not metabolized by oral microbes and thus no risk of tooth decay. It also has an antibacterial effect on oral bacteria and helps reduce dental plaques.

4.4 Fructooligosaccharide

Fructooligosaccharides (FOS) (oligosaccharide fructans) are an alternative sweetener generally obtained from blue agave plants. Fruits, vegetables, grains, and cereals are also the source of FOS, and it is also referred to as oligofructose or oligofructan (Campbell et al. 1997). Among the cultured plants, the Jerusalem artichoke together with the blue agave has maximum concentrations of FOS.

Because of its prebiotic property, the FOS is now becoming a popular sweetener in Western countries. It acts as a substrate for intestinal microflora, thereby improving the overall intestinal health (Sabater-Molina et al. 2009). FOS is also reported to encourage calcium absorption in lab animals and also in human intestine (Morohashi et al. 1998; Ohta et al. 1998). By reducing gut pH, it improves calcium availability in the bloodstream from ingested food (Morohashi et al. 1998).

At the commercial level, FOS is produced by inulin degradation or transfructosylation (Sangeetha et al. 2005; Mutanda et al. 2014; Wang et al. 2016). According to reports, the FOS may also be fermented by other pathogenic bacteria, such as *Klebsiella*, *E. coli*, and *Clostridium*, that results in gas formation in the intestines (Mao et al. 2015). The FOS is listed in GRAS, although many countries have their own regulations to use it.

4.5 Glycyrrhizin

Glycyrrhizin is obtained from the roots of licorice (Hayashi and Sudo 2009). Glycyrrhizin is 50 times sweeter than sucrose and has a low glycemic index. Because of the strong licorice flavor, it is not used as a sweetener on its own but for sweets, chewing gum, lozenges, and medicine. Glycyrrhizin has its main application in the treatment of ulcers and in the manufacture of cough mixtures and toothpastes (Gao et al. 2009; Fu et al. 2013). The admissible limit of its intake is 100 mg/day, but excessive intake may imbalance sodium and potassium in the body.

4.6 High Fructose Corn Syrup

High fructose corn syrup (HFCS) is obtained from corn and contains both glucose and fructose. In the United States, it is used in processed food and drinks as a replacement for regular sugar. A syrup is made from genetically modified corn followed by converting its glucose into fructose by enzymatic treatment (Skryabin and Tutelyan 2013). The HFCS includes varying amounts of fructose, such as HFCS 90 contains 90% fructose and it is the most concentrated form, while the HFCS 55 is like sucrose as it contains almost 50% glucose and 50% fructose. Difference between an HFCS and regular sugar is that its liquid contains 24% water compared to dry and granulated sugar. Chemically glucose and fructose are not bounded in HFCS as in regular sugar. In our body, liver metabolizes significant amounts of fructose and turns the overdose into fat that may contribute to fatty liver (Collison et al. 2009). High fructose is also linked to body ailments, namely, insulin resistance, obesity, and type 2 diabetes (Basciano et al. 2005). All these problems arise due to excessive sugars, not because of fruit consumption that also contain other nutrient fibers and antioxidants.

4.7 Inulin

Inulin is a fiber (soluble) extract from a root vegetable primarily chicory. It has low sweetness and is used as low-calorie sugar substitutes mainly to add bulk to products. Inulin has zero glycemic index and is good for diabetes (Kalyani Nair et al. 2010). It is also prebiotic, known to promote the growth of bacteria in the colon, and improves nutrient absorption (Struck et al. 2014). The excess intake of insulin is associated with cramps, and it also demonstrates the laxative effects (Den Hond et al. 2000).

4.8 Isomalto-Oligosaccharide

Isomalto-oligosaccharide (IMO) occurs naturally in honey (in small quantities) and in fermented foods (miso and soy sauce) (Park et al. 2016). It is a moderately sweet carbohydrate consisting of 3 to 6 glucose molecules with indigestible glycosidic bonds. IMO is generally used to make protein bars and health bars. It contains half the calories of sugar and has a very low glycemic index. Like inulin, IMO also adds fiber to the diet and acts as prebiotic (Oku and Nakamura 2003). It also helps the body to absorb minerals from food.

4.9 Isomaltulose

Isomaltulose is a disaccharide carbohydrate made up of glucose and fructose. It is naturally found in honey and sugarcane extracts (Eggleston and Grisham 2003). In taste, it is like table sugar but with half sweeteners. Commercially, it is produced from isomerization of sucrose from beet sugar by enzyme treatment. Isomaltulose is approved to be used as sweetener in many countries including Japan, United States, and European Union. Because of its physical property and similarity to sucrose, it can easily be used as a replacement for sucrose in different recipes and processes. Isomaltulose is a reducing sugar and has low glycemic index compared to sucrose.

4.10 Luo Han Guo

Luo Han Guo popularly known as monk fruit or Luohan guo (*Siraitia grosvenorii*) is native to Guangxi province in Southwest China (Kasal et al. 1989). The plant is cultivated mainly for its fruit. In China, it has been known for more than 800 years. It is being used for medicinal purposes and as a major antioxidant. The sweetening taste is due to mogrosides which is 300 times sweeter than sucrose. Monk fruit has a zero glycemic index, has no calories, and thus suitable for diabetics. This sweetener is used as a bulking agent and appropriate for cooking and baking.

4.11 Mabinlin

Mabinlins (Sweet tasting proteins) are obtained from the seeds of a Chinese plant mabinlang (*Capparis masaikai* Levi.). It has four homologs of which mabinlin–2 (Mol wt. 10.4 kDa) was first isolated in 1983 (Hu and He 1983). Mabinlin–2 has the highest thermostability due to the four disulfide bridges (Guan et al. 2000).

Mabinlins are 100–400 times sweeter than sucrose on a molar basis and 10 times sucrose on a weight basis. Heat stability and solubility in water make it a good choice as a sweetener. Attempts are also made to produce mabinlin–2 at the industrial level (Kohmura and Ariyoshi 1998). Efforts were also made to produce Mabinlin–2 through a transgenic approach. (Sun et al. 2000; Hu et al. 2009).

4.12 Maltodextrin

Maltodextrin is a group of complex sugars produced enzymatically from starch. Its complexity depends on the method of production. Maltodextrin is not suitable for diabetics due to the high glycemic index (85–105) (Sardarian et al. 2020). It is used in the food industry for various purposes, such as thickening the sauces and broth, soup powder, coffee whiteners, and in pharmaceutical industry as binders. Maltodextrin is hugely popular among bodybuilders as it helps in quick recovery after workout.

4.13 Maple Syrup

Maple syrup, a popular natural sweetener, is made from sap or fluid of sugar maple trees (Lebedev 2010). Eastern Canada is the world's largest producer of maple syrup. It is available in different grades based on color. Grade A has light color while Grade B is the darkest. The darker syrups have a strong maple flavor. Maple syrup is rich in minerals and antioxidants. It is about two-third of table sugar and has its overconsumption associated with health issues like heart disease, type 2 diabetes, and obesity.

4.14 Miraculin

Miraculin is a protein obtained from the “Miracle Fruit” from West Africa. Berries coat the tongue upon chewing and change the taste perception for a period (Kurihara 1992). It has a zero glycemic index and hence is good for diabetics. The commercial potential of miraculin is not fully explored yet accepted for its use in the sweetening of sodas and ice lollies (Brouwer et al. 1968). Miraculin is helpful for patients suffering from poor taste of food due to certain treatments. It does not have GRAS approval in United State but in Japan and certain other countries. (Hirai et al. 2010)

4.15 Monatin

Monatin, commonly known as arruva, is obtained from the roots of a shrub that is native to South Africa. It is a natural sweetener found as four distinct molecules in the bark and root. Monatin is 3000 times sweeter than sugar. In taste, it is close to aspartame and superior over stevia and monk fruit. The industrial production through extraction or artificial synthesis is not possible for this molecule (O'Donnell and Kearsley 2012). It has zero glycemic index and classified as intense sweetener (Kulik and Waszkiewicz-Robak 2018).

4.16 Monellin

Monellin is also a natural sweeter with 1500 times more sweetness than sucrose. It is obtained from Serendipity Berry (native to Central and West Africa) (Morris et al. 1973). The Serendipity Berry is also featured in the 1972 Guinness Book of World Record. It became the first natural protein sweetener found in 1969. It contains four calories per gram but does not show any heat and pH stability (Kinghorn and Compadre 2016). Consequently, it is not appropriate for cooking or processing foods. So far, this sweetener has been approved only in Japan (Kim and Kinghorn 2002a).

4.17 Osladin

Osladin, a saponin, is isolated from the rhizome of *Polypodium vulgare*. It is 500 times sweeter than sucrose (Yamada and Nishizawa 1995).

4.18 Pentadin

Pentadin comes from the Oubli plant (native to West Africa). It is 500 times sweeter than sugar and contains four calories per gram (van der Wel et al. 1989). This sweetener was discovered in 1989 but remained unpopular and shadowed by brazzein. In terms of sweetness and flavor, it is not much appreciated. Furthermore, its pharmaceutical and food applications need to be examined.

4.19 Stevia

Stevia (*Stevia rebaudiana*) is a plant native to Paraguay in South America. Its leaves contain two compounds, stevioside and rebaudioside, which are 300 times sweeter than sugar. It has zero glycemic index and not harmful to teeth (Ashwell 2015). Stevia is now being cultivated in many countries of the world. It is heat stable and hence suitable for cooking and processing food. The product is sold in the market as powdered leaves or concentrated stevioside. Coca-Cola and Pepsi both are using stevia in their products called Truvia and PureVia, respectively. In Japan, it is being used since 1970s and approved there as a sweetener.

4.20 Thaumatin

Thaumatin is a protein that comes from katemfe fruit (*Thaumatococcus daniellii* Bennett) native to West Africa (Green 1999). It stands 2000 times sweeter than sugar. It has a zero glycemic index and is thus suitable for diabetics. It has GRAS in the United States and European Union as E957.

5 Natural High-Potency Sweeteners

Due to the increased demand for non-nutritive natural sweeteners, the search is being undertaken in all parts of the world. There are many natural non-carbohydrate sweet-tasting compounds known to man. Among the natural sweeteners, sweet proteins are unique in that they have no modified amino acids. These protein sweeteners have high potency compared to sugar and decompose into amino acids on hydrolysis. Such proteins also have an advantage that they can be used as probe molecules for basic science studies. Thaumatin and monellin are the most studied protein sweeteners. Recently, many other protein sweeteners have been discovered for which a brief comparative is compiled in Table 2 along with the information on artificial sweeteners in Table 3.

6 Sugar Alcohol

Polyols differ from other saccharides by reducing aldehyde or ketone functions. Some sugar alcohols are present in nature, especially in the vegetable kingdom, but since their extraction is hardly a viable proposition, they are produced industrially by the hydrogenation of the corresponding saccharides. The chemical structure of different plant-derived sweeteners is compiled in Fig. 3. Substitution in a sugar of

Table 2 Natural high potency sweeteners of plant origin

Class of sweeteners	Example	Plant source (plant part used)	Found in	Sweet principles	$P_w(10)$	References
Protein sweeteners	Thaumatin	*Thaumatococcus daniellii* Benth (Katemfe berry)	Tropical Western Africa	Thaumatin I and II	1600	Inglett (1976), Ayodeji et al. (2016)
	Monellin	*Dioscoreophyllum cumminsii*, (serendipity berry)	Western Africa	Sweet protein	3000	Morris and Cagan (1972), Morris et al. (1973), Wlodawer and Hodgson (1975)
	Sweet albumins	*Capparis masaikai* Levi (seeds)		Mabinlin I and mabinlin II	11,600 and 10,400	Liu et al. (1993), Nirasawa et al. (1993)
	Sweet protein	*Pentadiplandra brazzeana* (fruits)	Tropical Africa	Pentadin	12,000	van der Wel et al. (1989)
	Curculin	*Curculigo latifolia* (pulp of the fruit)	Western Malaysia	114 amino acid polypeptide	24,000	Yamashita et al. (1990), Barre et al. (1997)

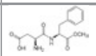
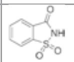
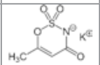
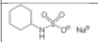
(continued)

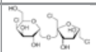
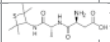
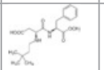
Table 2 (continued)

Class of sweeteners	Example	Plant source (plant part used)	Found in	Sweet principles	$P_w(10)$	References
Terpenoid sweeteners	Monoterpenoid	*Perilla frutescens*		Volatile oil	770	Liu et al. (2017), Dong et al. (2019)
	Sesquiterpenoid	*Lippia dulcis* Trev.		Hernandulcin	1800	Douglas Kinghorn and Kennelly (1995), Souto-Bachiller et al. (1996)
	Diterpenoid	Pine tree; *Stevia rebaudiana* Bertoni	Northeastern part of Paraguay	Rosin; diterpenoid glycosides	1600	Barton (1949), Yadav et al. (2011), Bouwmeester (2019)
	Triterpenoid	*Glycyrrhiza glabra* L. (roots)	Europe and Central Asia	Glycosides glycyrrhizin (Licorice "the crude extract of the plant")	33	Batiha et al. (2020)
		Periandra dulcis Mart.	Brazilian Licorice	Glycyrrhizin, oleanane-type triterpenoid glycosides		Negri and Tabach (2013)
		Polypodium vulgare L. (rhizomes)		Osladin	300	
		Polypodium glycyrrhiza	Pacific northwest region of the United States	Polypodoside A	600	Kim et al. (1988)
		Mamordica grosvenorii		Aglycone mogrosides IV and V	150	Kinghorn et al. (1986), Kinghorn (1987), Pawar et al. (2013)
		Bryonia dioica Jacq		Bryodulcosigenin A derivative of aglycone		Lavie and Glotter (1971)
		Hemsleya carnosiflora		Glycosides V and VI		Kinghorn et al. (1995)
		Abrus precatorius L. (leaves)		Abrusoside		Choi et al. (1989)

Class of sweeteners	Example	Plant source (plant part used)	Found in	Sweet principles	$P_w(10)$	References
Polyketide sweeteners	Dihydroisocoumarin	*Hydrangea macrophylla* (leaves)		Phyllodulcin, A 3,4-dihydroisocoumarin	400	Kinghorn et al. (1986)
	Dihydrochalcone.	*Smilax glyciphylla* (leaves)		Glycyphyllin		Soumyanath (2005)
		Symplocos microcalyx (leaves)		Trilobatin		Kinghorn et al. (1986)
		Lithocarpus litseifolius (leaves)	Yunnan, China	Phlorizin and trilobatin		Rui-Lin et al. (1982), Chen et al. (2009), Wei et al. (2020)
	Flavanone	Citrus fruits		Neohesperidin		Rouseff et al. (1987), Kroeze (2000)
		Engelhardtia chrysolepis (leaves)	Guangdong, Guangxi and Fujian, China	Dihydroflavonol rhamnoside		Kasai et al. (1991), Kim and Dubois (1991), Meng et al. (2020)
		Tessaria dodoneifolia (shoots)	Paraguay	Dihydroflavonol acetate	80-, 400	Kim and Kinghorn (2002b)

Table 3 Artificial sweeteners and their properties

Sweetener	Structure	Discovered/ developed in	Discovered/ developed by	Molecular formula	Molecular mass in g·mol^{-1}	Melting temperature in °C	Sweetness	Use in	Side effects
Aspartame		1965	James M. Schlatter	$C_{14}H_{18}N_2O_5$	294.307	246–247	200	Tabletop sweeteners, foods, and beverages, recipes that don't require too much heating and as a flavoring in medicines.	Aspartame is tried to be linked with many health problems such as cancer, heart diseases, stroke, dementia, headaches and migraines, etc.
Saccharin		1870s	Ira Remsen and Constantine Fahlberg	$C_7H_5NO_3S$	183.18	229–230	300	Food, beverages, and confectionery products	Headaches, breathing difficulties, diarrhea, and skin problems
Acesulfame K		1967	Clauss and Jansen	$C_4H_4KNO_4S$	201.24	225	200	Tabletop sweeteners, puddings, soft drinks, cough syrups, and toothpaste	Contains methylene chloride (a carcinogen). Its long-term exposure can cause headaches, depression, nausea, mental confusion, liver effects, kidney effects, visual disturbances, and cancer in humans
Cyclamate		1937	Michael Sveda	$C_6H_{12}NNaO_3S$	201.22	169–170	30–50	Baked goods, confections, desserts, soft drinks, preserves, and salad dressings.	Headaches, breathing difficulties, diarrhea, and skin problems

Sweetener	Structure	Discovered/ developed in	Discovered/ developed by	Molecular formula	Molecular mass in g·mol^{-1}	Melting temperature in °C	Sweetness	Use in	Side effects
Sucralose		1977	Tate and Lyle	$C_{12}H_{19}C_{13}O_8$	397.64	125	600	Food and beverage	Gastrointestinal problems, seizures, dizziness, and migraines, blurred vision, allergic reactions, blood sugar increases, and weight gain
Alitame		1980s	Pfizer	$C_{14}H_{25}N_3O_4S$	331.431	--	2000	Cooking and baking	No side effects
Neotame		1992	Claude Nofre and Jean-Marie Tinti	$C_{20}H_{30}N_2O_5$	378.469	80.9–83.4	8000	Flavor enhancer in foods (except in meat and poultry)	Low body weight gain

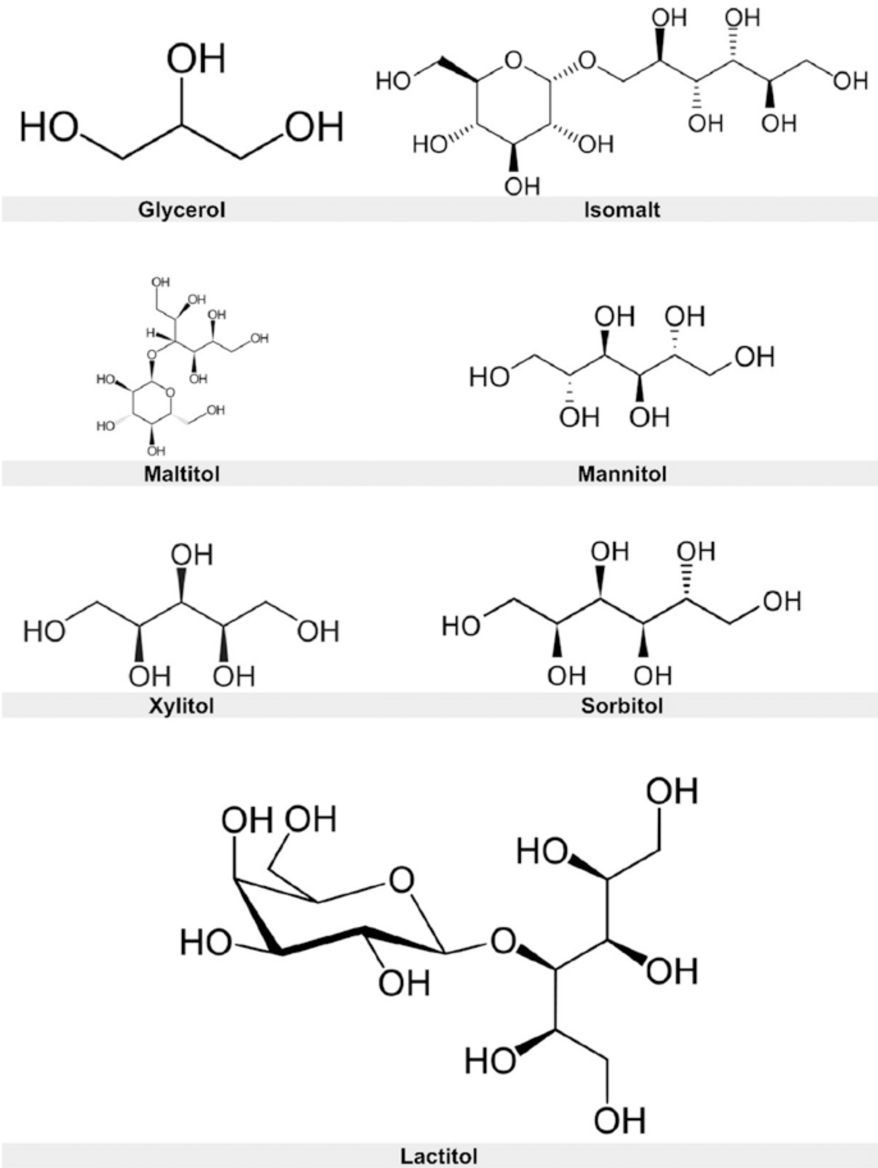


Fig. 3 Chemical structure of sugar alcohols

an alcohol function rather than an aldehyde or ketone group turns a cyclical form into a linear form and has the following implications:

- Greater chemical stability
- Higher affinity for the water
- Lower capacity to crystallize
- Lack of the Maillard response

6.1 Glycerol

Glycerol or glycerin usually obtained from soybean, coconut, or palm oils is called vegetable glycerin and made from animal and petroleum products. Glycerin is an odorless, low-calorie (4 calories per gram), and with a mild-sweetening taste sugar alcohol (polyol). It has a low glycemic index (Only 3—sugar is 65) which makes it good for diabetics, but it is not very popular as a sweetener. Vegetable glycerin has its main application in cosmetics. Glycerin has its applications in surgery, in laxative, and as part of many lotions and creams. Glycerin is harmless to teeth with no side effects except discomfort on taking it to excess.

6.2 Hydrogenated Starch Hydrolysates

Hydrogenated starch hydrolysates (HSH) is a sugar alcohol produced from starch. This sugar alcohol contains a high amount of sorbitol and maltitol. HSH is used in foods to provide bulk and texture. It also has a low glycemic index which makes it a suitable part of a diabetic diet. HSH is used to make sugar-free sweets and other low-calorie foods.

6.3 Isomalt

Isomalt is sugar alcohol with no effect on blood sugar levels. Its energy values account for half of sugar (Duffy and Anderson 1998). Like other sugar alcohol, it also carries a risk of stomach distress when consumed in large quantities. Its blend with high-intensity sweetener like sucralose is just as sweet as plain sugar. Isomalt is approved for use in many countries including the United States, Australia, Canada, Mexico, European Union, etc.

6.4 Maltitol

Maltitol is a sugar alcohol with less calories but a high glycemic index which makes it unsuitable for diabetics. It is described as natural sweetener due to its presence in chicory leaves (Rozzi 2007). Still, it is produced commercially from cereal crops. Maltitol is being used in processed foods such as sugar-free chocolate and coating of hard candies and chewing gums (Saraiva et al. 2020). Like other sugar alcohols, it also has a slightly laxative effect once consumed in large quantities (Saraiva et al. 2020). Maltitol has been approved for use in many countries.

6.5 Mannitol

Mannitol (a sugar alcohol) has low glycemic index which makes it appropriate for diabetics (Chen et al. 2020). However, its caloric count is not very low compared to sugar (1.6 calories/ gram). Because of its nonhygroscopic property, it is suitable for coating candy, pills, and tablets. Mannitol has numerous medical applications like in the treatment of head trauma, kidney failure cystic fibrosis, and as laxative for children (Chen et al. 2020). Mannitol is commercially manufactured from fructose or glucose syrup. Cargill is a world leader in the production of mannitol under brand names Mannidex and Roquette.

6.6 Xylitol

Xylitol is a sugar alcohol (polyol) with lower calories and very less glycemic index (Natah et al. 1997). Like the other animals, our body naturally produces it during metabolism (approximately 5 to 15 gm per day). Xylitol is found in small quantities in vegetables and fruits. Birchbark contains its highest natural concentration. Xylitol was found in 1890 and was widely used during World War 2 (Delgado Arcaño et al. 2020).

6.7 Sorbitol

Sorbitol also known as glucitol is sweet in flavor and widely used sugar alcohol. It is produced primarily from the potato starch and by the reduction of glucose. Sorbitol is also found in the wild in many fruit crops such as apples, peaches, prunes, etc (Forni et al. 1992; Lee 2015). Sorbitol is an isomer of mannitol that is another sugar alcohol. Sorbitol contains two-third calories of table sugar and its sweetness is 60%. It does not contribute to dental wear but not fully digested in the bowel. Sorbitol is used in the making of sugar-free chewing gum and liquid prescription. Overconsumption of sorbitol is sometimes linked to bloating and diarrhea (Jain et al. 1985; Badiga Jain et al. 1990). It is also viewed as less risky, non-stimulative laxative. Despite having so many adverse effects, sorbitol is approved by regulatory agencies in various countries.

6.8 Lactitol

Lactitol is a synthetic disaccharide primarily used for the treatment of constipation and liver encephalopathy (Morgan and Hawley 1987). It is like a lactulose-like glucose molecule that contains galactose as well as sorbitol. Lactitol is just 40%

sweeter than sugar and good for low-calorie diets. Due to its high stability, it is also used in making various bakery products (van Velthuijsen 1979; Zhang et al. 2020). Lactitol is used as prebiotic and in the treatment of constipation.

7 Effect of Sweeteners on Health

7.1 Effect on Dental Health

Over the past decade, the prevalence of dental caries among children, teenagers, and young adults has dropped substantially in most developed countries. This has resulted in a growing percentage of caries-free individuals and improved dental health. Dental caries is a complex sugar-dependent bacterial disease in which three main factors can be identified: host with susceptible teeth, substrate, and cariogenic microorganisms. The presence and interaction of all three factors are needed if dental caries are to develop.

The bacteria mainly *Streptococcus mutans* and *Lactobacilli* play a key role in fermenting dietary carbohydrates and converting them to acidic end products (lactic acid) followed by initiation of caries and demineralization of tooth surface (Hamada 2002). *Streptococcus mutans* can tolerate high sucrose concentrations. The effect of different plant-derived sweeteners and other sweeteners on dental health are already discussed above.

7.2 Effect on Metabolism

With the increased use of sweeteners, their health implications have become a major concern. The way these sweeteners affect metabolism and problems that are encountered by the patient with metabolic diseases such as diabetes and phenylketonuria require research focus (Finer 1991).

The basis of knowledge on metabolisms of different foodstuffs is the study of their single doses. However, actual digestion, absorption, and metabolisms of food depend on its physical condition which is addressed only very recently.

Absorption depends on its various factors, namely, rate of gastric emptying, digestion, and time of transit through the gut, etc. Bacteria in large bowel ferment undigested food (carbohydrates) into metabolites, including carbon dioxide, hydrogen, and methane which leads to abdominal pain and diarrhea.

7.3 Effect on Body Weight

Consumers are always concerned about their body weight, shape, figure, and fitness. Additionally, the doctors have raised the concern to avoid obesity and its related degenerative diseases. The role of sugars in obesity is only profound when sugar-rich diets or drinks are habits and susceptibility to weight gain (Devaux et al. 2011; Choo et al. 2015; Rippe and Angelopoulos 2016). People are mostly conscious about oily food on their diet but not about sugar. Hence, the role of low-calorie sweeteners becomes more profound in connection with this. Such alternative sweeteners provide a sweet taste and low or no calories. These low-calorie sweeteners (LCS) replacement in diet can benefit in weight management. LCS can be made part of more beverages and baking products. However, at the same time, the safety and health benefits of available sweeteners are a major concern. Many studies are underway to ensure the safety of LCS and are recognized by various international scientific expert committees such as the USFDA and JECFA managed jointly by the Food and Agriculture Organization of the United Nations (FAO) and WHO. In India, LCS is regulated by FSSAI (Kroger et al. 2006; Roberts 2016).

8 Conclusion

People are more aware of their weight management and controlling sugar element appears to be one of the effective ways. Completely removing sugar from the diet is not possible since it is one of the major ingredients of our households. Their concern ends up with the emergence of low-calorie sweeteners. Low-calorie sweeteners are used as food additives in place of sugar. There are many low-calorie or zero-calorie sweeteners available in the market. The source of these sweeteners is either natural or man-made (artificial). Sweeteners from natural sources have some limitations such as odd taste profile, unsuitable physical and chemical properties, stability, shelf-life, raw material scarcity, etc. At the same time, the cost of producing natural sweeteners is also less competitive. Hence, we see the market is now flooded with many artificial sweeteners. However, many researchers are conducting studies on the safety of both type of sweeteners. There has been an increased awareness of health problems caused by artificial sweeteners. Therefore, a clear tilt of consumers can be seen toward natural sweeteners. Thus, it is obligatory to conduct a more detailed study on the cost-effective production of natural sweeteners and its impact on human health. The recent advancements in the field of biotechnology can boon the large-scale production of natural protein-based sweeteners. Sweetener enhancers, bitterness blockers, and approved sweeteners are well into commercial development

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Nutritional, Pharmaceutical, and Industrial Potential of Forest-Based Plant Gum

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Contents

1 Introduction

The research on forestry and forest products has introduced a new robust research agenda on multidisciplinary fields. Using the forest source, many bio-based materials have been developed as green, nontoxic, renewable, and safe materials, which have been proved to be good candidates for food and medical application. Recently, biopolymers have received much attention for minimizing the hazardous effects of synthetic polymers. In this light, polysaccharides of natural gums obtained from the

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forest have manifested a prosperous improvement in the aspect of bioeconomy and biotechnology. Most importantly, plant gum polysaccharides-based versatile green materials can be applied in health care, biomedicine, energy, tissue engineering, environment, pharmaceuticals, automobiles, food, and space industries (Madhusudhan et al. 2019). In particular, plant gums open up a new area in pharmaceutical and food industries due to their availability, structural diversity, unique physicochemical and rheological properties, and functional properties (Adnan et al. 2020; Alle et al. 2020b; Bandi et al. 2020).

From the forest, gums, resins, and latexes are collected and being utilized in our everyday consumed products. Because of their nontoxicity and cost-effectiveness, natural gums are used to prepare food products and consumed as safe food. In pharmaceutical preparations, they are implemented as an emulsifier, suspending agent, film coating agent, oral viscous syrup, ophthalmic formulation, and in the potential drug delivery system. Gum-based polymers are very interesting to the food scientist and any others involved with polymer application. Since natural polymers possess a great chemical and biological attributes, many researchers have effectively applied to wound healing dressings, artificial tissue engineering, nutrition, agriculture, environment, and chemical engineering (Whistler 2012; Hamdani et al. 2019; Barak et al. 2020). The present book chapter discusses the source, composition, classification advantages, food, industrial, and pharmaceutical application of gum polysaccharides.

1.1 Plant Gums

Gums are the natural exudate (plant's defense mechanism) of plants under stressed conditions (Barak et al. 2020). During dry and hot seasons, plants produce high amount of gums (Fig. 1) that can be enhanced by cutting and incising of the plant's bark (Kennedy et al. 2012). To define, gums are composed of sugars (covalent-bound) other than glucose, known as polysaccharides or complex carbohydrates, and commonly found in many higher plants (Shit and Shah 2014). They are colorless, chemically inert, tasteless, biocompatible, inexpensive, odorless, nontoxic, and widely available and also possess tunable physical, chemical, and biological properties. The common feature of gums is to produce viscous solution even at very low concentration (Saha et al. 2017). Hence, they have widespread demand in food and pharmaceuticals industries.

1.2 Chemical Composition and Characterization

The physical characteristics and functional potentiality of gums may vary depending upon their chemical composition and molecular structure (Varma 2012; Mohammadinejad et al. 2019). However, most of the gum polysaccharides are heterogeneous, containing a group of hydrophilic substances with high molecular

Fig. 1 Natural gum formed on the wounded branch of a tree (Cecil 2005)

masses which are commonly called "water-soluble gums" or "hydrophilic polymers" or "hydrocolloids" (Mirhosseini and Amid 2012). Chemically, hydrocolloids are composed of multifarious structures connecting through glycosidic bonds with a huge quantity of repeated hydroxyl (–OH) groups. Such excessive number of hydroxyl groups can simply interact with water not only within the lattice arrangement via hydrogen bonding but also inside the spaces creating composite molecular conformation. For this reason, gums are used in food and pharmaceutical products (Phillips and Williams 2000; Mirhosseini and Amid 2012). Various natural gums and their source, constituent units, and surface charge are shown in Table 1.

Usually, hydrolysis of the gums results in simple sugar units such as xylose, glucose, arabinose, uronic acids, and galactose, etc (Rana et al. 2011). The monomer of these sugars can be identified using various chromatography techniques. For the depolymerization of the gums, enzymatic hydrolysis (Willför et al. 2009) and acid methanolysis (Gifford et al. 1995) are implemented, whereas the linkage between gum's monosaccharides can be explored through methylation (Kang et al. 2015), periodate (Sarika et al. 2014), and lead tetra-acetate oxidation process (Perlin 2006). Further characterization including chemical composition, crystallinity level, monosaccharides contents, and thermal stability of the natural gums can be revealed by FTIR (Fourier transform infrared spectroscopy), XRD (X-ray diffractometer), HPLC (high-performance liquid chromatography), and TGA (thermogravimetric analysis) analysis (Brummer et al. 2003).

1.3 Classification

Based on the sources of fabrication, natural gums are divided into many groups (Fig. 2), such as plant (ghatti gum, karaya gum, kondagugu gum, tragacanth gum, and arabic gum), microbial (xanthan, curdlan, and gellan, dextran), seaweed (carrageenan, alginate, furcellaran, and agar), and botanical (gaur, locust bean, and pectin) (Phillips and Williams 2000; Bemiller 2008). Another classification of gums is

Table 1 Various natural gums and their source, constituent units, and surface charge (Ahmad et al. 2019)

Natural gum	Source	Constituents units	Surface charge
Gum arabic	Acacia arabica and acacia Senegal	β-D-glucopyranuronic acid, α-L-rhamnopyranose, β-D-galactopyranose, β-D-4Me-glucopyranuronic acid, α-L-arabinosefuranose, α-D-galactopyranose	Anionic
Gum karaya	Sterculia urens	α-L-rhamnopyranose, β-D-galactopyranose, α-D-galacturonic acid, β-D-glucopyranuronic acid	Anionic
Tragacanth gum	Astragalus gummifer	β-D-galactopyranose, β-D xylose, α-L-fucose, L-arabinose, α-D-galacturonic acid, α-D-galacturonic acid methylester	Anionic
Guar gum	Cyamompsis tetraganolobus	β-D-mannopyranose, α-D-galactopyranose	Nonionic
Xanthan gum	Xanthomonas campestris	β-D-glucose, β-D-mannose, α-D-mannose D-glucuronic acid	Nonionic
Gum ghatti	Anogeissus latifolia	β-D-glucopyranuronic acid, β-D-galactopyranose, α-L-arabinosefuranose, α-L-arabinopyranose, β-D-mannopyranose	Anionic
Locust bean gum	Ceratonia siliqua	β-D-mannose, α-D-galactose	Nonionic
Gellan gum	Pseudomonas elodea	α-L-rhamnose, β-D-glucose, β-D-glucuronic acid	Anionic
Tara gum	Caesalpinia spinosa	β-D-mannopyranose, α-D-galactopyranose	Nonionic
Gum kondagogu	Cochlospermum gossypium	β-D-glucopyranuronic acid, β-D-galacturonic acid, β-D-galactopyranose, α-L-arabinosefuranose, α-D-glucopyranose, β-L-rhamnopyranose, β-D-glucopyranose	Anionic

based on their surface charge which includes nonionic gums (tamarind gum, guar gum, xanthan gum, and locust bean gum) and anionic gums (carrageenans, karaya gum, gum arabic, and gellan gum) (Prajapati et al. 2013).

However, the regulatory status of gums in different countries depends on their safety status; for example, generally recognized as safe gums (carob bean gum, gaur gum, acacia, and gum ghatti) have been used as food or food additives, approved by the Canadian regulatory bodies "CLANI (Canadian list of acceptable non-medicinal ingredients"). Similarly, many licensed pharmaceuticals commonly use xanthan gum, acacia, gaur gum, and sodium alginate as an excipient in nonparenteral medicine (Deshmukh and Aminabhavi 2015). Depending upon the major applications, all such gums are extensively used throughout the world as one of the most biocompatible, sustainable, biodegradable, biosafety, and renewable industrial raw materials (Rana et al. 2011; Shao et al. 2015).

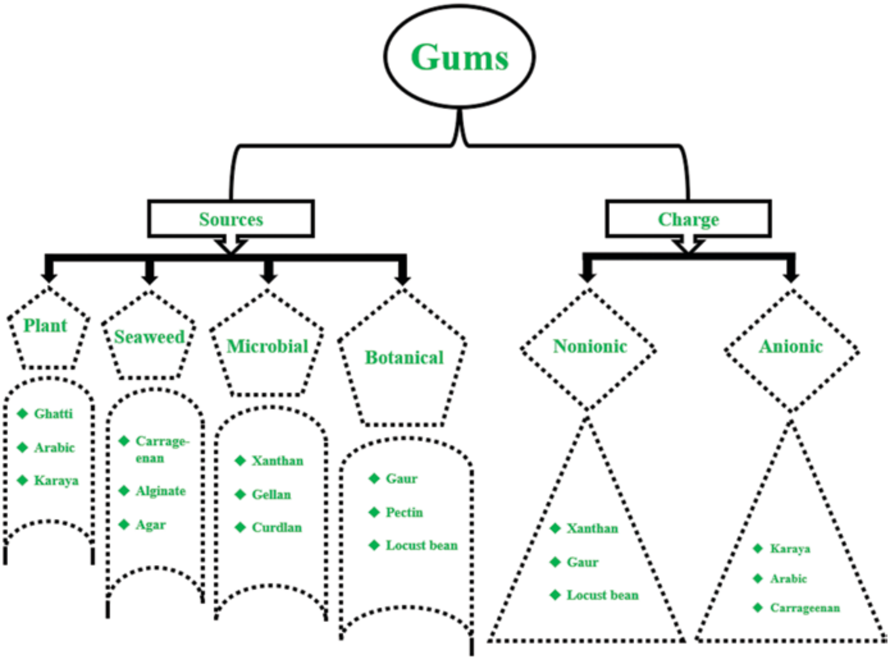

Fig. 2 Schematic representation of the classification of natural gums

1.4 Advantages of Gums

1.4.1 Edible Sources and Environment-Friendly Coating Agent

Recently, plant gums have become a source of interest in food applications due to their gelling, stabilization, emulsification, and thickening actions. The ancient history and toxicological reports indicate that some natural gums including tragacanth, ghatti, acacia, and karaya gum have been consumed as safe food (Barak et al. 2020). In addition, plant gums have great advantages as an edible coating agent for fruits and vegetables (Saha et al. 2017). Gums provide a protective layer on the surface of fruits and vegetables, thus enhancing their shelf-life and post-harvesting quality (Mohebbi et al. 2012). Usually, gum polysaccharides show strong barrier activities in low relative humidity conditions (Mellinas et al. 2016). Upon addition on the surface of the food commodities, gums create a semipermeable barrier that modifies the internal atmosphere and controls metabolic degradations (e.g. teste, color, quality, nutraceuticals, and antioxidants properties) by blocking gas and moisture exchange (Lima et al. 2010). The presence of a large number of hydrophilic moieties and other polar groups in the structure of gums produce hydrogen bonds that play pivotal roles in its film formation (Janjarasskul and Krochta 2010). The edible

Table 2 Advantages and applications of plant gum-based edible coatings (Saha et al. 2017)

S.N	Advantages	Coated food	Components of coating
1	Control transfer of moisture and oxygen, better wet ability	Seriguela, acerola, caja, mango and Pitanga fruits	Gum obtained from *Caesalpinia pulcherrima* and *Adenanthera. pavonina* with glycero
2	Reduces weight loss, color changes, and gas transfer rate	Cake, cheese	Galactomannan, glycerol, oil
3	Reduce microbial growth, increased shelf life	Cheese and cheese product	Galactomannan extracted from *Gleditsia triacanthos* with nisin
4	Improved appearance, shelf life extended	Fortune mandarin	Locust bean gum combined with beeswax and glycerol
5	Improved firmness, crispness, juiciness	Golden delicious apple	Locust bean gum in combination with lipid/hydrocolloid
6	Protect against mechanical injury, decrease respiration rate	Apple, mango	Gum obtained from *C. pulcherrima* and *A. pavonima* with collagen protein
7	Improvement of quality, texture	Citrus fruits	Guar gum, locust gum combined with wax

coating film formation on the surface of the fruits or vegetables generally depends on various factors which include (1) wettability, composition, and viscosity of the edible coating solution; (2) surface property of food commodities; (3) concentration and temperature of the cross-linking agent; (4) thickness of edible coating solution; (5) controlled environment; and (6) drying of the coating (Hershko et al. 1996; Saha et al. 2017). The advantages and application of plant gums are shown in Table 2.

1.4.2 Safe and Biodegradable

Gums are the naturally obtained biodegradable polymers that are produced by living organisms. Such biopolymers have been used in food, pharmaceuticals, and drug delivery purpose since they have no side effects on the environment and human health (Bhardwaj et al. 2000).

1.4.3 Availability and Cost-Effective

The source of the gums is abundant, mostly obtained from plant source; hence, gums-based polymers are cheap compared to that of synthetic polymers. Due to its wide industrial demand, many countries are increasing its production by farming (Bhardwaj et al. 2000; Singh and Sharma 2014).

Table 3 Natural gums and their medicinal uses

S.N	Gum	Traditional use
1	Bengal Kino (butea gum)	Diarrhea and dysentery (Evans 2002)
2	Cordio gum	Antifungal (Mukherjee et al. 2008)
3	Ferula gum	Chronic bronchitis asthma (Enauyatifard et al. 2012)
4	Grewia gum	Anti-inflammation (Martins et al. 2008)
5	Guar gum	Appetite suppressant and medicine for constipation (Baweja and Misra 1997)
6	Guggal gum	Anti-inflammatory (Kokate et al. 2003)
7	Kino gum	Used to treat boils and other skin diseases (Evans 2002)
8	Leucaena seed gum	Used to control stomach ache and contraception (Verma and Razdan 2003)
9	Lemon-scented gum	Used to treat bladder inflammation (Kokate et al. 2003)
10	Mango gum	Used to treat laxative and antioxidant (Nayak et al. 2011)
11	Mastic gum	Used for intestinal ulcers and muscle aches (Takahashi et al. 2003)
12	Odina gum	Used as anti-inflammatory, respiratory irritation (Jena et al. 2014)
13	Red gum (eucalyptus Kino)	Used as astringent (Kokate et al. 2003)
14	Malva nut gum	Used as Chinese medicine as a coolant (Evans 2002)
15	Myrrh gum	Used in uterine stimulant (Kokate et al. 2003)

1.4.4 Traditional Value of Gums

Traditionally, natural gums have been utilized for the treatment of various diseases. For example, Egyptians use gum arabica in the bandage of the mummies adhered quickly ([CSL STYLE ERROR: reference with no printed form.]). From ancient times until now, gums are being used for diseases like diarrhea, dysentery, inflammation, and chronic asthma (Table 3).

1.4.5 Health Benefits

The polysaccharides of plant gums can be used in almost every food industry, for example, gums are used in a number of foodstuffs to boost consistency and organoleptic properties. In addition to the various functions, however, gum polysaccharides offer many health benefits. As we know plant gums act as a dietary fiber during metabolism (Theuwissen and Mensink 2008). Intake of dietary fiber leads to decreased risk of heart disease, improved immunity, increased satiety, and weight control (Slavin and Green 2007; Fiszman and Varela 2013). Importantly, gum polysaccharides remain undigested in the small intestine and reach to the colon which elevates the weight of feces and travel time and thus defends constipation (Elleuch et al. 2011). All these attributes are crucial in evaluating the function that plant gums improve the security of our health (Phillips et al. 2008; Chawla and Patil 2010). Many researchers also report the bioactive functions of plant gums in antioxidant potential and free radical scavenging, which is important to minimize the body's inflammatory responses (Kamboj and Rana 2014; Hamdani and Wani 2017). Table 4

Table 4 Reported health benefits with proposed mechanism of action of plant gums (Hamdani et al. 2019)

Health claim	Plant gum	Proposed mechanism
Regulating satiety	Guar gum	Slows gastric emptying owing to high viscosity of the meals, reduces appetite and desire for eating
Regulating colon function	Acacia gum	Acts as dietary fiber, is fermented by colon microflora to short-chain fatty acids
	Karaya gum	Increases stool weight, is fermented by colon microflora to short-chain fatty acids
	Guar and tragacanth gum	Act as probiotic
Promoting cardiac health	Acacia gum	Regulates the cystolic and diastolic blood pressure in patients with chronic renal failure
Reducing blood cholesterol	Acacia gum	Inhibits lipolysis due to strong interaction of its protein moiety with the lipid/water droplet interface, blocking lipase activity
	Guar gum	Increases the fecal excretion of bile acid and sterol. It is also hypothesized to induce the key enzymes of cholesterol metabolism
Promoting tooth remineralization	Acacia gum	Contains the minerals like calcium, magnesium, and potassium, regulates calcium metabolism in the body
Prevention of renal failure	Acacia gum	Lowers the levels of urea in body by decreasing the urea nitrogen excretion in urine and increasing its excretion in stools
	Artemis sphaerocephala Krasch. (ASK) seed gum	Reduces the oxidative damage of kidney in diabetic rats
Prevention of diarrhea and dehydration	Acacia gum	Improves intestinal absorption of water and electrolytes like sodium
Anti-diabetic activity	Guar gum	Inhibits the digestion and absorption of carbohydrates in the intestine reducing glucose transmission into the hepatic portal. Guar gum lowers insulin resistance and improved insulin sensitivity as well as b-cell function
	Locust bean gum	Affects viscosity and food structure, it can alter the rate of carbohydrate degradation during digestion regulating postprandial blood sugar and insulin levels
	(ASK) seed gum	Increases superoxide dismutase activity and reduced the malondialdehyde and hydroxyl levels in the liver and serum of diabetic rats

(continued)

Table 4 (continued)

Health claim	Plant gum	Proposed mechanism
Antioxidant activity	Acacia, apricot and karaya gum	Presence of phenolic compounds, free radical scavenging, metal chelation, reducing power
	Guar and locust bean gum;	Presence of phenolic compounds, free radical scavenging, metal chelation, reducing power
	ASK seed gum	Precise mechanism is not known
	Corn fiber gum	Presence of phenols

demonstrated the essential bioactive functions of plant gum polysaccharides and potential body pathways.

2 Application of Natural Gums in Food Industries

The demand for naturally obtained gums in food industries has interestedly increased due to their wide range of functional, organoleptic, and nutraceutical properties (Hamdani et al. 2018). Most of the gums are combined as food additives with the salad, cake, sauces, ice creams, cured meat, and soup which not only improve the overall consistency (taste, sight, rheology, texture, and stability) of food products but also have defensive action against microbial and fungal growth (Kapoor et al. 1999; Xue and Ngadi 2009; Valdez 2012). Due to such desirable qualities and exceptional attributes, gums are being implemented in dairy, beverage, and confectionery industries with different labels such as thickening, suspension, bulking, coating, adhesive, emulsifying, and as a fat replacer in various food formulations (Williams and Phillips 1998). Furthermore, a matrix made from gums is integrated into many functional and processed foods to elevate the yield, texture, and slice ability of the finished food products (Valdez 2012; Adnan et al. 2019).

In food industries, gluten is a very important component that enhances the viscosity during food processing and improves the overall quality of bakery products(Gómez et al. 2007). Gluten provides cohesiveness and stimulates the retention of carbon dioxide production during fermentation and thus plays a key role in achieving crumb texture of bread and cake (Le-Bail et al. 2011; Elgeti et al. 2015; Martínez and Gómez 2017). However, gluten consumption causes enteropathic abnormalities, known as celiac disease, and gluten is prohibited for gluten-intolerant patients (Rizzello et al. 2007; De Simas et al. 2009). Celiac is a genetically developed serious auto-immune digestive disorder with manifestation of diarrhea, abdominal pain, inflammation, and depression. Usually, people with gluten intolerance or wheat allergy are very prone to this disease (Rizzello et al. 2007; Horstmann et al. 2017). Gluten is a kind of protein found in wheat, ray, and barley, mainly damage the small intestine, and most of the nutrients remain unabsorbed from the intestine. Hence, interest in gluten-free bakery products has increased to the clinically diagnosed celiac patients (Farrell and Kelly 2001; Rocha Parra et al. 2015). To produce a gluten-free food product is very challenging for food scientists, and due to such gluten sensitivity, food scientists have been searching for an alternative source to replace gluten (De Simas et al. 2009). Recently, gums have been revealed as an alternative food ingredient for celiac patients. Addition of gums (as gluten substitutes) in various food formulations results in gluten-free breads and cakes (Salehi 2019). Many researchers have proved the successful application of natural gums in preparing gluten-free bread, batter, and cakes (Gallagher et al. 2004; Salehi 2019). However, some well-recognized natural gums that are widely used in a variety of food formulations are described below.

2.1 *Acacia or Arabic Gum*

Acacia or Arabic gum (AG) possesses a number of outstanding properties including suspending, emulsification, encapsulating, coating, thickening, viscosity, and well nutritional properties (Shishir and Chen 2017). Among all the features, the most important use of this gum is to encapsulate the essential oils, unpleasant odor, less evaporative and degradative volatile components, bioactive compounds to increase the encapsulated product's stability and shelf-life (Renard et al. 2006). A study showed that AG encapsulated a highly lipophilic and poorly bioavailable nutraceutical components "curcumin" by forming the polyelectrolyte complexation with chitosan to deliver and stabilize the curcumin effectively. Such development of the polysaccharide-based nanoparticles led to controlled release and superior antioxidant activity of curcumin (Tan et al. 2016). In another experiment, AG and gelatin-based coacervation encapsulation technique was applied for the preparation of a heat-resistant flavor nanocapsule to entrap the volatile flavor compounds of *jasmine* essential oil, resulting in a strong heat resistance capability against 80°C humid heat (Lv et al. 2014). In addition, many researchers utilized AG to encapsulate kaffir lime oil (Triyono et al. 2018), fish oil (Ilyasoglu and El 2014), thyme essential oil (Hassani and Hasani 2018), docosahexaenoic acid (DHA) (Singh et al. 2018), vitamin B_{12} (Oliveira et al. 2013), vitamin E (Ozturk et al. 2015), crocin (Mehrnia et al. 2016), thymol (Li et al. 2018), and geraniol(De Oliveira et al. 2018). AG is commonly known as a carrier agent. During transition from fruit juice to powder, AG addition (as a carrier) assists in the spray drying of juice through the expansion of glass transition temperature which decreases the stickiness of fruit powder (Renard et al. 2006). In confectionery and bakery foodstuffs, reduction of sucrose crystallization, fat components emulsification, gloss, and flavor release action are maintained by applying the AG. In beverage products like beer and soft drinks, AG is used as clouding agent and foam stabilizer. Some functional foods specially for diabetic patients are developed by the AG because of its bulking action which does not increase the calories of food products (Verbeken et al. 2003).

2.2 Xanthan Gum

Xanthan gum (XG) is one of the most widely used food industrial polymers. XG covers a broad range of various industrial applications due to its unique features such as highly resistant to enzymatic degradation, enhancing solution viscosity upon addition of low concentration, excellent thermal stability, vastly soluble in hot and cold water, stable under acidic and alkaline environments, and strong stability in presence of salts (Kim and Yoo 2006; Kaur et al. 2015; Ozkoc and Seyhun 2015). Many bakery products are prepared by mixing XG with other gums that significantly increases the volume of bakery products, for example, cake volume (Salehi 2019).

Recently, a new food formulation of XG combined with carboxymethyl cellulose gum has been exposed as a gluten substitute, and XG is being used to produce gluten-free cakes and breads in bakery (Lucca and Tepper 1994; Gallagher et al. 2004). In a study, various percentage of XG was added in a gluten-free food composite "cassava-wheat dough," which improved loaf volume, cell area, oven spring, sensory, and crumb softness of cassava-wheat bread. It was reported that 1% of XG was optimal to maintain the overall acceptability of the bread (Shittu et al. 2009). Some gluten-free rice cakes containing various types of gums (xanthan, xanthan-gaur blend, gaur, k-carrageenan, and locust bean gum) were developed by a research group, and their quantitative macro- and micro-structure analysis revealed that cakes prepared by xanthan and xanthan-gaur blend had the highest pore area fraction (Turabi et al. 2010). Kaur et al. (2015) studied the quality properties of buckwheat flour by separately adding 1 g of gaur, tragacanth, arabic, and xanthan gum to 100 g of buckwheat which manifested good water and oil absorption capacity, improved sensory scores, and emulsion activity of buckwheat flour (Kaur et al. 2015). The flour mixed with each gum was subjected for the biscuit's preparation, demonstrated lower fracture strength and higher weight, diameter, moisture content, thickness of the product. Among all the gums, biscuit produced through xanthan gum added buckwheat flour showed significant organoleptic (flavor, color, and appearance) and increased emulsion activity (Kaur et al. 2015). Regarding encapsulation and controlled release of hydrophobic food bioactive compounds, XG was used to make a novel carrier for curcumin by electrospinning of viscoelastic gel of XG-chitosan which resulted in maximum encapsulation and good stability of curcumin. In that study, the authors concluded that curcumin encapsulated in XG-chitosan nanofibers was released at highest extent and absorbed three-fold higher in the Caco-2 cells compared to free curcumin (Shekarforoush et al. 2018).

2.3 Karaya Gum

Karaya gum (KG) has received remarkable attention due to its GRAS (generally recognized as safe) status from the FDA (food and drug analysis). However, KG is mostly popular as a stabilizer, but its wide application in various areas of food industry is limited (Abo-Shosha et al. 2008). Usually, the addition of KG in food composites stops free water flow and impedes ice crystal formation which improves the textural and sensory qualities of food products (Verbeken et al. 2003). Hence, KG is frequently used in frozen dairy products like ice-cream, slush ices, frozen desserts, fruit ices, ice pops, and sherbets. The optimal concentration of KG used in food products is around 0.2% to 0.5%.To improve the spreadability and water flow prevention in the processed cheese products, KG is utilized as a stabilizer due to the acidic nature (Lujan-Medina et al. 2013). The strong binding capability of KG allows for its use in bakery products, sausage casings, pasta, and even in the development of low-calorie functional food. As a viscosity enhancer, it can use in salad dressings as well as emulsion stabilizer in various dressings. Moreover, due to good water holding capacity, KG can be used in the ground or minced meats products (Abo-Shosha et al. 2008).

2.4 Gaur Gum

The quality of bakery products (bread and cake) mainly depends on their appearance, volume, and crumb texture that are achieved by using plant-derived natural gums during food processing (Ibañez and Ferrero 2003; Mirhosseini and Amid 2012). One such gum is gaur, stronger than arabic and xanthan gum (Cui and Mazza 1996), very viscous at minimum concentration, and used as a water binding, thickening, and stabilizing agent (Sahraiyan et al. 2013). Its moisture-holding capacity can elevate mixing tolerance, improve the shelf-life of the food products, and stabilize the frozen products (Kaur et al. 2015). A study showed that presence of gaur gum (GG) in the rice starch–galactomannan mixtures exhibited high shear-thinning effects with higher viscosity than any other types of gum used. GG is used for the prevention of syneresis or weeping of the cheese products by controlling water phase and thus maintain the textural quality of the cheese (Verbeken et al. 2003; Yoo et al. 2005). GG was also applied for the encapsulation of the folic acid by the electrospraying technique in order to improve the stability of the folic acid (Pérez-Masiá et al. 2015).

2.5 *Tragacanth Gum*

Tragacanth gum (TG) with multidimensional applications (emulsifier, stabilizer, thickener, enhancing viscosity, and gelling formation) has the high demand as a food additive and health beneficial representative to the consumers and food industries (López-Franco et al. 2009). As an efficient emulsifier, TG shows the dual nature manifested by decreasing the oil–water interface tension and simultaneously increasing the aqueous phase viscosity. Due to such distinctive attributes, TG is being applied to produce low or non-fat food processing, food bioactive encapsulation, formation of film or coating on the vegetables or fruits, and colloid-based products. Among all the functions, stabilizing capacity of GT is excellent which was exposed in various real food products (Verbeken et al. 2003). In the beverage field, GT has been used as a strong stabilizer for the acidic dairy drink, flavored (date syrup) milk, flex weed seeds drink, and low-fat ice cream. In addition, GT has extensive application to the fat replacer functional food production, such as low-fat cheese, nonfat yogurt, low-calorie dairy desserts, and reduced-fat sausages. For the preservation of food products including dried banana slices, fresh-cut apple slices, mushroom, and cheddar cheese, GT has been used as an edible film and coating (Phillips and Williams 2000; Whistler 2012).

3 Application of Natural Gums in Pharmaceutical Industries

Plant gum-derived polymers possess high cohesive and adhesive physical characteristics and have immense demand in pharmaceutical preparations (Prajapati et al. 2013). Natural polymers are nontoxic, ecofriendly, biodegradable, and highly water swellable; hence, they are used during formulation of tablets (disintegrates, diluent, and binders), suspension (protective colloids), oral liquids (thickener), and gels (gelling agent). Due to the diverse physicochemical properties of natural gums, many researchers exploit them in drug delivery, nanofibers, tissue engineering, film formation, nanoparticles, and wound healing dressings (Zatz and Kushla 1989; Whistler 2012). The major application of natural gums in different fields of pharmaceuticals is shown in Fig. 3.

3.1 *Gum Used in Pharmaceutical Formulations*

Owing to the high adhesive (ability to attach on the surface) quality, gums have incredible use as a binder in the tablet formulation (Jani et al. 2005). Generally, pharmaceutical tablets are produced by compressing the granules that are formed by imparting cohesiveness to the powder mass through the addition of natural gums. Another potential attribute of gums is the water absorption and swelling capacity

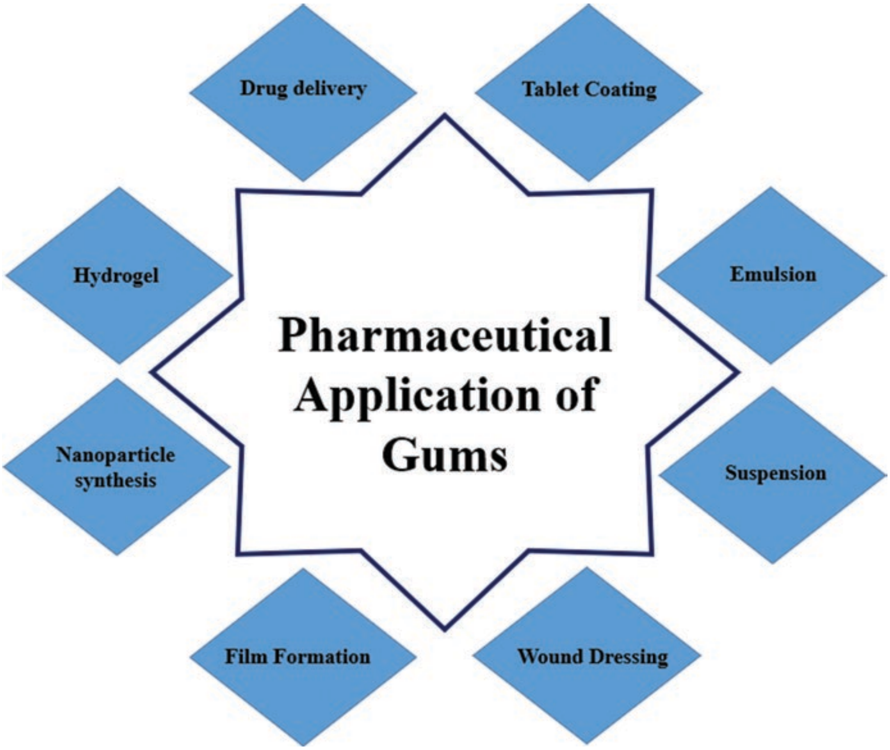

Fig. 3 Major application of natural gums in different fields of pharmaceuticals

even five times higher than the original volume, which rises the dissolution of the tablets by breaking them into smaller fragments (Jani et al. 2005; Kaith et al. 2012).

As an efficient stabilizer, gums can reduce the interfacial tension of the emulsion and lead to the fabrication of the condensed films of high tensile strength, resulting in inhibition of the amalgamation of droplets. Mechanistically, oil in water (O/W) emulsions stability can be reached through the development of a sustainable multi-molecular film around each oil bubble. As a result, the oil and water phases cannot be aggregated due to the hydrophilic barrier formation between them. Thus, the long-term stability of the emulsion can be enhanced by using natural gums (Prajapati et al. 2013).

Gums can also be implemented as a suspending agent which forms hydration layers (through hydrogen bonding and molecular interaction) with high tensile strength around the suspending particles. Moreover, the high dispersibility of the gums in the water rises the viscosity of the solution, where solid particles can suspend uniformly and maintain proper dose of the suspension (Deshmukh and Aminabhavi 2015). The name of some common gums and their pharmaceutical application are given in Table 5.

Table 5 Pharmaceutical application of natural gums (Prajapati et al. 2013)

S.N	Name of gum	Botanical name	Pharmaceutical application
1	Carrageenan	*Chondrus cryspus*	Gelling agent, stabilizer in emulsions and suspensions, in toothpaste, demulcent, and laxative
2	Guar gum	*Cyamompsis tetraganolobus*	Binder, disintegrant, thickening agent, emulsifier, laxative, sustained release agent, colon targeted drug delivery, cross-linked microspheres
3	Gum acacia	*Acacia arabica and Acacia senegal*	Suspending agent, emulsifying agent, binder in tablets, demulcent and emollient in cosmetics, osmotic drug delivery
4	Gum ghatti	*Anogeissus latifolia*	Binder, emulsifier, suspending agent
5	Gum tragacanth	*Astragalus gummifer*	Suspending agent, emulsifying agent, demulcent, emollient in cosmetics, and sustained release agent
6	Karaya gum	*Sterculia urens*	Suspending agent, emulsifying agent, dental adhesive, sustaining agent in tablets, bulk laxative, mucoadhesive
7	Xanthan gum	*Xanthomonas campestris*	Suspending agent, emulsifier, stabilizer in toothpaste and ointments, sustained release agent, buccal drug delivery system
8	Gellan gum	*Pseudomonas elodea*	Disintegrating agent, floating drug delivery system, ophthalmic drug delivery, sustaining agent, hydrogels
9	Sodium alginate	*Macrocytis pyrifera*	Suspending agent, gelation for dental films, stabilizer, sustained release agent, tablet coating, mucoadhesive microspheres
10	Locust bean gum	*Ceratonia siliqua*	Thickener, stabilizer, and controlled release agent

The formulation of sustained release and extended release drug by following the matrix system is very common in pharmaceutical industries. Matrix system implies an embedded tablets formulation, where additives and retardant materials are added during the compression of a blend of drug, which modifies the dissolution and dispersion rate of a drug by delaying and controlling the drug release (Alle et al. 2015). Gum-derived polymers and their semi-synthetic derivatives are the key materials for the matrix system drug formulation. Due to the hydrophilic nature, gums produce gel when coming in contact with water, and drug release from the gel is extended over a prolonged time (Bhardwaj et al. 2000; Deshmukh and Aminabhavi 2015).

Basically, gums contain multiple sugar units in their structure having abundant hydrophilic (hydroxyl and carboxylic) groups that participate during the gelling formation. Gums build several inter- and intramolecular links to make a three-dimensional network by the formation of hydrogen bonding and van der Waal forces, where a high volume of water molecules are held. Various types of gums including sodium alginate, gellan gum, pectin, gelatin, and carrageenan as gelling agents are utilized during drug processing. For the paracetamol delivery, a soft gel was made by using gellan gum with citrate ions. However, the concentration of gum can influence the gelation strength, for example, xanthan gum at very low concentration can form a strong gel compared to other gums and polymers. The branched structure of the gums may be the possible reason for the variation in the galling strength (Prajapati et al. 2013; Deshmukh and Aminabhavi 2015; Kar et al. 2019).

For the sustained release of a drug, coating is mandatory on the surface of the drug which can also protect against drug degradation in the stomach. Natural gums have been reported to be used for oral drug delivery (tablet coating and granular coating). Due to the presence of repeating sugar unit composition in gum's structure, it can exhibit strong biodegradability and easy microflora digestion in the colonic region (Kulkarni et al. 2002; Bravo et al. 2004). Niranjan et al. utilized xanthan and gaur gum (during compression coating of tablet) as a coating agent for colon-targeted drug and manifested sufficient release of drug in the colonic region without any premature drug release in the upper gastrointestinal tract. In another experiment, grewia gum was implemented as aqueous film coating for the praziquantel tablet, and the result revealed that tablets with grewia gum coating were unbroken, unaffected, and durable when challenged against catastrophic fall (Niranjan et al. 2013).

3.2 Gum Used in Nanoparticles Synthesis

The introduction of green synthesis in nanotechnology has brought a revolutionary change in the area of non-specific drug delivery to targeted drug delivery. The utilization of natural products as processing materials is a major part of green nanotechnology which aims to design sustainable nanomaterials for the diagnosis and treatment of various diseases. The use of plant gums as nontoxic and renewable reducing and stabilizing agents for nanoparticles and nanomaterials synthesis has been a fascinating idea. The mixing of gum solution with the solution of metal salt and by using various synthesis mediums can produce the nanoparticles (Ji et al. 1999; Madhusudhan et al. 2019; Alle et al. 2020a). Each synthesized nanoparticle has a unique application, for example, silver-based nanomaterials have high demand due to their potent antimicrobial and antiviral properties. Gum-mediated silver nanoparticles or silver/gum nanocomposites have been explored for the safe application in biomedicine, particularly in drug delivery, biosensor, wound healing, gas sensor, and water treatment (Zare et al. 2019). An effective antibacterial bi nanocomposites films for the food packaging materials was developed by combining the gaur gum solution with silver–copper nanoparticles, which showed promising antibacterial activity against *Salmonella typhimurium* and *Listeria monocytogenes* (Arfat et al. 2017). Silver nanoparticles that incorporated hydrogel for wound dressing were produced by radiation-induced cross-linking of tragacanth/acacia gum which demonstrated good wound healing with potential antibacterial and antioxidant activities (Zare et al. 2019). It was reported that upon anchoring AgNPs on the bacterial cell wall, the stabilized AgNPs generate reactive oxygen species that might initiate oxidative stress and subsequently inhibit bacterial cell growth (Fig. 4).

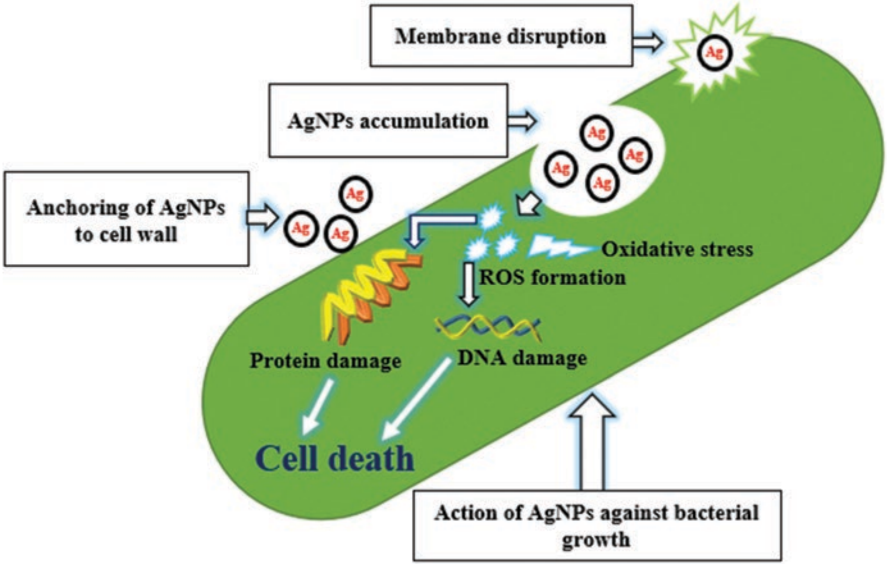

Fig. 4 Mechanism of action of AgNPs to inhibit bacterial cell growth

Among various nanoparticles, gold nanoparticles (AuNPs) have numerous advantages, especially are used as nanomedicine for the human body. Because of its stability and size variation, they can easily go for systemic circulation. Research revealed that AuNPs synthesis by using natural gums was very stable, even for several months without any cluster formation (Alle et al. 2020a, b). A research reported that gum Arabic was the best reducing and stabilizing agent for the rapid synthesis of AuNPs which exposed strong stability (six months) in the aqueous medium at room temperature (Madhusudhan et al. 2019). Dhar and his research group conducted an experiment regarding the stability of gellan gum capped AuNPs in presence of various pH and electrolytes solutions which resulted in greater stability compared to citrate and sodium borohydride reduced AuNPs(Dhar et al. 2008). An ultrafast synthesis of gold nanoparticles using carboxymethylated xanthan gum was reported which were used for the anticancer (doxorubicin) drug loading and showed promising anti-tumor activity (Alle et al. 2020a). The synthesis of gold nanoparticles by carboxymethylated xanthan gum (CMXG) and its anticancer activity is displayed in Fig. 5.

Some other nanoparticles such as titanium oxide, copper oxide, zinc oxide, iron-based nanostructure, platinum, aluminum oxide, and magnesium oxide have been synthesized by using natural gums. In addition, gums were also investigated to produce carbon nanotube-based composites, graphene oxide-based composites, carbon dots, and carbon nanofibers (Zare et al. 2019).

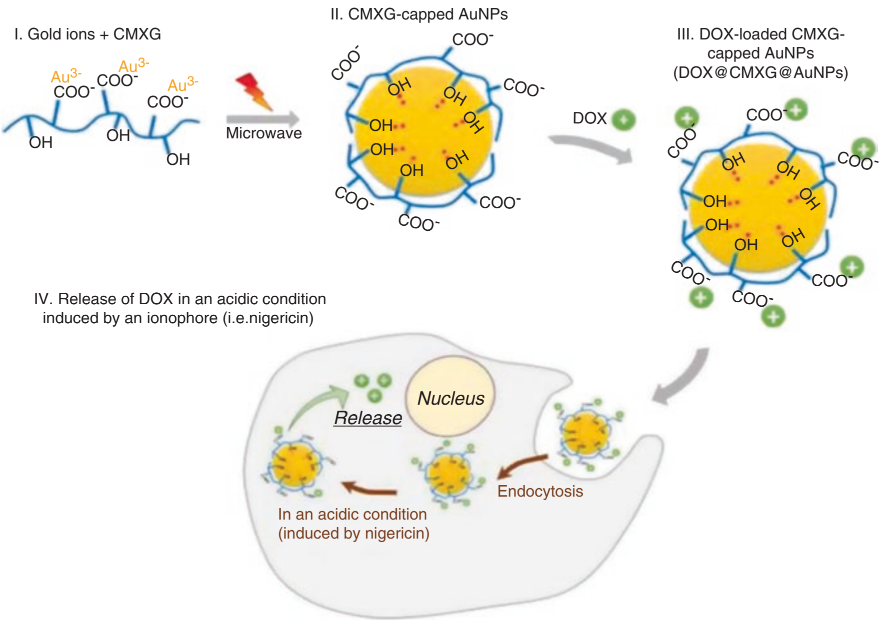

Fig. 5 Doxorubicin–carboxymethyl xanthan gum-capped gold nanoparticles and revealing their anti-cancer activity (Alle et al. 2020a)

3.3 Gum Used in Drug Delivery

Current research on delivery system has changed the entire perception of traditional methods of drug delivery. In general, drug delivery implies the intravenous or intramuscular injections of drugs which have been replaced by the novel delivery methods of drug to the infected sites without any pain sensation. At present, researchers have focused their interest on the development of porous structure of hydrogels and films where specific drugs can be entrapped and protected in the matrix (Ahmad et al. 2019).

The hydrogel system can be prepared from natural gums merging with various amount of other constituents lead to three-dimensional cross-linked network structure (Fig. 6). Gum-derived hydrogel has high water retention capability, biocompatibility, biodegradability, and even no disintegration in excess amount of water (Singh and Sharma 2008). To enhance the efficiency and optimum release, drug molecules or nanoparticles are incorporated into the hydrogen or films, for example, chitosan nanoparticles were loaded into the tara gum films which exposed potential antimicrobial activity, wound healing, and water treatment properties (Zare et al. 2019).

Drugs with high lipophilicity and low bioavailable profile can be incorporated into the hydrogel by conjugating with the different functional groups possess in the gums. In a study, gellan gum was used to prepare self-assembled nano hydrogels,

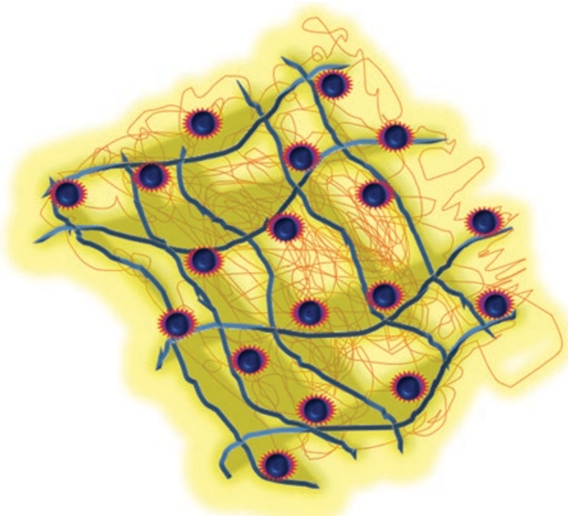

Fig. 6 Gum-based hydrogel and entrapment of drug molecules

where a lipophilic anti-inflammatory drug "prednisolone" was chemically coupled with carboxylic functional groups, resulting in higher bioavailability of prednisolone (D'Arrigo et al. 2012).

4 Conclusion

The purpose of this chapter is to provide deep insight into the beneficial effects, source, composition, classification advantages, and food and pharmaceutical application of natural gums obtained from natural source. Natural gums have multidimensional applications as emulsifier, stabilizer, thickener, enhancing viscosity, and gelling formation. Natural gums play pivotal role from nutraceuticals and pharmaceuticals point of view. They have high demand to design and produce nontoxic and safe substances, particularly, as a food additive and health beneficial representative to the consumers and food industries. In various field of pharmaceutical, the use of natural gums is attractively increasing because of their availability, biodegradability, eco-friendliness, and tunable physical and chemical properties. Undoubtedly, gum-based polymers are very effective than synthetic polymers; hence, their contribution in drug delivery is promising which will be interestingly increased in near future. Overall, this chapter demonstrates a full picture of the recent application of natural gums in the food and pharmaceuticals arena.

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Commercial, Cosmetic, and Medicinal Importance of Sandal (*Santalum album*): A Valuable Forest Resource

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Contents

1 Introduction

Sandal/sandalwood (*Santalum album* Linn.) is a species belonging to the family Santalaceae from the Indian subcontinent and is considered a prominent and expensive tree that has enormous uses from perfumes to cosmetics and medicinal industries worldwide (Azad et al. 2016). Indian sandalwood is also known as "Chandan" in Hindi. It is an evergreen hemi-root parasitic tree that has larger geographical distribution ranging from 0 to 700 m (altitude variation); 0 to 38°C (varied temperature area); and 500–3000 mm (annual rainfall areas). Sandalwood normally prefers stony red soil but shows germination potential in other soil types too (Azad et al. 2016). Sandalwood can tolerate a pH up to 9.0 but unable to tolerate waterlogged conditions (Luna 1996; Rangaswamy et al. 1986; Radomijac 1998). The oil derived from sandalwood is extensively used as the medicine for the treatment of weakness, aromatherapy, skin infections, urinary infection, inflammation, etc. (Misra and Dey 2013a). It is also used in the manufacturing of

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incense sticks (Agarbatti) (Srinivasan et al. 1992). Researchers have described sandalwood oil has anti-oxidant, antiviral, anti-bacterial, and many more properties (Benencia and Courreges 1999; Ochi et al. 2005; Misra and Dey 2012, 2013b).

Despite the large geographical distribution of sandalwood, the germination is not so high. It may be due to various factors such as seed quality, heterozygous seedlings, light intensity, unsuitable temperature and weather, insect pest, and disease-causing micro-organisms (Uniyal et al. 1985; Srimathi and Nagaveni 1995). Seeds should be from mother plant of at least 20-year-old, but due to the excessive pressure on sandalwood tree for its hardwood, they are being harvested before its silvicultural rotation age. enormous uses and religious significance have been described due to high Santalol oil content in the heartwood. The oil derived from the *S. album* contains approximately 90% a&b Santalol. Indian sandalwood (*Santalum album*) is qualitatively and economically important when compared to the other species of genus *Santalum* (Radomijac 1998). The heartwood of *S. album* is being used for many centuries in rituals and ceremonies, as a product for skincare, beauty aid, for carvings, prayer poles, valuable handicrafts, fuel for funeral pyres, coffins, and joss sticks (Jayappa et al. 1981; Rai 1990; Radomijac 1998). Sandalwood oil is largely used in perfumer and cosmetic industries and also as a coolant astringent, antipyretic, antiseptic, antiscabietic, diuretic, and aphrodisiac (Goswami and Tah 2018). Sandalwood oil has been used as a medicine since ancient times as per the Indian traditional system of medicine, Ayurveda. The oil provides relief from migraines and Herpes (Soundararajan et al. 2015). Sandalwood oil is obtained from the heartwood of stem by steam distillation process with an average yield of 4–6%; however, for an individual tree, the estimate ranges between 0.2 and 7.25% depending on the tree age, site, and position of heartwood within the tree (Rai 1990; Haffner 1993). The heartwood is close-grained, very fine, even-textured, hard (specific gravity: 0.92 and weight: 897–137 kg/m^3), durable, and renowned as a carving material (Luna 1996). The sandalwood heartwood and oil were selling at the rate of 12 Lakhs INR/tonne and 22,000 INR/kg, respectively (Jain et al. 2003). The prices of heartwood and essential oil are dependent on the quality of wood. The bark of sandalwood contains 12–14% tannin and is used as a substitute for betel nuts in few villages (Radomijac 1998). The sandalwood trees growing in dry/harsh conditions has lesser height, canopy, and diameter, but the oil content is similar to individual trees growing in fertile tracts (Kumar et al. 2011). Considering the religious and cultural importance, and uncontrolled harvesting of sandalwood, planned scientific efforts should be made to conserve it (Sandeep and Manohara 2019).

There is a dispute about the origin of *S. album* from India or other areas. Brand (1994) suggested that sandalwood is introduced to India from Indonesia, whereas Srinivasan et al. (1992) mentioned the use of Chandan in India from natural stands traced to 2300 years ago. Rai (1990) described that sandalwood is mentioned in the ancient epic Ramayana around 2000 B.C. Genus *Santalum* comprises 16 known species worldwide. Subasinghe (2013) mentioned *S. album* ranked one among major oil-yielding species of sandalwood followed by *S. yasi, S. asutrocaledonicum,* *S. macgregorii, S. spicatum,* and *S. lanceolatum*. As of other species in genus *Santalum*, *S. album* is a xylem-tapping, obligate root hemi-parasite (Srinivasan et al. 1992) which means it has the potential to meet a considerable proportion of its net requirements for carbon through its photosynthesis (Cechin and Press 1993). Initially, sandalwood requires a primary host in the early seedling stage and a secondary host at a later stage in the field (Annapurna et al. 2006).

Naturally, sandalwood is distributed majorly in Andhra Pradesh, Karnataka, Kerala, Madhya Pradesh, Orissa, Tamil Nadu, and other states (Arunkumar et al. 2016). Besides India, *S. album* is available from Australia, Indonesia, Malaysia, Philippines, and Sri Lanka, and, also, successfully introduced in few countries like Bali, China, Java, Kenya, Nepal, Nigeria, Papua New Guinea, Tanzania Uganda, and Zimbabwe (Li and Yu 1984). The flowering and fruiting seasons in *S. album* depend upon the locality and climate. Most of the individuals of *S. album* show flowering and fruiting twice a year (Radomijac, 1998). In India, the first flowering and fruit maturity begin in May and September, respectively (Srimathi and Nagaveni 1995). The second flowering and fruit maturation commence in November and February, respectively (Radomijac 1998). An individual tree may have flowers, mature fruits, and buds all together at a given time (Barrett 1988).

Natural regeneration is through the root suckers and seed dispersal by birds (Radomijac 1998). Natural regeneration can be profuse by using both seed germination and root-sucker techniques, provided there are suitable host plants available, low incidence of weed species, lateral shading from hosts, and protection from fire and grazing (Luna 1996; Radomijac 1998). Rai (1990) reported that under normal environmental conditions, *S. album* prefer to parasitize leguminous species. Under adequate vegetative cover and well-drained soils, seed germination is abundant. Under the optimum conditions, growth is fast with up to 30 cm height by the end of the first wet season (Luna 1996). Sandalwood requires a host which is neither too vigorous that outcompetes the tree nor too frail that the host is exhausted (Havel and McKinnell 1993). In practice, three or more types of hosts are required when establishing a seedling plantation: a short-term host (post host) in the nursery stage and two or more intermediate and long-term hosts (Radomijac 1998). The seed dormancy in *S. album* can break by nicking the testa or soaking in the Gibberellic acid (Nagaveni and Srimathi 1981; Ananthapadmanabha et al. 1988; Jayawardena et al. 2015). In India, direct sowing of seeds under potential host plants is commonly practiced, although success was also observed using seedling plantation at some places (Rai 1990; Srinivasan et al. 1992). Due to the declining status, *S. album* has been assigned with the vulnerable status by the IUCN Red list in 1998 (Awasthi 2007; Sandeep and Manohara 2019) and still assessed as vulnerable in the year 2018. Arunkumar et al. (2019) mentioned that over the last three generations due to overharvesting and illegal global trade, the population of sandalwood declined by 30% and is decreasing continuously.

2 Commercial Importance

Sandalwood is a tree species of high commercial importance due to its heartwood and essential oil. Sandalwood oil is used as fixture and base for splendor perfume manufacturing, beauty soap industries, cosmetic and pharmaceutical industries, and mostly in aromatherapy (Clarke 2006). Sandalwood oil is being used mostly in religious ceremonies, functions, and other rituals of Muslims, Hindus, Parsis, Buddhists, and others. Luxury perfume manufacturing companies, including Calvin Klein, Chanel, Yves St Laurent, and Christian Diaor, utilize sandalwood oil for their perfume-based products. Market Research Future (2020) mentioned the key players in the global sandalwood oil market as Albert Vieille SAS (France), Doterra International LLC (Utah), Eden botanicals (US), Santanol Group (Australia), Plant Therapy Essential Oils (US), Aditi Essentials (India), Haldin International (Indonesia), Jiangyin Healthway (Japan), Kanta Enterprises (India), PerfumersWorld Ltd. (Thailand), Ancient Healer (US), Khadi Natural (India), Vedic Vaani (India), Cliara Essential Oils (Sri Lanka), and Sallamander Concepts Pty Ltd (South Africa).

The commercial use of Sandalwood oil is enormous. Oil is extracted by the process of steam distillation of sandal heartwood. Sandalwood oil is being used for external application as well as for consumption. It acts as an antiseptic agent and helps in fighting against ulcers, infections, and healing wounds. Studies also suggested that sandalwood oil has anticancer effects (Santha and Dwivedi 2015). Sandalwood oil can prevent skin cancer if applied on skin regularly which helps in getting the surge in commercial value of sandalwood oil. Sandalwood oil has moisturizing properties (Kapoor and Saraf 2010) and can help to nourish the skin, which can increase the demand for sandalwood oil in the global market. Moreover, sandalwood oil has a very exotic woody fragrance, so being used in aromatherapy; these factors are driving the growth of global sandalwood oil market. India accounts for approximately 90% of the world's total sandalwood production. Majority of the sandalwood production in India is by the states of Tamilnadu, Karnataka, and Kerala. Previously, sandalwood trees having a diameter less than 100 cm and below 60 years of age were not considered for harvesting but treated as a young tree due to substandard features of heartwood volume, essential oil (%), and its chemical content (Clarke 2006). According to Baldovini et al. (2011), a tree receives the utmost quality and quantity of oil once it attains the age of 60–80 years. Also, the fragrance would be of superior quality. They reported the average production of sandalwood oil lies approximately between 4.5% and 6.25%, and a larger portion of oil is recovered from its root portion (10 percent of weight) (Santha and Dwivedi 2015). Misra and Dey (2012) have mentioned that 230 different chemical compounds are present in the heartwood of *Santalum albums*, of which most are terpenoids (Baldovini et al. 2011). Phytochemical studies of sandalwood extracts show high content of saponin, tannins, and phenolics besides terpenoids (Misra and Dey 2012).

Sandalwood oil is known commercially because of its chemical constituent's α-santalol and β-santalol together known as santalol (Fig. 1). They are responsible for the high-quality fragrance emerging from sandalwood oil (Misra and Dey 2012).

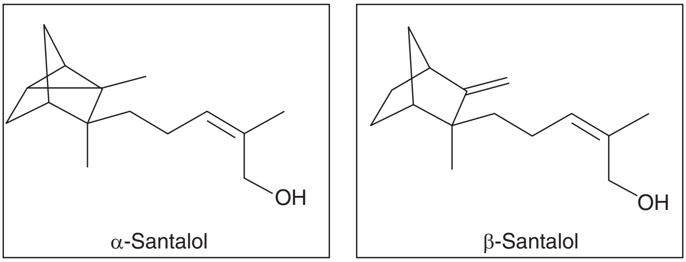

Fig. 1 Structure of α-santalol and β-santalol

Besides these, other chemical constituents of sandalwood include α-santalal, β-santalal, α-santalene, α-bergamotol, spirosantalol, and epi-β-santalal (Skaria et al. 2007) (Table 1). The chemical formula of santalol is $C_{15}H_{24}O$. Both α- and β-santalol are isomers that are used in various industries and exhibit high commercial importance. α-Santalol is mainly known for its anticancer properties (Santha and Dwivedi 2015). Sandalwood can be grown by any farmers, but they have to take prior permission from the forest department for harvesting. It is not illegal to grow sandalwood trees in India. In fact, the forest department distributes the sandalwood saplings as part of the social forestry program. In Tamilnadu, the selling of sandalwood is being regulated by the officers of the forest department. The capacity for the sale of sandalwood to individuals and temples is fixed for any officer depending upon their hierarchy. The selling price of sandalwood is being fixed and revised every year by the forest department.

States like Karnataka have legalized the commercial plantation of sandalwood. In other States, it is not illegal to grow the tree in private property, but once planted the tree shall be government property, and a pass is required to be obtained from the local forest department to harvest it. Sandalwood cultivation provides good economic return to the cultivator around the globe. The excellent quality and quantity of santalol in sandalwood oil make the Indian and Australian varieties superior to sandalwood from other countries. This is due to the high chemical content and excellent heartwood in the native species. Arunkumar et al. (2019) reported that the statue of gods and mythological figures carved from the wood has a huge demand in the Indian market and other carved objects have great cultural values throughout the world (Baldovini et al. 2011).

Brokers procure the heartwood through government auctions and reach to the producer for selling them in the powdered form. Further, through the process of distillation, the sandalwood oil is extracted from the heartwood. Eventually, oil is exported to different countries in solution form after packing in an aluminum flask. Kumar et al. (2019) reported that sandalwood seed oil in reaction with ZnCl could be used to prepare a suitable base for manufacturing insulation tapes. Also, vulcanizable oil could be obtained after reaction of sandalwood seed oil with sulfur at 220 °C. The product obtained after dissolving rosin in oil can be utilized for the manufacturing of colored enamel. Various products can be obtained after reacting

Table 1 Medicinal uses of important constituents of sandalwood

Medicinal properties	Sandalwood constituents	Biological activities	References
Antiviral	α-Santalol and β-santalol	Against HIV and RNA viruses; human papillomavirus (HPV), DNA pox virus	Benencia and Courreges (1999), Chattopadhyay et al. (2009)
Skin care	α-Santalol and β-santalol	Allergy, acne, lesions, staphylococcal/streptococcal acne; psoriasis, eczema, warts, dermatitis	
Anticancer	α-Santalol	Anticancer against skin carcinogenesis, CD-1 and SENCAR mice, breast and prostate cancer (in vitro model)	Dwivedi et al. (2006), Misra (2010)
Antigastric	Sesquiterpenoids	Against *Helicobacter pylori*: Anti-ulceration	Takaishi et al. (2005)
Insecticidal	Sandalwood oil	Mosquito repellant (*Culex*, *Anopheles*), against termites; acaricide (honeybee)	Zhu et al. (2008)
Cancer chemopreventive	α-Santalol	Against UV-B radiation-induced skin tumorigenesis, in SKH-1 hairless mice	Dwivedi et al. (2006)
Antimicrobial	α-Santalol and β-santalol	Antimicrobial activity; axillary bacteria, *Salmonella typhimurium, Staphylococcus aureus, Bacillus mycoides, Candida albicans*	Jirovetz et al. (2006)
Antitumor	Sesquiterpenoids	Antitumor promoting activity; for in vitro Epstein- Barr virus early antigen (EBV-EA) stimulation and in vivo carcinogenesis assay	Kim et al. (2006)
Antiviral	Sandalwood oil	Herpes simplex viruses (HSV) 1&2, inhibition of replication; in RC-37 cells	Misra and Dey (2013a)
Proapototic	α-Santalol	Proapototic and caspase activation, tumor suppression in human epidermal carcinoma A431 cells	Arasada et al. (2008), Bommareddy et al. (2012)
Diet	Sandalwood oil	Dietary factors/supplements, PUFA content increased	Burdock and Carabin (2008)
Nervous system stimulants	Santalols	Aphrodisiac, insomnia, alertness, olfactory stimulants of central nervous system; sedative, stimulation through calcium refluxes	Bieri et al. (2004), Ohmori et al. (2007)
Metabolism and physiology	Sandalwood oil	Attentiveness; alertness, calmness, mood relaxation, vigor, sound hearing, sedation	Kovatcheva et al. (2003), Heuberger et al. (2006)

sandalwood seed oil and with other chemical substances. Antimicrobial plasticizer, lather promoter, and solidifying and moistening substance could be formed using the sandalwood-based oil. The sapwood of sandal tree also has a variety of uses. It is mostly used in agarbatti industries and in making decorative statues/models, platforms, tables, chairs, and others. In Asia, sandalwood is consumed as a custom and culture (Clarke 2006). The powder of oil-devoid heartwood is prepared into incense sticks by the gluing process. Due to extensive use, sandalwood is in high demand in the United States and Asian countries. But there is a huge gap between demand and supply of sandalwood, and thus it leads to a sharp surge in price. Only 25% of overall trade demand is being fulfilled due to lesser production. The Asia Pacific dominates the global sandalwood oil market (Market Research Future). The consumption of sandalwood is highest in India. Tamilnadu is the largest supplier of legal sandalwood. In India, northern Tamil Nadu and southern Karnataka are considered naturally distributed areas of sandalwood. These two states together account for more than 90% of the natural population of *S. album* in India (Dhanya et al. 2010). Arunkumar et al. (2016) suggested cultivating sandalwood in places other than forest land to minimize the gap between demand and supply. Pallavi (2018) reported that Karnataka has initiated programs for sandalwood farming and inspiring the growers. During 2009, Karnataka amended its law to enable the grower to sell the sandalwood produce straight to quasi-governmental corporation/organization, for example, Karnataka Soaps and Detergents Limited (KSDL) and other, rather than selling only to the forest department. While in Kerala and Tamilnadu, the selling is being regulated by the state forest department only (Dhanya et al. 2010).

The production of sandalwood throughout the world is largely affected by unscientific harvesting and insect pest attacks. Sandalwood Spike Disease (SSD) is a major threat to the plantation and affects the production (Mondal et al. 2020). In North India, no such disease with this extent has been reported till date, but the disease is prevalent in South India. Thus, agrarian of Himachal Pradesh, Punjab, Uttarkhand, and Uttar Pradesh may have a worthy opportunity by which they can earn good money from sandalwood farming.

Pallavi (2018) reported the declining production of sandalwood in India. It was mentioned earlier that 80% of the global sandalwood requirement was fulfilled by India, but now the production has fallen to 400 tonnes/year. A similar condition was also reported in Australian sandalwood production, although, during 2018, the overall sandalwood demand was largely supplied by Australia only. The commercial significance of a sandalwood tree solely depends on the following factors: quality and quantity of essential oil distilled out from heartwood and quantity of heartwood. The price of sandalwood in India is increasing continuously. Despite the availability of sandalwood from various countries, the Indian variety is considered as best over others due to its superior class heartwood (Soundararajan et al. 2015). Soundararajan et al. (2015) mentioned that India utilizes most of its sandalwood production and small pieces in the form of statues/idols/handcrafts (maximum fifty grams) can only be exported. In the year 1984, Food and Agriculture Organization, United States, stated the importance of sandalwood and categorized it as a significant tree for the conservation effort. After this, the demand for sandalwood essential oil and handicraft increased. There is global sandalwood demand of at least 10,000 metric tonne/year mostly by the United States and Western Europe.

India produced around 4000 tons of heartwood annually during the 1930s–1950s, but now declined to 500 tons annually. Meanwhile, the cost was 20,000 INR/Ton in the year 1980 which goes to 2,00,000 INR/Ton in the year 1990, and 40,00,000 INR/Ton during the year 2004 which rose to 75,00,000 INR/Ton in 2014 (Sadhu 2017). Soundararajan et al. (2015) reported that sandalwood oil import was about 61 ton during 2008–2009. Sandalwood is a potential species showing a business of one billion dollars worldwide. The global sandalwood oil market is anticipated to reach a compound annual growth rate (CAGR) of 6.99% from 2019 to 2024 and reach USD 156 million by the end of 2024 (Market Research Future 2020).

3 Cosmetic Importance

Most of the fatty acids obtained through the process of hydrolysis are being utilized in the preparation of beautification products (Kumar et al. 2019). The seed oil of sandalwood exhibits exceptional stability and enormous pharmaceutical importance (Li et al. 2013). Oil derived from the sandalwood seeds may be useful in the cure of dermatological problems and has cosmetic effects (Kumar et al. 2019). The oil contains Santalbic (Ximenynic) acid, which helps to keep the skin naturally glowing and young due to its antiaging characteristics (Kumar et al. 2019). Seed oil has diuretic, antiviral properties, and is being used in the treatment of atopic dermatitis, rashes, chronic psoriasis, etc. Ravikumar et al. (2018) reported through an experiment on rodents that consumption of sandal seed oil may keep fit and healthy from unnecessary fat. Also, cutaneous circulation systems can be maintained and regulated by using sandalwood seed oil (Kumar et al. 2019).

Sandalwood oil is a major ingredient of face cleanser, facials, skin toner, beauty enhancer, etc. Powder products of *S. album* are being sold in the market under various brand names that can be used with a suitable mixture such as clay (Multani Mitti) for an easy face pack. The concentrated form of sandal oil should not be used directly on the skin as it may cause harm (Nautiyal 2019). Sandalwood oil is being used as a homemade therapy for skin problems due to ultraviolet sun rays (Fig. 2). It is mostly used to cure sunburn, skin irritation, and itching. Sandalwood essential oil is used against skin injuries and helps to heal them fast. Agglomeration of collagen, skin rupture, scratches, and sensitivities can be prevented and treated by applying sandalwood-based products (Karuppusamy and Pullaiah 2016). Sandalwood oil has antiseptic properties that prevent the development of microbes on the skin including bacteria that causes inflammation/acne and other dermatological problems. It was advised to use sandalwood paste (sandal talc+milk) over the infected area (Jirovetz et al. 2006; Nautiyal 2019). Big brands manufacture facewash and skin creams that provide comfort from tiredness and purify the skin from dirt (Singh et al. 2013). Sandal oil is also used to provide relief to the protein which

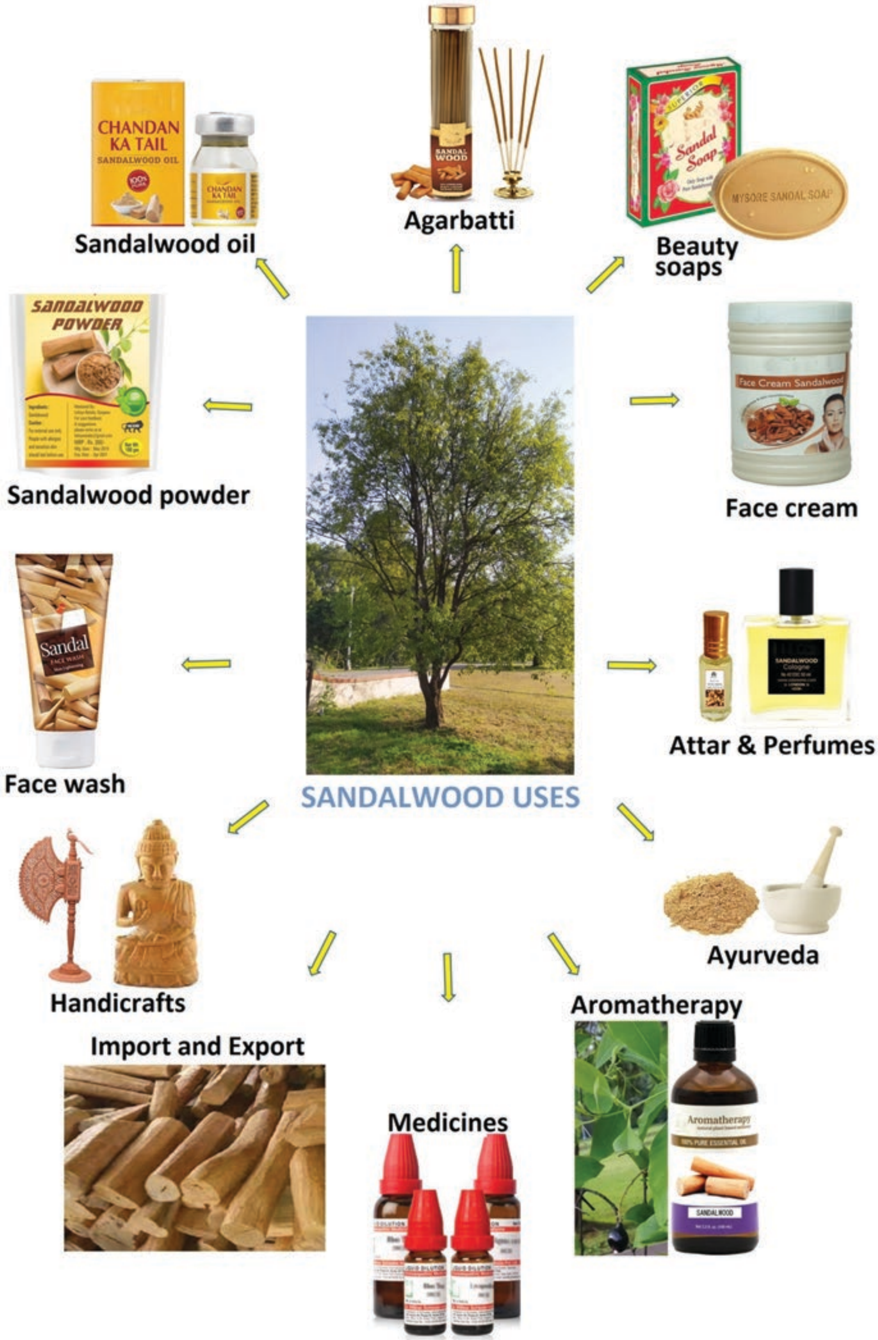

Fig. 2 Uses of sandalwood in commercial, cosmetic, and medicinal industries

helps in signaling without any side effect. Sandalwood oil possesses antioxidant property, which comforts the skin from the effect free radicals (Scartezzini and Speroni 2000).

Sandalwood oil is being used in hair care as one of the essential ingredient in shampoos and conditioners (Fig. 2). Also, sandalwood oil has antifungal properties against zoophilic dermatophyte fungus (Chaumont and Bardey 1989). Santalbic acid present in seed oil can be beneficial in problems such as erysipelas, varicosities, cellulitis, and alopecia (Hettiarachchi et al. 2013). It also helps in removing harmful toxic substances from the skin, prevents the oxidation process, enhances skin robustness, and prevents elastosis (Ravikumar et al. 2018). Deepak et al. (2014) described that the sandalwood leaf constituent saponin causes hemolysis of RBCs. Sandalwood tree has great ethno-botanical importance such as the paste of sandalwood and Shikakai (*Acacia concinna*) is used for marking on the forehead, and this will keep the mind cool and concentrated (Sharma and Kumar 2013). Also, brides use sandalwood to perfume their bodies. Sandalwood finds a special place on various auspicious occasions, such as the birth of babies, thread ceremonies, marriages, and other religious functions. Sandalwood attar is manufactured by the process of distillation which is an important constituent in a variety of products, such as agarbattis, soaps, perfumer, beauty creams, and hair care merchandises (Skaria et al. 2007) (Table 1).

4 Medicinal Importance

Sandalwood essential oil has remarkable uses in our daily life, including cosmetic, commercial, and aromatherapy. Besides this, a major portion of sandalwood is known for its importance as a medicinal tree. Changing consumer preferences toward organic products over synthetic substances showed strong demand for essential oils and plant extract in pharmaceutical and cosmetic industries. There is increasing interest in essential oils throughout the world. The essential oil can be collected from *Eucalyptus*, Lavender, Mint, and Tea (Clarke 2006), but the sandalwood oil is above all. Sandalwood essential oil is being used in aromatherapy (Skaria et al. 2007) since ancient times. In women, during pregnancy, sandalwood oil is one of the safe essential oil which is allowed to be used (Skaria et al. 2007).

Sandal is very important as a medicinal plant. Therefore, it is being promoted by the National Medicinal Plant Board (NMPB) as a priority medicinal plant. Sandalwood oil can be used against fever, germs, disease-causing microbes, scabies, and can help in promoting diuresis. Sandal oil is also beneficial in the treatment of colds, congestion, inflammation in the chest, UTI (urinary tract infection) issues, inflammation of the bladder, and painful urination (Goswami and Tah 2018). Similarly, the use of santalbic acid against swelling and sensitivity is reported by Kumar et al. (2019). Indian sandalwood contains significantly higher quality and quantity of α-santalol and β-santalol. Santalols (C15 isoprenoids) also called sesquiterpenoids are major bioactive principles of sandalwood oil (Misra and Dey

2013c). Heartwood oil exhibits anti-inflammatory actions and is suitable to treat skin infections including pimples. Santha and Dwivedi (2015) mentioned α-santalol as an anticancerous agent and can be utilized as a chemopreventive substance that is nontoxic and proven against tumorigenesis.

Sandalwood has antioxidant activity and is being utilized as homemade medicines (Scartezzini and Speroni 2000). Misra and Dey (2013b) reported through the experiment conducted on Albino mouse that sandalwood oil has the capability to lower blood glucose level and oxidation process. Also, antitumor and anti-angiogenic potential actions of α-santalol have been identified in *Homo sapiens* malignant hepatoma cells brought by liver carcinogen, DEN (diethylnitrosamine) in rodents (Hegde et al. 2014). Sandalwood is beneficial in cardiovascular inflammation like myocarditis (Khan et al. 2014). Zhang et al. (2012) conducted the phytochemical analysis of VOCs (Volatile Organic Compounds) from fruits oils of Indian sandalwood through hydro-distillation and solvent extraction. It was reported that there are almost 66 volatile compounds of which hexadecanoic acid and omega-9 fatty acids account for almost up to 70%. Other compounds included were α- and β-santalol, sesquiterpene, derivatives of carboxylic acids, Squalene, and plant sterols. Squalene is a triterpene hydrocarbon that shows anticancerous properties and prevents cell damage by free radicals (Owen et al. 2000). It helps prevent the growth of cancerous cells formed due to chemicals and protects from (Deoxyribonucleic acid) DNA oxidation.

Essential oils and aroma chemicals stimulate olfaction and amygdala. The brain starts being calm by inhaling the aroma or fragrance of sandalwood oil (Skaria et al. 2007). Sandalwood is important medicine benefitting against coughs due to its soothing characteristics. It is excellent in regulating high blood pressure and starts acting soon after its application on the epidermis (Nautiyal 2019). The essential oil derived from sandal is useful in reducing pain and inflammation (Misra and Dey 2013c). It is used in suppressing muscle and neurological spasms. As per the classical medicinal system, heartwood-derived oil helps in relieving mental health disorders, UTI issues, gastrointestinal problems, and other ailments (Ravikumar et al. 2018; Nautiyal 2019). The bark, root, and stem of sandalwood are effectively utilized for relief against gonorrhea, hypoglycemia, and skin ailments (Jeevan Ram and Raju 2001). In Western Australia, Seed kernels were made into a paste with water and boiled for a considerable time; further, the paste was applied over sores, bruises, lesions, and aching joints and muscles as a medicine (Hettiarachchi 2014). Cribb and Cribb (1981) mentioned that the European settlers used to consume locally available *Santalum spicatum* and *S. accuminatum* seeds for arthritic pain.

Novel technologies are making it easier to identify the constituents of any biological substance and where it can be used. Technologies could help us to utilize these chemical constituents derived from any compound in the treatment of any disease/disorder through drug designing (Misra and Dey 2013a). New possibilities of application could be identified, such as α-santalol derived from sandal heartwood can be useful in curing the disease like “Senile dementia” and tumor (Kim et al. 2006; Bommareddy et al. 2012). A similar report was suggested by Misra and Dey (2013d) about the use of sandalwood and its oil as a classical medicine. These days, people rely more on herbal medicine and avoid chemical-based medicines. So, sandalwood and other similar important medicinal plants have great potential to take over the allopathic system of medicine. Misra and Dey (2013d) mentioned that sandalwood finds extensive applications in traditional medicinal systems and is gaining importance in modern pharmacological investigations as a source of anticancer (Bommareddy et al. 2012), anti-*Helicobacter pylori* (Ochi et al. 2005), and antiviral (Benencia and Courreges 1999) biomolecules.

5 Conclusion

Indian sandalwood (*Santalum album*) is an important tree species due to its aromatic heartwood, containing α-santalol and β-santalol, which is used in medicines, cosmetics, perfumes, and aromatherapy. The major component of the sandalwood essential oil is α-santalol and β-santalol. Indian sandalwood is of high grade when compared to other regional varieties and thus high in demand. Tamilnadu and Karnataka are the largest producers of Indian Sandalwood, although it is available throughout India as a plantation and in natural habitat. Commercially, sandalwood is an expensive tree species due to its extensive uses in various industries. In religious functions, sandalwood is an essential ingredient in various rituals. In India, the sandalwood market is being regulated in collaboration with the forest department. It is expected that the global sandalwood oil market will reach CAGR of 6.99% from 2019 to 2024 and touch USD 156 million by the end of 2024. Sandalwood has high cosmetic importance due to its application in various product manufacturing. Sandalwood oil is being used in the preparation of beauty products, face packs, moisturizers, treatment of skin infections, and wounds. The oil exhibits antiseptic, anti-tremorogenic, and antiaging properties. Sandalwood is known to be used in our ancient medicinal system, Ayurveda. Sandalwood has shown its uses in hepatoprotective activity, central nervous system effects, antiulcer activity, antibacterial activity, antifungal activity, antiviral activity, antioxidant efficacy, anticancer activity, hemolytic activity, antipyretic activity, anti-inflammatory activity, antihyperglycemic, cardioprotective activity, physiological effects, metabolic effects, genitourinary system effects, insecticidal activity, and aromatherapy. Future research should be conducted on this important tree as it has enormous capabilities of treating various diseases/ailments. Farmers should be motivated in the cultivation of sandalwood with the necessary support and mechanism for its harvesting in collaboration with the forest department. Such policies and guidelines should be formed which helps the farmers to get support from seeding to final harvesting including the plantation management.

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Forest-Based Edible Seeds and Nuts for Health Care and Disease Control

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Contents

1 Introduction

Wide varieties of forest-based plants have been playing a very significant role in human life for thousands of years. Plant parts and products such as seeds, fruits, nuts, roots, shoots, leaves, flowers, berries, fats, and oils have been consumed for

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food, medicine, fiber, and several other purposes (Joshi et al. 2003; Borai and Husen 2003; Husen and Nautiyal 2004; Turner et al. 2011; Rai et al. 2013a; Husen 2013; Bachheti et al. 2018; Aryal et al. 2018; Bachheti et al. 2020). Also, they have been consumed as food for wild and domestic animals. Wild edible plants are of high concern, as they serve as alternatives to staple food during periods of food scarcity, a possible source of nutrient complements against malnutrition as well as income sources for rural peoples (Basumatary and Narzary 2017). The exponential growth of world populations directly contributes to the potential increase in the demand for plant products that can directly involve food value and health care as well as disease control. With this regard, seeds and nuts are highly consumed foodstuffs in the human diet among different plant parts throughout the world. Seeds are biologically mature ovules, while nuts are simple dry fruit entailing one or two edible kernels inside a nonedible hard shell (De 2020). As confirmed by different research works, seeds and nuts are known to be nutrient-rich food as they are potential sources of proteins, fats, fibers, minerals, and vitamins (Carlsen et al. 2011; Chang et al. 2016; Tucker 2017; De 2020).

Moreover, edible seeds and nuts have been reported for their incredible role in antioxidant activities and antimicrobial activities, and play a vital role in lowering the risk of cancer and cardiovascular disease (Kirbaslar et al. 2012; Souza et al. 2015; Aune et al. 2016; Tucker 2017). Relying only on domesticated and commonly cultivated plant categories such as seeds and nuts increase overcrowdings on their consumption for diet, health care, and disease control. Hence, searching for edible forest-based alternatives is a good insight to reduce such dependence and highly important to fill the food scarcity gap. Forest-based edible seeds and nuts are those plants with edible parts that grow naturally on farmland and unplanted or uncultivated land (Duguma 2020). Edible tree seeds and nuts collected from the forest are a critical component in the pursuit of food and nutritional security. Most tree products from the forest such as seeds and nuts are valuable sources of both macronutrients and micronutrients (Rai et al. 2013b; Dawaki et al. 2017), hence contributing to health care and disease prevention and helps in reducing starvation and malnutrition. Therefore, consuming forest-based seeds or nuts and their products for health care and disease prevention is highly important in reducing direct relay on staple foods, obtaining advanced income, and contribute to reducing hunger especially in the least economic countries. In this chapter, we describe and deal in detail with the health benefits of some edible forest-based and semidomesticated seeds and nuts noticed around the world and their role in preventing various diseases.

2 Forest-Based Edible Seeds and Nuts

According to Shaheen et al. (2017a), edible wild plants are defined as "Plants which as whole or they are any part (roots, leaves, or fruits) are acceptable for eating purpose by urban and rural communities." Food and Agricultural Organization (FAO) on the other hand put the definition of edible wild plants as "Plants that grow spontaneously in self-maintaining populations in natural or seminatural ecosystems and can exist independently of direct human action" (Shaheen et al. 2017a). Therefore, wild edible plants can be described as plants encompassing edible parts that are found growing naturally on forests, farmlands, and unplanted or on noncultivated areas (Tebkew et al. 2018; Duguma 2020). Forest-based edible seeds and nuts are subsets of edible forest products that are derived directly from natural forests. Edible seeds and nuts used as main foods, those used as trivial food supplements, leafy vegetables, fresh fruits, condiments edible oil fruit drinks, etc. are some plant components that are categorized under forest-based edible products.

According to Shaheen et al. (2017b), wild edible plants, which comprise edible seeds and nuts, have been put into different classes as Hill's classification: food plants (cereals, millets, pulses, vegetables, and fruits), food adjuncts (spice and beverage), drug plants (medicinal plants, fumitories, and masticatories), and industrial plants (fiber, timber. rubber, gum, and resin plants). The Brouk's classification of wild edible plants includes plants consumed by man, those consumed by livestock, economically important plants, shelter plants, ornamental plants, industrial plants, and medicinal plants. The other wild edible plant classification according to Shaheen et al. (2017b) is Singh and Arora's classification. In this classification, edible wild plants are categorized as plants with edible underground parts, those with edible greens, flowers, edible fruits, and other edible kinds. Turner et al. (2011), on the other hand, categorized edible wild plants into root vegetables (such as true roots and bulbs, corms, tubers, and rhizomes); edible greens (leaves, stems, shoots, marine algae); fleshy fruits; grain seeds; and nuts. Some common forest-based edible seeds and nuts from different families across the world are listed in Table 1 and presented in Fig. 1.

3 Historical Aspect of Forest-Based Edible Seeds and Nuts

Human societies from different directions of the world have been depending on plant products derived directly from forests. The greatest parts of the forest and tree-based systems found in the biosphere today have profound historical origins, developed and enriched over generations through research and adaptation to changing environmental conditions and societal needs (Powell et al. 2015). More than 1.6 billion people's livelihoods across the world estimated to rely on forests and other tree-based production systems such as agroforests (Vinceti et al. 2015. The products have been used for food (either as a staple or supplementary food for people and wild as well as domestic animals), timber, fuel, fodder, fibers, house construction (especially by rural communities), as raw materials for chemical industries, and medicinal purposes throughout human history. Besides, plants have played incredible roles in human societies and many people across the world, as we are highly dependent on many wild species particularly for food and medicines starting from early hunter-gather to various adaptation stages (Duguma 2020). Nuts and seeds have been parts of the human diet and employed in traditional medicines since

Table 1 Commonly used forest-based edible seeds and nuts; and their details

Botanical name	Family	Description and distribution	Key references
Adansonia digitata	Bombacaceae	Native to Africa, Madagascar, and Australia, and commonly called Baobab. The African variety is known by different names such as dead rat tree, Ethiopian sour gourd, Judas's bag, lemonade tree, monkey bread tree, monkey tamarind, Senegal calabash, and upside-down tree. The whole parts of the plant have many uses in food medicine and beverages. The Seed parts are employed as a thickening agent in soups, as a flavoring agent, or roasted to substitute coffee and eaten as snacks	Zahra'u et al. (2014), Sundarambal et al. (2015), and Braca et al. (2018)
Aesculus indica	Hippocastanaceae	Commonly known as Indian horse chestnut. The tree is distributed in the hilly areas or temperate region from Kashmir to Nepal and is widely distributed in India. The seeds are lethal, if consumed without processing or raw; need to be decorticoid, crushed and soaked overnight in water for 10–12 days with repeatedly changing water, and then dried under sunlight before consumption, due to the presence of anti-nutrients like saponin and tannin	Khan et al. (2015) and Mishra et al. (2018)
Amaranthus viridis	Amaranthaceae	Commonly spread in various parts of the world and the seeds are eaten as dry or crushed. Some harvested in wild as food like *A. hybridus* L., *A. quitensis* Willd. ex Spreng. and *A. powellii* S. Wats. Seeds are edible after cooking in ghee and honey and making into round balls	Aryal et al. (2018), Achigan-Dako et al. (2014), Santra and Schoenlechner (2017), Thapa and Blair (2018)

(continued)

Table 1 (continued)

Botanical name	Family	Description and distribution	Key references
Amygdalus scoparia and *Amygdalus pedunculata*	Rosaceae	*Amygdalus scoparia is a* deciduous tree shrub native to Iran and also grows in neighboring countries. It is also known as wild almond, It is drought resistant and traditionally used to treat cardiovascular and respiratory diseases, rheumatism, and headaches, also for wound healing, and its antihyperglycemic effect has been proven recently. *Amygdalus pedunculata* Pall. is an important sand-fixation plant in northwest China that has great ornamental and medicinal value. Its seeds are comestible after eliminating amygdalin via treatment with boiling water	Khadivi-Khub and Anjam (2014), Hojjati et al. (2016), Amirshaghaghi et al. (2017), Wang et al. 2019, and Zahedi et al. (2020)
Anacardium occidentale	Anacardiaceae	A multipurpose nut, which is locally known as cashew or monkey nut an evergreen, fast-growing, and drought-resistant perennial tree native to Brazil and currently it has been widespread in many other parts of the world such as tropical South and Central America, Asia, and Africa. It has been widely consumed as food in different parts of the world and mainly important in nutrition, healthcare, and industrial uses	Dendena and Corsi (2014), Tola and Mazengia (2019), and Tufail et al. (2019)
Araucaria angustifolia	Araucariaceae	Naturally grows in mixed forests in Brazil, Argentina, Paraguay, and Chile and one of very important biomes that occurs naturally. Its seed called in Brazil as “pinhão”, and are eaten as a traditional high-calorific food during the winter season	Gomes da Costa et al. (2013), Peralta et al. (2016), and Zortéa-Guidolin et al. (2017)
Araucaria araucana	Araucariaceae	Known by common name as Araucaria or Pehuen is a coniferous tree endemic to Chile and Argentina, mainly available in the xeric forest. Their seed kernels have been collected and eaten by indigenous people and are also consumed by domestic livestock	Henríquez et al. (2008), Turner et al. (2011), Besoain et al. (2019), and Gallia et al. (2020)

(continued)

Table 1 (continued)

Botanical name	Family	Description and distribution	Key references
Bertholletia excelsa	Lecythidaceae	Commonly known by the name Brazil nut. Is native to amazon rainforest in south America and adjacent area in Brazil, Bolivia and Peru One of the most significant non-timber forests producing tree species in the Amazon whose fruits are mainly collected from natural forests by Amazonian communities. An extensive portion of the nut for international trade is harvested from the wild	Thomas et al. (2014), Kluczkovski et al. (2015), and Caetano Andrade et al. (2019)
Brosimum alicastrum	Moraceae	Commonly known by the name Maya nut or Ramon nut. A fast-growing and massive tropical rainforest tree indigenous in Central and Northern South America It was consumed as one of major chief food for ancient Maya peoples and used as an alternative food sources when crop production reduced. Moreover, the seed has been employed for baking, drinks, and sauces after being drying roasting, and grinding	Ozer (2017) and Moo-Huchin et al. (2019)
Carum carvi	Apiaceae	Caraway (*C. carvi*), also known as meridian fennel or Persian cumin. A biennial plant with spicy tasting seeds, which is native to western Asia, Northern Africa, and Europe	Rasooli and Allameh (2016) and Lasram et al. (2019)
Carya illinoensis	Juglandaceae	Pecan (*Carya illinoensis*) is native to North America but also grows in Australia, Brazil, Canada, Mexico, Israel, and South Africa. Extensively consumed in North America as a popular snack and a dessert ingredient. Is a major wild and plantation crop	Turner et al. (2011), Alvarez-Parrilla et al. (2018), Atanasov et al. 2018 and Casales et al. (2018)
Carya ovata	Juglandaceae	Known by common name Shagbark hickory; the nut is sweet tasting and can be used in any recipe as an alternative to walnuts or pecans. Native to North America especially the mountainous area of Mexico and Atlantic coast. The plant is dominant in oak–hickory forests and also moderately available in other types of mixed-oak forests	Trozzo et al. (2012) and Wilgan et al. (2020)

(continued)

Table 1 (continued)

Botanical name	Family	Description and distribution	Key references
Castanea sativa	Fagaceae	*Castanea sativa* Mill. is the only natural species in Europe and Turkey and it has also widespread from East Black Sea to the Mediterranean region of Europe and western Asia. Widely cultivated and grown in Southern Europe, and also harvested from wild growing trees. It's nuts rich in starch and high-quality protein and consumed as flour, bread, porridge, sweetmeats	Turner et al. (2011), Avşar et al. (2016), and Míguez-Soto et al. (2019)
Cola acuminate and *Cola nitida*	Sterculiaceae	Locally well-known by the name bissy, cola, or kola nuts in west African countries an evergreen originally endemic to West Africa (particularly Northern Nigeria, Ivory Coast, Sierra Leone, Liberia, and Sudan) and has been distributed to many tropical countries the nut is culturally chewed by many West African peoples as coffee stimulants, which can ease hunger cramps, stimulates digestion and is also used for euphoric qualities	Kanoma et al. (2014), Lowe et al. (2014) and Dah-Nouvlessounon et al. (2015)
Cola lepidota	Malvaceae	Commonly called as monkey Kola whose edible tasty seed are eaten by native southern Nigeria and the Cameron peoples and some wild primate animals such as monkeys and baboons	Essien et al. (2015) and Udousoro and Essien (2017)
Corylus spp. (such as *Corylus avellana*)	Betulaceae	Commonly known by the name Hazelnut or Filbert, and has economic importance as edible nuts and a good quality timber. It is a monoecious, multistemmed deciduous shrub native to mild temperate regions of Asia, Europe, and North America. It is cultivated and also harvested from forests, and its nuts are employed in baking and confections	Turner et al. (2011), Nikolaieva et al. (2019), Preece and Aradhya (2019)

(continued)

Table 1 (continued)

Botanical name	Family	Description and distribution	Key references
Delonix regia	Caesalpiniaceae	A beautiful, semi-deciduous tree known as flame of forest in Nigeria. Leaves, roots, and seeds widely employed in the treatment of many diseases and ailments, Since mature seeds are reported to be poisonous due to their antinutrient composition, only the immature seeds have been found to be edible	Amata and Nwagu (2013), Kumar et al. (2013), and Oyedeji et al. (2017)
Euryale ferox	Nympheaceae	An aquatic crop is known by the name Gorgon nut or Fox nut. Widely distributed in stagnant perennial water bodies like ponds, land depressions, oxbow lakes, swamps, and ditches of India and China. The seed is eaten as part of diet during fasting time of various religious people and used in the preparation of Ayurvedic medicines (analgesic and aphrodisiac) in India and China.	Francis (2018)
Fagus grandifolia and *Fagus sylvatica*	Fagaceae	Common forest tree known by the name beechnut (American and European beechnuts). Dominantly distributed in Northern hardwood forests (North Eastern parts of North America and Europe). Used for foods preservation purposes and roasted nuts are used as a coffee substitute in France. Eaten when roasted and row nuts are also edible but should be in small quantity as a row *Fagus sylvatica* nut stated to be comprising low molecular weight toxic compounds.	Cleavitt, and Fahey (2017), Siger et al. (2017), Musara, and Maroyi (2020), and Cartier (2020)
Foeniculum vulgare	Apiaceae	It is a perennial plant, which is native to the Mediterranean area and central Europe. Traditionally employed for treating gastrointestinal and neurological disease, kidney stones, vomiting, and diarrhea. Its fragrant seed is used as a culinary spice	Diao et al. (2014), Kooti et al. (2015), and Ahmad et al. (2018)

(continued)

Table 1 (continued)

Botanical name	Family	Description and distribution	Key references
Garcinia kola	Gattiferae	Commonly called Bitter kola and false or male kola sometimes an evergreen, perennial tropical moist low land forest tree that is commonly found in tropical West African countries mainly in Nigeria and Sierra Leone. The native western African tribes chew the seed part of the plant as stimulants (astringent taste, resembling that of row coffee bean) and consumed culturally to relieve cough and hoarseness, treatment of liver disorders, improving the singing voice, and also used as an antihypertensive	Indabawa and Arzai (2011), Seanego and Ndip (2012), Omeh et al. (2014), and Dah-Nouvlessounon et al. (2015)
Juglans (Walnut)	Juglandaceae	The domesticated species (*Juglans regia*) and wild Manchurian species (*Juglans mandshurica*) trees occur in the hilly parts of northern China. The Manchurian walnut is commonly used as folk medicine for the treatment of diseases such as dermatosis, cancer, gastritis, and diarrhea in Korea	Park et al. (2017), Zhang et al. (2017), and Li et al. (2018)
Mentzelia albicaulis	Loasaceae	Commonly known by the name whitestem blazingstar. Seed parts are collected, parched, and eaten by native communities of the Great Basin and California	Turner et al. (2011) and Brokaw et al. (2015)
Myrrhis odorata	Apiaceae	Commonly named as Sweet Cicely and its seed, leaves, and stalks are beneficial in Scandinavia as sweet-smelling herb providing fresh fragrant. Mainly distributed in the mountainous areas of Europe; native to central and southern Europe. The plant has been used as a sweetener in desserts and food condiments, and good substitute for anise, fennel, or even licorice	Dobravalskytė et al. (2013) and Ferrer et al. (2016)

(continued)

Table 1 (continued)

Botanical name	Family	Description and distribution	Key references
Pinus spp. (*Pinus pinea*, *P. sibirica, P. edulis*, *P. cembra, P. koraensis*)	Pinaceae	Are non-wood forest products (NWFP); usually known by the name pine nuts. Widely distributed in different parts of world especially in Mediterranean coniferous forests, middle east, southwest United States, Europe, and Asia. Locally important and traditionally consumed as specialty food by native tribes	Awan and Pettenella (2017), Zhang and Zhang (2019)
Quercus spp. (oak)	Fagaceae	Popular categories of perennial, deciduous trees from temperate and tropical climatic areas (mainly in Asia, Europe, and North and Central America). The white oak (*Section Quercus*) species are distributed throughout North America and Europe while red oaks (*Section Lobatae*) varieties are endemic to North America. The nut of oak is known by the name acorn nutrient-rich constituent, which is valued wild food and feed source for native peoples, hence justifying secondary food source for humans	Vinha et al. (2016), Sekeroglu et al. (2017), Löf et al. (2019), and López-Hidalgo et al. (2020)
Trapa spp. (*Trapa natans* and *T. bicornis*)	Trapaceae	Commonly called water caltrop. Annual, floating-leaved aquatic plants broadly cultivated species in many European countries and Asia (especially southern China). The fruit has been consumed as a nutritious food resource in China and many European countries. Can also be consumed for diverse food and energy applications, and used as habitat for fish and recreation even in North America	Li and Yuan (2016) and Zhu (2016)

ancient times of human history. The use of plant parts, such as seeds and nuts, and their products as a natural drug for the treatment of diseases, is as old as mankind (Bhattacharya 2020). They are still extensively employed as herbal drugs, either in their crude form or as preparations thereof, or as sources of medicinally active natural products to be used in traditional as well as modern medicine.

Fig. 1 Forest-based seeds and nuts (**a**) *Aesculus indica*, (**b**) *Pinus gerardiana,* (**c**) *Afzelia africana,* (**d**) *Cola nitida,* (**e**) *Prosopis africana,* (**f**) *Juglans* spp., (**g**) *Perilla frutescens,* (**h**) *Cannabis sativa,* (**i**) *Delonix regia,* (**j**) *Amaranthus viridis,* (**k**) *Terminalia bellirica,* and (**l**) *Quercus* spp

4 Socioeconomic Aspect of Forest-Based Edible Seeds and Nuts

Globally, human beings are tremendously dependent on plants and plant-derived products mainly for food, medicine, shelter, timber, industrial purposes, and other days to day activities. More than 84% of human diet and nutrition currently derived from plants worldwide and about 90% of the average human diet were obtained from plants in Africa, Asia, and the Pacific, and the near east according to the report by United Nation Food and Agricultural Organization (FAO 2011; Joshi and Shrestha 2019). Humans, on the other hand, are dependent on a few crops, and only about 30,000 of the world's 300,000 to 500,000 existing plant species are considered edible (Shaheen et al. 2017c). Among known edible plant species, only 7000 plants are cultivated and consumed as food from prehistoric times. Unfortunately, 20 species alone out of known edible species contribute to 90% of world food requirements, and among that about 60% of human diet depends solely on wheat, maize, and rice (FAO 2011; Shaheen et al. 2017c).

FAO in the State of World's Forest 2014 report (FAO 2014) has documented the socioeconomic benefits of forests in food and nutritional security, generating income, basic human needs, and improving quality of life. Moreover, forests provide a wide variety of social and economic benefits, ranging from easily quantified economic values associated with forest products, to less-tangible services and contributions to society (FAO 2010). Forest-based seeds and fruits are cheap and useful and are a good source of fat, protein, antioxidants, vitamins, fibers, minerals, and other nutrients. When eaten, these plant parts can protect the human body from various diseases (such as cardiovascular disease, chronic cancer, diabetes, pneumonia, etc.) and can be used for a variety of ailments (Shaheen et al. 2017a).

Lots of people in the world, especially in developing countries, depend on edible forest-based medicinal seeds and nuts to fulfill their dietary needs and for their health care. They are also valuable sources of energy and micronutrients. Edible seeds and nuts obtained from forests are not only vital for being part of the human diet but also important sources of income for both rural and urban communities. For instance, Afghan export Chilgoza pine nuts (*Pinus gerardiana*) obtained from chilgoza pine forest and Kinnauri tribal peoples of Western Himalaya socioeconomically dependent on such nuts to improve the income and livelihood of their rural communities (Shalizi and Khurram 2016; Rahimzadeh, 2020). Many non-timber forest products (NTFPs), such as seeds and nuts, may be used for survival, while others are the chief or only source of income in traditional forest communities (Caspa et al. 2020). Thus, in addition to food values, forest-based seeds and nuts play an important role in economic growth, especially in developing countries. To do this, we need to focus on improving people's cultural knowledge.

5 Nutrient Composition (Macro and Micronutrients) of Forest-Based Edible Seeds and Nuts

The chemical and nutritional composition of seeds and nuts directly contribute to their participation in the medication and healing activities of different diseases. The phytochemicals and other micro and macronutrient contents of edible seeds and nuts are extensively documented. It has been reported that they are a good source of macronutrients (plant-based amino acids, unsaturated fats, and carbohydrates) and micronutrients (vitamins and minerals) in addition to tocopherols, phytosterols, and polyphenols (Bolling et al. 2011; Carlsen et al. 2011; Derewiaka et al. 2014; Alasalvar and Bolling 2015; Souza et al. 2015; Tucker 2017). Similarly, edible forest tree seeds and nuts also have a valuable amount of macro and micronutrients and can be consumed as alternative food that could probably reduce critical food scarcity and malnutrition. Forest-based plants, primarily seeds and nuts, are considered a valuable source of essential nutrients and other beneficial phytochemicals. The phytoconstituents (micro and macronutrients) of some selected edible forest-based seeds and nuts are summarized in Table 2. Forest-based edible seeds and nuts and the obtained phytoconstituents, macronutrients, and micronutrients (Fig. 2) are discussed in the following sections.

5.1 Proteins

Proteins are complex biomolecules (macromolecules) that consist of one or more long-chain amino acid (monomer) residues joined by peptide bonds. It plays a critical role in building and repairing our body tissue and facilitates metabolism in addition to maintaining a proper pH and fluid balance. Sufficient uptake of protein in our daily diet contributes to the healthy functioning of our cells and helps in protecting our body from foreign pathogens. Edible seeds and nuts are rich in proteins, especially in essential amino acids in addition to lipids, dietary fiber, and minerals (Freitas et al. 2012; De 2020). Bioactive proteins from different forest-based edible seeds and nuts exhibit potentially exploitable activities, including antiproliferative, antitumor, and immunomodulatory activities, and are beneficial in defending and protecting the body against pathogenic microorganisms and predatory insects (Hernandez-Ledesma et al. 2011).

Various studies have shown that wild-harvested forest-based seeds and nuts are important sources of different amino acids. It has been recently reported that *Amygdalus scoparia* (Amirshaghaghi et al. 2017) and *Amygdalus pedunculata* Pall. (Wang et al. 2019) are among edible wild almond species having valuable sources of proteins. Both species are abundant in acidic amino acids (glutamic and aspartic acid), and the latter also contains essential amino acids (43.24 g/100 g) and sulfur-containing amino acids (2.43g/100g). Surprisingly, the total essential amino acid content (342.4 mg/g protein) of *Amygdalus pedunculata* Pall. is comparatively better than that of peanuts. Similarly, the seed of baobab (*Adansonia digitata*) is reported to have the highest total amino acid value (106.64 g/100g crude protein), especially concentrated in aspartic and glutamic nonessential amino acids and also contain arginine and tyrosine as major essential amino acids (Ibrahim et al. 2016). Also, some seeds and nuts such as *Araucaria angustifolia* (Peralta et al. 2016), *Bertholletia excelsa* (Yang 2009), *Castanea sativa* (Turner et al. 2011), *Euryale ferox* Salisb. (Francis 2018), *Cola lepidota* (Udousoro and Essien 2017), and *Brosimum alicastrum* (Ozer 2017; Moo-Huchin et al. 2019) are reported to be a good source of protein when taken as an alternative or together with staple food items.

Table 2 Major bioactive constituents of some forest-based edible seeds and nuts and their roles in disease control

Seeds and or nuts	Bioactive compounds and nutrients (chemical constituents)	Biological activities roles in healthcare and disease control	Key references
Adansonia digitata	Rich sources of proteins, carbohydrates, fibers, vitamins (thiamine, lysine), and minerals (mainly Ca, Fe, P, Mg)	Seeds are used in cases of hiccough. Oil extracted from seeds is used for inflamed gums and to ease diseased teeth	Zahra'u et al. (2014) and Braca et al. (2018)
Aesculus indica	Total phenols, tannins, flavonoids, contain sugar, starch, and minerals (calcium, potassium, phosphorus, copper, zinc, manganese, and iron)	Anti-allergic, anti-inflammatory, antimicrobial, anticancer, antiviral, and antidiarrheal activity in addition to aches, colic, nervous tonic, chest diseases, anthelmintic, and jaundice	Khan et al. (2015) and Mishra et al. (2018)
Amaranthus viridis	Flavonoids, tannins, and cardiac glycosides	Antimicrobial, antioxidant activities, anti-inflammatory, in venereal diseases, vermifuge, diuretic, antirheumatic, antidiabetic, antiulcer, analgesic activities, and fight against diabetes mellitus	Pandhare et al. (2012), Ahmed et al. (2013)
Terminalia bellirica and *Terminalia chebula*	Glucoside, tannins, gallic acid, corilagin, ellagic acid, ethyl gallate, galloyl glucose, chebulagic acid, and arjunolic acid. Fatty acids, proteins, lignanamide, and coumaroylamino glycoside derivative	Antioxidant, anti-inflammatory, immunomodulatory, antimicrobial, hepatoprotective, renoprotective, antidiabetic, antihyperlipidemic, anticancer activities and used to treat coughs/colds	Aryal et al. (2018), Kumar and Khurana (2018), and Gupta et al. (2020)
Cannabis sativa	Fatty acids, protein, lignanamide, and coumaroyl aminoglycoside derivative	Immunomodulatory effects, reduce cholesterol, cardiovascular effect, amelioration effects, used in dermatological disease and the treatment of gastrointestinal disease	Cheng et al. (2011), and Zhou et al. (2018)
Cola acuminate, *Cola nitida* and *Garcinia kola*	Free amino acids, dietary fibers, sugars, flavonoids, alkaloid, tannins, glycoside, steroids, saponins, vitamins, and fatty acids	Antioxidant, anticarcinogenic, antimutagenic, and cardioprotective effects, used in the treatment of malaria and fever	Kanoma et al. (2014), Lowe et al. (2014), and Dah-Nouvlessounon et al. (2015)

(continued)

Table 2 (continued)

Seeds and or nuts	Bioactive compounds and nutrients (chemical constituents)	Biological activities roles in healthcare and disease control	Key references
Delonix regia	Tannin, saponin, phenolics, flavonoids, reducing sugars, triterpenoids, anthraquinones, alkaloids, and amino acids. Its seed oil contains, essential fatty acids, vitamins acylglycerols, and essential minerals such as sodium, potassium, calcium, phosphorus, and iron	Anti-inflammatory, antimicrobial, anti-ulcer, and antioxidant properties. The seeds are a good source of oil, energy-rich, good for consumption, and can be used as protein supplement	Amata and Nwagu (2013), Kumar et al. (2013), and Oyedeji et al. (2017)
Brosimum alicastrum	Phenolic acids (mainly, gallic acid, *p*-hydroxybenzoic acid, vanillic acid, caffeic acid, and *p*-coumaric acid) and flavonoid	Antioxidant activity	Ozer (2017) and Moo-Huchin et al. (2019)
Cola rostrata and *Cola lepidota*	Alkaloids, saponins, terpenoids, carbohydrates, flavonoids, proteins (mainly essential amino acids), minerals, and vitamins (B & K)	Antioxidant activity	Essien et al. (2015) and Udousoro and Essien (2017)
Perilla frutescens	Phenolic compounds (Rosmarinic acid, caffeic acid, ferulic acid), flavonoids (luteolin, apigenin), phytosterols, tocopherols, policosanols, and fatty acid	Anticancer, antidiabetic, antiasthma, antimicrobial, anti-inflammatory, antioxidant, and cardioprotective effect, and helps to treat depression-related disease, anxiety, asthma, chest stuffiness, vomiting, coughs, colds, flu, phlegm, tumors, allergies	(Ahmed 2019 and Dhyani et al. 2019)
Quercus spp.	Polyphenols (phenolic acids (particularly gallic and ellagic acids and their derivative compounds), flavonoids (particularly flavan-3-ols), and tannins), aliphatic alcohols, proteins, vitamins (mainly A & E), starch, and fatty acids	Antioxidant, anticarcinogenic, and cardioprotective properties and used in the treatment of specific diseases such as atherosclerosis, diabetes, or Alzheimer's disease	Vinha et al. (2016), Gezici and Sekeroglu (2019), and López-Hidalgo et al. (2020)

(continued)

Table 2 (continued)

Seeds and or nuts	Bioactive compounds and nutrients (chemical constituents)	Biological activities roles in healthcare and disease control	Key references
Terminalia catappa	Amino acids (mainly tryptophan and lysine), oleic acid, linoleic acid, alkaloids, flavonoids, saponins, phenols, and terpenoids	Antioxidant, anti-inflammatory, antitumor, antiviral, and ant diabetic activities	Janporn et al. (2015), Santos et al. (2016), and Yenrina et al. (2020)
Amygdalus pedunculata and *Amygdalus scoparia*	Proteins, fatty acid (oleic acid and linoleic acid), sugars (fructose, glucose, sucrose, maltose, and lactose), mineral (Zn, Ca, and Se), vitamin E, vitamin B_3, folate, phytosterols, phenolic, and flavonoid	Antioxidant activities, high content of plant sterols, particularly β-sitosterol and campesterols are used to prevent or at least minimize the risk of heart disease.	Wang et al. (2019) and Zahedi et al. (2020)
Zanthoxylum armatum	Terpenoids, alkaloids, sterols and steroids	Anti-larvicidal, antifungal, hepatoprotective and allelopathic properties, and traditionally used as carminative, stomachic and anthelmintic, in the treatment of toothache	Singh and Singh (2011) and Shan et al. (2019)

5.2 *Fatty Acids*

Fats are a major storage form of energy in our body, and they function as structural building blocks of the body and carry fat-soluble vitamins and many physiological processes such as blood clotting, wound healing, and inflammation. Plant-based fats are abundantly available in seeds, nuts, and fruits than other plant parts. Nuts and seeds are known to be good nutritious sources of unsaturated fatty acids (Li and Hu 2011). Many studies reported that seeds and nuts wild collected (obtained from the forest) are rich in fatty acids, especially polyunsaturated fatty acids. To mention, *Urtica dioica*, *Avena fatua*, *Pinus pinea*, *Pinus pinea*, *Centaurea depressa*, *Carthamus dentatus*, *Chenopodium album*, *Chenopodium album*, *Eruca sativa*, *Diplotaxis tenuifolia*, *Cardaria draba*, *Borago officinalis*, *Pistacia atlantica*, and *Amaranthus retroflexus* are some Mediterranean edible seeds rich in polyunsaturated fatty acids (Guil-Guerrero and Torija-Isasa 2016). Moreover, the seeds of *Araucaria angustifolia*, a native gymnosperm of the Atlantic forest in Brazil (da Silva et al. 2016; Peralta et al. 2016), and *Adansonia digitata* L., an African baobab (Ibrahim et al. 2016; Erwa et al. 2019), are known to be an excellent source of unsaturated fatty acids, mainly linoleic, oleic, and palmitic acid. Similarly, it has been reported that the unroasted (raw) nuts of *Amygdalus scoparia* (Moayedi et al. 2011; Hojjati et al. 2016) and *Amygdalus pedunculata* Pall. (Wang et al. 2019), also called wild almonds, are rich sources of linoleic, oleic, and palmitic unsaturated fatty acids. According to López-Hidalgo et al. (2020), the fatty acid profile of Holm

Fig. 2 Seeds and nuts as a rich source of various phytoconstituents, macro, micronutrients, vitamins, etc

oak (*Quercus ilex*) is fairly similar to that of olive oil with oleic acid being the most dominating (almost 60%) followed by linoleic and palmitic acids (nearly 18%) and approximately 4% stearic acid.

5.3 Polyphenols

Polyphenols are naturally occurring organic molecules that abundantly exist as multiple phenol units in plants and are structurally diverse. They are plant secondary metabolites that are very important molecules in human health and disease prevention. Having plant-based polyphenols in the human diet plays a crucial role in health through the regulation of metabolism, weight, chronic disease, and cell proliferation, and various polyphenolic compounds are known by their antioxidant as well as anti-inflammatory properties that could have preventive and/or therapeutic effects for cardiovascular disease, neurodegenerative disorders, cancer, and obesity (Cory et al. 2018; Olivares-Vicente et al. 2018; Fraga et al. 2019). Among different health benefits, polyphenolic compounds such as flavonoids and phenolic acids take a great portion in antioxidant activity, including scavenging of free radicals, inhibition of lipid oxidation, and reduction of hydroperoxide formation (Li et al. 2014; Brglez Mojzer et al. 2016). The presence of polyphenol-rich nuts and seeds, even in moderate amount, in nutrition are good antioxidants (Zujko and Witkowska 2014; Chang et al. 2016; Hayes et al. 2016), and those harvested from the forest are important alternatives to reduce direct rely on staple food items for preventing disease caused by oxidative reactions in the body.

According to Popović et al. 2013; Vinha et al. (2016) most wild edible nuts of *Quercus* species such as *Q. acuta*, *Q. acutissima*, *Q. alba*, *Q. cerris*, *Q. faginea*, *Q. glauca*, *Q. ilex*, *Q. macrocarpa*, *Q. marilandica*, *Q. muhlenbergii*, *Q. myrsinaefolia*, *Q. palustris*, *Q. petraea*, *Q. phylliraeoides*, *Q. pyrenaica*, *Q. robur*, *Q. rubra*, *Q. rotundifolia*, *Q. salicina*, *Q. suber*, and *Q. virginiana* are rich in polyphenolics, especially in phenolic acids (particularly gallic and ellagic acids and their derivative compounds), flavonoids (particularly flavan-3-ols), and tannins. Besides, López-Hidalgo et al. (2020) investigated some phytochemicals of *Quercus ilex* and reported the seed of the plant is a rich source of phenolic compounds (benzoics, cinnamics, coumarins, stilbenes, flavonoids, lignans, and tannins), which are important antioxidant molecules. Some other forest-collected edible plants such as wild almond mainly, *Amygdalus pedunculata* Pall. (Wang et al. 2019) and *Amygdalus scoparia* (Hojjati et al. 2016), *Araucaria angustifolia* (da Silva et al. 2016; Peralta et al. 2016), *Brosimum alicastrum* (Ozer 2017), *Garcinia kola* (Omeh et al. 2014), *Cola acuminate*, and *Cola nitida* (Kanoma et al. 2014) have been reported to possess phenolic, polyphenolic, and other related compounds in their seeds and nuts

5.4 Carbohydrates and Fibers

Carbohydrates are important biomolecules, which our body needs every day as it plays vital roles as an energy fuel for the synthesis of glycoproteins and glycolipids and also used as a general precursor for most complex organic compounds in the body. It has been documented that a well-balanced vegan diet can meet all macro and micronutrient intake recommendations and is high in fiber and carbohydrates (Melina et al. 2016). This is mainly because poor nutrition habits and high intakes of processed meat products and sodium and low intakes of fruits and vegetables are associated with roughly half of the cardiometabolic deaths in the United States and may also result in obesity (Micha et al. 2017; Kahleova et al. 2018). Some forest-based seeds and nuts have been reported to be a good source of carbohydrates, such as starch, sugar, cellulose, and fiber, and can be used as part of the human diet. For instance, *Cola lepidota* (commonly called Monkey Kola) is reported to have relatively higher carbohydrate content (about 86%) in its seeds when compared to its fruit pulp (84.33%) and fruit pericarp (80.68%) (Udousoro and Essien 2017). Some edible forest seeds and nuts such as Cola Nuts (*Cola nitida* and *Cola acuminata*) (Kanoma et al. 2014), *Garcinia kola* (Omeh et al. 2014), acorn (*Quercus ilex*) (López-Hidalgo et al. 2020), Wild almond (*Amygdalus pedunculata* Pall.) (Wang et al. 2019), *Araucaria angustifolia* (da Silva et al. 2016; Peralta et al. 2016), fox nut (*Euryale ferox* Salisb) (Francis 2018), African baobab (*Adansonia digitata* L.) (Ibrahim et al. 2016) have been reported as good sources of total carbohydrates, glycosides, sugars, starches, and fibers.

5.5 Vitamins and Minerals

Vitamins and minerals are micronutrients that are considered to be essential nutrients, as they perform hundreds of roles in our body. They play a pivotal role in boosting the immune system, wound healing, repair cellular damage, and help shore up bones. Consumption of vitamins and mineral-rich seeds and nuts from forests is very important to reduce malnutrition and starvation, especially in developing countries, and also crucial to protect from the various diseases globally. Dau et al. (2016) and Dawaki et al. (2017) investigated the mineral and vitamin content of forest-based edible seeds of *Adansonia digitata*, *Afzelia africana*, *Moringa oleifera*, *Prosopis africana,* and *Terminalia catappa*. Their report reveals that *Adansonia digitata*, *Moringa oleifera*, *Prosopis africana*, and *Terminalia catappa* are rich sources of vitamin A, C, and E, while *Afzelia africana* is highly enriched in vitamin C. Similarly, the seed of *Terminalia catappa* is highly enriched in calcium (789.61 mg/100 g), potassium (7233.50 mg/100 g), magnesium (687.58 mg/100 g), and iron (422.00 mg/100 g). African baobab (*Adansonia digitata* L.) seed is a good source of some minerals, such as Mg (86.92 mg/100 g), potassium (36.36 mg/100 g), sodium (22.56 mg/100 g), and also a small concentration of iron and calcium is also present (Erwa et al. 2019). Besides, wild almond (*Amygdalus pedunculata* Pall.) is known to be rich in vitamins (mainly thiamine, riboflavin, niacin, pantothenic acid, vitamin B6, folate, and vitamin E) and abundant in minerals (especially calcium, potassium, phosphorus, and magnesium) (Wang et al. 2019).

6 Role of Forest-Based Edible Seeds and Nuts in Health Care and Disease Control

According to the United Nations Food and Agriculture Organization, nearly two billion people worldwide are highly exposed to various diseases due to micronutrient deficiencies (FAO 2011). This indicates that the world food supplying capacity from existing crops only is not sufficient enough to fulfill the nutrient requirements of people, especially in developing nations. Therefore, seeking alternative food resources such as seeds and nuts obtained from forest is very crucial to reduce malnutrition and susceptibility to different diseases, as they are dense in micro and macronutrients. Numerous studies have shown that plants (vegetables, seeds, fruits, fruits, roots, etc.) and their food products are rich in various phytochemicals, such as alkaloids, carotenoids, and phenolics, in addition to vitamins, minerals, proteins, carbohydrates, fatty acids, and other nutrients, which are important for health care and reduce human diseases (Narzary et al. 2016; Basumatary and Narzary 2017; Giampieri et al. 2017; Kapinova et al. 2017). Forest-based edible seeds and nuts containing a number of bioactive and health-promoting components are economically inexpensive and can alternatively involve in health care and disease control, as they have been employed as folk medicine in prehistoric periods. Table 2 summarizes the major chemical constituents and health benefits of some previously explored edible forest seeds and nuts.

6.1 Against Cancer

Cancer (especially trachea, bronchus, and lung cancers) is categorized among the most ten deadliest diseases according to the World Health Organization report (Siegel et al. 2015). Currently, it is being the most controversial issue, and much research has been devoted to dietary phytochemicals that resulted in preventing and healing the case. Evidence have confirmed that bioactive components of natural plants and their derivatives showed promising anticancer activities (Li et al. 2015; Griffiths et al. 2016; Newman and Cragg 2016; Al-Dabbagh et al. 2018), and most anticancer drugs approved by the United States Food and Drug Administration throughout the last three decades are natural products and their derivatives (Bishayee and Sethi 2016). Plants are known to exhibit various pharmacological traits and astonishing therapeutic activities and have afforded more effective, more selective, and less toxic compounds as anticancer, antitumor, and antiproliferation agents (Gezici and Sekeroglu 2019). Accordingly, the seed and fruit extracts of *Terminalia bellirica* have shown antiproliferative activities against breast, colorectal, prostate, neuroblastoma, and endometrial cancer cell lines (Gupta et al. 2020; Patra et al. 2020). Furthermore, polyunsaturated fatty acid (mainly the ω-6-linoleic acid) and (ω-9-oleic acid) in edible seed extracts of perilla in China are important in lowering the risk of colon cancer in addition to various biological activities, such as reducing the cholesterol and triglyceride levels in serum and preventing the excessive growth of visceral adipose tissue (Ding et al. 2012; Ahmed 2019).

6.2 Cardiovascular Prevention

Cardiovascular disease (CVD) is the ischemic or hemorrhagic disease of the heart, brain, and systemic tissue mainly caused by hyperlipidemia, blood viscosity, atherosclerosis, and high blood pressure (Yang et al. 2019). According to Wightman and Heuberger (2015), CVD accounts for approximately 30% of the total number of deaths in the world each year. Edible plants and their products are not only important in being part of the human diet for food but also useful in health care and disease prevention such as cardiovascular prevention. Since nuts and seeds are rich in healthy unsaturated fats, proteins, carbohydrates, minerals, and phytochemicals such as carotenoids, polyphenols, tocopherols, their consumption is highly associated with lowering the risk of cardiovascular and other degenerative diseases (Alasalvar and Bolling 2015; Souza et al. 2015; De 2020). Bioactive such as anthocyanins, phenolic acids, and quercetin glycosides from edible berries (blueberry, mulberry, bilberry, cranberry, raspberry, blackberry) help fight against CVD by regulating blood lipids, proper platelet aggregation, lowering oxidative stress (OS), and improving endothelial function, which is a possible risk factor for CVD (Yang et al., 2019; Wightman and Heuberger 2015). Besides socioeconomic, cultural, and religious benefits, edible forest-based seeds and nuts have auspicious activities in reducing the risk of cardiovascular disease.

6.3 Antioxidant and Anti-inflammatory Activities

Oxidative stress (OS) due to reactive oxygen species (ROS), can cause different degenerative diseases in the human body. It has been implicated in the progression of different ailments, such as CVD, chronic obstructive pulmonary disease, chronic kidney disease, neurodegenerative diseases, and cancer (Liguori et al. 2018; Singh et al. 2019). Exogenous molecules such as phenolic antioxidants (resveratrol, phenolic acids, and flavonoids) obtained from plants take gigantic parts in fighting against OS in the body in addition to endogenous molecules such as enzymes (Liguori et al. 2018). Forest plant products like edible seeds and nuts are enriched with various phytochemicals and are capable of fighting against reactive oxygen and nitrogen species (RONS) to reduce OS and also important in anti-inflammatory activities. Accordingly, phenolic compounds such as rosmarinic acid, rosmarinic acid-3-*O*-glucoside, and flavonoid luteolin were the dominant phenolic antioxidants with strong activity from cold-pressed *perilla* var. *arguta* seed flour, which can neutralize reactive free radicals (Zhou et al. 2014; Ahmed 2019). Likewise, Wang et al. (2018) isolated a perillaketone-type and alkaloid compounds from aerial parts of perilla that showed the remarkable inhibitory effect on proinflammatory cytokines (TNF-α and/or IL-6) and inflammatory mediator (NO) in LPS-stimulated RAW264.7 cells and showing that such compounds might be active components for inflammatory disorders. In addition, *Quercus ilex* (acorn) contains different phytoconstituents having strong antioxidant and anti-inflammatory activities (López-Hidalgo et al. 2020). Therefore, edible seeds and nuts from the forest are not only an alternative food during starvation and crop failure but also help to reduce oxidative stress, thereby preventing the development of chronic diseases, including diabetes, cancer, cardiovascular disease, neurogenesis, and inflammation.

7 Conclusion

Forest and forest-based products have played an important role in human life. They have been used and continued to be employed as a shelter for various biomes and primary contributor for ecological and climatical balances. Their products have been used for food, medicine, fiber, timber, fuel, fodder, and also employed as input for the manufacturing industry as raw material directly or indirectly. Currently, human beings from different directions, especially from developing countries, are suffering from malnutrition and starvation and are highly susceptible to various diseases due to a lack of appropriate food supply and medication. This is directly related to the extreme reliance on a few food crops such as wheat, rice, and barley (approximately 90%) and to the inadequate usage of wild and forest food sources. Consuming edible forest-based seeds and nuts plays a vital role in reducing direct relay on few commonly consumed crops and thereby participate in health care and disease control, as they are reported to possess various phytoconstituents including macro and micronutrients, polyphenols, carotenoids, alkaloids, aliphatic and aromatic compounds, and many other bioactive constituents that are capable of fighting against different ailments. Despite their nutritional role and enrichment in biologically active compounds, most people are not aware of their huge roles in health care and disease control and are not extensively consumed. Therefore, an emphasis should be given to improve indigenous knowledge of the peoples so that the products can widely be used as parts of the human diet as an alternative to staple dishes and sources of income for both rural and urban communities in the future.

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Medicinal Plants of Himalayan Forests

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1 Introduction

Plants play a vital role in our diet and are an excellent reservoir of proteins, carbohydrates, antioxidants, vitamins, and other important components required for our existence (Vella 1990). Among such important components, secondary metabolites have received increasing attention, as they contain medicinal values with huge therapeutic significance, besides being major contributors to health care improvements (Eloff 1998). Such secondary metabolites are often named active compounds or phytochemicals and display renowned biological effects, such as antimicrobial, antioxidant, antitumor, antidiabetic, antinociceptive, cardioprotective, and immunomodulatory properties, among others. Indeed, the increasing importance on the use of herbal preparations and medicinal plant is that they have low or even no side effects when compared to synthetic drugs and are simultaneously more potent against several diseases and disorders.

From time immemorial, a variety of indigenous and cultivated plants have been exploited for their therapeutic properties, and globally they are analyzed for the assessment of their efficiency as a result of increasing demand by the worldwide population by plant-based medicine. The World Health Organization (WHO) has reported that the business of medicinal plants and herbal medicine and the demand for herbal raw material is increasing annually at a growth rate of almost 15% (Neupane and Lamichhane 2020). However, it is expected that the global market of medicinal or pharmaceutical products extracted from plant sources will surpass $111 billion by the year 2023 (Sofowora et al. 2013; Neupane and Lamichhane 2020). Hence, the research for identifying new species of medicinally important plants and the search for biologically active compounds from them is in progressing phase, due to which the demand for these medicinal plants has increased a lot in the market.

The forest richness of the Himalayan region is inexhaustible with exceptional medicinal flora and incredible economic significance (Pandey 2007). Flora from the Himalayan region is used by native communities for different reasons, including food, fuel, and medicinal purposes (Detwiler and Hall 1988; Bhat et al. 2020). A huge range of Himalayan plants has been cited by researchers around the world, with multiple therapeutic virtues underlined as well as their major role in traditional medicinal systems of different countries.

Currently, numerous herbal medicines and their active components have been used directly or indirectly in the modern medical system. A plethora of biologically important active compounds has been isolated from plant species found in the Himalayan region. Among such active compounds, linoleic acid, quercetin, gallic acid, ascorbic acid, piperine, myricetin, curcumin, taxol, palmitic acid, cinnamaldehyde, nerolidol, taxiresinols, amarogentin, swertiamarin, mangiferin, hesperidin, picroliv, and apocynin have been extracted and/or isolated at considerable amounts from a variety of plants, including *Anogeissus latifolia*, *Justicia adhatoda*, *Curcuma longa*, *Punica granatum*, *Piper nigrum*, *Aegle marmelos*, *Rhododendron arboreum*, *R. campanulatum*, *Podophyllum hexandrum*, *Saussurea obvallata*, *Taxus* *wallichiana*, *Pinus roxburghii*, *Swertia chirayita*, *Picrorhiza kurroa*, etc., to whom excellent therapeutic activities have been attributed, such as antimicrobial, anticancer, anti-inflammatory, antiproliferative, antioxidant, antiatherogenic, anti-asthmatic, antifungal, antidiabetic, immunomodulatory, anti-HIV, anti-Parkinson, and anti-hepatitis effects (Rajeshkumar and Kuttan 2001; Juyal et al. 2014; Painuli et al. 2015; Kumar and Van Staden 2016; Painuli and Kumar 2016; Painuli et al. 2016; Semwal 2017; Adnan et al. 2019; Semwal and Painuli 2019; Soni and Grover 2019). In this sense, this chapter aims to address the important medicinal plants from the forests of the Himalayas and their traditional uses, promising bioactive molecules along with therapeutic potential.

2 From Himalayan Mountain Diversity to New Drug Sources

The Himalaya, a crescent-shaped continuous belt of mountain system located in Asia, is known to be the highest and youngest mountain range worldwide. It extends over about 2500 km from Nanga Parbat in the west to Namja Barwa in the east, ranging up to 350 km of width in the west to 150 km in the east. This mountain belt is mainly distributed across the territories of five countries, namely, Pakistan, India, Nepal, China, and Bhutan (Roy and Purohit 2018). From west to east, the Himalayan belt is sectioned into three well-defined regions: western, eastern, and central Himalayan. With a complex and diverse geological pattern in terms of hydrology, environment, erosion, and mass movement, in the Himalayan belt, there is a marked climate variation at different zones, drifting from the tropical climate at the bottom and everlasting snow at the top of the mountain, with regional ecosystem transformations depending on elevation. In fact, both altitudinal and climatic variations make the Himalayan vegetation extremely rich and broadly distributed in forests and grasslands (Hajra and Rao 1990). Himalaya forest systems vary markedly in their topography, soils, rainfall, and weather, harboring rare and valuable flora and fauna. The variation in Himalayan vegetation ranges from tropical deciduous forests at the lower altitude to temperate forest at middle altitude, while at higher altitudes, coniferous forest, subalpine, and alpine forests are found, ranging from alpine grasslands and meadows to scrublands and permanent snowline.

Among the wide plant biodiversity of the Himalayan forest, which includes medicinal, aromatic, and wild edible plants, orchids, ferns and fern allies, bamboos, and ornamental plants (Hajra and Rao 1990), with increasing elevation, the flora shows even greater diversity profile (Manish and Pandit 2018; Bhat et al. 2020). The major plant species in the Himalayan tropical and subtropical forests include *Acacia catechu, A. procera*, *Albizia lebbeck*, *Bombax ceiba*, *Careya arborea*, *Dalbergia sissoo*, *Duabanga grandiflora*, *Garuga pinnata*, *Gmelina arborea*, *Haldina cordifolia, Kydia calycina*, *Mesua assamica*, *M. ferrea*, *Oroxylum indicum*, *Pinus roxburghii*, *Quercus lamellose*, *Semecarpus anacardium*, *Shorea robusta*, *Terminalia tomentosa*, and *T. bellirica*; however, in the Himalayan temperate forest, species like *Abies delavayi*, *A. densa*, *A. pindrow*, *Acer* spp., *Berberis* spp.*, Cedrus deodara*, *Larix griffithii, Lithocarpus pachyphyllus*, *Magnolia* spp., *Picea smithiana*, *Prinsepia utilis, Quercus cerris*, *Q. lamellose*, *Rhododendron* spp., and *Tsuga dumosa* predominate (Manish and Pandit 2018). In the shrubby region, *Artemisia*, *Berberis*, *Cotoneaster,* and *Ephedra* species are major elements, while in subalpine and alpine zones, *Aconitum heterophyllum*, *Aster albescens*, *Anemone*, *Berberis*, *Cotoneaster*, *Geranium*, *Iris*, *Juniperus*, *Lloydia*, *Potentilla*, *Primula*, and *Rhododendron* dominate (Srivastava et al. 2017; Manish and Pandit 2018). Table 1 enumerates the list of some Himalayan plants along with their distribution.

3 Traditional Uses of Himalayan Plants

The traditional system of medicine (TSM) comprises folk knowledge-based medicines, exercises, manual techniques, and spiritual healing along with other medical aspects developed over generations by several communities for diagnosis and prevention of a plethora of diseases. According to the WHO, "*the traditional medicine is the sum total of the knowledge, skills, and practices based on theories, beliefs and experiences indigenous to different cultures, whether explicable or not, used in health maintenance as well as prevention, diagnosis, improvement or even treatment of physical and mental illness*" (Che et al. 2017). TSM uses natural compounds, extracted from herbs, animals, organic matter, and minerals, for preventing or curing diseases, with medicinal plants being used for preparing a plethora of herbal drug formulations. TSM, including Ayurveda, Yoga, Unani, Naturopathy, Siddha, Homeopathy, and Chinese medicine system (TCM) used Himalayan medicinal plants as a leading source for efficient and effective herbal drug formulation. Among all, the Ayurvedic medicinal system is the oldest system of medicine developed and is in practice since 1500 BC (Ravishankar and Shukla 2007). These different TSMs are practiced in India, Nepal, Srilanka, Pakistan, Bangladesh, Bhutan, China, and Tibet, among other places (Rosenberg 2012; Samal and Dehury 2016).

Among the renowned plant species that play important roles in these TSM, *Andrographis paniculate*, *Artemisia maritime, Asparagus racemosus*, *Bacopa monnier*, *Barbarea vulgaris, Berberis vulgaris*, *Cedrus deodara*, *Curcuma longa*, *Datura innoxia*, *Dioscorea deltoidea*, *Equisetum arvense*, *Girardinia heterophylla*, *Ocimum sanctum*, *Paeonia emodi*, *Picrorrhiza kurroa*, *Pinus gerardiana*, *Podophyllum hexandrum*, *Rheum emodi*, *Rhododendron arboreum*, *Saussurea obvallata*, *Terminalia chebula*, *Tulipa gesneriana*, and *Withania somnifera* are the most widely recognized (Kurup 2002; Khare 2008; Gautam and Bhadauria 2009). These herbal plants exhibit numerous biological properties and have been used to treat high blood pressure, migraine, parasitic and fungal infections, fever, skin problems, cancer, stomach ache, uterine infection, inflammation, microbial infection, stress, fatigue, liver, and kidney problems (Joshi and Joshi 2013; Chaudhury and Rafei 2002). Some of these traditionally important plants and their traditional uses are mentioned in Table 2.

Table 1 Some popular Himalayan plants and their distribution

Species name	Family	Distribution
Aconitum heterophylloides (Brühl) Stapf	Ranunculaceae	Pakistan, India, Nepal
Aconitum heterophyllum Wall. ex Royle	Ranunculaceae	Pakistan, India, Nepal
Allium carolinianum DC.	Amaryllidaceae	Afghanistan, India, China, Pakistan, Nepal
Allium rubellum M. Bieb.	Amaryllidaceae	Asia, Europe
Anoectochilus roxburghii (Wall.) Lindl.	Orchidaceae	China, Tibet, Japan, Sri Lanka, India, Nepal
Arisaema propinquum Schott	Araceae	Pakistan, India, Nepal, Tibet
Aster falconeri (C.B.Clarke) Hutch.	Asteraceae	Arctic, Africa, Asia, America
Atropa acuminata Royle ex Lindl.	Solanaceae	Afghanistan, Iran, Pakistan, India
Begonia picta Sm.	Begoniaceae	China, India, Nepal, Bangladesh, Myanmar
Berberis aristata DC.	Berberidaceae	Asia, Europe, and America
Berberis lyceum Royle	Berberidaceae	India, Pakistan, Nepal
Bombax ceiba L.	Malvaceae	Asia, Africa, Australia
Calanthe davidii Franch.	Orchidaceae	China, India, Japan, Nepal, Taiwan, Vietnam
Calanthe plantaginea Lindl.	Orchidaceae	India, Nepal, Bhutan
Cardiocrinum giganteum (Wall.) Makino	Liliaceae	India, Pakistan, Nepal
Cicer microphyllum Benth.	Leguminosae	India, Pakistan, Afghanistan, Nepal, Tibet, Bhutan
Colchicum luteum Baker	Colchicaceae	Afghanistan, Turkestan, Pakistan, India
Cymbidium iridioides D.Don	Orchidaceae	Bhutan, India, Myanmar, Nepal, North Vietnam
Cymbidium lowianum (Rchb.f.) Rchb.f.	Orchidaceae	India, China, Japan, Indonesia, Australia
Dactylorhiza hatagirea (D.Don) Soó	Orchidaceae	India, Pakistan, Afghanistan, Nepal, Tibet, Bhutan
Dendrobium heterocarpum Wall. ex Lindl.	Orchidaceae	India, Nepal, Bhutan, Myanmar, Sri Lanka, Pakistan
Dendrocalamus strictus (Roxb.) Nees	Poaceae	India, Peninsula, Bangladesh, Myanmar, Thailand
Dioscorea deltoidea Wall. ex Griseb.	Dioscoreaceae	China, Pakistan, Nepal, Bhutan, India, etc.
Elaeagnus rhamnoides (L.) A.Nelson	Elaeagnaceae	Asia, Europe
Eremurus himalaicus Baker	Xanthorrhoeaceae	Afghanistan, India, Pakistan, Nepal
Euryale ferox Salisb.	Nymphaeaceae	India, Europe, China, Japan
Fraoaria nubicola Lindl. ex Lacaita	Rosaceae	China, Nepal, India, Myanmar
Gentiana kurroo Royle	Gentianaceae	Pakistan, India, Nepal

(continued)

Table 1 (continued)

Species name	Family	Distribution
Hedychium spicatum Sm.	Zingiberaceae	Pakistan, India, Nepal
Hypericum hookerianum Wight & Arn.	Hypericaceae	India, Pakistan, China, Nepal, Bangladesh.
Myrica esculenta Buch.-Ham. ex D Don	Myricaceae	India, Nepal, China, Japan, Pakistan, Singapore
Nardostachys jatamansi (D.Don) DC.	Caprifoliaceae	Afghanistan, China, Tibet, Nepal
Nasturtium officinale R.Br.	Brassicaceae	Asia, Europe, Africa
Nymphaea nouchali Burm. F.	Nymphaeaceae	India, Africa
Nymphoides peltata (S.G. Gmel.) Kuntze	Menyanthaceae	China, India, Nepal
Picrorhiza kurrooa Royle	Scrophulariaceae	Pakistan, India, Nepal
Pinus gerardiana Wall. ex D.Don	Pinaceae	Afghanistan, India, China, Pakistan, Nepal
Podophyllum hexandrum Royle	Berberidaceae	India, Afghanistan, China, Pakistan, Nepal, Bhutan
Primula denticulata Sm.	Primulaceae	Bhutan, India, Myanmar, Nepal, China, Pakistan
Rheum webbianum Royle	Polygonaceae	India, Pakistan, Afghanistan, Nepal, Tibet, Bhutan
Rhodiola imbricata Edgew.	Crassulaceae	China, India, Nepal, Pakistan
Rhododendron arboreum Sm.	Ericaceae	India, Nepal, China, Bhutan, Sri Lanka, Pakistan
Rubus ellipticus Sm.	Rosaceae	China, Nepal, India, Philippines
Saussurea costus (Falc.) Lipsch.	Asteraceae	India, Pakistan, China
Saussurea obvallata (DC.) Edgew.	Asteraceae	India, Pakistan, China, Tibet, Nepal
Sinopodophyllum hexandrum (Royle) T.S.Ying	Berberidaceae	Afghanistan, India, China, Pakistan, Nepal
Taxus baccata L.	Taxaceae	Asia, Europe, America, Iran
Urtica dioica L.	Urticaceae	Africa, America, Asia, Australasia, Europe
Valeriana hardwickii Wall.	Valerianaceae	Afghanistan, India, Pakistan, Myanmar
Valeriana jatamansii Jones	Valerianaceae	Afghanistan, Bhutan, China, India, Pakistan

On the other hand, the TCM system was written around 100 or 200 BC, and the Chinese Materia Medica was published in 1977 (Yuan et al. 2016). Regarding the most frequently used Himalayan medicinal plants in TCM, *Aquilaria sinensis*, *Bergeria purpurascens*, *Cistanche salsa*, *Coptis omeiensis*, *Coptis teeta*, *Cordyceps sinensis*, *Dendrobium* spp., *Dioscorea deltoidea*, *Dioscorea ipponica*, *Dioscorea zingiberensis*, *Dracaena cochinchinensis*, *Ephedra sinica*, *Epimedium brevicornum*, *Erigeron breviscapus*, *Eucommia ulmoides*, *Fritillaria* spp., *Gastrodia alata*, *Gentiana macrophylla*, *Gentiana scabra*, *Glycyrrhiza uralensis*, *Homalomena*

Table 2 Some popular medicinal plants and their traditional uses

Name of the species	Traditional uses	References
Abrus cantoniensis Hance	Chronic hepatitis, rheumatism, traumatic injury	Hong et al. (2015)
Abutilon indicum Linn. Sweet.	Paralysis, cough, chronic cystitis	Khare (2008)
Acanthopanax trifoliatus (L.) Merr.	Rheumatic arthritis, traumatic injury, sciatica, eczema	Hong et al. (2015)
Aconitum heterophyllum Wallich ex Royle	Stomach ache, fever	Uniyal et al. (2006)
Acorus calamus L.	Diarrhea	Hong et al. (2015)
Acorus calamus L.	Skin wounds, cough, cold, roundworm, hookworm	Ambu et al. (2020)
Adenanthera pavonina Linn.	Diarrhea, paralysis, pulmonary affections	Khare (2008)
Aesculus indica (Colebr. ex Cambess) Hook.	Pregnancy food for ladies	Uniyal et al. (2006)
Ajuga bracteosa Wall. ex Benth.	Stimulant, aperient, diuretic, blood purifier, fever	Khare (2008)
Allium humile Kunth	Breathing problem, stomach disease, jaundice	Bano et al. (2014)
Amygdalus persica Linn.	Cough, chronic bronchitis	Khare (2008)
Angelica glauca Edgew	Fever and cold	Uniyal et al. (2006)
Artemisia capillaris Thunb.	Decoction, hepatitis, jaundice	Hong et al. (2015)
Artemisia sieversiana Ehrh.	Pneumonia, joints, boils, wounds, swelling	Bano et al. (2014)
Asparagus racemosus Willd	Immunoregulatory, tonic	Ojha et al. (2020)
Astragalus psilocentros Fisch	Teeth cleaning, stomach problems	Bano et al. (2014)
Berberis asiatica Roxb. ex DC.	Diabetes, Jaundice	Uniyal et al. (2006)
Berberis lycium Royle	Eye disease	Uniyal et al. (2006)
Bergenia ciliata (Haw.) Sternb.	Diarrhea, asthma, urinary problems, ophthalmia	Bano et al. (2014)
Betula utilis D. Don.	Rheumatism, dropsy, stones in the kidneys, eczema	Khare (2008)
Cannabis sativa L.	Paralysis, joint pain, piles	Uniyal et al. (2006)
Cedrus deodara (Roxb.) Loud.	Astringent, antidiarrheal, febrifuge, skin disease	Khare (2008)
Chenopodium album L.	Rheumatism, swollen feet, sunstroke, sunburn	Bano et al. (2014)

(continued)

Table 2 (continued)

Name of the species	Traditional uses	References
Chirita eburnea Hance	Grinding, decoction	Hong et al. (2015)
Citrus hystrix DC.	Gastrointestinal	Ojha et al. (2020)
Dactylorhiza hatagirea (D.Don) Soo	Bleeding, wounds	Ojha et al. (2020)
Dioscorea deltoidea Wall	Could, cough, joint pain, wounds, constipation, etc.	Semwal et al. (2021)
Dioscorea opposita Thunb.	Grinding, decoction, weakness, frequent urination	Hong et al. (2015)
Eclipta prostrata (L.)	Diarrhea, hematuria, hemoptysis, socioeconomic	Semwal et al. (2017)
Ficus benghalensis Linn.	Diabetes, dysentery, wounds	Khare (2008)
Ficus palmate Forsk.	Cuts, wounds	Ojha et al. (2020)
Grewia optiva Drummond ex Burret	Joint pain	Uniyal et al. (2006)
Hedychium spicatum Buch. Ham. ex Smith	Respiratory, intestinal problems, purgative, laxative	Ojha et al. (2020)
Hypericum sampsonii Hance	Traumatic injury, pain, indigestion, chest congestion	Hong et al. (2015)
Jasminum arborescens Roxb.	Astringent, stomachic	Khare (2008)
Juniperus excelsa M. Bieb.	Kidney stone, rheumatism, respiratory disorders	Bano et al. (2014)
Malva parviflora L.	Abortion	Uniyal et al. (2006)
Myrica esculenta Buch.-Ham. ex D. Don	Constipation, diarrhea, asthma, bronchitis	Ambu et al. (2020)
Paeonia emodi Wall. ex Royle.	Nervous affections, uterine diseases, blood purifier	Khare (2008)
Paeonia officinalis Linn	Antispasmodic, sedative, vasodilatory, hypotension	Khare (2008)
Picrorhiza kurrooa Royle ex Benth.	Joint pain, fever	Uniyal et al. (2006)
Podophyllum hexandrum Royle	Dermatological	Ojha et al. (2020)
Polygonum amplexicaule D.Don	Wounds in the eyes	Uniyal et al. (2006)
Quercus leucotrichophora A. Camus	Indigestion, diarrhea, asthma	Semwal et al. (2018)
Rhaphidophora glauca (Wall.) Schott	To promote pregnancy	Ambu et al. (2020)
Rheum australe D.Don	Fractured bone	Uniyal et al. (2006)

(continued)

Table 2 (continued)

Name of the species	Traditional uses	References
Rhododendron arboreum Smith	Nasal bleeding	Uniyal et al. (2006)
Rumex nepalensis Sprengel	Anti-allergic	Uniyal et al. (2006)
Saussurea costus (Falc.) Lipsch.	Joint pain	Uniyal et al. (2006)
Saussurea obvallata (D.C.) Edgew	Paralysis, mental illness, cough, chronic cystitis	Semwal et al. (2020)
Senecio chrysanthemoides DC.	Rheumatic pain, wounds, sore throat	Bano et al. (2014)
Swertia chirayita (Roxb. ex Fleming)	Skin infection in children's	Uniyal et al. (2006)
Swertia petiolata Royle	Opthalmia, liver tonic, stomach inflammation	Bano et al. (2014)
Taxus baccata Linn.	Nervousness, epilepsy, asthma, chronic bronchitis	Khare (2008)
Thalictrum foliolosum DC.	Stomach pain, gastric trouble	Uniyal et al. (2006)
Viola betonicifolia J.E. Smith	Antidote	Ojha et al. (2020)
Viola pilosa Blume	Fever, cold, cough	Uniyal et al. (2006)
Zanthoxylum armatum DC	Respiratory, gastrointestinal, spices, and condiments	Ojha et al. (2020)
Zanthoxylum nitidum (Roxb.) DC.	Ulcer, rheumatism, diarrhea, malaria, chronic gastritis	Hong et al. (2015)
Zingiber officinale Rosc	Cold, cough	Ojha et al. (2020)

occulta, *Panax ginseng, Panax pseudoginseng*, *Paris polyphylla* var. *yunnanensis*, *Picrorhiza scorophulariiflora*, *Psammosilene tunicoides*, *Rauwolfia yunnanensis*, *Rheum officinale*, *Salvia miltiorrhiza*, *Saussurea lappa*, *Sinopodophyllum emodi*, *Stephania epigaea*, *Stephania yunnanensis*, *Taxus chinensis*, and *Taxus wallichiana* are the most evident (Shengji et al. 2009). Indeed, the Himalayan flora has a long history in traditional or alternative treatments, and presently researchers are not only searching for new active components but also exploring the mechanism of action of many of these plant-derived extracts and even single components.

4 Plant-derived Bioactive Compounds

Bioactive compounds are essential and nonessential elements extracted from natural sources, especially from plants that help fulfill vital health requirements. Secondary metabolism produces these specialized compounds as a self-defense mechanism, conferring protection against herbivores, insects, pathogen, pests, pathogens, and harsh environmental conditions (Egbuna et al. 2018). These secondary metabolites, also known as phytochemicals, phytoconstituents, or even active compounds, have microbicidal, insecticidal, and pesticidal effects and are also of huge interest for the production of several pharmaceutical drugs. Moreover, they also have numerous biomedicinal properties, such as antioxidant, anti-inflammatory, cardiovascular, anti-allergic, antihypertensive, and anticancer potentialities, being, therefore, a rich source of nutraceutical and pharmaceutical products (Hussein and El-Anssary 2018).

The Himalayan flora are known worldwide for their wide spectrum of biological activities, attributed to the presence of high-valued secondary metabolites (Semwal et al. 2020). The plant species at higher altitudes have high diversity and a significant amount of several phytoconstituents, as they face high radiations, low soil nutrients, moisture stress, harsh temperature, and other adverse environmental conditions (Pandey et al. 2018; Yang et al. 2018). At higher altitude, phytoconstituents also help in pollination and confer protection and defense against several biotic and abiotic stresses (Demasi et al. 2018), with this plant–environmental interconnection being responsible for the unique mixture and composition of active compounds (Yang et al. 2018; Jurić et al. 2020).

Despite being put in the background for several years, today, there has been a growing interest in plant secondary metabolites over synthetic molecules because of several properties, such as low or no side effects, less toxicity, cost-effectiveness, and easy availability (Zeb et al. 2014). Many studies have suggested that natural compounds that are directly or indirectly isolated from plant origin actively participates in the formulation of effective and potent drugs. Currently, the field of synthetic chemistry is well developed yet, with more than 850 plant-derived active molecules being used in pharmaceutical formulations and with more than 100 plant-based compounds/molecules in the phase of clinical trials (Fowler 2006; Katiyar et al. 2012). Aspirin, ephedrine, colchicine, taxol, digoxin, camptothecin, atropine, and artemisinin are some of the plant-based active phytochemicals used in modern medicine (Jan and Abbas 2018; Calixto 2019).

Secondary metabolites are majorly classified into four main groups, such as alkaloids, terpenes, terpenoids, and polyphenolic compounds. Glycosides, tannins, and saponins are part of them, given their specific structure. Alkaloids are well-studied plant metabolites with remarkable anticancer, antimalarial, antihypertensive, anti-asthmatic, antimicrobial, analgesic, and vasodilatory activities (Roberts and Wink 1998; Raymond et al. 2010; Cushnie et al. 2014). Terpenes and terpenoids are major constituents of plant essential oil and exhibit great anti-inflammatory, anticancer, and antimicrobial activities (Trombetta et al. 2005; Salminen et al. 2008). Polyphenols are a vast group of phytochemicals, which include flavonoids, phenolic acids, isoflavonoids, lignans, curcuminoids, and tannins, possessing immense biomedicinal potentialities like anticancer, antimicrobial, anti-inflammatory, antioxidant, antidiabetic, neuroprotective, and antiallergic effects, among others (Huang et al. 2010; Ghasemzadeh and Ghasemzadeh 2011; Ferrazzano et al. 2011; Egbuna et al. 2018).

4.1 Alkaloids

Alkaloids are a group of naturally occurring organic compounds obtained from bacteria, plants, and fungi that contain at least one nitrogen atom in their heterocyclic ring (Mueller-Harvey and McAllan 1992). Ancient records have shown that alkaloids have been used for medicinal purposes since 4000 BC and are probably the first natural compounds (e.g., morphine) extracted from plants (Rao et al. 1978; Roberts and Wink 1998). Indeed, the therapeutic use of poppy and opium by Persians, Egyptians, Arabs, Greeks, and Sumerians has been mentioned in various ancient manuscripts.

Although they are known for their exceptional biomedicinal properties, several alkaloids with high toxic effects have been reported to cause death in minor amounts. For example, the evaluation of active compounds from *Kopsia* genus leads to the revelation of various classes of alkaloids, with antitumor, anti-leishmania, and antimitotic properties (Chen et al. 2012). Thus, based on their heterocyclic ring, alkaloids are classified as pyrrolidine alkaloids, pyridine alkaloids, pyrrolidine–pyridine alkaloids, pyridine–piperidine alkaloids, quinoline alkaloids, and isoquinoline alkaloids (Jan and Abbas 2018). These groups are comprised of medicinally important alkaloids, including hygrine, isopelletierine, piperine, coniine, nicotine, myosmine, quinine, taxol, hyoscyamine, scopolamine, papaverine, morphine, codeine, narcotine, and heroine (Saxena et al. 2013). Moreover, some alkaloids, including anabasine and nicotine, have insecticidal properties, while others like tetrahydropalmatine, isoquinoline, zephyrantine, berberine, palmatine, atropine, scopolamine, atropine, quinine, colchicine, ephedrine, hyoscyamine, morphine, taxol, emetine, and narcyclasine glucoside have a long history of medicinal applications and are pharmacologically important (Bribi 2018; Jan and Abbas 2018; Badri et al. 2019).

In general, various therapeutic activities have been reported to alkaloids, such as anticancer, antihyperglycemic, antimalarial, anti-asthmatic, vasodilatory, anti-arrhythmic, cholinomimetic, and analgesic effects (Roberts and Wink 1998; Sinatra et al. 2010; Russo et al. 2013; Kittakoop et al. 2014; Cushnie et al. 2014), with Himalayan plants, like *Aconitum balfourii*, *Aconitum heterophyllum*, *Atropa belladonna*, *Berberis asiatica*, *Camellia sinensis*, *Cinchona officinalis*, *Colchicum luteum*, *Corydalis govaniana*, *Datura innoxia*, *Dicentra canadensis*, *Ephedra gerardiana*, *Eupatorium cannabinum*, *Rauvolfia serpentina*, *Saussurea lappa*, *Taxus baccata*, *Thalictrum foliolosum, Valeriana dubia*, *Vinca rosea*, and *Withania somnifera* being extremely rich sources of such class of biologically active molecules (Khare 2008; Sharma and Gaur 2012; Chhetri 2014).

4.2 Terpenes and Terpenoids

Terpenes and terpenoids are one of the most common and diverse groups of plant secondary metabolites, with around more than 22,000 compounds occurring in all plant sorts (Adeyemi 2011). Briefly, terpenes are simple hydrocarbons consisting of five-carbon isoprene units, assembled in thousands of different ways. On the other hand, terpenoids are modified terpenes with different functional groups and oxidized methyl group present or absent at several locations (Tiwari and Rana 2015; Perveen and Al-Taweel 2018). They are the main constituents of essential oils (Joshi et al. 2016), namely, sesquiterpenes, saponins, iridoids, cardiotonic heterosides, alpha-terpineol, γ-terpinene, terpinolene, and terpinen-4-ol (Joshi et al. 2016). Organoleptically, terpenes, and terpenoids are responsible for the aroma and flavoring properties of plants, with compounds like linalool, caryophyllene, menthol, and geraniol being widely renowned for it. They also possess a broad range of pharmacological and biological properties, such as anti-inflammatory, antiparasitic, antioxidant, anticancer, antiviral, antimicrobial, insecticidal, and antihyperglycemic effects (Zhu et al. 2003; Trombetta et al. 2005; Salminen et al. 2008; Hanuš and Hod 2020). Himalayan flora, namely *Abies pindrow*¸ *Achillea millefolium*, *Achyranthes bidentata*¸ *Aconitum chasmanthum*, *Aconitum ferox*, *Aconitum palmatum*, *Adiantum capillus-veneris*, *Andrographis panicultata*, *Artemisia maritima*, *Artemisia vestita*, *Baliospermum montanum*, *Blumea balsamifera*, *Bridelia montana*, *Bupleurum flacutum*, *Callicarpa macrophylla*, *Caltha palustris*, *Cedrus deodara*, *Cetraria islandica*, *Cimicifuga racemose*, *Curcuma angustifolia*, *Daphne oleoides*, *Delphinium denudatum*, *Euonymus tingens*, *Eupatorium cannabinum*, *Galium aparine*, *Inula racemose*, *Juniperus communis*, *Kalanchoe integra*, *Madhuca butyracea*, *Nardostachys jatamansi*, *Perilla frutescens Picea smithiana*, *Quercus incana*, *Rhododendron arboreum*, *Rhododendron campanulatum*, *Rhododendron cinnabarinum*, *Roylea cinereal*, and *Saussurea lappa*, are well recognized for their rich contents in terpenes and terpenoids, with multiple applications in chemical, cosmetic, and pharmaceutical industries (Khare 2008; Painuli et al. 2015; Painuli et al. 2016; Rawat et al. 2019).

4.3 Phenolic Compounds

Polyphenols are widely known for their excellent antioxidant properties and ability to enhance the function of endogenous antioxidants, vitamins, and enzymes to prevent oxidative stress-induced damages by the high amount of reactive oxygen species (ROS). This group of biologically active molecules is considered to have chemical features related to phenolic substances and is composed of various subgroups, namely, phenolic acids, flavonoids, phytoalexins anthocyanins, lignin, tannins, and furanocoumarins (Tsao 2010; Singla et al. 2019). Synthesized by malonic and shikimic acid pathways occurring in plants, there are over 8,000 known structures of phenolics of which more than 4,000 are recognized as flavonoids (Bravo 1998; Harborne and Willians 2000; Cheynier 2005). Polyphenols possess a wide range of biological activities, including antioxidant, antiaging, anticancer, anti-inflammatory, anti-atherosclerotic, anti-apoptotic, cardioprotective, and neuroprotective abilities (Han et al. 2007; Soto-Hernández et al. 2017), with the major groups responsible for such effects being phenolic acids and flavonoids.

Himalayan flora is also a rich source of secondary metabolites and particularly has high contents of polyphenols. Many studies have proved that plant species from higher altitudes contain high and diverse polyphenolic forms. Among the Himalayan plants, *Aegle marmelos*, *Ampelocissus latifolia*, *Artemisia sp.*, *Berberis asiatica*, *Bergenia ciliate*, *Dendrobenthamia capitata*, *Fagopyrum esculentum*, *Ficus palmata*, *Ficus subincisa*, *Grewia optiva*, *Hippophae rhamnoides*, *Hypecoum leptocarpum*, *Hypericum perforatum*, *Leea asiatica*, *Meconopsis aculeata Royle*, *Morus alba*, *Morus serrata*, *Nardostachys jatamansi*, *Paris polyphylla*, *Pinus Species*, *Podophyllum hexandrum*, *Potentilla fulgens*, *Prunus cerasoides*, *Pyracantha crenulata*, *Reinwardtia indica*, *Rubus ellipticus*, *Satyrium nepalense*, *Saussurea obvallata*, *Taxus wallichiana*, *Viburnum mullaha*, *Vitis jacquemontii*, *Ziziphus mauritiana*, *Ziziphus nummularia*, and *Vaccinium glaucoalbum* have been reported to have high polyphenolic content with rich biological activities (Prakash et al. 2007; Kaur et al. 2009; Ratan and Kothiyal 2011; Singh et al. 2015; Kundu et al. 2016; Feng et al. 2017; Mishra et al. 2018; Mohd et al. 2018; Painuli et al. 2018; Bahukhandi et al. 2019; Semwal and Painuli 2019; Singh et al. 2019; Rawat et al. 2019; Belwal et al. 2020; Gauchan et al. 2020; Tewari et al. 2020).

5 Biological Activities

At present, the earth's population exceeds 7 billion and is continuously increasing at the rate of 1.05% per year, and as a consequence, humans have directly or indirectly influenced almost all parts of the planet (Vitousek et al. 1997; Lindahl and Grace 2015). The rise in anthropogenic activities not only influences the planet's environment but also triggers human health problems (Myers and Patz 2009). There are a number of factors, like food and water scarcity, climate change, globalization, urbanization, among others, that are a root cause of diseases and disorders in humans. According to the WHO Report in 2016, ischemic heart disease, stroke, respiratory infections, cancer, diabetes, and tuberculosis are some of the diseases with highest mortality rates. The factors responsible for such disorders can be intrinsic (e.g., genetic disorders, malfunctioning of the immune system, and hormonal imbalance) and extrinsic (e.g., radiations, harmful chemicals, bacteria, viruses, and fungi). Presently, in our day-to-day life, we are more exposed to these external factors, especially harmful radiations, chemicals, and mutated pathogens, like multidrug resistance bacteria and viruses, like severe acute respiratory syndrome (SARS) and Middle East respiratory syndrome (MERS), due to which we suffer from deadly diseases.

The Himalayan region is one of the major habitats for medicinally important plant species for millennia. Dhar (2002) reported that the Himalayan region has a rich biodiversity, with around 21 vegetation types, 11 forest formations, and 10 forest types. The diverse climatic and geological conditions of the Himalayas are responsible for different types of flora and active compounds found in them, accountable for multiple medicinal properties. As previously referred, Himalayan plant species have remarkable antioxidant, anticancer, antimicrobial, antidiabetic, antiparasitic, analgesic, neuroprotective, antihepatotoxic, antihypertensive, anti-inflammatory, antiallergic, and anti-stress abilities (Khare 2008; Joshi et al. 2016). For example, *Aconitum heterophyllum* possesses antioxidant, anti-inflammatory, alexipharmic, antiflatulent, and analgesic effects, while the diterpenoid alkaloid isolated from the plant shows antioxidant and anticholinesterase properties (Ahmad et al. 2017; Paramanick et al. 2017). On the other hand, *Arctium lappa* is reported to possess anticancer, hepatoprotective, antidiabetic, anti-inflammatory, and antihuman immunodeficiency virus (HIV) properties (Chan et al. 2011; Gao et al. 2018). *Atropa acuminata* ethanol extract has revealed anti-arthritic effects, while the plant-derived phytoconstituents possess anticholinergic, antimicrobial, and anti-inflammatory activities and have wide medicinal uses in cardiology, gastroenterology, and ophthalmology (Rahman et al. 2018). *Berberis aristata* is reported to have antidiarrheal, hepatoprotective, antimicrobial, anticancer, antidiabetic, antiplatelet activating factor (paf), cardiotonic, and anti-inflammatory effects (Potdar et al., 2012). *Dioscorea deltoidea* is used for its prominent therapeutic effects in solving female reproductive system problems, central nervous system (CNS) and skin diseases, autoimmune diseases, oncology, cardiovascular system, bones and joint diseases, and metabolic disorders (Dangwal and Chauhan 2015). *Hedychium spicatum* holds anti-inflammatory, anti-asthmatic, anti-allergic, analgesic, antiulcer, hepatoprotective, antihyperglycemic, anticancer, and cytotoxic effects (Rawat et al. 2018). *Nardostachys jatamansi* is reported to possess antifungal, hepatoprotective, CNS, anticonvulsant, neuroprotective, anti-Parkinson's, and antidiabetic activities (Purnima and Kothiyal 2015). *Picrorhiza kurrooa* has antioxidant, antimicrobial, hepatoprotective, antimutagenic, and anticancer activities (Masood et al. 2015). Podophyllotoxin is an active compound from *P. hexandrum* used in the synthesis of the anticancer drugs etoposide and teniposide (Giri and Narasu 2000). *Rhododendron arboreum* possesses antioxidant, adaptogenic, anti-inflammatory, antinociceptive, hepatoprotective, antidiabetic, cardioprotective, antimicrobial, and immunomodulatory activities (Popescu and Kopp 2013; Painuli et al. 2018). *Swertia chirayita* exhibits a broad range of bio-medicinal properties, like antiviral, antidiabetic, anti-inflammatory, anticancer, antioxidant, and antimicrobial effects (Kumar and Van Staden 2016). In addition, *Artemisia*, *Cinnamomum*, *Cymbopogon*, *Junipers*, *Nepeta*, *Origanum*, and *Valeriana* species are some other important plant genus from the Himalayan region with a wide range of polyphenols and with significant biomedicinal activities (Joshi et al. 2016). Different biological applications of the plants are presented in Fig. 1.

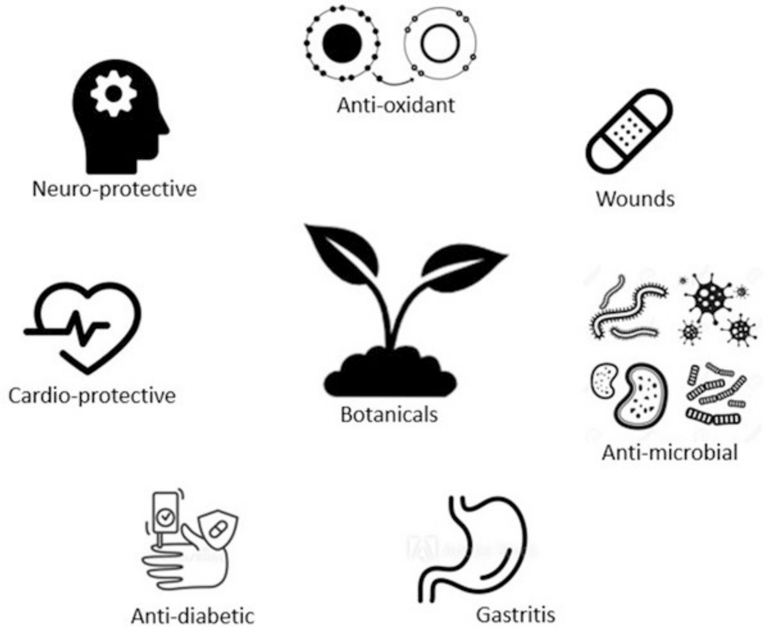

Fig. 1 Different biological applications of the plants

6 Pharmacological Effects of Himalayan Plant-derived Phytochemicals

6.1 Anticancer Activity

Cancer is considered the second major cause of mortality worldwide. Broadly, it not only affects the mental and physiological status of individuals but also has a huge social impact on the worldwide economy. Cancer therapy seems to be difficult, as most existing drugs and treatments are not very potent in conferring complete protection against the disease. The major steps involved in anticancer drug development are to assess both safety and efficacy in human models through clinical trials. Despite the huge amount of molecules with promising potential, from these studies, normally consisting of 4 phases (Phase I, II, III, and IV), unfortunately only one of every 5000–10,000 anticancer drugs get approval from the FDA, and only 5% of oncology drugs enter the phase I clinical trial (Paul et al. 2010; Petsko 2010; Shibue and Weinberg 2017; Bedard et al. 2020). Thus, the developmental cost of synthetic anticancer agents is extremely high; however, it can be reduced by introducing plant-based anticancer agents. Plant-derived active compounds have been detected to be effective in experimental and clinical trials against cancer. For example, the compound genistein (isoflavone) extracted from legumes and used for the treatment of various diseases including breast cancer, osteoporosis, obesity, and menopause reveals to be safe and effective at low cost (Zhang et al. 2020). In addition, Vincristine (*Catharanthus roseus*), Vinblastine (*Catharanthus roseus*), 5-Fluorouracil (*Withania somnifera*), Paclitaxel (*Taxus brevifolia*), Bullatacin (*Annona squamosa*), Theabrownin (*Camellia sinensis*), Solamargine (*Solanum nigrum*), Psoralidin (*Psoralea corylifolia*), Kaempferol galactoside (*Bauhinia variegata*), Skimmianine (*Aegle marmelos*), Podophyllotoxin (*Podophyllum hexandrum*), and Plumbagin (*Plumbago zeylanica*), among others, are some important anticancer phytochemicals extracted from plant species found in the Himalayan region (Ashraf 2020). **Table 3** lists the anticancer effects of some Himalayan plants.

6.2 Neuroprotective Activity

Neurodegenerative diseases comprise an anomalous group of disorders that are described by continuous declining or worsening of the peripheral nervous system or CNS structure and function. These neurodegenerative diseases are basically age dependent (Heemels 2016), with Alzheimer's disease (AD) and Parkinson's disease (PD) being the most common, despite Huntington's disease (HD), amyotrophic lateral sclerosis (ALS), spinocerebellar ataxias, and frontotemporal dementia being increasingly diagnosed.

AD is a progressive and irreversible brain disorder that gradually damages the memory and thinking skills and eventually results in inability to perform simple tasks. PD is characterized by a continuous loss of dopamine resulting in movement disorder, rigidity, and tremor, as well as neuron demise in cholinergic and catecholaminergic nuclei. Sparreboom et al. (2004) reported that a huge population of Australia, Europe, and North America are using plant-derived medicines for treating such conditions. Although many modern medicines are available in the market for neurodegenerative diseases, plant-based drugs have also left their promising impression in this field. In fact, among the Himalayan flora, *Artemisia absinthium*, *Bergenia ciliate*, *Centella asiatica*, *Crocus sativus*, *Curcuma longa*, *Elaeagnus umbellata*, *Lindera neesiana*, *Myrica esculenta*, *Panax ginseng*, *Swertia chirayita*, *Valeriana officinalis*, and *W. somnifera* are some examples of plants with remarkable neuroprotective abilities (Table 4).

6.3 Antidiabetic Activity

Diabetes is a chronic metabolic disease with a huge public health impact (Modak et al. 2007; Osadebe et al. 2014) that results from either insulin dysfunction or insulin deficiency in the body. Currently, there are three major types of diabetes, type I, type II, and gestational diabetes, which are responsible for sickness and premature fatality rate (Cade 2008). Indeed, diabetes is considered as a fifth leading cause of death in the twenty-first century, and as per data, more than 2.8% of the world's

Table 3 In vitro and in vivo anticancer effects of plants from the Himalayan region

Plant species and used part	Used Doses	% Inhibition	Used model (In vitro, In vivo)	References
Aconitum heterophyllum Wall.; (Roots, Areal part)	50[a]	12–65, 4–36	In vitro (A-549, MCF-7, MiaPaca, HCT-116)	Mushtaq et al. (2017)
Albizia lebbeck (L.) Benth.; (Leaves)	12.5–200[a]	6–88	In vitro (HT-29, MCF-7)	Aditya et al. (2014)
Annona squamosa L.; (Seed)	33.8[a]	50	In vitro (KB cells)	Biba et al. (2013)
Annona squamosa L.; (Seed)	0.25–13[a]	50	In vitro (A-549, Hela, MCF-7, Hep G2)	Chen et al. (2012)
Arisaema flavum (Forssk.) Schott; (Whole plant)	500[a]	1.2–83	In vitro (MCF-7)	Nisa et al. (2011)
Arnebia euchroma (Royle) I.M. Johnst.; (NA)	2.7–6.8[a]	50	In vitro (A-549, Bel-7402, MCF-7, LLC)	Xiong et al. (2009)
Artemisia argyi H. Lév. & Vaniot; (Leaves)	10[a]	75	In vitro (Hela)	Lee et al. (2005)
Asclepias curassavica L.; (Areal parts)	0.02–0.69[a]	50	In vitro (HepG2)	Li et al. (2009)
Azadirachta indica A. Juss.; (Leaves)	250–500[b]	85	In vivo (Swiss male mice)	Paul et al. (2011)
Azadirachta indica A. Juss; (Leaves)	10[a]	30–60	In vitro (MCF-7)	Bibi et al. (2012)
Berberis lycium Royle; (Areal part)	50[a]	9–81	In vitro (A-549, MCF-7, MiaPaca, HCT-116)	Mushtaq et al. (2017)
Butea monosperma (Lam.) Taub.; (Flowers)	0.1–10[a]	50	In vitro (Huh7, HepG2, AML12 [CRL 2254])	Choedon et al. (2010)
Butea monosperma (Lam.) Taub.; (Flowers)	100–400[b]	80	In vivo (Transgenic mouse model [X15-myc])	Choedon et al. (2010)
Carissa spinarum L.; (Fruits)	200–500[a]	65–99	In vitro (MCF-7)	Sahreen et al. (2013), Nisa et al. (2013)
Centella asiatica (L.) Urb.; (Whole plant)	10–82[a]	25–95	In vitro (MCF-7)	Babykutty et al. (2009)
Centella asiatica (L.) Urb.; (Whole plant)	50[b]	50	In vivo (Swiss male mice)	Jayashree et al. (2003)
Dianthus superbus L.; (Aerial Parts)	20.5–200[a]	50	In vitro (Bel-7402, HepG2, HeLa)	Yu et al. (2007)
Euonymus hamiltonianus Wall.; (Berries, areal part)	50[a]	22–81, 10–75	In vitro (A-549, MCF-7, MiaPaca, HCT-116)	Mushtaq et al. (2017)
Euphorbia wallichii Hook.; (Roots, areal part)	50[a]	24–62, 27–84	In vitro (A-549, MCF-7, MiaPaca, HCT-116)	Mushtaq et al. (2017)

(continued)

Table 3 (continued)

Plant species and used part	Used Doses	% Inhibition	Used model (In vitro, In vivo)	References
Ficus carica L.; (Roots)	50[a]	16–87	In vitro (A-549, MCF-7, MiaPaca, HCT-116)	Mushtaq et al. (2017)
Ligustrum lucidum L.; (Berries)	50[a]	1–34	In vitro (A-549, MCF-7, MiaPaca, HCT-116)	Mushtaq et al. (2017)
Semecarpus anacardium L. f.; (Kernels)	0.1–5.9[a]	50	In vitro (CEM, CEM/VLB, MCF-7, MCF-10 A, SW620, SW620Ad300)	Nair et al. (2009)
Semecarpus anacardium L. f.; (Oil)	0.1–100[a]	10–90	In vitro (HL-60, K-562, MCF-7, HeLa)	Chakraborty et al. (2004)
Solanum americanum Mill.; (Fruits)	1.25–100[a]	16–80	In vitro (HeLA Vero, SMMC-7721, HepG2, MCF-7)	Patel et al. (2009), Ding et al. (2012), Son et al. (2003)
Syzygium cumini (L.) Skeels; (Fruits)	100[a]	25–70	In vitro (AML)	Afify et al. (2011)
Taxus wallichiana Zucc.; (Stem bark)	0.063–50[a]	50–90	In vitro (MCF-7, MDA-MB-231, HEK-293, COLO-320, $CaCO_2$)	Reddy et al. (2009)
Taxus wallichiana Zucc.; (Stem bark)	10[b]	60–100	In vitro (Virgin female Sprague Dawley rats)	Reddy et al. (2009)
Viburnum grandiflorum Wall. ex DC.; (Berries)	50[a]	1–19	In vitro (A-549, MCF-7, MiaPaca, HCT-116)	Mushtaq et al. (2017)
Viscum album L.; (Aerial)	50[a]	5–21	In vitro (A-549, MCF-7, MiaPaca, HCT-116)	Mushtaq et al. (2017)
Xanthium strumarium L.; (Roots)	0.161–0.434[a]	13.55–67.93	In vitro (MCF-7, SKMEL cell)	Milton et al. (2013)
Xanthium strumarium L.; (Roots)	20–400[b]	73–92	In vivo (Swiss male mice)	Milton et al. (2013)

[a]Indicates μg/mL
[b]Indicates mg kg^{-1} day^{-1}

population is suffering from diabetes, and it is expected that the number of cases will raise to more than 5.4% by 2025 (Mukesh and Namita 2013; Kazi 2014). Pharmacotherapy, diet therapy, and insulin therapy are the most common modern therapeutic strategies for such conditions. Although modern treatments are available, complete treatment and prevention of diabetes still seem impossible due to some disadvantages, including side effects, drug resistance, and even drug-related toxicity (Kooti et al. 2016). Therefore, plant-based drugs have been highly recommended for the treatment of such affections (Kooti et al. 2015). Phytochemicals, like flavonoids, alkaloids, terpenoids, and glycosides, have shown interesting antidiabetic effects (Afrisham et al. 2015), with some Himalayan plants revealing an interesting potential (Table 5).

Table 4 Bioactive compounds with neuroprotective effects

S.N	Neuroprotective bioactive compounds	References
1	6-MSITC	Morroni et al. (2018)
2	Berberine	Velmurugan et al. (2018), Yuan et al. (2019)
3	Caffeine	Hussain et al. (2018), Pohl and Lin (2018)
4	Cannabidiol	Watt and Karl (2017)
5	Catechin	Hajialyani et al. (2019)
6	Curcumin	Khazdair et al. (2019), Manzinea et al. (2019)
7	Delta-9-tetrahydrocannabinol	Maurya and Velmurugan (2018)
8	Epigallocatechin-3-gallat	Manzinea et al. (2019)
9	Galantamine	Hussain et al. (2018), Libro et al. (2016)
10	Hesperidin	Hajialyani et al. (2019)
11	Huperzine A	Hussain et al. (2018), Libro et al. (2016)
12	Huperzine A	Wang et al. (2005)
13	Isorhynchophylline	Hussain et al. (2018)
14	Moringin	Libro et al. (2016)
15	Morphine	Hussain et al. (2018), Libro et al. (2016)
16	Nicotine	Libro et al. (2016), Hussain et al. (2018)
17	Physostigmine	Omar et al. (2017), Hussain et al. (2018)
18	Piperine	Hussain et al. (2018)
19	Quercetin	Hajialyani et al. (2019)
20	Resveratrol	Colica et al. (2018), Wang et al. (2018)
21	Rosmarinic acid	Fachel et al. (2019)
22	Sulforaphane	Libro et al. (2016), Pohl and Lin (2018)

6.4 *Antimicrobial Activity*

Worldwide, the burden of infectious diseases is increasing at a frightening rate, causing death in millions (Bhutta et al. 2014). To fight such infectious diseases, many modern medicines have become available in the market, but along with their therapeutic activity, severe side effects have also been reported. In addition, currently, an increasing amount of multidrug-resistant microorganisms (MDRM) have become a key matter of concern. Therefore, it becomes an urgent and important need to develop powerful and safe drugs against microbial diseases at the right time.

Worldwide, many research groups are showing greater interest in developing antimicrobial drugs from plant source as they are more effective against microbial infections and have been safer for both humans and the environment, along with that where existing antibiotics showed no or less activity against multidrug resistance microorganisms (MDRM), plant-based drugs naturally boost immunity and show promising activity against MDRM (Subramani et al. 2017). A wide range of phytoconstituents, such as phenols, flavonoids, tannins, quinine, and coumarins, have been reported with significant antimicrobial activities (Cushnie and Lamb 2005; Kurhekar 2016; Cueva et al. 2010; Al-Majedy et al. 2017; Scalbert 1991; Antika

Table 5 Himalayan plant species with antidiabetic potential

S.N	Species name	References
1	*Ampelopsis grossedentata* (Hand.-Mazz.)	Wan et al. (2017)
2	*Centella asiatica* (L.) Urb.	Abas et al. (2016)
3	*Coptis chinensis* Franch.	Gu et al. (2010)
4	*Curcuma longa* L.	Tranchida et al. (2015)
5	*Gardenia jasminoides* J. Ellis	Shen et al. (2016)
6	*Zanthoxylum armatum* DC.	Khan et al. (2020)
7	*Acacia catechu* (L.f.) Willd.	Rao et al. (2015)
8	*Acacia modesta* Wall.	Jawla et al. (2011)
9	*Acanthopanax senticosus* (Rupr. & Maxim.)	Saito et al. (2016)
10	*Allium sativum* L.	Sudha et al. (2011)
11	*Aloe vera* (L.) Burm.f.	Rashidi et al. (2013)
12	*Amaranthus cruentus* L.	Kunyanga et al. (2012)
13	*Angelica sinensis* (Oliv.) Diels	Zhi (2009)
14	*Artemisia parviflora* Roxb. ex D.Don	Ahuja et al. (2011)
15	*Artemisia princeps* Pamp.	Yamamoto et al. (2011)
16	*Artemisia gmelinii* Weber ex Stechm.	Yuan et al. (2010)
17	*Primula denticulate* Sm.	Singh et al. (2014)
18	*Abrus precatorius* L.	Joshi (2011)
19	*Astragalus membranaceus* (Fisch.) Bunge	Fu et al. (2014)
20	*Berberis aristata* DC.	Khan et al. (2016)
21	*Berberis vulgaris* L.	Rahimi-Madiseh et al. (2017)
22	*Butea frondosa* Roxb.	Kumar and Malik (2012)
23	*Butea monosperma* (Lam.) Taub.	Rao et al. (2015)
24	*Citrus sinensis* (L.) Osbeck	Shakthi Deve et al. (2014)
25	*Curcuma longa* L.	Sukandar et al. (2015)
26	*Dioscorea opposita* Thunb.	Xie and Du (2011)
27	*Embelia ribes* Burm.f.	Ratnasooriya et al. (2011)
28	*Ficus amplissima* Sm.	Arunachalam and Parimelazhagan (2013)
29	*Ficus racemosa* L.	Trinh et al. (2016)
30	*Zaleya decandra* (L.) Burm.f.	Meenakshi et al. (2010)
31	*Viola odorata* L.	Rao et al. (2015)
32	*Ocimum sanctum* L.	Upadhyay (2017)
33	*Paeonia lactiflora* Pall.	Yoon et al. (2014)
34	*Rheum emodi* Wall.	Arvindekar et al. (2015)
35	*Solanum nigrum* L.	Sohrabipour et al. (2014)
36	*Swertia chirayita* (Roxb.) Buch.-Ham.	Kar et al. (2003)
37	*Syzygium jambolanum* (Lam.) DC.	Baliga et al. (2013)
38	*Taxus baccata* L.	Rao et al. (2015)
39	*Terminalia arjuna* (Roxb. ex DC.)	Rafe (2017)
40	*Tinospora cordifolia* (Willd.) Miers	Kar et al. (2003)
41	*Vaccinium bracteatum* Thunb.	Qian et al. (2017)

(continued)

Table 5 (continued)

S.N	Species name	References
42	*Withania coagulans* (Stocks) Dunal	Maurya et al. (2008)
43	*Withania somnifera* (L.) Dunal	Jonathan et al. (2015)
44	*Zanthoxylum armatum* DC.	Thakur et al. (2016)
45	*Zanthoxylum humile* Waterm.	Pamhidzai and Isaac (2013)

et al. 2020). Moreover, from a long back, the Himalayan region communities have been using native plant species to treat different microbial diseases from which some important species are mentioned in Table 6.

6.5 Antioxidant Activity

Recently, more interest has arisen toward natural antioxidants and their role in human health maintenance and disease prevention. Briefly, in healthy individuals, antioxidants regulate the homeostasis between free radicals' production and scavenging; however, antioxidants depletion results in higher production of free radicals triggering oxidative stress, which ultimately leads to several disturbances in the whole organism. As a matter of fact, oxidative stress is responsible for oxidation at both cell and molecular levels and further leads to cells/tissues damage being associated with a plethora of diseases, like neurodegenerative, metabolic, osteoarticular, cardiovascular and immune system disorders, and even cancer (Jonah 2013).

The Himalayan medicinal plants are highly acknowledged for their nutritional phytoconstituents and antioxidant effects. Indeed, phytoconstituents, like flavonoids, lignans, catechins, phenols, coumarins, isocatechins, isoflavones, and anthocyanins, have been widely recognized for their antioxidant properties (Prior 2003; Cai et al. 2004).

The determination of the antioxidant potential of plants, its derived extracts, and even isolated constituents can be analyzed by different in vitro (2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid [ABTS], 2,2-diphenyl-1-picrylhydrazyl [DPPH], oxygen radical absorbance capacity (ORAC), thiobarbituric acid reactive substances [TBARS], ferric reducing antioxidant power [FRAP] and Trolox equivalent antioxidant capacity [TEAC] assays) and in vivo methods, with a series of medicinal plants already been studied by different research groups around the world. As some examples, the crude methanol extracts from *Bunium persicum* (seeds), *Dactylorhiza hatageria* (tubers), *Satyrium nepalense* (tubers), *Viscum album* (fruits), and *Urtica dioica* (leaves) have revealed interesting antioxidant effects by the DPPH assay, with IC_{50} values of 0.09, 0.21, 0.04, 0.42, and 0.14 mg/mL, respectively (Kawra et al. 2020). Also, the methanol extracts from *Trillium govanianum* rhizome, leaf, and stem showed maximum DPPH, ABTS, and FRAP activities with 16.06 milli molar ascorbic acid extract/gram fresh weight (mM

Table 6 Antioxidant and antimicrobial studies in different Himalayan regions

S.N	Plant species name	Antimicrobial profiling (ZOI)		Antioxidant profiling		References
1	*Acorus calamus* L.	*Bacillus subtilis*	6–10[a]	NT		Rawat et al. (2016)
		Staphylococcus aureus	7[a]			
		Micrococus luteus	6–9[a]			
		Escherichia coli	6–9[a]			
2	*Acorus calamus* L.	*Escherichia coli*	0.40[b]	DPPH	01.61–02.16[d]	Verma et al. (2021)
		Klebsiella pneumoniae	0.40[b]	FRAP	76.76–91.68[c]	
		Salmonella typhimurium	0.80[b]			
		Staphylococcus aureus	0.40[b]			
		Pseudomonas aeruginosa	0.20[b]			
3	*Bunium persicum* Boiss.	NT		DPPH	0.09[e]	Kawra et al. (2020)
4	*Dactylorhiza hatagirea (D.Don) Soó*	NT		DPPH	0.21[e]	Kawra et al. (2020)
5	*Ficus palmata* Forssk	NT		ABTS	114.03–265.14[f]	Tewari et al. (2020)
				DPPH	80.97–175.08[f]	
				FRAP	139.89–364.84[f]	
				CUPRAC	228.86–344.64[f]	
6	*Fraxinus micrantha* Lingelsh	*Agrobacterium tumefaciens*	16[a]	DPPH	43.93[d]	Kumar and Sati (2020)
		Bacillus subtilis	22[a]	H_2O_2	68.90[d]	
		Erwinia chrysanthemi	19[a]	FRAP	38.27[h]	
		Escherichia coli	18[a]			
		Xanthomonas phaseoli	11[a]			
7	*Habenaria intermedia* D.Don	*Bacillus subtilis*	6–11[a]	NT		Rawat et al. (2016)
		Staphylococcus aureus	6–9[a]			
		Micrococus luteus	6–9[a]			

(continued)

Table 6 (continued)

S.N	Plant species name	Antimicrobial profiling (ZOI)		Antioxidant profiling		References
		Escherichia coli	6–11[a]			
8	*Hedychium spicatum* Sm.	*Bacillus subtilis*	6–7[a]	NT		Rawat et al. (2016)
		Staphylococcus aureus	0[a]			
		Micrococus luteus	6–9[a]			
		Escherichia coli	6–9[a]			
9	*Origanum vulgare* L.	NT		DPPH	5.85–72.70[d]	Bhatt et al. (2020)
				FRAP	45.7–266.0[d]	
				Iron-chelating activity	51.4–146.0[d]	
10	*Pinus gerardiana* Wall. ex D.Don	*Escherichia coli*	15–19[a]	DPPH	54.8–71.2[d]	Sharma et al. (2020)
		Pseudomonas aeruginosa	20–25[a]	NO_2	18.7–76.3[d]	
		Staphylococcus aureus	17–23[a]			
		Klebsiella pneumoniae	17–23[a]			
11	*Pinus roxburghii Sarg.*	*Escherichia coli*	15–18[a]	DPPH	51.7–67.3[d]	Sharma et al. (2020)
		Pseudomonas aeruginosa	17–23[a]	NO_2	59.0–71.2[d]	
		Staphylococcus aureus	17–20[a]			
		Klebsiella pneumoniae	18–22[a]			
12	*Pinus wallichiana A.B.Jacks.*	*Escherichia coli*	13–17	DPPH	58.4–69.8[d]	Sharma et al. (2020)
		Pseudomonas aeruginosa	15–22	NO_2	62.0–73.0[d]	
		Staphylococcus aureus	15–21			
		Klebsiella pneumoniae	15–21			
13	*Rhododendron arboreum*	NT		DPPH	91.67[c]	Painuli et al. (2016)
				ABTS	96.65[c]	
				FRAP	429.07[j]	
				TRP	292.27[k]	
14	*Rhododendron campanulatum*	NT		DPPH	91.27[c]	Painuli et al. (2016)

(continued)

Table 6 (continued)

S.N	Plant species name	Antimicrobial profiling (ZOI)		Antioxidant profiling		References
				ABTS	96.53[c]	
				FRAP	378.73[j]	
				TRP	283.26[k]	
15	*Roscoea procera* Wall.	NT		ABTS	1.47[i]	Rawat et al. (2017)
				DPPH	0.75[i]	
				FRAP	1.01[i]	
16	*Roscoea procera* Wall.	*Bacillus subtilis*	6–9[a]	NT		Rawat et al. (2016)
		Staphylococcus aureus	6–10[a]			
		Micrococus luteus	6–9[a]			
		Escherichia coli	6–12[a]			
	Rubia cordifolia L.	*Staphylococcus aureus*	22–32[a]	NT		Boominathan et al. (2020)
		Escherichia coli	21–32[a]			
17	*Satyrium nepalense D.Don*	NT		DPPH	0.04[e]	Kawra et al. (2020)
18	*Saussurea obvallata* (DC.) Edgew.	*Pseudomonas aeruginosa*	13.90–20.50[a]	DPPH	29.25–82.88[c]	Semwal and Painuli (2019)
		Escherichia coli	10.83–13.90[a]	H_2O_2	39.75–41.05[c]	
		Staphylococcus aureus	12.83–20.43[a]			
		Klebsiella pneumoniae	11.53–19.90[a]			
		Candida albicans	13.90–14.57[a]			
		Candida glabrata	15.43–15.90[a]			
		Candida tropicalis	8.30–13.17[a]			
19	*Tagetes minuta* L.	*Micrococus luteus*	3–8[a]	NT		Walia et al. (2020)
		Staphylococcus aureus	3–11.33[a]			
		Klebsiella pneumoniae	1.33–4.00[a]			
		Pseudomonas aeruginosa	0.50–1.00[a]			
20	*Thalictrum foliolosum* DC.	*Saccharomyces cerevisiae*	13–20[a]			Kumar et al. (2020)

(continued)

Table 6 (continued)

S.N	Plant species name	Antimicrobial profiling (ZOI)		Antioxidant profiling		References
		Candida albicans	11–18[a]			
		Candida albicans	11–19[a]			
21	*Thymus linearis* Benth.	*Staphylococcus aureus*	5–16[a]	NT		Kumar et al. (2019)
		Staphylococcus epidermidis	3–21[a]			
		Enterococcus faecalis	2–10[a]			
		Staphylococcus epidermidis	4–25[a]			
		Candida albicans	5–28[a]			
		Candida tropicalis	6–25[a]			
		Candida glabrata	8–24[a]			
22	*Urtica diocia* L.	NT		DPPH	0.42[e]	Kawra et al. (2020)
23	*Valeriana jatamansi* Jones	NT		ABTS	2.60–6.82[g]	Jugran et al. (2020)
				DPPH	2.07–6.88[g]	
				FRAP	3.64–14.75[g]	
24	*Valeriana jatamansi* Jones	*Bacillus subtilis*	6–11[a]	NT		Rawat et al. (2016)
		Staphylococcus aureus	6–8[a]			
		Micrococus luteus	6–9[a]			
		Escherichia coli	6–9[a]			
25	*Viscum album* L.	NT		DPPH	0.14[e]	Kawra et al. (2020)
26	*Zanthoxylum armatum* DC.	*Bacillus subtilis*	15.72–17.04[a]	NT		Phuyal et al. (2020)

NT not tested
[a]Zone of inhibition in mm
[b]MIC value
[c]Percent
[d]IC_{50} value in μg/mL
[e]IC_{50} value in mg/mL
[f]mg TE/g
[g]mM/100g AAE dw
[h]AAE/g dry
[i]mM ascorbic acid equivalent/100 g dry weight
[j]μg TE/g
[k]μg AE/g

AAE/g fw), 4.39 mM AAE/g fw, and 2.17 mM AAE/g fw, respectively (Kundra et al. 2020). Moreover, Painuli et al. (2018) reported antioxidant effects of *Rhododendron arboreum* and *Rhododendron campanulatum* leaves aqueous and methanol extract by DPPH, FRAP, ABTS, and total reducing power assay. *Saussurea obvallata* leaves and flowers methanol and water extracts also displayed DPPH and H_2O_2 free radical scavenging activities (Semwal and Painuli 2019). Other plant extracts, such as *Acorus calmus* (rhizome), *Habenaria intermedia* (tuber), *Hedychium spicatum* (rhizome), *Roscoea procera* (rhizome), and *Valeriana jatamansi* (root), also revealed interesting antioxidant effects through DPPH, ABTS, and FRAP assays (Rawat et al. 2017). Few other antioxidant-rich Himalayan plant species are listed in Table 6.

7 Conclusion and Upcoming Perspectives

The Himalayan region is famous worldwide for its unique, diverse, valuable, and endemic flora and fauna. Several highly valuable medicinal plants have been documented from this region, and these plants play a notable role in the human health care system. Many research groups have been increasingly devoted to the study of the therapeutic applications of a plethora of plants as well as on phytoconstituents' identification and related mechanism of action. However, despite the advance stated so far, many phytochemicals remain to be identified, and the mechanism of action of many others against various diseases is still unclear; therefore, much research is needed in this regard. On the other hand, medicinal plants in the Himalayan region face erratic harvests due to the growing demand for essential oils, herbal preparations, and drug formulation due to which many important plants have been extinct and many are on the verge of extinction. Thus, exploring more data on such plant species and their respective properties is an important issue, while protection and sustainable conservation too.

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Forest-Based Medicinal Plants for Cardiovascular Diseases

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Contents

Abbreviations

CAD	Coronary artery disease
CHD	Congenital heart disease
CK-MB	Creatine kinase myocardial band
CVD	Cardiovascular diseases
HDL	High-density lipoproteins
LDL	Low-density lipoprotein

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1 Introduction

The heart is one of the most vital organs of the body, as it is responsible for keeping other organs alive by pumping blood to the different organs and parts of the body. The entire body system collapses if the heart fails to function. The heart problems are not accompanied by clear signs; therefore, a routine checkup is required to if everything is alright in this organ (Fredriksen et al. 2009). However, there are some signs and symptoms that make it clear to detect the abnormalities well within time (Albert et al. 2010). These symptoms include chest discomfort, nausea, indigestion, heartburn, radiating pain, dizziness or lightheadedness, snoring, sweating, irregular or abnormal heartbeat, and swelling of body parts.

Heart disease is the leading cause of death for people around the world. According to an estimate, for every 36 s, a person dies due to cardiovascular disease (Lopez et al. 2020).

Cardiovascular diseases include coronary artery disease, such as angina and myocardial infarction (commonly known as a heart attack), and various other types of cardiovascular diseases. Some of the major reasons for death due to heart disease are mentioned in Fig. 1.

2 Causes of Heart Disease

There are various causes of heart disease such as high blood pressure, diabetes mellitus, lack of exercise, obesity, poor diet, high blood cholesterol, and alcohol consumption. Out of these causes, high blood pressure is alone responsible for more than 13% of CVD deaths (Mensah et al. 2019). According to an estimate, every year 17.9 million people are losing their lives due to CVD. Four (counts 85%) of five CVD deaths are due to heart attack and stroke (Mensah et al. 2019). More than 75% of deaths due to CVD occur in low- and middle-income countries. Therefore, globally CVD is responsible for immense health and economic burden on each level of society.

3 Symptoms of Heart Disease

Angina or chest pain is the most common symptom of coronary artery disease (CAD) which is marked by discomfort, heaviness, aching, burning, and painful feeling in the chest. Sometimes, it is mistaken for indigestion or heartburn. Besides the chest, angina can also be felt in the shoulder, arms, neck, jaw, or back. The other symptoms of CAD are shown in Fig. 2.

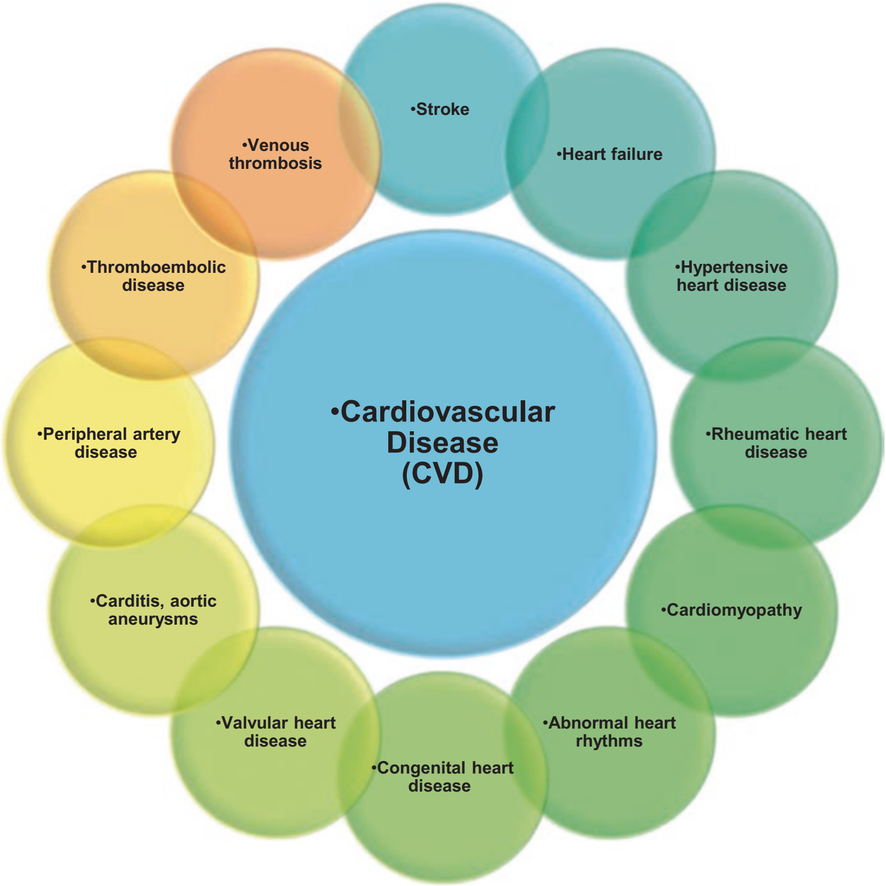

Fig. 1 Types of cardiovascular diseases

4 Biochemical Basis of Heart Diseases

Generally, the increase in blood cholesterol and lipoproteins along with reduced HDL cholesterol leads to dyslipidemia and heart disease. The various biochemical bases of CHD are presented in Fig. 3 and Table 1.

5 Forest as a Source of Drugs

It is generally observed that the dependency of any community on forests and trees for the well-being of humans varies according to their social, economic, and cultural contexts (Bahuguna 2000). The vicinity of a forest environment helps a person

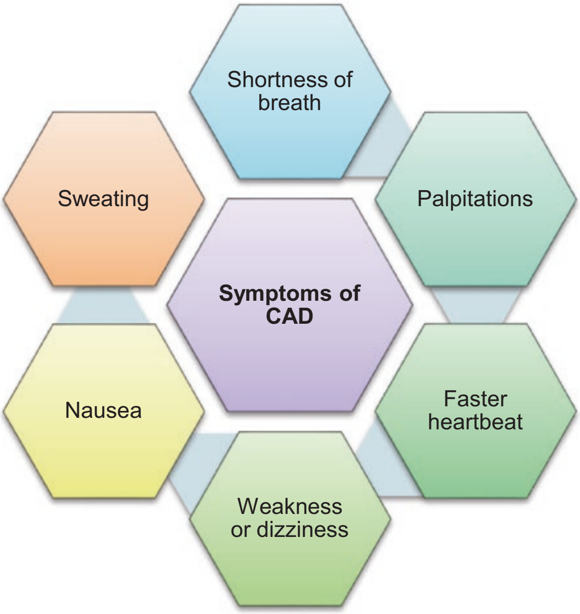

Fig. 2 Symptoms of coronary artery diseases (CADs)

adopting a healthy lifestyle and can certainly improve their physical and mental health. We generally see that rural communities use forest-derived medicines and food more than urban communities. Forest contributes to the peoples' mental and physical health in many ways (Dwyer et al. 1992; Pretty 2004). One way forest providing health benefits is through pharmaceutical products. People from developing countries living in the rural areas are often more reliant on traditional medicines and have knowledge about the medicinal properties of plants. Forests are the source of many important pharmaceutical products. Even the economic value of forest-derived traditional medicines is very substantial (Brown 1994; Dwyer et al. 1992). In the last two decades, there is a considerable increase in knowledge and interest in traditional medicines. From forest resources, many new commercial products are being produced, including pharmaceuticals, medicines, cosmetics, personal care products, and many new medically active compounds. These wide varieties of bioactive compounds are being used as anticancer drugs and antioxidants, which mainly comprise alkaloids, namely, reserpine, quinine, ephedrine, caffeine, several antibacterial, and other medicinal drugs. There is an enormous wealth of knowledge on forest medicines, which is being acknowledged around the world, but studies related to the side effects of these traditional medicines are still in dearth (Taylor 1996; Patwardhan 2000).

In the last few decades, there is an increased demand for herbal and traditional medicines both in developing and in developed nations. Millions of people around the world use herbal medicines. In India and Africa, more than 65% and 70–80% of

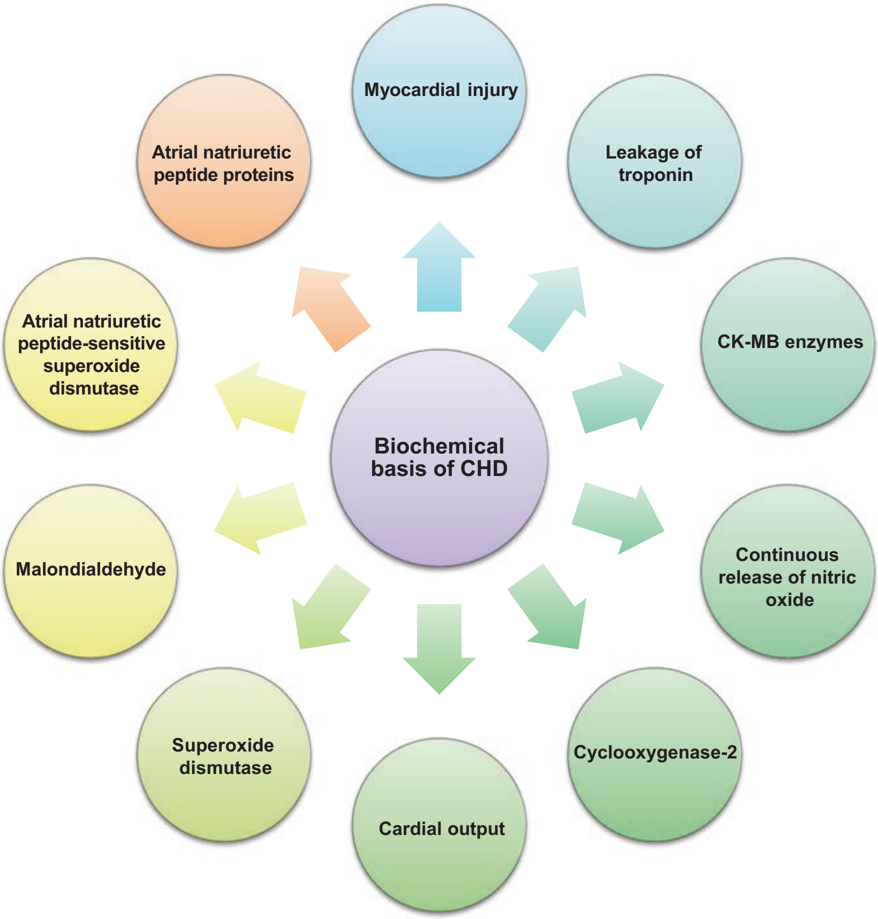

Fig. 3 Biochemical basis of *congenital heart disease* (CHD)

people, respectively, use traditional medicine. The forest-derived medicines account for more than 75 Billion USD annual value. In the countries like Nepal, medicinal plant export is the most valuable export (Shrestha et al. 2020). The use of medicinal herbs also gained some controversy related to the appropriation of the knowledge about the forest genetic material by Western pharmaceutical companies and the possible danger associated with their use. Therefore, a comparison of traditional medicinal herbs with other health care options should be considered. People living in or near forests get very little or no benefit from the commercial development of medicines from forestry species. The Nagoya Protocol of the Convention on Biological Diversity addresses the issues related to patents, fair distribution of profits, and recognition of the traditional knowledge in botanicals and allied industries (Buck and Hamilton 2011). According to The International Union for Conservation of Nature, more than 10,000 medicinal plants are facing imminent

Table 1 Scientific basis of herbal therapy of heart disease

Herbal therapy	Supplements	Function	References
Herbal supplements that open blood vessels	*Ginkgo biloba*	• Improves blood flow • Reduce blood stickiness	Belwal et al. (2018)
	Policosanol	• Lower bad cholesterol (LDL) • Increase (HDL)	Gouni-Berthold and Berthold (2002)
	Guggulipid	• Lower bad cholesterol (LDL) • Increase (HDL)	Szapary et al. (2003), Urizar and Moore (2003)
	Vitamin B complex	• Reduce levels of homocysteine	Yazaki et al. (2006)
	Chromium	• Manage cholesterol levels	Anderson (1998)
	Garlic	• Reduce cholesterol and triglyceride levels	Jain et al. (1993), Khoo and Aziz (2009)
Supplements that strengthen the heart muscle	Magnesium	• Controls muscle contraction and relaxation • Regulate blood pressure • Reduce blood clotting	Faryadi (2012), Jain et al. (2010)
	Coenzyme Q10	• Strengthen heart muscle	Langsjoen (2000), Crane (2001)
	Hawthorn	• Strengthen heart muscle	Singh et al. (2018), Vierling et al. (2003), Wang et al. (2019)
Dietary supplements	Grape seed extract	• Rich source of flavonoid compounds • Potent antioxidants • A powerful blood vessel strengthener	Sharma (2013)
	Green tea	• Contains polyphenols • Lowers LDL cholesterol • Protects blood vessel linings from oxidative damage	Barclay (2008)
	Fish oil	• Rich source of omega-3 fatty acids • Prevent platelets from clumping together • Reduce blood pressure • Lower triglycerides	Shapiro et al. (2011)

threat of extinction (Chen et al. 2016; Reed et al. 2011). Open access of the resources, illegal harvesting, use, and sale of these medicinal plants are connected to their survival. Hence, there is an urgent need to balance the commercial exploitation of forest species for pharmaceutical and livelihood purposes.

6 Historical Perspective of Traditional Herbal Medicines

Since time immemorial the ethnomedicines also called traditional medicines are being practiced by human beings (Table 2). These herbs are any form of plant or plant-based product (Tachjian et al. 2010). Around the world in many civilizations, these herbs have been a common source of medicine as a natural compound or in the form of some plant extracts (Shaito et al. 2020). Medicinal plants are being used since the beginning of human civilization, and now considerable research has been done by scientists. They have investigated the properties of several different medicinal plants and herbs (Frishman et al. 2004; Mahmood et al. 2010). *Salix alba* L., *Digitalis purpurea*, *Ephedra sinica*, *Monascus purpureus* L., *Taxus brevifolia*, and *Rauvolfia serpentina* are some of the names of plants that yield Aspirin, Digoxin,

Table 2 The earliest record of herbal drugs

Record	Time	Documented plant/ derived compounds	References
Sumerian clay slab from Nagpur	3000 BCE	Contains 12 recipes for drug preparation referring to over 250 various plants	Jamshidi-Kia et al. (2018)
"Pen T'Sao," a Chinese book (by Emperor Shen Nung)	2500 BCE	365 drugs	Nair et al. (2012)
Vedas		–	Kapoor (1993)
Mesopotamia	2600 BCE	1000	Böck (2009), Powell (2019), Sharma et al. (2020), Teall (2014), Wiseman (1983)
Egyptians' Ebers Papyrus	1550 BCE	700	Glesinger (1954)
Chinese Materia Medica Record	1100 BCE	52	Wilson (1962), Ritner (2000), Aboelsoud (2010)
Indian Ayurvedic Record	1000 BCE	800	Jaiswal et al. (2016), Nair and Mohanan (1998)
Homer's epics (The Iliad and The Odysseys)	800 BCE	63	Petrovska (2012)
Hippocrates	459–370 BCE	300	Petrovska (2012)
Theophrastus (De Causis Plantarium"—Plant Etiology and "De Historia Plantarium"—Plant History)	371–287 BCE	500	Katic (1958), Pelagic (1970)
De re medica (By Celsus)	25 BCE–50 AD	250	Kanchan and Menezes (2009), Petrovska (2012)

Ephedrine, Lovastatin, Taxol, and Reserpine, respectively (Cragg and Newman, 2013; Frishman et al. 2009; Harvey 2000). From the very famous examples of two drugs, namely, Quinine from *Cinchona* species and Artemisinin from *Artemisia annua* L., it can be understood how the ethnomedicines led to the discovery of plant-based drugs (Cragg and Newman 2013).

7 Herbs in the Cure of Heart Disease

The plant extracts are in use for thousands of years as evidenced by the ancient literature (Kapoor 1993; Nair and Mohanan 1998; Teall 2014). According to an estimate, 25% of the commercialized medicines are derived from plants (Hamburger and Hostettmann 1991). This increased use of plant-derived drugs in commercial medicines has paved the way to research the beneficial properties of various herbs along with studies on their side effects. Some of the researchers have also worked on the negative effects of herbal medicines on CVDs. Liperoti et al. (2017) reported the use of some herbal products, namely, *Garlic* and *Ginkgo* were used in the treatment of hypertension and cognitive disorders, respectively. Both the herbs have a negative effect on platelet function followed by increased bleeding risks when used along with aspirin and other anticoagulants (Gardner et al. 2003; Vaes and Chyka 2000). Hawthorn (*Crataegus* spp., a genus comprising approximately 300 species), a flowering shrub used in the treatment of heart's failure and hypertension, is also reported to have side effects (Tassell et al. 2010)

Glycyrrhiza glabra, commonly known as licorice used in the treatment of cirrhosis, cough, sore throat, and infections, also potentiate the risk of digoxin toxicity (Harada et al. 2002; Kaur et al. 2013). Similarly, the Red Sage or *Salvia miltiorrhiza* also increases the risk of bleeding by lowering the binding of warfarin (prevents blood from clotting) to serum albumin (Chan 2001; Milić et al. 2014).

Hypericum perforatum, known as perforate St John's-wort, common Saint John's wort, is used in the treatment of depression and reported to reduce the effectiveness of warfarin and other similar drugs (Barnes et al. 2001; Henderson et al. 2002; Milić et al. 2014). Similar report is available for green tea which is used for mental alertness, weight loss, etc (Cooper 2012).

Grapefruit juice also has plenty of benefits, such as weight loss, and promotes cardiovascular health reported to increase the effects of statins.

From the era of human civilization, medical plants are being used for pharmacotherapy. For the various aliments of CVDs, the use of herbal medicines is also reported to be very common and historic. However, today the use of herbal medicines is lacking the proper scientific assessment of their toxic effects or drug–drug interactions. Many researchers reported the beneficial as well as the side effects of herbal medicines used in CVDs. The side effects of these herbal formulations come in the form of their interaction with conventional medicines (Izzo and Ernst 2001; Sørensen 2002).

8 Congestive Heart Failure

For many decades, various drugs such as digitoxin from (*D. purpurea*) and digoxin (from *D lanata*) are reported to have potent effect in the treatment of congestive heart failure. Plant glycosides are obtained from *D. purpurea* (Hollman 1985), *Adonis microcarpa* (Hollman 1985) and *Adonis vernalis* (Hollman 1985), *Apocynum cannabinum* (Nonami 2002), *Asclepias curassavica* (Kupchan et al. 1964) , *Asclepias friticosa* (Warashina and Noro 1994), *Calotropis precera* (Mossa et al. 1991), *Carissa spectabilis* (wintersweet) (Radford et al. 1986), *Cerebra manghas* (sea mango) (Tsai et al. 2008), *Cheiranthus cheiri* (wallflower) (Erum 2017), *Convallaria majalis* (lily of the valley, convallaria) (Löffelhardt et al. 1979), *Cryptostegia grandiflora* (rubber vine) (Dwivedi and Chopra 2015), *Helleborus niger* (black hellebore) (Akbar and Akbar 2020), *Helleborus viridus*, *Nerium oleander* (oleander) (Khan et al. 2010), *Plumeria rubra* (frangipani) (Radford et al. 1986), *Selenicerus grandiflorus* (cactus grandiflorus) (Rashmi and Mishra 2016), *Strophanthus hispidus* (Gundamaraju et al. 2014) and *Strophanthus kombe* (strophanus) (Makarevich and Kovalev 2006), *Thevetia peruviana* (yellow oleander) (Kohls et al. 2012), and *Urginea maritima* (squill) (Dizaye and Hamed 2010). In many cases of accidental intake, or during the suicidal attempt, the poisoning of the cardiac glycosides is reported (Kanchan and Menezes 2009; Tsai et al. 2008).

9 Hypertension

In the ancient Hindu literature and practices, the use of *R. serpentina* which is the source of natural alkaloid reserpine is being reported for the treatment of hypertension and psychoses (Kass and Brown 1955). However, the Western countries have adopted it in the late nineteenth century. Now the use of *R. serpentina* root as a whole is reported, where the 200–300 mg whole root powder is equivalent to 0.5 mg of reserpine (Gupta et al. 2006). Similarly, in traditional Chinese medicine, the herb *Stephania tetrandra* is reported to treat hypertension. The alkaloid tetrandrine extracted from this herb shows the property of calcium ion channel antagonist. The root of one more medicinal herb *Lingusticum wallichii* is also reported to act as a circulatory stimulant and sedative. Tetra methylpyrazine extracted from the *L. wallichii* lowers blood pressure by vasodilation.

Uncaria rhynchophylla produces indole alkaloids, rhynchophylline, and hirsutine, and is also reported to treat hypertension (Ndagijimana et al. 2013). *Veratrum* is a perennial herb known to produce veratrum alkaloids that enhance muscle and nerve excitability (Krayer and Acheson 1946). Veratrum induces bradycardia and hypotension that is treated with atropine.

10 Angina Pectoris

Crataegus hawthorn is one of the most accepted herbal plants used particularly for angina and widely distributed around the world (Rigelsky and Sweet 2002). This plant contains many active substances such as flavonoids, oligomeric procyanins, and catechins obtained from its leaves, flower, and fruits, etc. Crataegus also inhibits the formation of thromboxane and has antioxidant properties. The Crataegus extract decreased the level of cholesterol, triglyceride, and low-density lipoprotein (LDL) and thus helps in the treatment of atherosclerosis. A high concentration, as well as oral and parenteral administration of Crataegus, is reported to increase the coronary blood flow. This may be due to the inhibition of 3′,5′-cyclic adenosine monophosphate phosphodiesterase.

The roots of *Panax notoginseng* in traditional Chinese medicine is used for the treatment of analgesia and hemostasis (Ng 2006). It is also used in the treatment of angina and coronary artery disease. Unlike the other drugs, its phraseological action is unique, as it interacts with the receptor medicated calcium ion channel rather than the L-type ion channel.

Notoginsenoside R1 and saponins from *P. notoginseng* are reported to affect the synthesis of plasminogen-activating inhibitor and interfere with the proliferation of smooth muscle cells, respectively (Lin et al. 1993). Due to its property to dilate coronary arteries, it is used in the treatment of angina; however, its use in the treatment of hypertension is not certain.

Salvia miltiorrhiza is reported to function similar to how the *P. notoginseng* works. It also dilates the coronary artery at all concentrations (Lei and Chiou 1986; Li et al. 2018). This traditional Chinese medicine is being used as a circulatory stimulant, sedative, and cooling drug. However, the adverse effect of these herbal drugs alone or in combination with some other drugs needs a proper evaluation.

11 Atherosclerosis

Garlic (*Allium sativum*) is one of the most used and the most examined herb by the scientific community. Garlic is beneficial in cardiovascular diseases due to its properties, namely, lowering blood pressure, enhancing fibrinolytic activity, lowering serum cholesterol, etc.; however, the precise effect of garlic in the treatment of all the mentioned complications is needed to be evident by more exhaustive research. Researchers tried to examine the effect of fresh cloves of garlic on thromboxane level to find its suitability in the treatment of thrombosis (Bordia et al. 1998; Kendler 1987).

One more tiny herb from India, *Commiphora mukul* (gugulipid), is reported in the ancient literature to treat lipid disorders. It is responsible for increasing the metabolism of LDL by the liver (Urizar and Moore 2003). Compared to modern hyperlipidemic drugs, *Commiphora mukul*, is more effective and safer. However, more trials to check its safety and efficacy will certainly help in endorsing it as an alternative therapy for the prevention of atherosclerosis.

12 Cerebral and Peripheral Vascular Disease

Ginkgo biloba (maidenhair tree) is one and the only living fossil saved from extinction. The use of root and kernels of *G. biloba* is reported in traditional Chinese medicine. The beneficiary effect of *G. biloba* was acknowledged in the late nineteenth century. Flavonoids and terpenes from this tree reduce capillary permeability, serve as a free radical scavenger, and inhibit the platelet-activating factor, respectively. *G. biloba* extract is also used for the treatment of vertigo, tinnitus, memory, mood, diabetic retinopathy, and peripheral vascular disease (Mahady 2002). Ginkgo is approved as a drug in Europe but not in the United States. Although the adverse effects of *G. biloba* extract are very rare, in some cases, it is reported to induce gastrointestinal disorders, headache, and skin rash (Belwal et al. 2018).

Rosmarinus officinalis (rosemary) is being used as a culinary spice and flavoring agent. Its leaves are known to increase circulation, elevate mood, and boost energy. The external application of its volatile oil is used in arthritis and baldness (Begum et al. 2013). In addition to this, its essential oil also has antimicrobial, hyperglycemic, and insulin inhibiting properties. The diterpenoids, namely, carnosic acid and carnosol isolated from rosemary leaves, show an antioxidant effect that stabilizes erythrocyte membranes and inhibits lipid peroxidation. There are few research evidence to support the use of rosemary in inhibiting atherosclerosis. However, more investigation needs to be done to study the effect of rosemary in prolonged improvement in peripheral circulation.

13 Conclusion

Forests are the reservoirs of a wide variety of medicinal plants whose potential is not fully explored yet. Continued research is needed to unravel the potential of different medicinal plants to treat human ailments. Furthermore, conservation and propagation of these medicinal plants should be a high priority. Cardiovascular diseases remain a threat due to the incomplete success of chemotherapy as shown in the form of high death rates. Moreover, there is a strong lack of scientific evidence in support of the efficacy of herbal medicines in the treatment of cardiovascular diseases. Much of the herbs affect the biological system associated with this disease, and there is also a lack of adequate clinical data in support. The potential side effects of the herbal drugs, their interaction, contamination, and or substitution with other medication are the major concerns. With the prevalence of plant-based medicines, comprehensive research is needed to ensure the beneficial and harmful effects of herbal treatment. We conclude that better-designed experiments and future clinical trials involving larger sample sizes are needed to examine the role of different medicinal plants and their underlying mechanisms in CVDs.

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Potential Role of Medicinal Plants in the Cure of Liver and Kidney Diseases

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1 Introduction

There are large ranges of plant and animal diversities present in forests worldwide. Forest ecosystems hold huge terrestrial species of the world. Sources of livelihoods for millions of people on the earth are different types of fishes, non-timber forest products, timber, fodder, pulpwood, firewood, and medicinal plants accessed from forests. A large number of wild plant species are still unknown for potential medicinal, industrial, and agricultural values. Plant species with medicinal properties are staging a comeback in the pharmaceutical and traditional herbal markets. People understand the safety of herbal products in comparison to synthetic drugs for human health and the environment. The synthetic medicines used for instant healing of humans and veterinary have surpassed the importance of herbal medicines, flavoring spices, and aroma. But the blind trust in synthetic medicines is over, and people are moving toward the natural system of healings with great hope of safety measures.

Medicinal plants comprise enormously, undocumented, and overexploited, and these are the most important healing resources for most people (Luper 1998a, 1998b; Nautiyal et al. 2002; Jha 2010; Thiengsusuk et al. 2013; Bahmani et al. 2016a; b; Bagherniya et al. 2018; Li et al. 2018; Razmpoosh et al. 2020). Developed and developing countries have a good demand for the medicinal plants, and only a few species are cultivated and a huge amount of raw materials is still required to explore from the forests. The survival of several herbal plant species is under serious threats to become extinct because of its increasing demand for national and international trade. The worldwide market value of medicinal plants was USD 71.19 billion in 2016, and it is expected to show profitable growth in the coming future (Hexa Research 2020). The increase in demand credited to the escalated preference of consumers toward an indigenous or traditional system of medicines such as

Ayurveda, Unani, Siddha, etc., which do not develop overdose toxicity and have lesser side effects. In fact, the health practices based on herbal medicines originated from time immemorial and developed gradually, to a large extent, by relying on practical experiences without significant references to modern scientific principles. These practices are passed on from one generation to another by oral or traditional literature. Herbal formulations are effective in the treatment of various diseases without scientific exploitation. Therefore, these traditional herbal-based drugs ought to have detailed studies in the light of modern medical science. Traditional systems of medicine need to be widely practiced on many accounts. The prohibitive cost of treatments, side effects of several allopathic drugs, population rise, and development of resistance to currently used medicines for infectious diseases have led to increased importance on the use of herbal materials as a source of medicines for various types of human diseases. For instance, WHO (2017) estimates that 80% of the world's population lives in countries with zero or very little access to controlled medicines for relieving moderate to severe pain. Thus, in this situation, these peoples have relied upon the use of traditional herbal medicines that are mainly derived from botanicals. Medicinal plants obtained from the forest and other resources provide biologically active compounds that have been used in effective herbal drug preparation by several herbal and pharmaceutical companies. These drugs have shown an enhanced activity against human diseases and at the same time reduced the toxicity. Several herbs, shrubs, and or tree-based biologically active compounds, for instance, apomorphine, artemisinin, camptothecin, forskolin, galantamine, morphine, quinine, steviol, salicylate, taxol, etc., have been explored in the preparation of important drugs. It has been reported that the global market for botanical and plant-derived drugs will grow from $29.4 billion in 2017 to around $39.6 billion by 2022 with a compound annual growth rate (CAGR) of 6.1% for the period 2017–2022 (BCC Research 2020). The current chapter mainly focused on the potential of medicinal plants (herbs, shrubs, or trees) including their families, major bioactive molecules or constituents, and associated therapeutic role in liver and kidney disease management.

2 Medicinal Plants in Cure of Liver Diseases

Liver in the human body plays a vital role in the regulation of physiological processes such as secretion, metabolism, and storage. Moreover, detoxification of different types of chemicals takes place in the liver. Secretion of bile is one of the most important functions of the liver that helps to digest food. Diseases of the liver are among the serious problems caused in the human body. It can be classified as chronic or acute hepatitis, cirrhosis, and non-inflammatory diseases. Liver diseases are mostly caused by toxic chemicals, infections, autoimmune disorders, and excess consumption of alcohol (Smuckler 1975). It has been studied that about 90% of acute hepatitis is due to viruses. The most important viral agents involved are Hepatitis B, A, C, D, E, and G. Of these, Hepatitis B infection often results in cirrhosis and chronic liver diseases. These viruses are also responsible to cause primary liver cancer. A phytotherapeutic approach in the development of modern medicines can make available very useful drugs from the medicinally important plant species. For instance, Ali et al. (2019) examined the role of 21 highly potential medicinal plants for their hepatoprotective activity in Sudan. In this investigation, the histopathological and liver markers-based parameters revealed that 90.5% of the medicinal plants were significant in liver protection, and only 9.5% of the plants were found to be ineffective. Some of the plants that have been used in traditional herbal drug preparations for the treatment of liver disease are displayed in Fig. 1. Further, the details of some of the potential medicinal plants used effectively in the cure of liver disease are given in Table 1. An additional description has been also discussed in subsequent subheads.

2.1 *Acacia catechu*

A. catechu is a thorny deciduous tree that belongs to the family Fabaceae. It is found in parts of South Asia and Southeast Asia, including India, Myanmar, Thailand, and Indonesia. Traditionally, the extract is used in sluggishness and swelling of the liver. Alkaloids of this plant act on mostly all system of the human body, including the liver, and maximum it contains antibacterial, antifungal, and anti-inflammatory properties. A range of studies has shown that *A. catechu* heartwood is a tremendous source of catechins and epicatechins as well as flavonoids that have an abundance of antioxidant activity. The heartwood extracts demonstrated a dose-dependent decrease in hepatic lipid peroxidation, iron, liver fibrosis, protein carbonyl, serum enzymes, and ferritin. It was observed that the extract reduces liver tumors by 63.5% (Tusskorn et al. 2021).

2.2 *Acalypha indica*

A. indica is an herbaceous annual plant of the family Euphorbiaceae. *A. indica* occurs generally all over Africa, Asia, and Europe. The root decoction is used to clean the liver and kidneys. The bioactive compounds present in *A. indica* are acalyphin, kaempferol, and glycosides. Scientifically, it has been proved that the indigenous knowledge documented from the tribal people of South India is true, and the extract has enough potential as a hepatoprotective agent (Mathew et al. 2011).

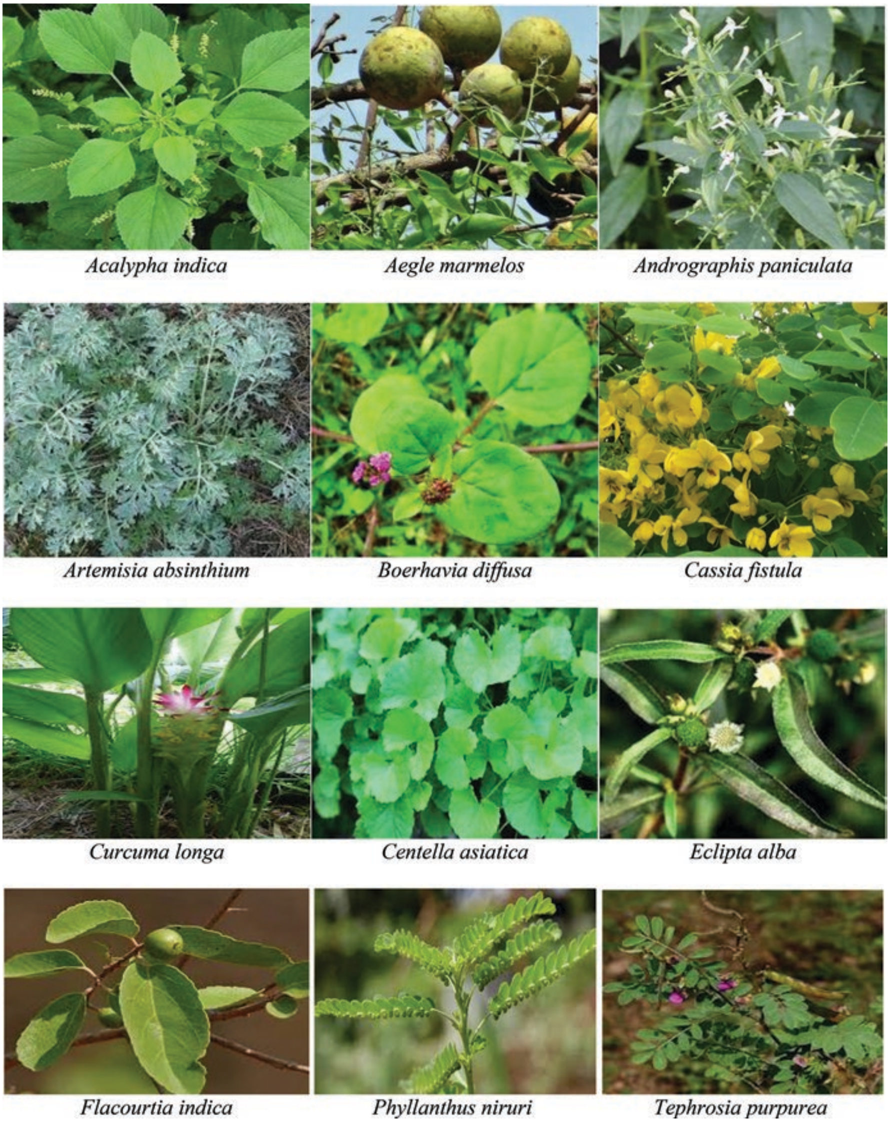

Fig. 1 Some of the medicinal plants used in traditional herbal drug preparations for the treatment of liver disease

2.3 *Aegle marmelos*

A. marmelos is a native tree of Southeast Asia, including the Indian subcontinent. It belongs to the family Rutaceae. The bioactive compounds present in the plant species are aegeline, alloimperatorin, and furocoumarins. Various diseases such as liver

Table 1 Medicinal plants used in the cure of liver disease

Botanical name (Family)	Common name (Part Used)	Bioactive compound	General use	Key reference
Acacia catechu (Fabaceae)	Catechu, Kher (bark, wood)	Catechins, epicatechins, and flavonoids	Liver tumor, sluggishness, and swelling of the liver, antibacterial, and antifungal	Tusskorn et al. 2021)
Acalypha indica (Euphorbiaceae)	Indian–Copper leaf (leaf, root)	Acalyphin, kaempferol, and glycosides	Hepatoprotective, anticirrhotic, and antineuropathic	Mathew et al. (2011)
Aegle marmelos (Rutaceae)	Wood apple, Bel (leaf, root)	Aegeline, alloimperatorin, and furocoumarins	Hepatoprotective, anti-inflammatory, antidiabetic, antifertility, and anticancer	Venthodika et al. (2021)
Aerva lanata (Amaranthaceae)	Polpala, Gorakhganja (root)	Metalloporphyrin	Jaundice	Tewari et al. (2017)
Andrographis paniculata (Acanthaceae)	Green Chirayta (whole plant)	Panicoline and diterpenoid lactone	Hepatorenal protective, antiprotozoan, immune stimulant, and antidiabetic	Alagesaboopathi et al. (1999)
Artemisia absinthium (Asteraceae)	Absinthe–wormwood (whole plant)	Sesquiterpene lactones and absinthin	Hepatoprotective, anticancer, antimalarial, and anti-inflammatory	Kordali et al. (2005)
Bixa orellana (Bixaceae)	Annatto, Sinduri (seed)	Orelline, bixin, and carotenoid	Hepatoprotective, expectorant, laxative, cardiotonic, and aphrodisiac	Singh et al. (2013)
Boerhavia diffusa (Nictaginaceae)	Red spiderling, Punarnava (whole plant)	Lunamarine, rotenoids, and quinolone	Hepatic disorders and jaundice	Gopal and Shah (1985)
Carum copticum (Apiaceae)	*Carom*, Ajowan (seed)	Thymol, gammaterpinene, and P-cymene	Liver protection, gastrointestinal, antispasmodic, cardio vasodilator, and respiratory	Zarshenas et al. (2013)

(continued)

Table 1 (continued)

Botanical name (Family)	Common name (Part Used)	Bioactive compound	General use	Key reference
Cassia fistula (Leguminosae)	Indian laburnum, Amaltas (fruit, seed)	Anthraquinon-esandflavan- 3-ol	Jaundice, rheumatism, and anorexia	Kaur et al. (2020)
Cassia tora (Caesalpiniaceae)	Sickle Senna	Glycosides, flavonoids, and saponins	Liver tonic, cardiotonic laxative, anthelmintic, and ophthalmic	Anonymous (1992)
Centella asiatica (Apiaceae)	Indian pennywort (whole plant)	Triterpene, asiaticoside and brahmoside	Jaundice, liver disorders, sinusitis, skin disorders, and memory improvement	Brinkhaus et al. (2000)
Curcuma longa (*Zingiberaceae*)	Turmeric (rhizome)	Curcumin, bisdeme-thoxycurcumin, germacrone, and zingiberene	Jaundice, liver cirrhosis, parasitic infections, and ulcers	Alshawsh et al. (2011)
Decalepis hamiltonii (Asclepiadaceae)	Swallow root (tuber)	Quercitin	Hepatoprotective, antimalarial, antidiabetic, and antioxidant	Harish and Shivanandappa (2010)
Eclipta alba (*Asteraceae*)	False Daisy, Bhringraj (leaf)	Coumestans, anthocyanin, and oleic acid	Liver cirrhosis, infectious hepatitis, and antiaging agent	Karthikumar et al. (2007)
Elephantopus scaber (Asteraceae)	Gobhi (whole plant)	Elephantopin	Hepatoprotective, antioxidant, antidiabetic, and anti-inflammatory	Lin et al. (1995)
Flacourtia indica (Salicaceae)	Governor's plum (fruit)	Flacourtin, limonin, quercetin, and tremulacin	Jaundice and spleen disorders	Kirtikar and Basu (1980)
Glycyrrhiza glabra (Fabaceae)	Liquorice (root)	Glycyrrhizin, Isoflavene, and glabrene	Hepatoprotective	Deng et al. (2013)
Halenia elliptica (Gentianaceae)	Spurred gentian (whole plant)	Norbellidifolin, sinapaldehyde, and 5-methoxy-2-	Hepatitis	Huang et al. (2010)

(continued)

Table 1 (continued)

Botanical name (Family)	Common name (Part Used)	Bioactive compound	General use	Key reference
Ocimum sanctum (Lamiaceae)	Holy basil, Tulsi (leaf, seed)	Eugenol, oleanolic acid, ursolic acid, and rosmarinic acid	Liver damage, cold, cough, and immunity	Handa et al. (1986)
Piper chaba (Piperaceae)	Choi Jhal (root, fruit)	Piperine, pipernonaline, and guineensine	Jaundice, stimulants, appetizers, stomachics, and expectorants	Choi and Hwang (2003)
Phyllanthus niruri (Phyllanthaceae)	Gale of the wind (whole herb)	Kaempferols, tannins, phenylpropanoids, and terpenoids	Jaundice, chronic dysentery, indigestion, and urinary tract diseases	Patel et al. (2011)
Picrorhiza kurroa (Scrophularia-ceae)	Kutki (rhizome)	Picroside, apocynin, and vanillic acid	Liver disorder	Ansari et al. (1988)
Rubia cordifolia (Rubiaceae)	Manjistha (root)	Anthraquinones	Hepatoprotective	Dev (2006)
Swertia chiraiyta (Gentianaceae)	*Chirayta* (whole herb)	Shamimin, mangiferin, and sawertiamarine	Digestive, hepatic, regulating blood sugar levels, and anthelmintic	Islam et al. (1985)
Tephrosia purpurea (Fabaceae)	Wild indigo, Sarponkha (leaf, root)	Glabratephrin, kaempferol, and quercetin	Liver, spleen, and heart	Khatria et al. (2009)

function, fungal disease, ulcer, inflammation, diabetes, and cancer are treated by using the leaves, bark, roots, fruits, and seeds of *A. marmelos* in the traditional system. Leaf extract of *A. marmelos* has hepatoprotective and antioxidant effects (Singh et al. 2013).

2.4 *Aerva lanata*

A. lanata is a perennial woody plant that belongs to the family Amaranthaceae. The species is native to Africa and Asia. The bioactive compound found in the plant parts is metalloporphyrin. *A. lanata* is antimicrobial, hepatoprotective, its administration significantly reverses the histopathological changes, reduces hepatic lipid peroxidation, and increases the ratio of albumin/globulin and serum total protein (Nevin and Vijayammal 2005). The juice of the crushed root is used for jaundice in Indian traditional system of medicine (Tewari et al. 2017).

2.5 *Andrographis paniculata*

A. paniculata is an herbaceous annual plant of the family Acanthaceae. The species is native to Sri Lanka and India. As a traditional medicine, the whole plant parts of *A. paniculata* are used for the treatment of various diseases. The bioactive compounds of the plant are panicoline and diterpenoid lactone. The plant extracts are generally used as hepatorenal protective, liver enzymes modulation, anti-inflammatory, antiprotozoan, antioxidant, antimicrobial, immune stimulant, antidiabetic, and anti-infective. Some of the tribal communities of India use this herb for different diseases, such as jaundice, malaria, gonorrhea, wounds, and skin diseases (Alagesaboopathi et al. 1999).

2.6 *Artemisia absinthium*

A. absinthium is a perennial herbaceous plant of Asteraceae family. The species is native to temperate regions Asia and Africa. Various experiments have demonstrated its hepatoprotective, anticancer, antimalarial, anthelmintic, anti-inflammatory, antidepressant, antiulcer, immune-modulatory, and antioxidant activities. The bioactive compounds present in the species are sesquiterpene lactones and absinthin. It has immense potential for the identification of new compounds, which could be used as drugs for curing common and critical liver diseases (Kordali et al. 2005).

2.7 *Bixa orellana*

B. orellana is a plant native to Brazil mostly grown in tropical countries and belongs to the family Bixaceae. Seeds of Bixa are used as a condiment as well as laxative, cardiotonic, expectorant, aphrodisiac, and antibiotic. Bioactive compounds of the plant are orelline, bixin, and carotenoid. *B.orellana*is a promising herbal drug against alcohol-induced hepatotoxicity (Singh et al. 2013).

2.8 *Boerhavia diffusa*

B .diffusa is a species of Nictaginaceae family. *B. diffusa* is a flowering plant that grows in a vast geographical range in India and the southern United States. Tribal communities of India used the roots of the plant in the treatment of liver disorders. Bioactive compounds of the species are lunamarine, rotenoids, and quinolone. The plant root is traditionally important for the treatment of jaundice (Gopal and Shah 1985).

2.9 *Carum copticum*

C. copticum is a plant of Apiaceae family. The nature of seeds of the plant species is hot and used as a food additive. Therapeutically, the seeds are used as liver protectant, antispasmodic, gastrointestinal, cardio vasodilator, and lowering of lipid effects. It is effective in the treatment of *Helicobacter pylori,* and gram-negative bacteria enter the liver (Zarshenas et al. 2013). Bioactive compounds present in the plant species are thymol, gamma-terpinene, and P-cymene. Its seed powder is the extraction of boiled seeds and is given to the liver patient.

2.10 *Cassia fistula*

C. fistula is a common tree species of Leguminosae family in the deciduous forest of India. All the plant parts of the species are useful in the treatment of jaundice, inflammatory diseases, skin disease, rheumatism, and anorexia (Guruvayoorappan and Kuttan 2008). Bioactive compounds of the plant are anthraquinones, flavonoids, and flavan-3-ol. *C. fistula* is generally used in the Indian traditional system of medicine in the treatment of liver and skin diseases (Dutta and De 1998).

2.11 *Cassia tora*

C. tora is a weed species of the family Caesalpiniaceae mostly found in tropical India. The leaves and seeds of the plant are used as a liver tonic, cardio-tonic, and expectorant. The seed extract of *C.tora* has bioactive compounds like glycosides, flavonoids, saponins, fats, and gums. The antioxidant and hepatoprotective properties of flavonoids, saponins, and glycosides are well known (Anonymous 1992).

2.12 *Centella asiatica*

C. asiatica is an herbaceous plant of the family Apiaceae. It is a perennial flowering plant native to the wetlands in Asia. Traditionally, *C. asiatica* is used as a medicinal herb and nutritious vegetable. It is usually given to jaundice patients with jaggery. The whole plant part is used by indigenous people and health practitioners in liver disorders, cough, sinusitis, skin disorders, and memory improvement. The bioactive compounds present in the plant species are triterpene, asiaticoside, and brahmoside. Its pharmacological and clinical functions are also scientifically validated both in vivo and in vitro globally. Therefore, traditional usage of *C. asitica* is re-established with research finding (Brinkhaus et al. 2000).

2.13 *Curcuma longa*

C. longa is a wild flowering plant that belongs to Zingiberaceae family. The plant is native to South Asia including India. Bioactive compounds of the plant species are curcumin, bisdemethoxy curcumin, germacrone, and zingiberene. Rhizome of the *C. longa* is a good spice and has therapeutic potential against jaundice, liver cirrhosis, parasitic infections, ulcers, and various skin diseases (Alshawsh et al. 2011).

2.14 *Decalepis hamiltonii*

D. hamiltonii is an important medicinal plant of the Asclepiadaceae family. It is endemic to peninsular India. The plant is traditionally used for centuries in the treatment of various diseases. Quercitin is a bioactive compound of the plant. Therapeutically, the plant extracts have properties such as hepatoprotective, anti-inflammatory, antiulcer, antibacterial, antimalarial, and antioxidant. Histopathological examination clearly reveals that the extract of *D. hamiltonii* works as a hepatoprotectant. The aromatic tuberous root of the *D. hamiltonii* is threatened in its natural forest habitat due to overexploitation (Harish and Shivanandappa 2010).

2.15 *Eclipta alba*

E. alba or False Daisy is a medicinal plant of the Asteraceae family. The plant is a cosmopolitan small annual herb. *E. alba* is traditionally used in the treatment of liver cirrhosis and hepatitis. Bioactive compounds of the plant are coumestans, anthocyanin, and oleic acid. Leaf extract of the plant has revitalizing property and is an reputed antiaging agent in Unani and Ayurvedic medicines (Karthikumar et al. 2007).

2.16 *Elephantopus scaber*

E. scaber is a tropical flowering plant of the Asteraceae family. It is native to Asia, Africa, and Australia. *E. scaber* has been traditionally used as a liver tonic. Bioactive compound of the plant is elephantopin. Some of the effective therapeutical actions of the plant are hepatoprotective, antioxidant, anti-inflammatory, antimicrobial, and wound healing. The aqueous root extract is used in the treatment of jaundice, biliousness, and blood impurity (Lin et al. 1995).

2.17 *Flacourtia indica*

F. indica is a flowering plant species of the Salicaceae family. The species is native to much of tropical and temperate Asia and Africa. Flacourtin, limonin, tremulacin, and quercetin are the bioactive compounds of *F. indica*. The traditional value of the fruit of the plant is used in Ayurvedic, Siddha, Tibetian, and folk medicine for jaundice and spleen disorders (Kirtikar and Basu 1980).

2.18 *Glycyrrhiza glabra*

G. glabra is a medicinal plant of the Fabaceae family. The plant species is a perennial legume of Asia and Europe. The bioactive compounds of the plant are glycyrrhizin, isoflavene, glabrene, and triterpene glycoside present in the aromatic root. Glycyrrhizic acid is the most important active ingredient used as a hepatoprotective compound (Deng et al. 2013).

2.19 *Halenia elliptica*

H. elliptica belongs to the family Gentianaceae. The plant species are abundantly found in the forest regions of Tibet. It is a very popular plant used as folk medicine in the treatment of jaundice and hepatitis. Norbellidifolin, sinapaldehyde, 5-methoxy-2-methylchromone, and 7-epi-vogeloside are the bioactive compounds of *H. elliptica*. It is one of the important potential medicinal plants for the treatment of liver diseases (Huang et al. 2010).

2.20 *Ocimum sanctum*

O. sanctum is a species of the family Lamiaceae. It is a perennial aromatic plant native to India and cultivated in a wide region of tropical region of Aisa. The bioactive compounds of the plant species are eugenol, oleanolic acid, ursolic acid, and rosmarinic acid. *O. sanctum* has a wide range of therapeutic potential. *O. sanctum* is effective against paracetamol, CCl_4, and lead-induced liver damage (Handa et al. 1986).

2.21 *Piper chaba*

P. chaba is a native plant species of Southeast Asia that belongs to Piperaceae family. It is a flowering vine with a spicy pungent flavor. Roots of the plant are very expensive because of its strong aroma and high market value. Bioactive compounds of the plant are piperine, pipernonaline, and guineensine. Traditionally, roots and fruits are used in medicine as stomachic, expectorants, appetizers, and stimulants. The fruit of *P. chaba* is used by the traditional medicine practitioner in treating acute jaundice and gastric pain (Choi and Hwang 2003).

2.22 *Phyllanthus niruri*

P. niruri belongs to the Phyllanthaceae family and is a common tropical species found in coastal areas. Kaempferols, tannins, phenylpropanoids, and terpenoids are the bioactive compounds of the plant. *P. niruri* is used in the traditional system of medicines in the treatment of jaundice, indigestion, chronic dysentery, urinary tract diseases, and skin problems. A preclinical study has reported that the extract of *P. niruri* is effective in liver cirrhosis (Patel et al. 2011).

2.23 *Picrorhiza kurroa*

P. kurroa is a perennial plant of the Scrophulariaceae family. The plant species is a native of the Himalayan region from Nepal to Sikkim and Kashmir. It is a good source of income for the tribal people as a nontimber forest produce. The plant species is a popular traditional herb of the Indian system of medicine. It is used in the treatment of liver disorders. Picroside, apocynin, and vanillic acid are the bioactive compounds of the plant. The rhizome of the plant is used as an ingredient of many herbal formulations for the treatment of liver diseases (Ansari et al. 1988).

2.24 *Rubia cordifolia*

R. cordifolia is a plant species of the Rubiaceae family. It is a flowering plant mostly cultivated to derive red pigment from its roots. The dried fruit and roots powder are used for the treatment of spleen and skin diseases. Anthraquinones are one of the bioactive compounds of the plant. The aqueous-methanol extract of the plant is used in hepatoprotective activity against acetaminophen and CCl_4-induced hepatic damage (Dev 2006).

2.25 *Swertia chiraiyta*

S. chiraiyta is a seasonal herb of the tropical hilly area that belongs to the family Gentianaceae. Infusion of the herb is taken as a tonic for the heart, liver, and eyes. The plant is prescribed for malaria and stomach problems. Bioactive compounds of the plant are shamimin, mangiferin, and sawertiamarine. It is an important medicinal plant having hepatic and digestive. *S. chiraiyta* and helps in reducing blood sugar, improving digestion, and killing intestinal worms (Islam et al. 1985).

2.26 *Tephrosia purpuria*

T. purpurea is a plant species of the Fabaceae family. The plant is mostly found in the wasteland of tropical regions. As a folk medicine, the leaf and root of the plant are used for the diseases of liver, spleen, and heart. Ayurvedic and Unani literature advocates the use of *T. purpurea* in liver disease. The bioactive compounds of the plant species are glabratephrin, kaempferol, and quercetin. The modern study is therefore being carried out to investigate the presence of hepatoprotective activity using the extract of *T. purpurea* (Khatria et al. 2009).

3 Medicinal Plants in Cure of Kidney Diseases

Another very important organ in the human body is the kidneys. They are responsible for getting rid of toxins and waste products through urine. The kidneys produce hormones, which stimulate red blood cells production and regulate blood pressure as well as control calcium metabolism. Kidney diseases may lead to complete kidney failure that needs dialysis treatments or transplants. Kidney infections and kidney stones can also damage the organ. Several local healers used different medicinal plants in the treatment of kidney stones, for instance, *Alhagimaurorum*, *Tribulus terrestris,* and *Nigella sativa* (Bahmani et al. 2016a; b). Chen et al. (2018)

have also suggested *Salvia miltiorrhiza*, a common medicinal plant, in traditional Chinese medicine system for effective prevention of urolithiasis in animals; however, the clinical application for urolithiasis remains unclear. Sasikala et al. (2019) have demonstrated that the *Eurycoma longifolia* prevents kidney injury and nephrotoxicity as evidenced by urine and serum biochemical analysis and histopathology of the kidney. Some of the plants that have been used in traditional herbal drug preparations for the treatment of kidney disease are displayed in Fig. 2. Further, the details of some of the potential medicinal plants used effectively in the cure of kidney disease are given in Table 2. An additional description has been also discussed in subsequent subheads.

3.1 Aegle marmelos

A. marmelos is a native tree species of Southeast Asia that belongs to the Rutaceae family. The bioactive compounds of the tree are coumarins, phenolic acids, flavonoids, and alkaloids. *A. marmelos* is used as a diuretic, anti-inflammatory, antidiarrheal, anticancer, and antiviral. Leaf, stem, and root of *A. marmelos* are taken in formulation for kidney and urinary problems in Ayurvedic and Unani systems (Ramnik and Rao 2010).

3.2 Alternanthera sessilis

A. sessilis is a plant of the Amaranthaceae family. It is a plant species of aquatic habitat found in broad regions of tropical and subtropical countries. Bioactive compounds of the plant are alkaloids, tannins, and ascorbic acid. The plant has diuretic, laxative, and cooling properties. Leaf extract of *A. sessilis* is used to treat urinary tract infections and Kidney troubles (Sunmathi et al. 2016).

3.3 Amaranthus spinosus

A. spinosus is a weed plant of the family Amaranthaceae. The plant is a native of tropical regions of America. It is also found in the countries of Asia and Africa. Bioactive compound of the plant is hydroxycinnamates, quercetin, and kaempferol. Traditionally, the water extract of the whole plant is used for diuretic, kidney stones, and jaundice (Tanaka and Nguyen 2007).

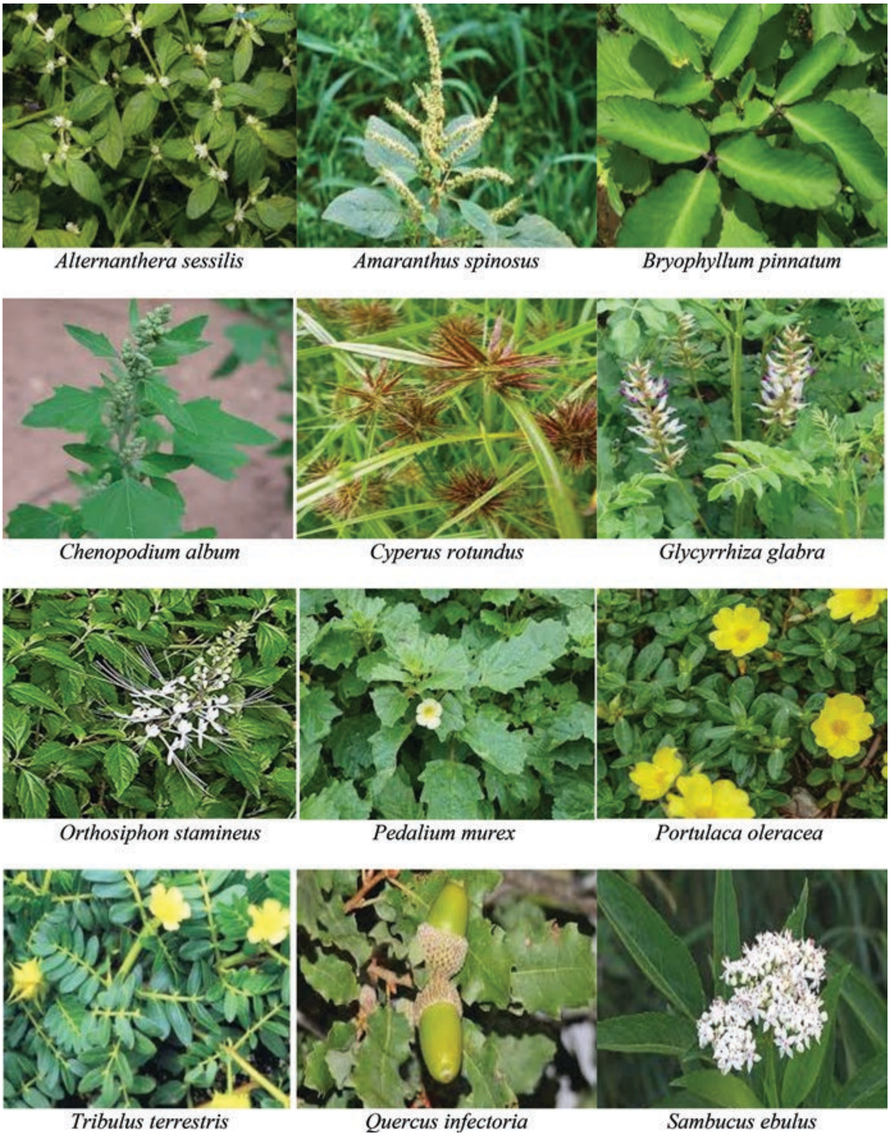

Fig. 2 Some of the medicinal plants used in traditional herbal drug preparations for the treatment of kidney disease

3.4 *Ammi visnaga*

A. visnaga is a member of the family Apiaceae. The plant species is present in a larger area of Asia, Europe, and Africa. It is an important herbal plant used in the treatment of kidney stones and urinary tract infections. The bioactive compound of the plant is khellin and visnagin obtained (Sneader 2005).

Table 2 Medicinal plants used in the cure of kidney disease

Botanical name (Family)	Common name (Part Used)	Bioactive compound	General use	Key reference
Aegle marmelos (Rutaceae)	Wood apple, Bel (leaf)	Coumarins, phenolic acids, flavonoids, and alkaloids	Diuretic, urinary tract infection, and kidney troubles	Singh et al. (2013)
Alternanthera sessilis (Amaranthaceae)	Sessile joy weed (whole plant)	Alkaloids, tannins, and ascorbic acid	Urinary tract infection and kidney troubles	Sunmathi et al. (2016)
Amaranthus spinosus (Amaranthaceae)	Spiny amaranth (leaf)	Hydroxy cinnamates, quercetin, and kaempferol	Diuretic, kidney stones, and jaundice	Tanaka and Nguyen (2007)
Ammi visnaga (Apiaceae)	Toothpick-plant (whole plant)	Khellin, ammiol, and visnagin	kidney stones and urinary tract infections	Sneader (2005)
Borassus flabellifer (Arecaceae)	Toddy palm (fruit)	Borassosides and dioscin	Diuretic, stimulant, and urolihtiasis	Shirisha et al. (2018)
Bryophyllum pinnatum (Crassulaceae)	Cathedral bells (leaf)	Flavonoids, glycosides, steroids, and bufadienolides	Urinary insufficiency and reducing calcium oxalate crystal in the kidney	Michael et al. (2007)
Citrullus colocynthis (Cucurbitaceae)	Desert gourd (pulp)	Cucurbitacins, saponarin, linoleic acid, and anthranol	Ddiuretic and laxative	Sen and Bhandari 1974)
Cissus quadrangularis (Vitaceae)	Veldt grape and hadjod (stem)	Stilbenes, triterpenes, ioridoids, and flavonoids	Diabetic kidney disease and joint pain	Murthy et al. (2003)
Chenopodium album (*Amaranthaceae*)	Lamb's quarters (whole plant)	Morphine, quinine, ephedrine and anthocyanidins, and saponins	Urinary and kidney stones	Kumar and Kumar (2008)
Curcuma aromatic (Zingiberaceae)	Wild turmeric (rhizome)	Alpha-curcumene, alpha, beta-turmerone, and alpha-pinene	Nephrotoxicity and gastrointestinal	Prabhu et al. (2009)
Cyperus rotundus (Cyperaceae)	Nut grass (rhizome)	Cadalene, cyprotene, and quercetin	Diuretic, analgesic, antispasmodic, and carminativ	Sivapalan (2013)
Eclipta prostrata (Asteraceae)	False daisy and bhringraj (aerial part)	Coumestans, thiophene, sterol, and triterpenes	Nephrotoxicity, hemorrhagic, and skin diseases	Humes and Weinberg (1986)
Glycyrrhiza glabra (Fabaceae)	Liquorice and jathimadh (root)	Liqcoumarin, glabridin, and glycyrrhizin	Antidiuretic, antiinflammatory, antiulcerous, and antihistamine	Olukoga and Donaldson (2000)

(continued)

Table 2 (continued)

Botanical name (Family)	Common name (Part Used)	Bioactive compound	General use	Key reference
Orthosiphon stamineus (Lamiaceae)	Java tea (whole herb)	Terpenes, flavonoids, and caffeic acid derivatives	Diuretic, renal protective, hepatoprotective, kidney infections, and kidney stones	Ameer et al. (2012)
Pedalium murex (Pedaliaceae)	Large caltrops and badagokhru (root, fruits)	Rihydroxy 5,7-dimethoxy flavones, and triacotanyl dotriacontanoate	Kidney stone, vesicle calculi, urinary discharge, and gonorrhea	Imran et al. (2015)
Portulaca oleracea (Portulacaceae)	Indian parselane (whole plant)	Alpha-linolenic acid and omega-3 fatty acid	Urinary tract and renal failure	Sultana and Rahman (2013)
Quercus infectoria (Fagaceae)	Aleppo oak, Majuphal (fruit)	Tannic acid, β-sitosterol, and amentoflavone	Nephropathy, benign prostate, and diabetic	Hwang et al. (2000)
Sambucus ebulus (Adoxaceae)	Dwarf elder (fruit)	Rutin, hyperin. Apigenin, chlorogenic acid, and lectins	Benign prostate and hyperplasia	Shokrzadeh and Saravi (2010)
Tribulus terrestris (Zygophyllaceae)	Puncture vine, Gokhru (fruit, leaf)	Furostanol, saponins chlorogenin, nuscogenin, and sarsasapogenin	Kidney stone, diuretic, and genitourinary tract disorders	Aggarwal et al. (2010)
Withania somnifera (Solanaceae)	Indian ginseng, Ashwagandha (leaf, root)	Triterpene lactones, withanolides, and cuscohygrine	Nephrotoxicity, immunemodulator, anti-inflammatory, and neuroprotective	Sankar et al. (2007)

3.5 *Borassus flabellifer*

B. flabellifer is native species of India and Southeast Asia that belongs to the family Arecaceae. The bioactive compound of the tree is borassosides and dioscin. The plant sap has been used traditionally as a stimulant, antileprotic, diuretic, and antiphlogistic (Shirisha et al. 2018). Parts of the *B. flabellifer*, such as root, leaves, fruit, and seeds, are used for various human diseases, including urolithiasis. Young roots are diuretic and anthelmintic, while the decoction of young roots is given in a certain respiratory disease (Jana and Jana 2017). The fruits and leaves of *B. flabellifer* have medicinal uses as a diuretic agent, as it contains terpenoids, tannins, flavonoids, and coumarins (Sujatha and Ranjitha 2018).

3.6 *Bryophyllum pinnatum*

B. pinnatum is a succulent plant native to Madagascar, belonging to the family Crassulaceae. The bioactive compounds of the herb are flavonoids, glycosides, steroids, and bufadienolides. In traditional medicine, the juice of the leaves is used in urinary insufficiency and reducing calcium oxalate crystal in the kidney (Michael et al. 2007).

3.7 *Citrullus colocynthis*

C. colocynthis is a desert vine plant of the Cucurbitaceae family. The plant is native to the Mediterranean Basin and Asia, especially Turkey. The bioactive compounds of the plant species are cucurbitacins, saponarin, linoleic acid, and anthranol. The fruit pulp of the plant is used in traditional medicine for the treatment of urinary and renal diseases and constipation (Sen and Bhandari 1974).

3.8 *Cissus quadrangularis*

C. quadrangularis is a plant species of the Vitaceae family. The plant species is native to tropical Asia and much of Africa. Stilbenes, triterpenes, iridoids, and flavonoids are the bioactive compounds of the plant. *C. quadrangularis* is part of many diets in many parts of the world and is used internally for a variety of reasons (nutritional supplementation, anemia, and wounds) and demonstrate the safety of the plant and or its extracts (Sen and Biplab 2012). *C. quadrangularis* is a plant that is rich in vitamin C and antioxidant. Its stem extract is used for diabetic kidney disease (Murthy et al. 2003).

3.9 *Chenopodium album*

C. album is a plant of the Amaranthaceae family mostly found in Asia, Europe, and Africa. It is a wild as well as a cultivated edible weed that grows in the winter season. Bioactive compounds of the *C. album* are morphine, quinine, ephedrine, anthocyanidins, and saponins. Traditionally, the leaf extracts of the plant have been used for urinary and kidney stones and renal diseases (Kumar and Kumar 2008).

3.10 *Curcuma aromatica*

C. aromatic is a plant species of the Zingiberaceae family. The plant is generally found in forests of South Asian countries. The species is endangered due to its over-exploitation by herbal industries. Rhizome of the plant is aromatic with high medicinal value. Bioactive compounds of the plant species are α-curcumene, α-β-turmerone, and α-Pinene. The rhizome and leaf of the plant are traditionally used for renal ailments, uric acid, arthritis, reducing creatinine, and gastrointestinal problems (Prabhu et al. 2009).

3.11 *Cyperus rotundus*

C. rotundus is a perennial plant species of the family Cyperaceae, native to Africa, Europe, and Southern Asia. Cadalene, cyprotene, and quercetin are the bioactive compounds of the plant species. The rhizome of the plant is diuretic, analgesic, antispasmodic, antibacterial, and carminative (Sivapalan 2013). The rhizome is traditionally used for treating kidney stones, cervical cancer, gastrointestinal spasms, and urinary problems (Chopra et al. 1986).

3.12 *Eclipta prostrata*

E. prostrata is a plant species of the family Asteraceae. It is widespread across much of the world. The bioactive compounds of the plant species are coumestans, thiophene, sterol, and triterpenes. Traditionally, the plant species are used for renal and urinary diseases and skin problems. A treatment with hydroalcoholic extracts of *E. prostrata* showed significant protection against nephrotoxicity induced by gentamicin treatment (Humes and Weinberg 1986).

3.13 *Glycyrrhiza glabra*

G. glabra is a perennial plant species of the Fabaceae family. It is also called liquorice, and the plant is native to Europe, India, and Middle East. Liqcoumarin, glabridin, and glycyrrhizin are the bioactive compounds of the plant. The dried root and stem of the plant give valuable compounds effective in the liver, kidney, throat lozenges, and cough ailments. The plant was used by the tribal people of ancient Arab for various diseases such as urinary and ulcer problems (Gibson 1978). Glycyrrhizin is effective for acute renal failure, expectorant, antihistamine, anti-inflammatory, and antiulcerous and muscle weakness (Olukoga and Donaldson 2000).

3.14 Orthosiphon stamineus

O. stamineus is a tropical plant species of the family Lamiaceae. The bioactive compounds of the plant are terpenes, flavonoids, and caffeic acid derivatives. The whole plant part is medicinally effective in renal ailments, inflammations, hepatic problems, diuretic, and microbial diseases. The aqueous extract of the leaf is used in kidney infections and kidney stones (Ameer et al. 2012).

3.15 Pedalium murex

P. murex is a plant of the family Pedaliaceae. It is a small herb found in the tropical regions of Asia and Africa. The bioactive compounds of the plant are dihydroxy 5, 7-dimethoxy flavones and triacotanyl dotriacontanoate. Traditional use of root extract of *P. murex* is for kidney stone, vesicle calculi, gonorrhea, and urinary discharge. Fruit of the plant is given for nephroprotective, anti-inflammatory, and genitourinary disorders (Imran et al. 2015).

3.16 Portulaca oleracea

P. oleracea is a plant of the Portulacaceae family that grows in the forest areas of Asia, Africa, Australia, and Europe. The bioactive compounds of the plant are α-linolenic acid and omega-3 fatty acid. *P. oleraceae* is a succulent annual medicinal plant used for kidney problems and urinary infection. Extract of the fresh plant is given to the patient for urinary problems (Sultana and Rahman 2013).

3.17 Quercus infectoria

Q. infectoria is a plant species of Fagaceae family. The plant is native to Asia and Europe. *Q. infectoria* is a popular medicinal plant traditionally used in toothache and diabetic nephropathy (DN). Bioactive compounds of the plant species are tannic acid, β-sitosterol, and amentoflavon. It is effectively used in the treatment of benign prostate hyperplasia (Hwang et al. 2000).

3.18 Sambucus ebulus

S. ebulus is an important herbal plant species of the Adoxaceae family. The plant species are mostly found in Europe and Asia. Rutin, hyperin, apigenin, chlorogenic acid, and lectins are the bioactive compounds of the plant species. The plant is traditionally used for centuries in the treatment of benign prostate hyperplasia, cold, joint pain, and infectious diseases (Shokrzadeh and Saravi 2010).

3.19 *Tribulus terrestris*

T. terrestris is a valuable medicinal plant species of the Zygophyllaceae family. It is an annual plant and is native to warm temperate and tropical regions in southern Eurasia and Africa. The bioactive compounds of the species are furostanol, saponins chlorogenin, nuscogenin, and sarsasapogenin. *T. terrestris* is useful in the treatment of kidney stone and renal diseases. The use of fruit and leaf extract inhibits the crystals of calcium oxalate (Aggarwal et al. 2010).

3.20 *Withania somnifera*

W. somnifera is a well-known medicinal plant called Indian Ginseng. The plant species belong to the Solanaceae family. Bioactive compounds of the plant species are triterpene lactones with anolides and cuscohygrine. The root extract of the *W. somnifera* is traditionally used for drug-induced nephrotoxicity. The important medicinal values of the plant species are building immunity, reducing inflammation, and inhibiting neurological problems (Sankar et al. 2007).

4 Conclusion

Forests are an important source of medicinal plants mostly used in traditional healing systems and provide crude materials required for modern pharmaceutical industries. Side effects of synthetic drugs on human health and the environment are major factors for the revival of herbal-based industries. But the high demand for herbal plants in international and national markets has created pressures on forest biodiversity. The rich floral diversity in forests is potentially valuable for many diseases. Medicinal plants including their leaf, stem, bark, bud, flower, seed, fruit, and root are important in the formulation of herbal medicines for liver and kidney diseases. In some cases, single or mixed herbal extracts are effective in disease and nutrient management. The efficacy of medicinal plants mentioned in this chapter is time tested, and it could be a great source for kidney and liver disease management. Overall, studies have shown that medicinal plants and their products in terms of important phytochemical compounds can play a key role in the health care sector and pharmaceutical sector and also helpful in growing the economics of the different countries. Preparation of efficient herbal medicines is required through pharmacological tests and clinical trials. Its production must be standardized for effectiveness and safety. Additionally, the sustainable use of herbs, shrubs, or trees obtained from the forest and other sources would help in the conservation of biodiversity and revival of useful indigenous traditional knowledge systems.

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Forest-Based Medicinal Plants for Cancer Cure

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1 Introduction

Since ancient times, plants are being used as a continuous source of medicinal products for animals and humans in rudimentary forms, such as syrups, powders, ointments, liniments, infusions, and decoctions (Ghorbani 2014). It is considered that about 70–95% of the human population in developing countries uses traditional medicines in their routine life in the form of herbal teas, plant extracts, powders, or plant parts. A plethora of evidence has reported the use of plant-derived active compounds in the treatment of cancer. Current data suggest that about 25–28% of all modern medicines have the presence of plant derivatives that explains the nutraceutical and medicinal potential of plants known for thousands of years in traditional medicine.

Cancer is one of the leading causes of mortalities worldwide and is the second major cause of death after cardiovascular diseases (Uscanga-Perales et al. 2019). The disease commences with the deformation of a normal cell caused by genetic defects and affects a large number of individuals worldwide. It is a common disease around the world and is a severe health concern. Breast cancer, lung cancer, colon or rectal cancer, blood cancer, bladder cancer, ovarian cancer, etc. are the most common cancers all over the world. The predisposing risk factors include smoking, consuming alcohol, obesity, lack of a healthy diet and physical activities, and excessive exposure to sun rays. According to the International Agency for Research on Cancer, the global cancer burden is estimated to have risen to 18.1 million new cases and 9.6 million deaths in 2018. As per the estimated data, 23.4% of the global cancer cases have been reported in Europe with 20.3% of the cancer deaths. America accounts for 21.0% of cancer incidence and 14.4% of mortality worldwide. In contrast, Asia and Africa contribute a higher proportion of cancer incidences (48.4% and 5.8%, respectively), and deaths (57.3% and 7.3%, respectively) (GLOBOCAN 2018). An estimated 2.25 million people are living with cancer in India and more than 1,157,294 new cancer patients have registered annually, while 7,84,821 people have died of cancer (4,13,519 men and 3,71,302 women) according to the National Cancer Prevention and Research Institute (NICPR 2018) (Ramu 2020)

Herbal therapy is an essential alternative approach concerning the treatment of cancer. According to the World Health Organization reports, around 80% of the world's population depends on conventional medicine as a means of primary health care (WHO 2019). Any realistic approach is of utmost importance in the fight against cancer. Herbal medicines preserve individuals' health and fertility, cure illnesses, and even avoid, suppress, or reverse cancer development without inducing toxicity. Herbal products are more than 50% of all modern medications in clinical use, and a lot of them can control cancer. More than 60% of cancer patients use herbal therapy, while recently much focus has been emphasized in the study on complementary and alternative medicine for cancer treatment (Nayeri et al. 2020).

In remote and rural areas around the world, people still rely on traditional medicines to treat various diseases. African traditional medicine has been regarded as holistic and is interwoven with divination, spiritualism, and herbalism. In Africa, traditional medical practitioners or traditional healers include the most trusted and experienced high priests, priestesses, witch doctors, midwives, spiritualists, and herbalists who use herbs, minerals, parts of animals, incantations, and other traditional methods for many ailments like heart disease, diabetes mellitus, HIV, gynecological illness, asthma, and mental disorders. In Japan and China, traditional medicines account for 70% and 40%, respectively, of the health care system and are actively prescribed by allopathic doctors for their patients. Similarly, 48% of the population in Australia, 70% in Canada, 42% in the United States, 38% in Belgium, and 75% in France have used traditional medicines in their life with the popularity of traditional medicines, the market value of herbal medicines has also increased tremendously. As per the WHO report, the world market for herbal medicines based on traditional knowledge is estimated for 2015 at the US $90 billion, while the annual market sales of herbal medicines in 2007, 2008, and 2009 were US$ 200 000, US$ 600,000 and US$ 1,300,000, respectively (WHO 2019).

Reducing the toxic side effects caused by chemotherapy and radiotherapy agents may make herbs useful for cancer control. One of the mechanisms of action of herbal biological modifiers is the inhibition of cancer by regulation of complex hormonal and enzymatic activities. The studies are now mainly focusing on the separation of active components from natural sources that may be having an application as an active anticarcinogen. Rasayana is an important component of the complementary and alternative medicinal system in which herbs help in alleviating the body's imbalances. These traditional means of therapy have a profound effect on shielding the body from the counter-effects of deleterious chemotherapy and radiation therapy specific to the tumor (Chakraborty et al. 2012).

The purpose of this chapter is to summarize some of the most effective medicinal plants reportedly to have a considerable anticancer effect. Also, the experimental evidence based on published research articles has been examined to overview active phyto-compounds responsible for the anticancer potential of these medicinal plants.

2 Cancer Therapies

Based on the clinical factors, such as type of cancer, its stage, metastasis and patient's age, there are patients at high or low risk, whereas individual risk groups go around with a different system for therapy. Therapists face a daunting series of obstacles as cancer is diagnosed. The available anticancer treatment options are apoptin, chemotherapy, cryotherapy, cytokine therapy, hormone therapy, immuno-adjuvant therapy, radiation therapy, surgery, etc. (Natesan et al. 2007a, b). In modern times, the application of gold-conjugated and carbon nanoparticles has enhanced the anticancer potential of drugs such as doxorubicin and paclitaxel (Bromma and Chithrani 2020). However, cancer therapies have several reported side effects like anemia, lymphedema, memory loss, peripheral neuropathy, etc. which might varies with the mode of the treatment, including traditional therapy or advanced targeted therapy. Chemotherapy drugs have a profound detrimental effect on cancer cells along with healthy leukocytes which makes the patient more vulnerable to other diseases and further deteriorate the health (CDC 2020).

Patients' survival under the umbrella of traditional treatment is extremely marginal (2.4%). However, confusion about the efficacy of such a cancer treatment strategy generates the urge for alternative therapies that cause fewer side effects and improve survival rates (Paul and Dredze 2011).

3 Herbal Medicinal Plants with Anticancer Potential

Around the world, ongoing research is underway to explore successful cancer treatments using herbal plants as therapeutics in cancer patients. Naturally occurring compounds in plants known for their ability to inhibit the growth of carcinogenic cells are used in the procedure of cancer treatment. Organically based therapies do not have the significant side effects of radiotherapy and chemotherapy, which is the most common method of treating cancer by physicians and specialists (Newhauser et al. 2016).

Several herbs protect the body against potential or current cancer, thereby contributing to providing flexibility in cancer treatment and strengthening the patient's immune system. The mechanism of action of herbal anticancer drugs has been divided into two different groups, i.e. direct cytotoxicity and immune-modulation cytotoxicity. Abnormal cell proliferation and the inhibition of cell apoptosis which is governed by some genes are responsible for causing cancer. In this respect, some oncogenes or tumor suppressor genes may be modulated by medicinal herbs. As far as immune-modulation is concerned in the case of malignancy, herbal medicines can enhance the immune response that has different therapeutic applications (Zhu et al. 2008).

Various communities have used many distinct anticancer herbs for medicinal purposes throughout time. With such a diverse range of herbs available globally, there are quite a few antiherbal plants with known anticancer potential. *Alfalfa* is one of the main anticancer herbs with the potential to combat the effects of chemotherapy and is considered one of the most nutritious foods accessible. With known antibacterial and antifungal properties, *Alfalfa* (*Medicago sativa*) is an effective infection fighter and body cleanser (Greenwell and Rahman 2015). It acts to increase white blood cell output and replace those that are damaged during treatment. *Andrographis* is another anticancer plant cultivated in Asia's forests and wastelands and is well studied for its use against cancer, AIDS, bacterial and viral infections. This herb has been shown to stop the abnormal growth of cancer cells in the stomach.

Similar to these medicinal plants, there are several other herbs with multiple health benefits. *Cnicus benedictus*, commonly called "Blessed thistle," exhibits an ability to decrease tumor size. The active ingredient of this plant is cnicin which is credited for eliciting antitumor and antibacterial effect. Another anticancer herb is *Arctium lappa* commonly called Burdock) having potent anti-inflammatory properties, which helps to rejuvenate the body and enhances the healing process. Herbal preparations can work in a mechanism similar to pharmaceuticals without having a chance of any side effects. Herbal plants possess natural anti-inflammatory compounds that widely contribute to their renowned health benefits. Thus, the need to investigate natural nonsteroidal anti-inflammatory substances for cancer prevention has therefore increased. Anticancer herbs also include rosemary (*Rosmarinus officinalis*) which is an effective antispasmodic and antiseptic antioxidant. Rosemary interferes with the early stage of cancer development mainly by aiding in averting the attachment of carcinogenic chemicals to cells and escaping cancer-causing mutations (Allegra et al. 2020). Some of the important herbs, shrubs and trees and their active phyto-compounds used in cancer cure are presented in Table 1.

3.1 Acacia nilotica

A. nilotica belongs to the family fabaceae, also known as babul or Indian gum arabic tree, has several known medicinal properties, and is used in the treatment of cancers and tumors of the ear and eye. The plant is also beneficial in the therapy against dysentery, diarrhea, ulcer, leprosy, diabetes, and various cancers (Roozbeh and Darvish 2016). It has been reported that the use of its various preparations decreases the tumor burden, tumor occurrence, and a cumulative number of papilloma during the periods of peri- and post-initiation of 7,12-Dimethylbenz[a]anthracene and croton oil use. Besides, in treatment groups, a substantial decrease in the occurrence of micronuclei was apparent, both of which were correlated with a decrease in total chromosomal aberrations (Sakthivel et al. 2012). In a recent study, *A. nilotica* extract showed reduced growth of Dalton's ascitic lymphoma (DAL) MDA-MB-231 (breast cancer), and HEp-2 (cervical cancer). The study also depicted a significant increase in hemoglobin and W.B.C count, while a decrease in the level of liver enzymes was reported in the treated mice model (Revathi et al. 2017).

Table 1 List of some plants and their active phyto-compounds used for the treatment of cancer

Plant name	Common name	Plant parts used for active phyto-compound isolation	Active phyto-compound(s)	Key References
Aegle marmelos	Bael fruit	Leaves and fruit	Lupeol and skimmianine	Akhouri et al. (2020)
Ammi majus	Amme, Bullwort	Fruit	Coumarin	Aydogmus-Ozturk et al. (2019)
Artemisia absinthium	Sage brush, wormwood	Leaves and flower	Artemisinin	Akrout et al. (2011)
Boswellia serrata	Olibanum or Indian Frankincense	Resin	Boswellic acid	Wang et al. (2018a, b)
Camellia sinensis	Tea plant	Leaves	Epigallocatechin gallate (EGCG)	Imran et al. (2019)
Catharanthus roseus	Madagascan periwinkle	Leaves and flower	Vincristine, vinblastine and vindesine	Harshini et al. (2020)
Cephalotaxus harringtonia	English Yew, Japanese Plum Yew	Bark and fruit	Homoharringtonine	Isah (2016); Yakhni et al. (2019)
Citrullus colocynthis	Bitter apple, desert gourd	Leaves, stem, root, and fruit	Quercetin and β-sitosterol	Perveen et al. (2021)
Clematis manhsrica	*Clematis*	Bark	Hederagenin saponin and embelin	Zhao et al. (2005); Cheng et al. (2018)
Combretum caffrum	Cape bushwillow tree, African willow tree	Bark	Combretastatin A-4 phosphate	Kwak et al. (2019)
Crocus sativus	Saffron	Stigma	Crocin, crocetin, picrocrocin, and safranal	Nassar et al. (2020); Veisi et al. (2020)
Curcuma longa	Turmeric	Rhizome	Curcumin	Liu and Ying (2020)
Ferula asafoetida	Asafoetida—Devil's Dung	Dried latex	β-sitosterol and oleic acid	Abroudi et al. (2020)
Glycyrrhiza glabra	Licorice	Root	Glycyrrhizin, glycyrrhetinic acid, glabridin, gycyrrhetinic acid, and glycyrrhizic acid	Wang et al. (2018a, b); Goel et al. (2020)
Lawsonia inermis	Henna tree, the mignonette tree	Leaves	Lawsone (2-hydroxy-1, 4-naphthoquinone)	Mungle et al. (2019)
Medicago sativa	Alfalfa	Leaves and flower	Coumarin, flavonoid, alkaloid, and terpenes	Brodribb (2018); Dziok et al. (2020)
Ocimum sanctum	Holi Basil	Leaves	Apigenin, β-D-glucuronic acid, ocimarin and luteolin	Harsha et al. (2020)
Olea europae	European olive	Leaves, fruit, and roots	Oleic acid, maslinic, and oleanolic acids	Ziberna et al. (2017)

3.2 *Achillea wilhelmsii*

A. wilhelmsii belongs to the family Asteraceae. A distinct race of *Achillea* exists; however, *A. wilhelmsii* is prevalent in Iran. The plant is a 15–40 cm grassy, perennial and short herb. The essential oil of the plant leaf contains a-Pinene and 1,8 Cineole, which have been studied to induce cytotoxic effects on colon cancer cells (HT-29), breast cancer cell lines and cervix cancer HeLa cells (Acar et al. 2020). It is reported that the plant methanolic extract contains phenolic compounds, in particular flavonoids, which inhibit the replication of cancer cells by inducing apoptosis (Sharma et al. 2011). In another study, the expression of telomerase reverse transcriptase (hTERT) in prostate cancer (PC3 cell lines) was reported to be reduced by the treatment of cells with hydroalcoholic extract of *A. wilhelmsii* at the concentration of 150 μg/mL concentration (IC50) (Ashtiani et al. 2017).

3.3 *Aegle marmelos*

A. marmelos belongs to the family Rutaceae and is commonly called the Bael tree in India. The plant has a rich presence of bioactive compounds, such as flavonoids, phenolics, alcohols, fatty acids, methyl esters, aldehydes, aromatic compounds and steroids by GC-MS analysis. Lupeol, a tri-terpenoid, is the main bioactive component of the plant and has significant anticancer activity against malignant ascites, multiple brains, primitive neuroectodermal tumors (PNET), thyroid cancer, and spinal cord malignant tumors (Lampronti et al. 2003). This plant has been explored for its antineoplastic and antimutagenic activity in animal studies. Skimmianine has been identified as a bioactive agent in leaf extract which may induce apoptosis in cancer cells. The fruit extract of *A. marmelos* has shown cytotoxicity against 7,12-dimethylbenz(a)anthracene (DMBA)-induced breast cancer in mice, where the extract showed significantly reduced growth of a mammary tumor and decrease in the level of TNF-α, serum malondialdehyde, and glucose (Akhouri et al. 2020).

3.4 *Aloe vera*

A. vera is a succulent plant from the family Asphodeloideae. It is one of the herbal plants that are used as a source of anticancer therapy as studied in vitro and in vivo for its anticancer potential. It is a rich source of carotenoids, steroids, terpenes, phytosterols, and enzymes, such as bradykinase, carboxypeptidase, cyclooxygenase, and carboxypeptidase. Oral administration of aloe leaf in Swiss albino mice at various levels of tumors, including second-stage skin carcinogenesis, was found to reduce papillomas in size and number. In contrast, to control groups, it reduced cancer growth and improved the latency time for papillomas. Also, the study reported a substantial decrease in the levels of lipid peroxidation, glutathione, DNA, protein, and catalase in the mice's skin (Chaudhary et al. 2008). Recent studies on hepatocellular carcinoma (HepG2) cells have indicated that the extract of *A. vera* could exert an anti-hepatocarcinogenic effect through modulation of apoptosis (Karpagam et al. 2019).

3.5 *Ammi majus*

It is a member of the family Apiaceae and is an annual, dicotyledonous, autumn-growing herb plant. *A. majus* is a native of Europe, the Mediterranean region, western Asia, and India. The plant is long and thin which grows to the length of about 100 cm in different habitats like saline grasslands, wet and soft soils, and coastal areas. The coumarin compounds (as part of the phenol compounds) are attributed to the plant's anticancer potential. Research has been conducted on the cell toxicity of coumarin on cancer cell lineages, and studies have confirmed the triggering of apoptosis as the mechanism of action of these compounds. Psoralens are the most essential coumarin compounds found in this plant which reportedly contributes to anticancer activity by suppressing the action of cytochrome p450 (Shokoohinia et al. 2014). Recent studies have identified the anticancer potential of visnagin, a furanochromone derivative, from *A. visnaga*, against malignant melanoma (HT 144) cell lines (Aydogmus-Ozturk et al. 2019).

3.6 *Andrographis paniculata*

A. paniculata (Kalmegh, a member of the Acanthaceae family has andrographolide, a bicyclic diterpenoid lactone, as a major element in the leaves. It exerts direct anticancer action via cell cycle arrest at G0/G1 level and induces reduced expression of cyclin-dependent kinase 4 (CDK4). Andrographolide also possesses immunostimulatory activity and is known to increase lymphocyte proliferation and interleukin-2 synthesis. It exerts indirect anticancer activity by enhancing the level of TNF-α and expression of CD marker leading to a substantial increase in the potency of lymphocytes against tumors (Paul et al. 2019). In a study conducted by Singh et al, hydroalcoholic extract of *A. apniculata* showed 51.12% inhibition of ovarian cancer cell lines (ovcar-5), while the combination of *A. paniculata* and *Silybum marianum* showed synergistic inhibition activity against liver cancer cells (HepG2) (Singh et al. 2013).

3.7 *Artemisia absinthium*

Artemisia has 200 and 400 species that belong to the Asteraceae family. The species, *A. absinthium* L, originates from moderate regions of Asia, northern Africa, and large areas of America. The plant could reach a height up to 80–120 cm and bears clustered, bitter, and yellow-colored flowers. Research has been reported for relevant anticancer properties of this plant on HeLa, HT-29, and MCF7 cancer cells (Koyuncu 2018). The active compound, artemisinin, has been reported to inhibit the growth of breast cancer cells via apoptosis and prevents angiogenesis, and cell migration. Besides artemisinin, the plant is recognized to possess phytocompounds like quercetin, kamfrolinalol, alphapinin, isorhamnetin, limonene, and myrecene. The anticancer potential of quercetin and isorhamnetin has been studied and reported to inhibit cancerous cell growth in cancer cells like MB-435, SKMEL-5, Du-145, and MCF-7. Artesunate is one of the most effective artemisinin that inhibits the production of the angiogenic factor VEGF, prevents angiogenesis, and exerts anticancer effects. A recent study has identified the anticancer potential α-pinene, β-pinene, limonene, and myercin found in *A. absinthium* against human breast cancer, hepatic cancer, colon cancer, and melanoma growth (Akrout et al. 2011).

3.8 Azadirachta indica

A. indica, also known as “the wonder tree” and “the drug store of nature,” belongs to the family of Meliaceae and is recognized for its enormous therapeutic and ethnomedicinal significance. Numerous reports are available citing the medicinal importance of its bark, leaves, seed oil, and related purified products. Terpenoids and steroids found in the bark, leaves and seeds of the plant are frequently used to treat and heal different cancers such as cervical, ovarian, and breast neoplasia. The plant has immunomodulatory and apoptotic activities against several types of cancers and is recommended for the prevention and inhibition of tumors (WHO 2019). The role of the active principles in the genesis of the forestomach, cervical cancer, and skin papilloma has been studied and identified to induce substantial carcinogen detoxification in the liver of Swiss albino mice. The anticancer effect of methanolic extract of *A. indica* has been studied against MCF breast cancer cells and showed inhibition of MCF cell lines in a dose-dependent manner. The concentration of 200 μg/ml of the extract was found to induce 65.5% of inhibition in the MCF cells (Malar et al. 2020).

3.9 Boswellia serrate

B. serrate is a medicinal plant also called Olibanum or Indian Frankincense and belongs to the order of the Spindales, family Burseraceae. Hydroalcoholic extract of this plant has been reported to induce death of cervical cancer cells in a time and dose-dependent manner (Akbar 2020). The resin made from the plant extract is an intrinsic part of the Asian and African folk medicine system and is also known to cure chronic inflammatory disease and other health conditions. The major phyto-compounds of frankincense resins that are shown to induce apoptosis in cancer cells include boswellic acid, monoterpene, diterpene, and triterpene. Frankincense extract induces apoptosis and causes significant cell damage by enhancing the production of reactive oxygen species (ROS) and caspases (Poornima and Deeba 2020). The anticancer potential of boswellic acids has been reportedly shown to induce apoptosis in myeloid leukemia cells, fibrosarcoma, metastatic melanoma, brain tumor cells, Hep G2 cell line, and HCT-116 human colon cancer cells (Wang et al. 2018a, b). Recently, a study conducted on 4T1 breast cancer mouse model showed inhibition of tumor growth (25.7%), and angiogenesis using *B. serrata* gum resin alcoholic extract (BSE) at the concentration of 150 mg/kg. The histopathological analysis of liver and lung tissues of cancer implanted mouse model also revealed inhibition of metastasis (Alipanah and Zareian 2018).

3.10 Camellia sinensis

C. sinensis is an evergreen shrub and belongs to the family Theaceae. The leaves are the source of tea that is one of the most consumed beverages in the world and is being used as a medicinal drink for centuries in the Chinese, Japanese, and Asian subcontinents. Based on the processing of leaves, there are mainly four tea varieties known as white, green, oolong, and black tea. The major components found in *C. sinensis* are catechins, epigallocatechin-3-gallate, epigallocatechin, epicatechin-3-gallate, and epicatechin, which exert an antioxidant, anticancer, and anti-inflammatory effect. Other than EGCG, other active compounds like rutin and quercetin have been studied to contribute to the inhibition of oxidative activation in carcinogenesis. There is a plethora of evidence indicating the anticancer potential of green tea and black tea. The anticarcinogenic effect is believed to be induced through controlling the proliferation of the cell and inducing apoptosis and angiogenesis in cancer cells (Anand et al. 2012). The in vivo studies have depicted anticancer efficacy of green tea on prostate cancer, where green tea was found to inhibit 5-alfardoctase enzymes that convert testosterone to dihydrotestosterone, a prostate carcinogenic agent to have an inhibitory effect on prostate cancer (Imran et al. 2019). In vitro and in vivo studies have reported that green tea catechins like epigallocatechin gallate (EGCG) inhibit the malignant growth of breast cancer cells bladder cancer, lung cancer, pancreatic cancer, liver cancer, and esophageal cancer (Filippini et al. 2020).

3.11 Camptotheca acuminata

C. acuminate belongs to the Nyssaceae family and possesses camptothecin which is a potential source of steroidal precursors for cortisone development. Its semisynthetic derivatives are topotecan and irinotecan known for their efficacy in the treatment of ovarian, colorectal and lung cancers (Bertino 1997). However, due to some cases of bladder toxicity reported, its application has now been discontinued. To counteract the side effects, broad-spectrum mode of action of camptothecin from *C. acuminata* against cancer cell lines have been well reported in the literature. The camptothecin has been shown to exhibit its inhibitory effect against topoisomerase-I activity (Chaudhari et al. 2020).

3.12 Careya arborea

One of the common vegetables in northeast Thailand, *C. arborea*, is usually consumed fresh as a side dish or eaten as a soup. It belongs to the family of Barringtonieacea. In the ancient ethnomedical system, the bark of *C. arborea* had wide application in the treatment of tumors. Scientific studies have reported the anticancer activity of bark's methanolic extract against Dalton's lymphoma ascites (DLA)-induced ascitic and solid tumors in mice (Natesan et al. 2007a, b). The experiments using young leaves and flowers have demonstrated the inhibition of metastasis and cell death in MCF-7 cells, followed by increased generation of ROS, stimulation of caspase-3 activity, and reduced mitochondrial function. *C. arborea* extract therapy had also shown reduced protein-inhibited cell viability of cyclin D1, protein, and protein-induced cell apoptosis of caspase-3 and cytochrome C protein. As a mode of action, *C. arborea* is reported to block the migration of breast cancer cells, followed by repression of MMP2 and MMP9 expressions (Buranrat et al. 2020).

3.13 Catharanthus roseus

The *C. roseus belongs* to the Apocynaceae family has a rich source of vinca alkaloids which possesses antimitotic and anti-microtubule activity. This group of alkaloids includes bioactive compounds such as vincristine, vinblastine, and vindesine which have depicted anticancer potential against human acute leukemia, hepatocellular carcinoma, Hodgkin's syndrome, non-Hodgkin's lymphoma, Swing's sarcoma, Wilms' tumor, neuroblastoma, and transmissible venereal tumor (TVT) (Harshini et al. 2020). The anticancer potential of vinca alkaloids includes microtubule destruction, inhibition of mitosis, protein and nucleic acid synthesis, increased concentration of glutathione oxidation and cAMP, and altered lipid metabolism (Tucker et al. 1977). In the treatment of hematological malignancies and few solid tumors originating in the lung and colon, vinca alkaloid has been identified to induce apoptosis through a pathway independent of cell cycle arrest and is still crucial along with its analogs. The effects of alkaloids of this plant on breast, prostate, and cervix cancer cells (MCF-7, PC3-1C, and HeLa) have been studied indicating that these alkaloids' tubular protein links changed its structure by blocking the division of cancerous cells, and thus these compounds having antioxidant properties preventing the cancer cells from progression (Sharma et al. 2016).

3.14 *Cephalotaxus harringtonia*

Homoharringtonine (cephalotaxine 4-methyl-2-hydroxy-4-methylpentyl butanedioate) is an active compound isolated from *C. harringtonia*var, a Chinese tree from the family Taxaceae. A racemic mixture of harringtonine and homo harringtonine has been successfully used in elderly cancer patients with acute myelogenous leukemia and chronic myelogenous leukemia. Due to its relatively mild cytotoxicity and high efficacy against different kinds of leukemia, Homoharringtonine is an FDA-approved anticancer drug considered to be a safer alternative therapeutic (Yakhni et al. 2019). Historically, its bark has been used as a traditional Chinese medicine to cure various cancers. The antileukemic effect of homoharringtonine esters, such as harringtonine, homoharringtonine, deoxyharringtonine, and isoharringtonine, has been well established on mouse P-388 and L-1210 cell lines. The mode of action in homoharringtonine involves protein synthesis inhibition in a dose and time-dependent manner blocking the cell cycle progression from G1 to S phase and G2 into M phase causing apoptosis (Isah 2016).

3.15 *Citrullus colocynthis*

The plant *C. colocynthis* is a member of the family Cucurbitaceae and a native to the Mediterranean Basin, Northern Africa, Turkey, Nubia, and Asia. It is also known as bitter apple, bitter cucumber, and desert gourd. The plant has been used as a traditional medicine for centuries. The active constituents of this plant such as quercetin and b-sitosterol have been studied to exert anticancer effect against liver (HepG2) and breast (MCF7) cancers. These compounds act by inhibiting the cell cycle and the induction of apoptosis (Perveen et al. 2021). In another related study, the anticancer potential of seed and pulp extracts of the fruit was reported to induce cell death through regulation of p53 pathways and mitochondrial regulated apoptosis. Using computational molecular docking tools, the study also identified isoorientin and isovitexin as the bioactive phytocompounds responsible for the inhibition of ROS production and proliferation of cancer cells (Joshi et al. 2019).

3.16 *Clematis mandshurica*

C. mandshurica plant belongs to the family Ranunculaceae. Due to the presence of saponins, *C. mandshurica* has apparent antitumor effects. The embelin derivatives of *C. mandshurica* include 1, 4-benzoquinone derivative 5-0 ethyl embelin (1) and 5-0 methyl embelin which are recognized to inhibit cancer progression. Experimentally, the saponins in plants have shown cytocidal effects on tumor cells like EAC cells, S180A cells, and HepA tumors. In another study, the *C. mandshurica* saponins have shown significant anticancer activities on Sarcoma-180, HepA and P388 transplanted mice (Zhao et al. 2005). Saponins like hederagenin saponin have shown to induce apoptosis in MCF-7 and MDA-MB-231 breast cancer cell lines through reduced activity of mitochondrial Apaf-1 and cytochrome *c* proteins (Cheng et al. 2018).

3.17 *Combretum caffrum*

C. caffrum is a South African tree that belongs to the Combretaceae family. Combretastatin A-4 phosphate is a natural antitumor compound isolated from *C. caffrum* and has shown significant cytotoxicity against colon, lung, and leukemia cancers (Ohsumi et al. 1998). It has antiangiogenic properties that cause tumors to shut down vascularly and contribute to tumor necrosis. Combretastatin A-2, a methylenedioxy derivative of combretastatin A-4, has been examined for its antiproliferative activities against human cancer cell lines (HeLa, SK-OV-3, A549, and HT-29) using molecular docking studies (Kwak et al. 2019).

3.18 *Crocus sativus*

The saffron plant *C. sativus* is a member of the Iridaceae family and is originally from Khorasan, Iran. The plant is a 10–30 cm long perennial herb with narrow leaves coming from the bulbs of this plant. There are between one and three purple flowers on this herb. The used part of this plant is stigma, known as saffron. The active constituents like crocin, crocetin, picrocrocin, and safranal extracted from saffron are reported to have induced cancer cell death via apoptosis (Nassar et al. 2020). The potential anticancer properties of saffron extract and its purified quercetin have been demonstrated against colorectal cancer cells, breast cancer cells (MCF-7), HeLa, and HepG2 cells. The study indicated the inhibition of DNA synthesis and angiogenesis in cancer cells as the mechanism of action of the saffron (Veisi et al. 2020).

3.19 *Curcuma longa*

The turmeric plant is scientifically known as *C. longa* is a member of the family Zingiberaceae. Cultivation of this perennial plant requires a wet and rainy climate. It is native to Africa and South America and hot areas of Asia, such as India, southern China, Pakistan, and Indonesia. The active compound has been used for the prevention of oral ulcerative cancer, breast cancer, skin squamous cell carcinoma, and malignant leukoplakia transformation. Dried rhizomes are the edible component of turmeric. The cytotoxic analysis of turmeric in Hep-2-liver tumor cells showed that curcumin-induced dose-dependent cytotoxicity contributes to cancer cell apoptosis through the mitochondrial pathway (San and Lee Yue 2020). Curcumin, the active component of turmeric, plays a major role in the prevention and treatment of primary ovarian cancer. Curcumin's anticancer potential has been demonstrated against leukemia, lymphoma, melanoma, intestinal cancer, urinary cancer, breast cancer, lung cancer, colon cancer, and brain tumors. In several cellular systems, an antioxidant, antitumor, and anti-inflammatory activity of *C. longa* were reported to induce apoptosis (Liu and Ying 2020). It prevents cancer growth by inhibiting the formation of deleterious eicosanoids such as PGE-2. The condensates of curcumin like 7, 12-dimethylbenz(a) anthracene (DMBA) and benzopyrene suppress the mutagenic influence of various mutagens. The experimental studies have also shown the potential of *C. longa* to inhibit nitrosamine production and an increase in glutathione levels, which improves the body's natural antioxidant functions (Rawal et al. 2015).

3.20 *Ferula asafoetida*

F. asafoetida is a herbaceous plant of the Umbelliferae family. It is mainly cultivated in different parts of Iran, Khorasan, Sistan, and Baluchestan. It is an evergreen perennial herb growing 1–1.5 m with strong, thick fibrous stems. The resin from this plant is exuded from the rhizome or taproot. Consumption of gum substantially shown to decrease the risk of colon cancer and breast cancer (Panwar et al. 2015). Sulfur-containing compounds such as β-sitosterol and oleic acid are the most important ingredients with anticancer potential. The anticancer effects of the ethanolic extract are being demonstrated by various mechanisms including inhibition of gene mutation, inhibition of DNA degradation, the effect on cell proliferation, and changes in enzyme activity. The significant mechanism of anticancer activity includes the induction of apoptosis. Furthermore, the epidemiological studies on the cytotoxic potential of phytochemical compounds of *F. asafoetida* have reported the inhibitory effect against ovarian carcinoma, colon cancer, breast cancer, Hepatocellular carcinoma, lung cancer, and melanoma (Verma et al. 2020). Recently, an investigation has demonstrated a significant increase in apoptotic activity and anticancer potential of ethanolic extract of *F. asafoetida* against adrenal tumor cells

(PC12) and MCF7 breast cancer cells at different concentrations of 7, 5, 10, and 2.5 μM in a time and dose-dependent manner (Abroudi et al. 2020).

3.21 *Glycyrrhiza glabra*

G. glabra, a member of the family Fabaceae, is also called Licorice. *G. glabra* is a wild vegetable plant native to the temperate regions of Asia, Southern Europe, and North Africa. It is cultivated in most parts of Iran, especially in Khatam Marvast, Azerbaijan, and Eghlid. The leaves are composed of four to seven leaflet pairs with one sticky leaflet due to the secretion of juice. The flowers are blue in color, and five to six brown seeds are found in the fruit. Its active phytocompounds include glycyrrhizin, glycyrrhetinic acid, glabridin, gycyrrhetinic acid, and glycyrrhizic acid. The key component glycyrrhizin has anticarcinogenic and anti-inflammatory properties and has demonstrated prevention from unwanted cell proliferation and inhibition of breast, liver, and skin tumor growth. Glycyrrhizin is a triterpene glycoside which is the key compound found in the root extract and acts as an antiproliferative agent against tumor cells, particularly breast cancer cell lines (MCF-7) and HEP-2 (Baltina 2003). In an experimental study, it has been reported that root extracts of *G. glabra* exert an anticancer effect on HT-29 cells and breast cancer cell lines through stimulation of apoptosis (Nazmi et al. 2018). The root extract of the plant has been shown to induce morphological changes in the mammary cell line 4T1 and reduction in cell viability. The root extract induces phosphorylation of BCL2 and stops the cycle of G2/M cells in the tumor cell line (Wang et al. 2018a, b). Licochalcone (LA) isolated from roots of *G. glabra* is a novel estrogenic flavonoid and has significant antitumor activity in different lines of human malignant cells. LA has shown to induce mild apoptosis and a noticeable effect on cell cycle progression, resulting in a reduced level of Cyclin B1 and cdc2 by arresting cells in the G2 or M process. The studies also depicted inhibition of Rb or S780 phosphorylation and decreased expression of transcription factor E2F, Cyclin D1, and CDK 4 and 6 (Lim 2015). Other active phytocompounds, namely glycyrrhetic acid, glabrol, and glabridin, isolated from the root extract *of G. glabra* also display the presence of anticancer activity and have been identified to exhibit significant cytotoxicity against C6 glial cells. These compound also shows inhibitory potential against topoisomerase *in silico* (Goel et al. 2020).

3.22 *Indigofera aspalathoides*

I. aspalathoides is a member of the family Papilionaceae. As a whole plant, it induces a cooling effect, is used as a demulcent agent and reduces oedematous tumors. In Swiss albino mice, the ethanolic extract of *I. aspalathoides* showed reduced growth of Dalton's ascitic lymphoma. The study also indicated its chemoprotective effect against N-nitrosodiethylamine-induced hepatocellular carcinogenesis in vivo in which the activity of tumor inducer N-nitrosodiethylamine was reduced with a further reduction in necrosis in the liver tumor of mice treated with ethanol root extract of *I. aspalathoides* (Claimer et al. 2012). In another study, the antioxidant potential of methanolic extract of *I. cassioides* was reported, and the extract induced enzymatic antioxidant defense system in mice implanted with EAC and DLA tumor-bearing mice (Kumar et al. 2011).

3.23 *Lawsonia inermis*

L. inermis, commonly referred to as Mehndi in India, is also a well-established medicinal plant and has been extensively studied for its anticancer activity. The study using solvent extracts of leaves and oil was conducted on a human liver cancer cell line (HepG2) that showed the induction of the apoptotic, DNA fragmentation, and chromatin condensation (Rahmat et al. 2006). Lawsone, 2-hydroxy-1, 4-naphthoquinone, is an active component of *L. inermis* (Henna). *L. alba* and other species of the family Lythraceae is claimed to possesses various medicinal properties including the anticancer effect (Mungle et al. 2019). The anticancer effect of *L. inermis* was demonstrated in mice and showed an increased level of antioxidant enzymes and reduced forestomach and liver papillomatosis. In animal studies, chemopreventive reactions were found to decrease the percentage of tumor-bearing animals and the multiplicity of tumors (Kapadia et al. 2013).

3.24 *Lepidium sativum*

L. sativum also referred to as watercress or garden cress is an annual herb with an approximate length of 50 mm and a width of 4 mm. It is also referred to as Jrjizbastany or Rashad in ancient Iranian medicine. It has light green leaves and small, softly fragrant, red or white flowers that appear together at the end of the branch. It is well documented that the plant and its seeds have a rich presence of active phytocompounds, like phenolic compounds, tocopherol, and terpenoids, conferring high antioxidant and anticancer activity. The methanolic extract of its seeds has shown cytotoxic effects on the bladder cell line (ECV-304). Experimental evidence on anticancer activity of the aqueous extracts of *L. sativum* leaves revealed inhibition of human tongue squamous carcinoma (CAL-27 cells), Leukemia (K562 cell line), and breast cancer cells (MCF-7) in a dose-dependent manner (Mahassni and Al-Reemi 2013; Aslani et al. 2014). In a recent study, the methanolic extract of *L. sativum* has demonstrated induced apoptosis and genotoxicity against colon and endometrium cancer cells at a concentration of 200 µg/ml (Selek et al. 2018).

3.25 *Medicago sativa*

M. sativa also called Alfalfa (father of all foods) is a perennial flowering plant from the Fabaceae family. The roots of the plant could reach a depth of 4–9 m in well-drained soil. It is commonly used as an herbal medicine for the treatment of hepatic disorders. Phytoestrogens in the plant have an estrogenic activity which is useful in the treatment of hormone-dependent cancers. Alfalfa contains considerable quantities of vitamins, digestive enzymes, coumarin, flavonoids, alkaloid, terpenes, and amino acids and is well known to have antioxidant, anti-inflammatory, and anticancer activities. The cytotoxicity and apoptosis in cell lines have been reported in doxorubicin-resistant counterparts suggesting inhibition of cancer cells mediated by DNA fragmentation (Dziok et al. 2020). Beneficial for breast cancer as well as for breast milk enhancement, alfalfa generates triconlin, alkaloids that play a hormonal role in the plant and are considered to have anticancer properties (Brodribb 2018).

3.26 *Morinda citrifolia*

M. citrifolia belongs to the family Rubiaceae is commonly familiar in India as large morinda, Indian mulberry. Its properties include immune stimulation, dietary supplementation, and the inclusion of bio-anticarcinogenic ingredients, which helps to resolve maximal side effects and improve the effectiveness of chemotherapeutic agents against cases of cancer. In rats with chemically induced tumors, the extracts have shown inhibition of tumorigenesis in the rat esophagus, peripheral T-cell non-Hodgkin's lymphoma, breast cancer, and gastric cancer (Taskin et al. 2009). Besides, the fruit juice of *M. citrifolia* has demonstrated antitumor activity and cytotoxic activity against Lewis Lung peritoneal Carcinomatosis (LLC) and various cancer cell lines such as neuroblastoma (LAN5) cell lines, breast cancer cell lines (MCF7), human laryngeal carcinoma cells (Hep2) and colorectal cancer cells (HCT-116, SW480, and LoVo) (Almeida et al. 2019).

3.27 *Ocimum sanctum*

The *O. sanctum* is a herbal plant with religious values in India. It is known as Tulsi and belongs to the Lamiaceae family. The plant also referred to as "the elixir of life" or "the queen of herbs" has traditional importance since almost all its parts are believed to be a healer of multiple health problems like cough, cold, diabetes, ulcers, inflammation, liver disorders, etc. (Jamshidi and Cohen 2017). The leaves possess several bioactive compounds such as eugenol, apigenin, apigenin-7-O-β-D--glucuronic acid, ocimarin, luteolin, ocimumosides A and B, ursolic acid, luteolin-5-O-β-D-glucopyranoside, and cerebrosides which have been recognized to possess anticancer, antimicrobial, and antioxidant activities. The topical application of extract has shown a significant reduction in glutathione content, increased activity of glutathione S-transferase, and reduced growth of papillomas in 7,12-Dimethylbenz(a)anthracene (DMBA)-induced skin papillomas in rats (Karthikeyan et al. 2008). Several in vivo studies have indicated anticancer potential of aqueous and ethanolic extracts of *O. sanctum* and shown to reduce tumor growth in Sarcoma-180 solid tumors implanted mice model (Harsha et al. 2020).

3.28 Olea europae

The olive plant, *O. europae*, contains approximately 35–40 species and belongs to the family Oleaceae. It is widely distributed in the Mediterranean, North Africa, South East Asia, North and South China, Scotland, and East Australia. The oleic acid, Oleuropein in leaves, is known to possess anticancer effects. The role of the phenolic compound oleuropein in olive oil has been greatly explored and is reportedly downregulates the her-2 gene expression in the breast cancer cell (Farooqi et al. 2017). The triterpenes compounds like maslinic acid and oleanolic acid have shown a suitable antitumor effect in the model of colon cancer in rats, and these compounds are important factors that inhibit tumor growth and angiogenesis (Zhu et al. 2015). In another study, restoration of apoptosis in colon cancer cells was shown by maslinic and oleanolic acids present in olive fruit extracts (Ziberna et al. 2017).

3.29 Podophyllum spp.

Epipodophyllotoxin (podophyllotoxin isomer) is a bioactive compound isolated from the roots of *P. peltatum* and *P. emodi*, family Berberidaceae. Its semisynthetic derivatives like etoposide and teniposide have anticancer effects and interfere with cell division, resulting in cell growth arrest in lymphoma, bronchial, skin, vertebral cancers, and testicular cancers. The plant rhizome contains a resin known as Indian Podophyllum resin that is derived from podophyllotoxin or podophyllin. Podophyllotoxin functions as a microtubule assembly inhibitor and is used to treat testicular cancer, prostate cancer, hepatoma, and neuroblastoma (Abad et al. 2012). A plethora of evidence has identified an antineoplastic potential of semisynthetic podophyllotoxins like etoposide, teniposide, and etopophos and suggested inhibition of DNA topoisomerase II as their mechanism of action (Ardalani et al. 2017).

3.30 *Taverniera spartea*

T. spartea grows on the Southern coast of Iran including Bandar Abbas, Minab, and Baluchistan. This woody plant from Leguminosae family grows to a height of between 50 and 110 cm and is covered with short shoots. The plant's flowers are purple and pink. The active compounds found in the plant include alkaloids and flavonoids eugenol, zingerone, ginger, cadence, and vanillin and are known to exert anticancer effect (Alsemari et al. 2014). The bioactive compound of *T. spartea* includes saponins and isoprenoids that are known to induce necrosis and apoptosis in cancer cells. Anticancer effects of the plant have been reported against breast cancer cell lines (MCF-7 and BT474) and human prostate cell lines (PC-3 and DU-145) (Khalighi-Sigaroodi et al. 2014).

3.31 *Taxus brevifolia*

T. brevifolia, also known as Pacific yew or Western yew, is an evergreen conifer that belongs to the family Taxaceae and is native to the Pacific Northwest of North America. The plant is well known for its chemopreventive activities imparted by the rich presence of diterpenoid derivatives termed taxanes (Sarli et al. 2020). The chemotherapeutic drug taxol (Paclitaxel) is an antineoplastic agent derived from the yew preparations from its needle and bark. The mode of action of taxol includes chromosome missegregation via inhibition of microtubules dissociation into tubulin and preventing mitosis and cell proliferation of cancer cells. Multiple experimental proofs have showcased the anticancer activity of taxol and other semisynthetic derivatives like Docetaxel and Cabazitaxel against lung cancer, liver cancer, pancreatic cancer, prostate cancer, breast cancer, and renal cancer. More recently, the anticancer activity of colloidal silver nanoparticles of *T. brevifolia* has been demonstrated against MCF-7 human breast cancer cell line (Sarli et al. 2020). However, there is accumulating evidence reporting acquired resistance to taxol mainly due to efflux of the drug, drug inactivation, mutation of the target protein that has become a major concern about its application as an anticancer drug (Ben-Hamo et al. 2019).

3.32 *Tinospora cordifolia*

T. cordifolia is also known as Guduci (one that safeguards the body), amrita, or nectar belongs to the Menispermaceae family. It is rich in glycoside, giloin, non-glycosides, tinosporin, tinosporic acid, gilenin, tinosporidin, sitosterol, tinosporide, gilosterol, berberine, and alkaloids. The studies have shown a decrease in metastasis and tumor mass reduction in B16F-10 melanoma cells and human colon adenocarcinoma (HCA-7) cell line treated with *T. cordifolia* extracts (Palmieri et al. 2019). It has a stimulatory effect on leukocytes, suggesting its use in cancer treatment as an adjuvant. The studies have also reported the stimulatory effect of *T. cordofolia* on macrophages and an increase in leukocytosis and neutrophil function improvement (Alsuhaibani and Khan 2017).

3.33 *Urtica dioica*

U. dioica is a grassy, herbaceous perennial with branched legs. The plant can be seen in the Iranian wilderness near Tehran, Karaj, on the Alborz and Shemiranat slopes and in the northern regions of Mazandaran and Gilan. Studies have shown its inhibitory effect on cell proliferation on prostate cancer cells (LNCaP and as hPCPs). A recent report has also shown anticancer effect of methanolic extract of *U. dioica* leaves against human non-small cell lung cancer cell lines (H1299 and A549 NSCLC). The study depicted the inhibitory potential of the extract with an IC50 of 52.3 and 47.5 μg/mL, respectively, against both cells (D'Abrosca et al. 2019).

3.34 *Withania somnifera*

W. somnifera, which belongs to the Solanaceae family, is known as Ashwagandha or Indian ginseng. The active compounds found in *W. somnifera* are Withanine, Withanolide A-Y (Steroidal lactones), tropanol, somniferinine, somniferiene, scopoletin, cysteine, chlorogenic acid, beta-sitosterol, anahygrine, and anaferine alkaloid. Withanolides have immunomodulatory activity, while Withaferin A and Withanolide D are known to inhibit cancer growth. In an experiment conducted on Benzo(a)pyrene-induced forestomach papilloma in mice, the extract has been shown to inhibit the papilloma genesis up to 60–92%. The studies have also demonstrated the anticancer potential of *W. somnifera* extract on skin papilloma genesis, colon cancer, lung cancer, brain tumor, and breast cancer (Dutta et al. 2019).

3.35 *Zingiber officinale*

Z. officinale (Ginger or ginger or Shengir) belongs to Zingiberaceae family. It is a medicinal and edible plant. It is grown in hot and humid areas. Ginger powder is an aromatic spice and used for savory dishes traditionally. The rhizome and leaves of ginger have been investigated to possess anticancer activity It has been explored that *Z. officinale* is effective on human colorectal cancer, breast cancer cells (MCF-7 line and MDA-MB-231), and have potential in the treatment and prevention of cancer (Mao et al. 2019).

4 Conclusion and Future Prospects

Cancer is the leading cause of mortalities around the world. Usually, chemotherapy with drugs, antibiotics, analog steroids, and alkylating agents used in the treatment of cancer is associated with adverse effects. The herbal plants are an excellent source of bioactive ingredients such as etoposide, taxols, vinblastine, and vincristine which show lower toxicity and better efficacy in numbers of oncological conditions such as testicular cancer, leukemia, breast cancer, brain tumor, etc. As the population increases enormously day by day, the demand for alternative therapy is becoming increasingly significant. Sophisticated therapeutic methods in the treatment and managing human cancer do not reach all human population in all parts of the world. Due to the high cost of modern medicines and treatment facilities, a significant number of people still rely on conventional alternative medicine systems based on plants to treat crippling diseases and cancers. Herbs and herbal supplements are plentiful, with effective anticancer activity therefore, these plants can be used and explore as a natural resource of potentially bioactive compounds to fight a battle against cancer diseases. To verify the effectiveness of many conventional herbal medicines, comprehensive safety, and quality assessment, comparative clinical trials using modern methods are required.

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Health Benefit, Traditional, and Modern Uses of Natural Honey

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Abbreviation

H_2O_2	Hydrogen peroxide
HMF	5-Hydroxymethylfurfural
IL-6	Interleukin
LDL	Induced low-density lipoprotein
MRSA	Methicillin-resistant *Staphylococcus aureus*
ROS	Reactive oxygen species
TNF-α	Tumor necrosis factor- α
VRE	Vancomycin-resistant Enterococci
VZV	Varicella Zoster virus
WHO	World Health Organization

1 Introduction

Honey is a natural, golden brown beehive product that is sweet in taste and viscous in consistency (Krishnakumar et al. 2020). It is produced from nectarous plants by the action of enzymes present in the gut of bees (Beegum et al. 2019). Owing to sweetness and therapeutic properties, it has been used for centuries as a sweetener, flavoring agent, and medicine (Beegum et al. 2019). Honey has been classified on the basis of its origin and method of harvesting and processing. Based on origin, honey can be blossom, honeydew, monofloral (unifloral), or multifloral (polyfloral). Honey collected mainly from plant nectar is called blossom honey, whereas honey produced after the collection of honeydew from plants is called honeydew or forest dew honey. Honey originated from single plant species (having total pollen content >45% from same plant species) is termed monofloral and is named according to the plant of origin such as acacia honey, manuka honey, etc. (Jibril et al. 2019). In contrast, honey produced from nectar of multiple plant species is known as multifloral honey and is named based on bee species, e.g., *Trigona thoracica* honey (Jibril et al. 2019). Monofloral honey is considered a better quality product and has high market value (Soares et al. 2015). Honey is also classified as natural or fabricated (synthetic) depending upon its collection by bees, i.e., from plant nectar or saturated solution of sugar and water (Zafar et al. 2020). In addition, honey can be raw or pasteurized. Raw honey is natural honey that is packed directly after harvest and contains impurities such as beewax, pollens, and microorganisms (yeast), whereas pasteurized honey is processed to remove impurities and improve shelf-life (Subramanian et al. 2007). Honey is primarily a carbohydrate-based liquid product containing proteins, acids, vitamins, minerals, enzymes, and secondary metabolites (flavonoids, phenols) in minor quantities which provide multiple health benefits (Waykar and Alqadhi 2016; Cenet et al. 2017). For instance, due to the presence of flavonoids, honey displays a potential to reduce the risk of heart diseases, asthma, skin ulcer, and microbial infections (Alvarez-Suarez et al. 2010a; Nik Man et al.

2015). The medicinal properties of honey are determined by its chemical composition, which varies with change in biotic and abiotic factors, such as floral species from which nectar has been collected, harvesting season, production method as well as environmental factors such as climate, geographical location, etc. (Ayaad et al. 2012; Cenet et al. 2017; Chew et al. 2018). Thus, the use and benefits of honey are function of variation in its quality and composition (Cenet et al. 2017). For example, the amount of 5-hydroxymethylfurfural (HMF) in honey is correlated with climatic condition of the plant source, aging of honey, and overheating during processing (Subramanian et al. 2007; Yap et al. 2019), and its concentration determines the degree of deterioration of honey (Umarani et al. 2015). The high value of HMF corresponds to greater loss of freshness and darkening of honey (Subramanian et al. 2007). The maximum limit of 40 mg/kg (80 mg/kg for tropical honey) for HMF has been set by Codex Alimentarium Standard Commission (FAO 1981).

2 Physicochemical Properties of Honey

Due to differences in botanical and geographical origin, honey has variable chemical composition and physical properties (da Silva et al. 2016). The basic chemical constituents and major physical properties of honey are shown in Fig. 1. Chemically, honey contains nearly 200 compounds (da Silva et al. 2016) and is mainly composed of water, sugars, proteins, organic acids, polyphenols, vitamins, and minerals (Nisbet et al. 2018). Carbohydrate, being the major constituent, comprises approximately 95% of the total dry weight and 80% of the total weight of honey (Krishnakumar et al. 2020). Sugars are present in both monosaccharides and oligosaccharides (disaccharides and polysaccharides) form; however, the percentage of monosaccharides is much higher than oligosaccharides (Santos-Buelga and Gonzalez-Paramas 2017). Fructose and glucose are chief monosaccharides representing approximately 38% and 31% of honey, respectively (Alvarez-Suarez et al. 2013). Honey also contains sucrose (disaccharide) comprising only 2% of the total composition (Chen et al. 2019). Monosaccharides are easily digested and transported through bloodstream; thus, honey is considered as a good source of energy. Consumption of 20 g of honey can fulfill 3% of daily energy requirement of humans (Bogdanov et al. 2008). Oligosaccharides like sucrose, maltose, trehalose, panose, raffinose, and others are also found in honey, and their concentrations vary depending on the type of honey. For instance, the concentration of oligosaccharide, raffinose, and melezitose is higher in honeydew when compared to blossom honey (Bogdanov et al. 2008).

The second important component of honey is water that constitutes less than 18% of the total weight (Krishnakumar et al. 2020). Other constituents such as proteins, minerals, vitamins, organic acids, etc. represent only a small fraction of honey and, nevertheless, are an important part in terms of health benefits. Proteins on average constitute 0.5% of the total weight of honey (Alvarez-Suarez et al. 2010b; Kek et al. 2017); however, its value varies according to floral source and species of

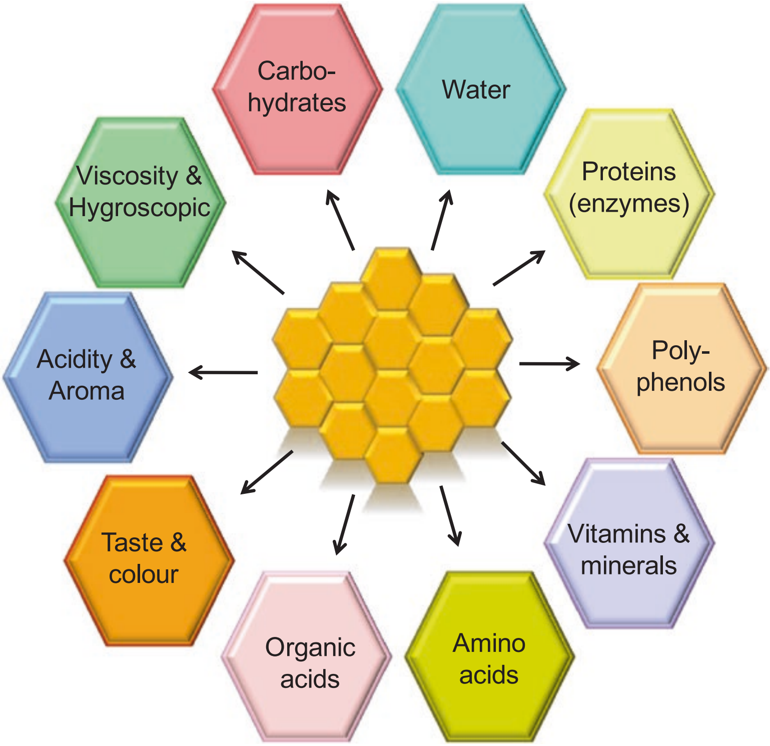

Fig. 1 Physicochemical characteristics of honey

honeybees (Nisbet et al. 2018). A small part of the protein represents enzymes like invertase (α-glucosidase), diastase (amylase), glucose oxidase, acid phosphatase, proteases, esterases, and catalase (Bogdanov et al. 2008; Santos-Buelga and Gonzalez-Paramas 2017). The primary function of enzyme invertase is the conversion of sucrose into glucose and fructose; amylase decomposes starch or glycogen into a simpler form of sugar; enzyme glucose oxidase transforms glucose into hydrogen peroxide (H_2O_2) and gluconic acid which facilitates calcium absorption; and catalase convert H_2O_2 into water and oxygen (Eteraf-Oskouei and Najafi 2013). Similar to protein, the amino acid content in honey depends on nectar plant source and honeybee species (Nisbet et al. 2018). Amino acid content varies from 50 to 300 mg/kg, with proline being the most abundant form (Nisbet et al. 2018). Besides these, honey contains a minute amount of vitamins (thiamin, riboflavin, niacin, ascorbic acid, and pantothenic acid) and minerals primarily potassium, magnesium, sodium, phosphorus, selenium, sulfur, and calcium representing the maximum percentage of total mineral content with a trace amount of manganese, iron, zinc, copper, and chromium (Bogdanov et al. 2008). Potassium is one of the major and most abundant element present in honey, representing one-third composition of total mineral content (Eteraf-Oskouei and Najafi 2013; da Silva et al. 2016). Polyphenol is a group of bioactive compounds like flavonoids (quercetin, kaempferol, apigenin) and phenolic acid that imparts antioxidant, antiviral, anti-inflammatory, antiulcer, and antineoplastic property to honey (Jibril et al. 2019). In various honey samples, >200 polyphenols have been identified (Jibril et al. 2019). Polyphenols' value ranges from 56 to 500 mg/kg depending on the type of honey. Organic acid in honey comprises 0.57% of its composition (Eteraf-Oskouei and Najafi 2013). Gluconic acid is the most dominant form of organic acid present in honey (Eteraf-Oskouei and Najafi 2013). Other acids found in honey include citric, butyric, oxalic, acetic, lactic, formic, aspartic, malonic, malic, succinic acids, etc. (Ball 2007). About 0.2% of each, dietary fibers, and ash are also present in honey.

The chemical composition of honey determines its physical properties such as taste, aroma, viscosity, hygroscopicity, acidity, and color. Honey is an acidic liquid with pH ranging from 3.2 to 4.5 (Zafar et al. 2020). The acidity of honey is due to the presence of organic acid predominantly gluconic acid (da Silva et al. 2016). Organic acids along with amino acids, polyphenols, and volatile compounds establish the aroma of honey (Bogdanov et al. 2008; Jibril et al. 2019). More than 500 different types of volatile compounds have been identified in different honey (Bogdanov et al. 2008), including a mixture of C1-C5 aldehydes and alcohols (Ball 2007). Honey is a supersaturated sugar solution hence has high refractive index (1.49) and viscosity value (Ball 2007). Sugars present in honey are the main taste-building element (Bogdanov et al. 2008). Honey with high fructose content is sweeter when compared to honey with high glucose concentration (Bogdanov et al. 2008). In addition, the taste of honey is also determined by polyphenol content (Jibril et al. 2019). Color is one of the important characteristics of honey that correlates with its taste. Darker honey is known to have more intense flavor (Ball 2007). The color of honey depends on various chemical and physical factors, such as polyphenol content, minerals, season, floral source, processing techniques, and time interval between nectar collection and honey harvest (Ball 2007; da Silva et al. 2016; Jibril et al. 2019).

3 Biological Properties and Health Benefits of Honey

Honey is a natural product known for millenniums for its nutritional and therapeutic attributes. Honey has a very long history for its medicinal uses as antimicrobial, anti-inflammatory, antidiabetic, antimutagenic, antioxidant, and wound- and sunburn-healing agent (Liu et al. 2013) (Fig. 2). Evidence in scientific literature has demonstrated the potential of honey in lowering the risk of gastric and cardiovascular diseases (Alvarez-Suarez et al. 2010b), reducing hypersensitivity, ameliorating hormones related to fertility (Mosavat et al. 2014) as well as in treating ulcers, bedsores, and skin infections (Nooh and Nour-Eldien 2016).

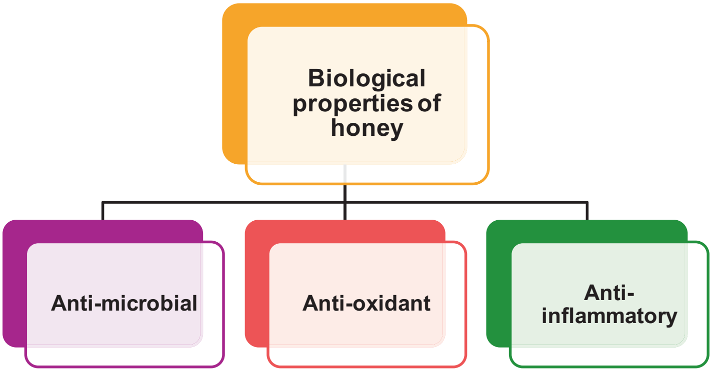

Fig. 2 Biological properties of honey

3.1 Antimicrobial Activity

Honey has been well recognized as antimicrobial agent that controls growth of numerous microorganisms (Rani et al. 2017). The antimicrobial activity of honey against a number of gram-positive and -negative bacteria, fungi, protozoa, and viruses such as *Helicobacter pyroli*, *Salmonella typhi*, *Staphylococcus aureus*, *Escherichia coli, Vibrio cholera*, *Aspergillus*, *Pencillium*, *Candida albicans*, *Giardia lambila*, rubella virus, herpes simplex virus, etc., has been reported (Eteraf-Oskouei and Najafi 2013; Mohammed et al. 2015; Rani et al. 2017; Khan et al. 2018). Shahzad and Cohrs (2012) documented antiviral activity of manuka and clover honey against Varicella Zoster Virus (VZV) under *in vitro* condition with EC50 = 4.5% (w/v). Similarly, antifungal activity of jujube honey investigated against *Candida albicans* and was found to inhibit the formation of fungal biofilm as well as disrupted the previously developed biofilm (Ansari et al. 2013). Honey acts as both bactericidal and bacteriostatic agent depending on concentration. The pasture and manuka honey demonstrated bacteriostatic property at 4–8% and 5–11% concentration, respectively, while at higher concentration, i.e., 5–10% and 8–15%, respectively, bactericidal effect was reported (Bansal et al. 2005). The antibacterial activity of honey has been attributed to its chemical composition and physical properties and possibly involves four mechanisms. (1) High osmolarity of honey due to high sugar content facilitates extraction of moisture from bacterial cell, thus causing dehydration; (2) acidic nature (low pH 3.2–4.5) of honey also responsible for inhibition of bacterial growth; (3) activity of enzyme glucose oxidase produces hydrogen peroxide that inhibits pathogen growth and is probably considered as the most important antibacterial mechanism; and (4) presence of phytochemical like methylglyoxal, defensin-1 (Kwakman et al. 2010; Eteraf-Oskouei and Najafi 2013; Bucekova and Majtan 2016; Rani et al. 2017). Long-term use of honey as antibacterial agents does not induce resistance in microorganisms (Emsen 2007). Even honey has been reported to be effective against microbes that are resistant to chemical antibiotics, such as Methicillin-Resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant Enterococci (VRE), etc. (Eteraf-Oskouei and Najafi 2013; Rani et al. 2017).

3.2 Antioxidant Property

Reactive oxygen and nitrogen species formed under stress oxidizes important biomolecules, such as proteins, lipids, and nucleic acid, leading to oxidative damage. The occurrence of oxidative stress has been linked to several physiological problems, such as cancer, immunological disorders, heart-related diseases, diabetes, gastrointestinal diseases, liver and renal injuries, respiratory disorders, and neurological degeneration (Chua et al. 2013; Talebi et al. 2020). Bioactive compounds like flavonoids, phenols, and many more are known to possess antioxidant properties by virtue of which they scavenge free radicals and prevent oxidative stress (Hemmati et al. 2015). Honey is a natural source of several enzymatic and non-enzymatic antioxidants, namely, catalase, peroxidase, superoxide dismutase, glucose oxidase, ascorbic acid, phenolic compounds, tocopherols, and flavonoids (Waykar and Alqadhi 2016). Owing to antioxidant capacity, honey has several pharmacological implications and aids in preventing reactive oxygen species (ROS)-induced low-density lipoprotein (LDL) oxidation and hence prevents several chronic diseases and disorders such as cancer, cataract, Alzheimer's and Parkinson's diseases, and cardiovascular disorders (Bertoncelj et al. 2007; Waykar and Alqadhi 2016; Ibrahimi and Hajdari 2020). Antioxidants present in honey act as natural antidepressants during high emotional, physical, and intellectual stress (Waykar and Alqadhi 2016). In addition, honey also has the ability to lower the complications that arise due to diabetes such as atherosclerosis (Hemmati et al. 2015) by improving glucose and lipid metabolism that increases secretion of adiponectin content which in turn is considered to modulate oxidative stress leading to antidiabetic stress. In a study, honey has been found to reduce oxidative stress-mediated lipid peroxidation in diabetic model rats (Nakanishi et al. 2005; Katsuki et al. 2006). The excellent antioxidant property of polyphenols, especially phenolic compounds, is due to high mobility of hydrogen present in the skeleton of their chemical structure (Chua et al. 2013). Phenolic compounds have hydroxyl groups in their molecular structure which participate in the scavenging of free radicals (Chew et al. 2018). The number and position of these hydroxyl groups determine their scavenging potential (Chew et al. 2018). The free radical quenching potential of phenols has been reported to be affected by the presence of carboxyl group next to hydroxyl group that causes steric hindrance by reducing ease of hydrogen donation. For instance, the scavenging activity of caffeic acid is higher than its counterparts such as ferulic acid and coumaric acid (Chen and Ho 1997).

3.3 Anti-inflammatory Action

Inflammation is a defensive response of the body to negative or harmful stimuli such as pathogens, irritants, tissue damage, etc. (Hadagali and Chua 2014). If inflammation persists for longer times, as a consequence, it results in hay fever, arthritis, rheumatoid, and many more (Hadagali and Chua 2014). Honey possesses the ability to reduce inflammation and modulate immune cells of the skin immune system and is thus often used as an anti-inflammatory (Hadagali and Chua 2014) and immunomodulatory agent (Majtan 2014). Treatment of wounds with honey not only reduces inflammation and exudation but also diminishes scars and provides a soothing effect (Khan et al. 2018). Immunomodulatory activity of honey increases the production of cytokinin such as interleukin (IL-6) and tumor necrosis factor-α (TNF-α) by immune cells that escalate wound healing at early stage (Majtan 2014; McLoone et al. 2016) and stimulate tissue regrowth (Hadagali and Chua 2014; Khan et al. 2018). Several clinical evidences have confirmed the anti-inflammatory properties of honey. For instance, dressing of burns of biopsy samples with honey reduced the number of anti-inflammatory cells when compared to dressing done using silver sulfadiazine (Subrahmanyam 1998). Honey has been found to reduce activities of enzymes cyclooxygenase-1 and 2 which are involved in inflammation (Khan et al. 2018). Similarly, consumption of honey has been linked with reduction in concentration of prostaglandins (prostaglandin E2 and F2α) that cause itchiness, heat, and pain due to inflammation (Kassim et al. 2010) and thromboxane in plasma of normal persons (Al-Waili and Boni 2003).

4 Traditional Uses of Honey

Honey has been used by humans since ancient times for dietary and therapeutic purposes. Several historical evidence clearly advocate the art of honey collection, and their uses were well recognized by our ancestors. Archeological records proclaim that wild honey harvesting was carried out by people around 10,000 years back (Zafar et al. 2020). Some references indicate that beekeeping was practiced by Egyptians in 2400 BC (Zafar et al. 2020). A scene of two individuals collecting honey from beehives comes across in an 8000-year-old rock cave in Bicorp near Valencia in eastern Spain (Crane 1977). Similarly, a post-mesolithic rock painting in Rajat Pratap in central India representing collection of honey from *Apis dorsata* (Crane 1977) was uncovered. The first written reference on honey was a Sumerian tablet dating back to 2100–2000 BC narrating the uses of honey as an ointment and a drug (Crane 1975). During the ancient Vedic period, honey was considered one of the most amazing gifts of nature to humans, and in Ayurveda honey is mentioned as "Madhu" or "Kshaudra" (Arawwawala and Hewageegana 2018). Traditionally, honey was used for its taste and health benefits as well as to treat wounds and intestinal diseases by ancient Egyptians, Chinese, Romans, Assyrians, Indians, and Greeks (Ayaad et al. 2012; Waykar and Alqadhi 2016). As per Prophet Muhammad, drinking honey was beneficial for health. In several ancient sacred books, honey has been referred to several times. In Egyptian text, the use of honey has been mentioned in 900 remedies (Eteraf-Oskouei and Najafi 2013). Similarly, a Sanskrit text Sushruta Samhita on Ayurveda medicine and surgery describes eight types of honey and its health benefits (Arawwawala and Hewageegana 2018). Honey is a Yogavahi substance, which means it carries other compounds effectively without changing its attributes; therefore, it was used in combination with other substances to enhance their properties as well as function (Arawwawala and Hewageegana 2018).

4.1 Therapeutic and Dietary Uses of Honey

According to Smith papyrus (an Egyptian text), dated from 2600 to 2200 BC, honey was used as wound ointment along with grease and lint. Use of honey as wound healer was preferred due to its antimicrobial activities. According to the Indian Ayurvedic literature, honey was used to aid in digestion and treating cough, urinary infections, diarrhea, wounds, nausea, and vomiting (Arawwawala and Hewageegana 2018). Honey was used to keep gums and teeth healthy (Eteraf-Oskouei and Najafi 2013). Honey shows hypnotic action and is used to treat insomnia during Vedic period (Eteraf-Oskouei and Najafi 2013). In addition to this, honey was applied on skin to treat skin disorders (Arawwawala and Hewageegana 2018). Honey was recommended for cardiac pain, palpitation, for curing all imbalances of lungs, and anemia (Eteraf-Oskouei and Najafi 2013). As per Ayurvedic text, young honey was used to gain weight, whereas old honey was effective in reducing weight (Arawwawala and Hewageegana 2018). In ancient Greek, honey was mixed with unfermented grape juice called Oenomel, which was sometimes used to treat gout and certain nervous disorders (Eteraf-Oskouei and Najafi 2013). In addition, honey was used to reduce pain in combination with vinegar as oxymel; to alleviate thirst, honey was used with water as hydromel; to treat acute fever, it is used along with water and certain medicinal compounds; and to cure problems like cough and sore throat, wounds, baldness, constipation, eye disease, prevention and treatment of scars (Eteraf-Oskouei and Najafi 2013). In the Islamic medicinal system, honey was considered a healthy drink, and its nutritional properties are described in Quran (Beegum et al. 2019).

4.2 Religious Use of Honey

In the Hindu religion, honey has been considered as one of the five elixirs of immortality (Panchamrita) and is offered by pouring over deities during a ritual known as "Madhu Abhisheka" (Beegum et al. 2019). In India and Bangladesh, Buddhists celebrate "Madhu Purnima" festival by offering honey to monks. Ancient Egyptians also used honey to offer deities as a sacrifice as well as for embalming the dead (Eteraf-Oskouei and Najafi 2013).

4.3 Honey as a Cosmetic and Eye Care Product

According to the archeological records of the predynastic age of Upper Egypt nomadic tribes of Tasian culture (around 4500 BC), honey was used along with malachite, fat, copper, and spar for making eye cosmetic. Sumerian (3000 BC) and Egyptian (1500 BC) archeological records state the use of honey in skin care (Beegum et al. 2019). According to Indian ayurveda, honey was considered to cure eye ailments and used by the people to improve their eyesight and prevent cataract (Eteraf-Oskouei and Najafi 2013; Arawwawala and Hewageegana 2018).

5 Modern Uses of Honey

Due to its rich nutritional and therapeutic properties, honey was always a significant part of traditional medicine and food. In the modern era also, the role of honey in food, skincare products, and medicines for treating health ailments like cancer, microbial infection, wounds, burns, etc. has been well recognized through laboratory and clinical studies (Cenet et al. 2017; Beegum et al. 2019). The list of commodities containing honey as an ingredient and their commercial marketed products is presented in Table 1.

5.1 Honey for Healing Wounds

Honey possesses antimicrobial, anti-inflammatory, and immune-modulatory activities and therefore is used for treating all types of wounds, burns, amputations, ulcers, and surgical incisions (Eteraf-Oskouei and Najafi 2013; Krishnakumar et al. 2020). The antimicrobial activity and high viscosity provide a barrier to prevent infection and moist environment around the wound, respectively, that facilitates healing (Waykar and Alqadhi 2016). Anti-inflammatory and immunomodulatory properties of honey alleviate inflammation, boost immune system responses which in turn promote tissue regeneration and accelerate wound healing activity (Eteraf-Oskouei and Najafi 2013; Waykar and Alqadhi 2016). The high osmolarity of honey due to high solute content causes osmotic outflow which facilitates the removal of dirt and debris from the wounds, and the presence of amino acids, vitamins, and minerals provide nutrition directly to regenerating tissues (Eteraf-Oskouei and Najafi 2013; Krishnakumar et al. 2020). Due to these properties, Russians used honey to treat wounds during World War I (Eteraf-Oskouei and Najafi 2013). Germans used honey along with cod liver oil to cure burns, boils, ulcers, and even fistulas (Bansal et al. 2005). Application of sterilized manuka honey dressing pad to non-responsive knee amputation severely infected with *Pseudomonas* and *Staphylococcus aureus* was found to heal completely within 10 weeks (Dunford

Table 1 Modern use of honey and commercial products available

Uses	Commodities	Commercial products
Medicines	Cough syrups	Dabur honitus cough syrup; Broxol honey cough syrup; Honicadd honey based cough syrup
	Ointment for wounds and burns	Derma science medihoney gel wound and burn dressing; Activon tube-medical grade manuka honey; L-Mesitran ointment
	Eye drops	Jiwadaya netraprabha plus ayurvedic herbal honey base eye drops
Oral health	Mouthwash	Melora manuka honey and oil mouthwash
Nutraceuticals	Health drinks and supplements	Rasna Native Haat HoneyVita (chocolate drink); Nourish vitals—Apple cidar vinegar with ginger, garlic, lemon, and honey
	Nutrition products	Nutriorg vedic chyawanprash
Food	Tea	Prince of peace—Instant ginger, honey crystals (instant tea); Tetley green tea–Lemon and honey
	Cookies	Hey grain honey oatmeal cookies; Polka honey almond cookies
	Yogurt	Basta goat milk yogurt–honey with banana; Waggy zone frozen yogurt–honey flavor; Again drinkable yogurt–Alphonso mango, honey
	Candies	PrakrutAgro pure honey amla candies; The honey shop–honey mango jelly; Worth 2 Deal–Honey amla
	Cereals	Nourish organics honey crunch muesli; Kellogg's cornflakes real almond and honey
	Baby food	Nestle cerelac with wheat, honey, dates
	Dry fruits	Nutri forest honey rose petals coated almonds; Zohran–Honey with figs; Food library the magic of nature-mixed nuts in honey
Cosmetics	Foot cream	dr.organic Manuka honey foot cream
	Lip balm	Forest essentials Luscious Kokum and Honey lip balm; Khadi Natural Kiwi Fruit Lip balm with beeswax and honey
	Scrubs	Oriflame Sweden Milk and Honey Gold sugar scrub
	Moisturize and day cream	Good vibes honey gel; VLCC almond honey body lotion
	Antiaging cream	Good vibes plus jojoba + Honey + moisturizing + nourishing night cream; Forest essentials India–Body mist honey and vanilla
	Eye creams	Wild Ferns Manuka honey eye cream; Antipodes Manuka honey skin brightening eye cream
	Body wash	Biotique bio-honey honey rejuvenating body wash; The body shop shower gel–Almond milk and honey
	Face wash and cleansers	Forest essentials women's face wash and cleansers; Khadi natural herbal sandalwood and honey face wash
	Soaps	The coco factory–Natural handmade coconut honey soap; TNW–The natural wash handmade oats and honey moisturizing soap
	Shampoo	Indus valley color protection shampoo; Forest essentials hair cleanser amla, honey, and mulethi

et al. 2000). Similarly, topical application of honey on cesarean and hysterectomies postoperative wound infection increased annihilation of bacterial infection and healing process and minimized consumption of antibiotics, formation, and recovery time (Al-Waili 2005).

5.2 *Honey as Medicine*

Honey due to its antimicrobial, anti-inflammatory, and anti-oxidant properties shows a number of therapeutic effects. Antimicrobial property helps to prevent microbial infections. Honey has been reported effective in treating gastrointestinal infections like duodenitis and gastric ulceration and skin infections like athletes' foot, dandruff, seborrheic dermatitis, and many more (Al-Waili 2001; Al-Waili 2005; Eteraf-Oskouei and Najafi 2013). Application of honey in the management of labial and genital herpes infection was found comparable to that of acyclovir creams with reduced signs and symptoms of recurring lesions (Al-Waili 2004). In an in vitro study, 20% solution of honey was found to inhibit the growth of bacteria *H. pyroli*, a pathogen responsible for causing gastritis (Ali et al. 1991). Honey has a considerably lower glycemic index than glucose and sucrose and produce lower serum level sugar (glucose and fructosamine) when compared to sucrose and dextrose (Erejuwa et al. 2012; Eteraf-Oskouei and Najafi 2013) and hence can act as an antidiabetic agent and used in place of artificial sugars in the diet of diabetic patients. Administration of honey has been reported to improve blood lipid profile (Al-Waili and Haq 2004; Erejuwa 2014), homocysteine, and C-reactive protein level in healthy as well as in hyperlipidemic individuals (Al-Waili 2004). In addition, honey has also been reported to promote serum level insulin production in diabetic rats (Al-Waili and Haq 2004; Erejuwa 2014). Honey also shows anticancer property by virtue of its ability to prevent cell proliferation, promote apoptosis, induce mitochondrial membrane depolarization, and modify cell cycle progression in the cancer cell (Pichichero et al. 2010; Aliyu et al. 2013; Yaacob et al. 2013; Erejuwa et al. 2014). Honey can cure respiratory ailments like sore throat, cough, asthma, and acute bronchitis by reducing microbial infection and inflammation (Nanda et al. 2017; Samarghandian et al. 2017). The World Health Organization (WHO) has also recognized honey as a potential demulcent treatment for cough and other upper respiratory tract infections (Raeessi et al. 2013). Honey possesses the potential to reduce risk of cardiovascular diseases owing to its flavonoid content. Flavonoids enhance the coronary vasodilatation, reduce the ability of blood platelets to clot, and prevent oxidation of LDL and thus alleviate the risk of cardiovascular diseases (Afroz et al. 2016).

5.3 Honey and Oral Health Care

In oral health care, honey is used to reduce plaque, dental caries, gingivitis, oral malodor, radiation-induced oral mucositis and xerostomia, and periodontal disease (Atwa et al. 2014; Beegum et al. 2019; Ramsay et al. 2019). The antimicrobial property of honey reduces microbial growth as well as abridges biofilm formation. Dental plaque caused by bacteria with the ability to form biofilm and produce acids demineralizes and deteriorates tooth structure and causes dental caries (Ramsay et al. 2019). Application of manuka honey has been reported to prevent plaque formation by inhibiting biofilm growth and reducing production of acid (Nayak et al. 2010). Oral problem gingivitis occurs due to inflammation of gingival tissues. The manuka honey-based mouthwash has been found to be nearly as effective as chlorhexidine in reducing gingival scores (Singhal et al. 2018). Atwa et al. (2014) investigated the effect of chewing honey on plaque formation and bacterial count. The result showed reduction in bacterial count, highlighting effective role of honey in the prevention of dental caries and gingivitis.

5.4 Honey and Ophthalmology

The role of honey in treating ophthalmological conditions is known since ancient times. Through clinical studies, it has been confirmed that topical application of honey is effective in curing non-responsive eye ailments like blepharitis, conjunctivitis, and keratitis (Emarah 1982). In the study, honey was applied as an ointment to the lower eyelid of 102 patients. It improved condition of 85% of the total patients while in the remaining 15% no deterioration or disease progression was documented (Emarah 1982). Honey has also been found to treat burns caused by chemical and thermal agents as well as corneal injuries and conjunctivitis due to antimicrobial and anti-inflammatory effects (Ajibola et al. 2012).

5.5 Honey in Food Industry as Preservative and Prebiotic

Several antioxidants and antimicrobial compounds present in honey prevent oxidation of food during storage and inhibit the growth of various bacteria and thus avoid food spoilage and hence is used as food preservative such as meat, juices, etc. (Bogdanov 2012). In contrast, honey also shows prebiotic effect and maintains the balance of intestinal microflora by supporting the growth of beneficial bacteria, such as bifidobacterium and suppressing other deleterious bacteria (Sanz et al. 2005). The prebiotic capacity of honey is associated with its oligosaccharide content. In a study, honey has been reported to support the growth of intestinal bacteria *Lactobacillus acidophilus* and *L. plantarum* in rats (Shamala et al. 2000). Unifloral honey originated from Clover, Sage, Sour-wood, and alfalfa have been reported to possess strong prebiotic property (Kajiwara et al. 2002). Honey due to its flavor, texture, and moisture content is used in food industry in products such as cake, cereals, cookies, and many more (Bogdanov 2012).

5.6 Honey in Nutraceuticals

Honey is a rich source of carbohydrates along with proteins, minerals, antioxidants, and vitamins (Ajibola et al. 2012). The carbohydrate content of honey provides more energy than artificial sugars due to high proportion of fructose than glucose and other sugars (Ajibola et al. 2012). Therefore, athletes consume honey before, during, and after resistance and stamina-building exercises as an energy source (Bansal et al. 2005). A small fraction of honey constitutes antioxidants that participate in free radicals scavenging. Intake of honey improves antioxidant status of a body and fortifies against oxidative stress (Ajibola et al. 2012). Honey contains enzymes and micronutrients that facilitate easy digestion and absorption of important dietary nutrients required for proper metabolism and functioning of a body (Ajibola et al. 2012). Due to several nutritional benefits, honey is preferred over artificial sugars as a sweetener (Ajibola et al. 2012). In addition, consumption of honey provides calcium, which is easily absorbed by the body and prevents bone-related disorders like osteoporosis or low bone mass in elderly people (Ajibola et al. 2012). Honey not only provides benefits to adult human beings but is considered a boon for children. Feeding honey to infants has been reported to improve their memory and growth, blood profile, nourishes skin, results in steady weight gain, boosts the digestive system, alleviates anxiety, reduces susceptibility to diseases, and enhances their overall performance in later life (Ajibola et al. 2012).

5.7 Honey and Cosmetics

Honey is used in various cosmetic and skincare products, such as face wash, moisturizer, shampoo, anti-wrinkle cream, soaps, anti-acne products, etc. (Pavlackova et al. 2020). Honey is hygroscopic in nature and shows keratolytic property and thus nourishes skin, keeps it moisturized, and prevents wrinkles (Bogdanov 2012; Pavlackova et al. 2020). Honey is used in shampoos, soaps, and other shower products due to its cleansing property (Burlando and Cornara 2013). Exfoliating property of honey is attributed by fruit acids and thus used for removing dead skin (Kurek-Gorecka et al. 2020). The flavonoid content of honey prevents skin irritation and hence it is used in sunscreens (Kurek-Gorecka et al. 2020). The antimicrobial property of honey reduces microbial infection and cures acne (Bogdanov 2012). Honey also strengthens the upper protective skin layer by maintaining mild acidic pH (Bogdanov 2012; Burlando and Cornara 2013). Honey is used in place of traditional emulsifiers in shampoos and body lotions (Pavlackova et al. 2020). Hydroxypropyltrimonium honey is used in shampoos and conditioners (Kurek-Gorecka et al. 2020). It nourishes hair and scalp and penetrates deep into the hair shafts and reestablishes its flexibility and elasticity (Burlando and Cornara 2013).

6 Conclusion

Honey is a wonderful organic compound that has been used for centuries for nutrition and curative purposes. Recent scientific studies have rediscovered the medicinal role of honey in curing multiple diseases and disorders, especially for treating wounds. Despite multiple beneficial attributes, the potential of honey is poorly utilized. The underutilized potential of honey is due to the lack of exact information regarding the biological role of every constituent of honey. Research has also demonstrated that different types of honey show variation in their physicochemical characteristics that affect their biological properties. Therefore, to maximize the unabridged potential of honey, it is important to ascertain the role of every component and standardize them through more scientific studies.

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Spices Obtained from Forest and Other Resources

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1 Introduction

Spices can be defined as dried roots, aromatic seeds harvested primarily to add flavours in various cuisine. In addition, these are used in medicines, curing health issues, cosmetics and insect repellents. During the last few decades, there has been a phenomenal increase in area, production, productivity and demand for spices all across the globe. Most of the spices which are well adapted to shade are found in the forest of Ethiopia (Furo et al. 2019). Some of the major spice-growing countries are India, Bangladesh, Turkey, China, Pakistan, Iran, Nepal, Colombia, Ethiopia and Sri Lanka (Kunnumakkara et al. 2014). United Food and Agriculture Organization reported that the total world production of various spices in the year 2011 was 2,063,472 metric tons. India is the leading spice-growing country in the world is known to be 'The land of spices'. Moreover, India is the world's largest consumer and exporter of spices. According to an analysis made by the Indian trade portal, in the year 2018–2019, total 1.10 million tons of spices and different spice products of Rs 19,505.81 crore (US $ 2.80 billion) has been exported to other countries. Further, it is an interesting fact to know that during the quarter ending in September 2019, essential spices like ginger showed maximum growth of 31% with 11,910 tons and pepper 21% with 8200 tons (Indian trade portal). Trading of spices in the Indian sub-continent started by the earliest 2000 BCE with prominent spices like cinnamon and black pepper. In the middle ages, spices like black pepper, cinnamon, cumin, nutmeg, ginger and cloves were among the most expensive spices. The importance of spices has been realized since the ancient period from the history that during late middle age, nearly 1000 tons of pepper and other major spices were imported into the Western part of Europe.

Esteemed organisations like World Spice Organisation (WSO) in Kochi (Kerala) deals with safety and sustainability of the spice industry at the field level on global standards. WSO is a non-profit organisation involving various stakeholders, industries and consumers. One of the major objectives of WSO is the availability of safe herbs and spices ensuring its excellent productivity and distribution across its entire supply chain. Another major institute dealing with research on various spices is ICAR–Indian Institute of Spice Research (ICAR-IISR) situated in Kozhikode, Kerala. A National Research Centre for Spices was established in the year 1986 with its headquarter in Kozhikode, Kerala, by merging with regional Station of Central Plantation Crops Research Institute (CPCRI) at Kozhikode and Cardamom Research Centre at Appangala, Karnataka. Spices like cloves, black pepper, turmeric, cardamom and ginger consist of different and essential parts such as seeds, fruits, berries, leaves, or kernels. There are almost 72 spices grown in different parts of the world, while in India, Kerala is the epicentre of spice production, and India is the prime producer of cardamom to the entire world. Anthropogenic activities like afforestation lead to a reduction in species of different spices; therefore, ICAR-Indian Institute of Spices Research (IISR), Kozhikode promotes collection and conservation of the biological diversity of spices (Saji et al. 2019).

Spices also play a very significant role in industrial use as natural food preservatives. Cinnamon is the most effective alternative to replace industrial preservatives, which are detrimental to human health (De La et al. 2015). On the pharmaceutical aspect, they have been used to flavour medicines. Clove is more often process to produce clove oil, which again is very useful for its medicinal purpose (Chaieb et al. 2007). One cannot deny from the fact that spices and herbs have a huge demand in the world market, as it has several antimicrobial properties to enhance the safety and shelf life of the food products against harmful pathogens and bacteria that can deteriorate the quality of various food products (Table 1). Spices and condiments industry contributed about 4.7% to the GVA. Spices contain volatile essential oils and hydrocarbons, which can stimulate gland-based secretion. According to Statista Research Department, India's total spice production till October 2020 is estimated to be around 9.4 million metric tons. The main objective of this chapter is to emphasize on the multidimensional use and future perspective of forest spices like bay leaf, star anise, curry leaves etc. Many other important aspects of spices are also highlighted, which are spice cultivation practices, current scenario of spices, spice trade and its health benefits.

1.1 Multidimensional Uses of Spices

- *Phytochemicals in spices:* Spices like cumin and fennel seeds consist of phytochemicals like monoterpenes, flavonoids, sterols and phthalides (Sharma 2015), which are aromatic compounds that help in giving peculiar fragrance to different spices (Shahidi and Hossain 2018). Some of the other major phytochemicals are cinnamic acid in cinnamon, eugenol in cloves, curcumin in turmeric etc. as shown in Table 1.
- *Natural preservatives*: Spices consist of essential chemical compounds like phenolic compounds and flavonoids that help in preserving the quality of spices and also protect it from inhibition of growth of harmful microbes (Gottardi et al. 2016).
- *Natural home remedies to enhance beauty*: Spices and herbs are being used to enhance the beauty of the skin from the ancient period. Turmeric has immense anti-microbial and antibiotic properties, which play a significant role in skin care by removing dead cells. Turmeric, cardamom, clove, coriander, saffron, garlic and sage are generally used in cosmetics.

Table 1 Active compounds found in spices and their biological activity

Botanical name of spices (family)	Common name	Activities/usage	Phytochemical/active substances	Key references
Cinnamomum cassia (Lauraceae)	Bay leaf or Tej Patta	Used for chest pain, kidney disorders, high blood pressure, cramps and cancer	The major compounds of the extract were cinnamaldehyde (24.58%), p-methoxy cinnamaldehyde (9.87%), cis-2-methoxy cinnamic acid (9.22%), cinnamic acid (7.39%) and coumarin (5.31%)	Ahmad et al. (2013)
Foeniculum vulgare (Umbelliferae)	Fennel seeds or Saunf	Aromatic and flavour enhancer for dishes, plant widely used as carminative, digestive, lactogogue and diuretic and in treating respiratory and gastrointestinal disorders	Minerals and vitamins present in *F. vulgare* are calcium, potassium, sodium, iron, phosphorus, thiamine, riboflavin, niacin and vitamin C	Rather et al. (2016)
Murraya koenigii (Rutaceae)	Curry leaves	Enhance aroma of food, curry leaves can also be used for weight loss	The oils from the curry leaves were found to contain mostly oxygenated monoterpenes	Rajendran et al. (2014)
Nigella sativa (Ranunculaceae)	Nigella seeds or Kalaunji	Flavour enhancer for many Indian dishes. Used in Indian snacks, breads and savoury dishes	The most important active compounds are thymoquinone (30%-48%), thymohydroquinone, dithymoquinone, p-cymene (7–15%), carvacrol (6–12%), 4-terpineol (2–7%), t-anethol (1–4%), sesquiterpene longifolene (1%-8%) α-pinene and thymol etc. Black seeds also contain some other compounds in trace amounts	Desai et al. (2015)
Piper nigrum (Piperaceae)	Black pepper or Kali Mirch	Important taste and flavouring agent in the majority of Indian dishes especially south Indian preparation and to make spice blends	Pepper contains moderate amounts of vitamin K (13% of the daily value or DV), iron (10% DV) and manganese (18% DV), with trace amounts of other essential nutrients, protein and dietary fibre	Damanhouri and Ahmad (2014)

2 History of Spices

According to Archaeologists' estimate, humans used the special qualities of aromatic plants and spices to help flavour their food since 50,000 BCE. Utilization of the sweet-smelling spices in order to make their food taste better was a common practice. Primitive men offered all sorts of aromatic herbs to their gods. Spices were also used to heal wounds since ancient times. From that moment on, spices played an important role in human beings. Also, trading of spices was developed throughout the Middle East in 2000 BCE with prominent spices like pepper and cinnamon. In 1000 BCE, China and India had a medical system based upon different herbs. India has a famous and profound history regarding excellent husbandry of major spices (Shahidi and Hossain 2018). The ancient Indian epic of 'Ramayana' mentions cloves. It is well known that the Romans utilize cloves in the first century AD as evident from Pliny the Elder' writings about them.

The trade of spices in Middle East made the region phenomenally rich during the middle ages. Spices like black pepper were imported from plantations in Asia and Africa, which made them extremely expensive. During the fifteenth century, the Republic of Venice had the monopoly on spice trade with the Middle East and along with its neighbouring Italian city-states (Shukla and Yadav 2018).

3 Different Spices and its Cultivation

Spices are the prime ingredients of all households, which not only have phenomenal history but also have an incredible future in terms of productivity. Practices regarding the cultivation of spices were prominent since the ancient period, and its yield, trading and demand in global market has been increasing with advancement in technology in the recent years. Some of the major spices and their cultivation details are discussed below:

3.1 Cardamom

Cardamom is used on a wide scale for flavouring the food and it also has a medicinal use. Cardamom is very well known as 'queen of aromatic spices'. IISR-Vijetha-1, IISR-Avinash (RR1) and Kodagu are varieties of small cardamom. It is a shade-loving spice. Well-drained laterite and forest loamy soil are considered best for cardamom. Ideal temperature range required for optimal production of this spice is 22–32°C with annual rainfall amount of 280–300 cm. Best growth of cardamom is observed under tropical rain forest situated mainly at an altitude of 1500 m. India alone accounts for about 80–90% of total cardamom production in the world. Kerala, Karnataka and Tamil Nadu are the major cardamom-producing states of

India. Under rainfed conditions, NPK ratio of 72:72:150 is considered best for cardamom (Jagdish Reddy 2015).

3.2 Curry Leaves

Curry leaves belong to the Rutaceae family, and its scientific name is *Murraya koenigii*. It grows on a wide scale in forest areas and Himalayan foothills. In India, Karnataka, Andhra Pradesh and Tamil Nadu are the leading producer of curry leaves. The aromatic curry leaves are commonly used to add flavour to the food. Apart from leaves, bark and stem of the curry plant are widely used to prepare medicines. Optimum temperature requirement of curry leaves is 26–37°C. This spice is significant as it can tolerate drought up to a certain extent. DWD 1 and DWD 2 are the improved varieties of curry leaves.

3.3 Chillies

Countries like Mexico (3 million tons), Turkey (2.2 million tons), Indonesia (2 million tons) and India (1.5 million tons) are the leading chilli-growing countries. In India, chillies are cultivated in Andhra Pradesh, Maharashtra and Odisha States. Guntur district of Andhra Pradesh is primarily famous for its chillies. Optimum temperatures range from 15 to 30 °C and moderate annual rainfall of 65–122 cm is considered best for chilli growth and development. Heavy to very heavy or less rainfall is detrimental for chillies production. It can be grown on a wide variety of soils like black cotton and loamy soils. It can be grown up to elevations of 1500 m. Application of 5–6 tons/ha of FYM is best suited for better production of chillies (Vikaspedia 2020).

3.4 Bay Leaf

Dried bay leaf is commonly used in various cuisine as it enhances flavour and aroma of food for many years. It has a pungent bitter taste. *Laurus nobilis* is a perennial shrub found on a large scale in various Asian, European, Mediterranean countries and tropical forest. It is a power house of several chemical compounds like alkaloids, tannins, methyl chavicol and eugenol. ‘Tej Patta’ is one of the most popular names of bay leaf. Soil should have good drainage conditions. The essential oil extracted from bay leaves by the steam distillation process has medicinal properties. The ideal temperature for its growth is 65–75°F.

3.5 Long Pepper

Long pepper is spread along the lower hill of Bengal, the forest of Western Ghats, Andaman and Nicobar Island and other tropical forest-covered parts of India. The common name of long pepper is pippali. About 20–25% of shady ambiance is favourable for its proper growth. The most common method of its propagation is by suckers. A total of 20–22 tons/ha of cow dung is essential for its growth. Optimum application of organic manure helps in enhancing the productivity of long pepper. The root and the fruits of long pepper have medicinal properties.

3.6 Star Anise

The scientific name of star anise is *Illicium verum*. The anethole compound present in star anise adds flavour. It is available on a wide scale in the subtropical to temperate forest regions. This spice has a 'star'-shaped appearance. In India, star anise is used on large scale in biryanis to increase its flavour and aroma. It is also known for its medicinal properties from ancient times. The optimum temperature favourable for its growth is 20–25 °C. Star anise belongs to the magnolia family. China is the leading producer of star anise.

3.7 Ginger

India is the leading producer of ginger with an overall production of 1,109,000 tons in an area of around 166,000 hectares. As ginger is a widely grown crop in tropical as well as subtropical areas, temperature range of 15–25 °C is best for its growth. IISR-Varada (180–200 days), Suprabha (230 days), Suruchi (215 days) and Suravi (225 days) are some of the major varieties of ginger. India is also a major exporter of ginger, despite its maximum consumption within the country. Kerala is the leading producer of ginger, as this state alone contributes around one-third of the total ginger production of the country. Ginger can be successfully grown in all types of terrain from sea level up to the height of around 1200 m altitude. In all, 30–35 tons/ha of FYM and 75:50:50 (NPK ratio) is ideal for its optimal growth (Vikaspedia 2020).

3.8 Pepper

Pepper too adds flavour in food. It is also known as the 'king of spices'. An ideal temperature range of 24–32 °C is required for its optimal growth and development. In addition, well-distributed annual rainfall of 135–200 cm is ideal for pepper. As pepper is a plant that grows well in humid tropics, the soil temperature of 25–28 °C is best for its root growth. Pepper is cultivated on a large scale in Western coast of India. Panniyur-1 and Panniyur-3 are some of the hybrids of pepper. NPK fertilizer application in the ratio of 50:50:150 is recommended for pepper. Serpentine and trench are the main methods for its propagation. Indonesia is the largest producer of pepper after India. Kerala, Karnataka and Tamil Nadu are the leading producers of pepper in India. India exports peppers to several countries like the United States, European countries, Egypt etc. (Homey Cheriyan 2015).

3.9 Turmeric

Turmeric is an important spice and also a natural antibiotic. It belongs to the family Zingiberaceae. Some of the most common varieties of turmeric are Suvarna, IISR-Prabha, IISR-Prathibha, Sudarsana, Co-1, BSR-1 and Suguna. The crop duration of these varieties varies from 190 to 250 days. Tropical climatic conditions favourable for turmeric are with a temperature range of 25–35 °C and annual rainfall around 1600 mm. Well-drained sandy loam soil is best for the growth of turmeric. India, Haiti, Jamaica, Peru, Thailand and Pakistan are some of the major turmeric-growing countries. India alone contributes around 70–80% of the overall world's turmeric production. In India, Andhra Pradesh is the leading turmeric-producing state covering 36% area of the total turmeric production in the country. Pre-sowing activities like land preparation before the arrival of the monsoon is a prerequisite. In all, 35–40 tons of FYM and NPK dose of 65:50:125 is ideal for its cultivation. Removing weeds from turmeric plantations in regular time intervals, i.e. after 65, 90 and 120 days, after sowing can help in giving optimal yield. As turmeric has a rough surface, processes like polishing can help in making the surface smooth. Around 80–90% of turmeric production in India is consumed in the country itself, and the remaining is exported in different parts of the world, which indicates the significance of turmeric among consumers (Vikaspedia 2020).

3.10 Areca Nut

Areca nut is one of the widely cultivated spices used in various religious occasions. The chewable nut of areca nut is also known as 'Supari'. Favourable temperature range for proper growth of areca nut is 25–35 °C and annual rainfall of 250–300 cm. Spacing of 2.8 m × 2.8 m is ideal for the best production of areca nut. India is not only the largest producer but also the largest consumer of areca nut. Leading areca nut growing states in India are Karnataka, Assam, Kerala, Tamil Nadu and West Bengal. Laterite clayey soil or loamy soil is suitable for its growth. Some common areca nut varieties are Vittal Areca Hybrid-1 (VTLAH-1), Swarnamangla (VTL-12), Thirthahalli and Shriwardhan. Thirteen- to 17-month-old seedlings are mostly recommended for transplantation in the main field, while 110:40:140 dose of NPK helps giving essential nutrients to the crop. Water stress conditions for long period can be detrimental to its growth (Vikaspedia 2020).

3.11 Nutmeg

Indonesia is the leading producer of nutmeg. Nutmeg is a seed ground spice that belongs to the genus Myristica. The amount of dietary fibre content in nutmeg is very high. It contains almost 80% of dietary fibre, which is good for digestion. It is found in dry deciduous and evergreen forest. Humid and warm climatic conditions (28–32 °C) are ideal for its growth. It responds well in clay loam to sandy loamy to red laterite soil. IISR-Viswashree is one of the Indian nutmeg varieties. Waterlogging condition on the field has an adverse effect on this spice. Pre-sowing operations like digging pits of 10 m × 10 m spacing 20 days prior to planting date is suitable for its growth, while 25–30 kg FYM should be applied in the field along with 22g urea, 22 g P_2O_5 and 55g K_2O (Vikaspedia 2020).

3.12 Cloves

Clove is an aromatic spice that mainly grows in clusters. In India, the hilly regions of Tamil Nadu, Karnataka and Kerala are major clove-growing States. It belongs to the family Myrtaceae. Cloves are widely used in Asian, Middle East countries, Africa and other parts of the world to add flavour to food. Mexicans majorly use cloves in their cuisine. Cloves are used since the first-century AD. Eugenol is an important chemical compound found in cloves that is responsible for its aroma. As clove is a tropical spice crop, it requires warm climatic conditions for its ideal growth: 25–30 °C temperature and annual rainfall of 200–250 cm. Application of urea-35–40 g, P_2O_5-100 g and K_2O-80–85 g is suitable for supplying sufficient nutrients to the crop (Vikaspedia 2020).

4 Processing of Spices

Industries play a major role in spice processing. Production, processing and trading of spices have a great impact on boosting the economy of different leading producers of spice-growing countries like India, Sri Lanka and Indonesia. For small- and large-scale production, major operations that are carried out by various spice-processing industries are cleaning, drying, grading, grinding and packaging (Thankamani et al. 2013).

4.1 Cleaning

Cleaning the harvested spices to remove all the dust and dirt particles is the first step and a prerequisite in spice processing. A large amount of water is required to wash the spices after winnowing. Dirty water must be rinsed, and harvested spices must be washed with clean water repeatedly.

4.2 Drying

Drying spices after cleaning is another major and second step carried out in the spice processing industry. Spices are spread properly on a mat under sunlight so that spices are dried up. Proper drying up declines the possibility of mould formation in the spices, which maintains their quality and aroma. If spices are not dried under sunlight for a long time, the mouldy infestation will occur in spices, leading to a huge decline of up to 50–60% in its market value. Different harmful food poisoning–causing bacteria can also develop on spices if proper sun drying is not done after cleaning spices. At the time of sun drying, solar drier is used to remove the dirt and dust particles from the spices. Solar drying also helps in drying of spices if it got drenched in light rainfall. Overdrying of spices can lead to decline in its quality. Overdrying of spices can severely affect the optimum moisture content of different spices (Bala and Janjai 2009)

4.3 Grading

Grading is the third stage of processing, where spices are sorted or separated based on size, colour and texture, the scale of quality or intensity at various standard levels. Grading of spices is essential to get the best price or net return, assuring the quality of spices in separation and milling process.

4.4 Grinding

Grinding of spices is an important processing operation carried out to add value to the product. Manual grinders are commonly used to grind different spices, which have small- to medium-scale production. The grinding mill can grind 25–28 kg/h of spices.

4.5 Packaging

Packaging of spices depends upon several factors as listed below:

- should have good aroma
- quality and size of spices
- ability to sustain spoilage or good shelf life
- spices should not show any adverse physio-chemical changes in any condition
- have optimum resistance against insects and pests infestations
- attractive appearance.

5 Equipment Used in Spice Processing

Texture and appearance of spices vary from berries, twigs, roots, bark and leafy parts. For grinding this complex form of spices into simple edible form in cuisines, various types of equipment are available for its proper and fine mixing, grinding and blending. Some examples of such equipment are Grinding Machine, Automated Coating Machine, Oil filters, Nut Roaster Metal Detector Machine etc.

6 Current Scenario of Indian Spices and Constraints in Spice Production

Chillies, turmeric, coriander, ginger, pepper, fenugreek, garlic, cloves, cumin, cardamom, Areca nut and tamarind are some of the prominent and widely grown spices in India. Karnataka, Kerala and Tamil Nadu are the major states producing pepper (Shinoj and Mathur 2006). In the year 2017–2018, Karnataka was the leading pepper growing state with total production of 35,200 tons in the acreage of 37,000 ha. In the same year, Kerala accounts for the maximum small cardamom production, which was nearly 18,000 tons in 39,000 ha area. Till 2018, the total production of chillies in Andhra Pradesh was recorded 993,000 tons in 209,300 ha land. The total production of ginger witnessed by Assam in 2018 was nearly 167,400 tons in an area of 18,790 ha. States like Rajasthan and Gujarat together produce 80% of the total seed spices of India (Singh et al. 2011). From the past decades, one of the most important spices like turmeric shows an increase in trend in terms of overall production and yield in major turmeric-growing states of India. Total production of turmeric in India during 2009–2010 was approximately 8 lakh tons which got an increase in the year 2018 to 11 lakh tons cultivated in 225,000 ha of land till 2018.

According to state agriculture/horticulture data, the Western States of India like Gujarat is the leading producer of spices like cumin and fennel seeds with an overall production of 291,500 tons and 87,800 tons, respectively, till 2018. Rajasthan is the leading producer of garlic and fenugreek seeds, with an overall production of around 7.3 lakh tons (in 107,900 ha) and 1.6 lakh tons (in 129,700 ha) in the same year. The southern state of Tamil Nadu is one of the leading producers of cloves with an overall production of around 970 tons in 990 ha of area. With increase in demand for spices in the global market, production, productivity and total area of different spices such as turmeric, ginger, cloves, garlic and Arecanut require an increase to meet the need for increasing population. Sustainable development is the major step to achieve this goal.

6.1 Constraints in Production of Spices

- Poor genetic potential of spices with respect to its quality and yield can more often lead to decline in the overall productivity of spices.
- Application of imbalanced fertilizers due to lack of awareness and poor post-harvest handling of spices (Bhardwaj et al. 2011)
- Lack of farm equipment, technological awareness and insufficient planting material/ seeds can also reduce the production of spices.
- Less flexibility in extension programmes to carry lab to land work.
- Lack of adoption of various insect pest management practices.
- Delay in presowing operations of lack of relevant agronomic practices.
- Not drying of seeds under sunlight before grinding or its processing.
- Hurdles in trading like non-tariff trade restrictions (Muthupandi et al. 2018)

7 Value Addition in Spices

After processing of spices, there is a value addition for its further application and distribution from producer to consumer, which also helps in enhancing economic growth in terms of foreign exchange. Trading operations like exporting the final value-added product of spices in foreign counties can lead to making the spice business and agriculture profitable. Merits of value-added spice products are:

- Its consumption in different cuisines for enhancing flavour all across the globe.
- Maintaining the standard quality of spices to get the best price in the market.
- Value-added products help it gaining foreign exchange.
- Drying spices under sun rays increases its shelf life and can be stored without the threat of any insect infestation. This further is an advantage for value-added products of spices.
- Aroma of spices is also intact after value addition.

7.1 Value-Added Products of Spices and its Application

- *Ground spices*: The coarse form of ground powder of spices is known as ground spices. Grinding mill is used to make this powdery form of spices for which large amount of heat is essential. Turmeric powder, red chilli powder, cumin powder, coriander powder and cinnamon powder are some of the important ground spices, which are used on a large scale in cuisine all over the world. As India is the leading producer of most spices, ground spices have an inevitable contribution in uplifting the quality of Indian cuisine.
- *Spice oils*: Granular extract of spices is widely used in the preparation of different products like shampoos, soaps, perfumes, toothpaste, mouthwashes, detergents and pharmaceuticals products. Spice oils are also used in dairy items like cheese. In the initial stage, spice oils are extracted from spices, before when it is subjected to solvent extraction. Spice oils are extremely volatile that adds flavour and aroma in different final products of processing and manufacturing industries. Steam distillation process plays a vital role in the extraction of oils from different spices. Pepper oil is extracted by steam distillation technique of dried form of black pepper. Seeds of cardamom are also steam distilled to obtain cardamom oil (Macwan et al. 2016).
- *Spice powder*: Different spices like turmeric, coriander, chillies, fennel, fenugreek and black pepper are blended and crushed to transform spices into powdery form. This spice powder is utilized to add flavour in curry paste, curry masala and its mixture. Spice powder also adds to the attractive colour and appearance of various cuisine, especially vegetables, meat and fish.
- *Oleoresin*: Oleoresin is an important value-added product of spices obtained naturally from the perfect combination of oil and resins, which are extracted from plants. It is a concentrated liquid form substance. Oleoresins are used in desserts, meat sauces, hair lotions, candles, soaps and frozen foods for enhancing the appearance/colour of eggs, butter and cheese.
- *Meats and fish*: Spice powder of chillies, black pepper, cloves and coriander are used more often in red meat, sausages, chilli chicken and other meat-relevant cuisine. Spices along with some prominent herbs are widely used in marinating the non-vegetarian delicacies to add more flavour to it. Variety of spices like turmeric, garlic and chillies are used in making fish curry or fried fish.
- *Snacks*: For adding flavour to a variety of snacks, salt and spices are dusted or sprinkled on snacks. Dusting of spices in snacks adds a base to its flavour and makes it crunchy. Seasoning (the process to add salts, spices in food to enhance its flavour) also helps in making the food attractive to consumers.
- *Pharmaceuticals and Cosmetic industries*: Spice oils and oleoresins are used in the manufacturing of medicines, cosmetic products like skin or cold creams, soaps, shampoos and lipstick (Bhagya et al. 2017). Herbal spice like turmeric is used on a wide scale by different pharmaceuticals and cosmetic industries because of its demand for skincare routine and enhancing immunity. Bacteria

present in spices like cloves and garlic gently clean the skin, as it is has antimicrobial properties (Arora and Kaur 1999).

- *Hygienic Products and mouth wash*: Toothpaste and soaps also contain spice oil. Further, mouth-wash available in the market contains spice oil to maintain good oral hygiene. Clove is used to cure several oral disorders. Phytochemicals present in spice and spice oil prevent and cure the attack of harmful microorganisms like *Mutans streptococci*, *Streptococcus mutans Streptococcus sobrinus* and lactobacilli (Sonal Dubey 2017).

7.2 Importance of Spices in Diet

- The essential components present in spices especially turmeric contain anticlotting properties and also play a significant role in increasing immunity.
- Heating or boiling of spices helps in curing severe cold and cough; therefore, it is an important ingredient for a person suffering from cold or cough.
- Spices are rich in mineral content, which helps in controlling blood pressure.
- Thyme water plays an important role in throat gargling during sore throat, and it is also used as an antiseptic mouth-wash.
- Onion, garlic and asafoetida add pungency, flavour and treat minor diseases (Patil et al. 2016).

8 Technologies involved in Spice production:

Spice cultivation activities like presowing, vegetative growth, planting, reproductive growth and harvesting can be severely affected by adverse weather conditions, such as flood, drought, flood, extensive heat or cold temperature or high wind. Excessive humid condition also acts as a catalyst for insect and pest attack on spices. This can drastically lead to gradual decline in spice yield and quality, which eventually leads to immense loss for farmers depending on spice crop production, spice dominant processing, manufacturing industries and agriculture-based trade sector. To overcome such constraints, there is a need for different innovations of new technologies to enhance spice production. Some of such technologies are described below:

- *Technologies to monitor plant health*: Pest Defender ratio or P: D ratio method helps in easily identifying the number of pests and insects (beneficial) that may attack the crop. This helps the farmers to make a decision regarding pest management practices to be undertaken.
- *Agro-Ecosystem Analysis (AESA) Technology*: In modern agriculture-based practices, maximum emphasis is given on AESA technology. This technology primarily helps farmers having large fields. AESA technology relies on nearby environmental conditions like temperature, rainfall, sunshine hours, wind speed,

soil condition, weeds, insect or pest attack on crops. These environmental factors play a vital role in determining crop health at various stages of the crop (Badr 2017).

- *Plant Growth-Promoting Rhizobacteria (PGPR)*: PGPR is a colony of bacteria that sets a colony around the plant root zone which also referred to as plant growth-promoting rhizobacteria. PGPR works efficiently against soil-borne pathogens which can help in regulating the growth and development of various spice crops. Seeds of fenugreek, fennel and coriander are highly susceptible to delay in germination, infestation of insects and pest under adverse conditions. To prevent such condition, this technology helps in coating the seeds of spices with PGPR to enhance the shelf life of seeds. It also protects the seeds from insect/disease attack during storage.
- *Detection of adulterants using DNA barcoding technique*: Any kind of adulteration in spices can be detected using the DNA barcoding technique. Before exporting or importing spices from one country to another, this technique is used to monitor any kind of adulteration in spices to avoid any kind of defamation of brand or nation and also to have a concern regarding the ultimate consumers. Any kind of foreign material detected in spice sample which is being traded can be easily detected using DNA barcoding technique (King et al. 2018).
- *Mechanical-based technologies*: For fabrication of spices, mechanical technology is a prerequisite. The mechanical setup includes machines like gearbox, rods for grinding, sterilization and grinding machines, dryers and oil-extracting machines are some of the major machines developed that helps in the processing of spices into value-added products.
- Infrared drying technology: To avoid any kind of infestation of micro bacteria such as *E. coli,* salmonella and moulds, infrared drying technology is used for sterilization which also helps in preventing overheating of essential oil present in spices.

9 Organic Farming and its Significance in Spice Production

In the recent years, organic farming has gained significant importance in the agriculture sector across the world. Farmers with small and large landholding are also showing awareness regarding adapting the organic method of crop cultivation. Extension workers are also promoting the organic method of farming by organizing training programmes, Kisan-mela and workshops, which helped farmers in switching to organic farming method from traditional methods. The demand for organic-based agriculture products like cereals, spices, fruits and vegetables has increased in the past few decades. At the global level, 51 million hectares of agricultural land is under organic farming. According to Agricultural and Processed Food Products Export Development Authority (APEDA), the total area under organic farming in India is around 5.7 million hectare with cultivable area of 26% till 2016.

In the year 1998, the Spice Board of India had taken initiative to prepare a detailed document regarding the development of organic-based spices. This includes all the guidelines relevant to standards, principles, concepts, certification, inspection and information regarding organic methods of spice cultivation. The board actively promotes farmers, NGOs and other organisations to adopt modern techniques related to organic farming, as it has no chemicals involved to fulfil nutrient demand of spices. The board also focuses on export and quality maintaining aspects of organic spices from India to other countries after the certification process. Besides countries like Vietnam and China, India is a prominent exporter of organic spices to different countries like Germany, United States and the Netherlands. This helps in boosting up the Indian economy by gaining foreign exchange. Input cost of organic farming is a little expensive when compared to chemical fertilizers, but it has no adverse effect on plants or human health while consuming its by-products. Spices obtained after organic farming can be a great source to increase immunity. In addition, organically raised spices do not have any harmful foreign material or toxic substances, high on anti-oxidants and thus prevent soil and water bodies to be contaminated.

10 Health Benefits of Spices

Every spice has its own significant taste and aroma. Every household uses different combinations of spices like black pepper, ginger, turmeric, coriander, fenugreek, cumin seeds and fennel seeds in various countries across the world. Therefore, knowledge regarding health benefits is a prerequisite. Spices not only add flavour to various cuisine but also is an excellent source of nutrients. The Health benefits of various spices are discussed below and presented in Fig. 1.

Pepper: Black pepper is known as ‘king of spices’. For a person suffering from obesity, it helps in the reduction of weight and enhances metabolism. Cayenne pepper contains capsaicin which helps in reducing the appetite and thus contributes to weight loss. Pepper when mixed with turmeric has anti-cancer properties. It provides instant relief from cough, cold or sore throat. Pepper eliminates toxic elements from our body and is a great source of detoxification. It also cleans the stomach and intestine, which prevents problems regarding digestion. Black pepper is rich in vitamin B, which treats skin-related problems like wrinkles of skin and skin pigmentation. During winter, if the person is suffering from joint pain, the medicinal property of black pepper helps in curing such joint pain.

Long pepper: It aids health issues due to a lack of proper liver functioning. Long pepper regulates the blood sugar level and thus is helpful for diabetic patients. It protects from bacterial infections. Long pepper has chemicals that provide relief from indigestion and diarrhoea. It also reduces the risk of asthma attack and cures respiratory issues.

Star anise: Star anise is an excellent source of important and essential compounds like gallic acid, quercetin and shikimic acid which have antimicrobial and

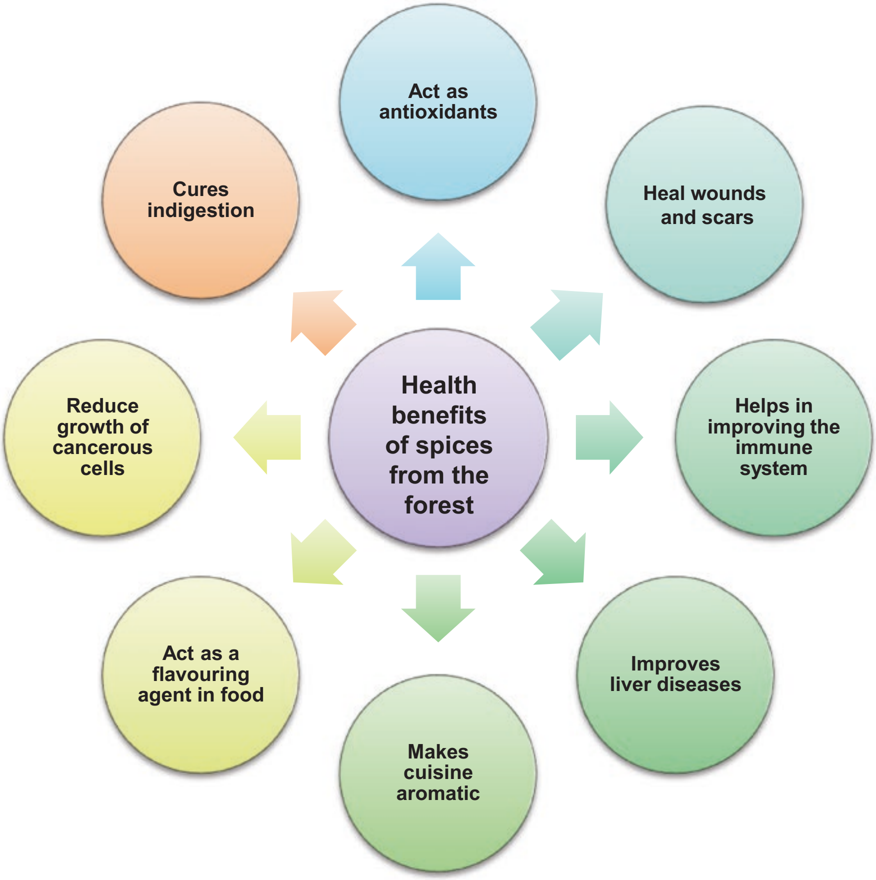

Fig. 1 Health benefits of spices from the forest

antifungal properties. Oil extracted from star anise consists of terpineol that cures cold and cough problem. It has ample amount of vitamins and is rich in antioxidants.

Curry leaves: It is a great source of antioxidants and has antibacterial properties. It protects from heart and liver-related diseases. Curry leaves are a rich source of iron; therefore, it is quite beneficial for anaemic patients. It is also good for eyesight, as curry leaves are rich in vitamin A. It also aids in digestion and is very beneficial for the proper growth of hair. Consuming curry leaves in diet maintains oral hygiene. Curry leaves are also commonly known as 'meetha neem' or 'kadi patta' in India.

Bay leaf: Bay leaf contains rutin and caffeic acid that cures several heart-related problems. It is helpful for diabetic patients by reducing the blood sugar level and protects our body from inflammation. Bay leaves also play a vital role in curing arthritis. As bay leaf has strong antibacterial properties, it helps in wound healing.

Cardamom: Cardamom or elaichi is also known as 'queen of spices'. It is a good source of vitamin A, C, zinc, iron and calcium. India is known to be the origin of cardamom. It is a boon for a patient suffering from blood pressure, as it maintains the blood pressure. Cardamom is rich in fibre and thus helps in digestion. It contains phytochemicals that have anti-bacterial and anti-inflammatory properties. Stomach ulcers can also be cured by consuming cardamom as it heals various kinds of ulcers. To prevent bad breath or maintain oral hygiene, cardamom is used as a mouth freshener. Due to its capability to fight bacteria and treat infections, cardamom is also known to have a great antibacterial effect. It is indeed helpful for diabetic patients, as cardamom can also maintain the blood sugar level. Cardamom protects the liver from getting enlarged and saves a person from fatty liver disease.

Cinnamon: Cinnamon is prepared by extracting the inner bark of the Cinnamomum tree. After drying this extraction, it is rolled to form cinnamon sticks. It lowers the risk of heart disease and controls the blood sugar level. Polyphenol is one of the most important antioxidants present in cinnamon, which protect our body cells against free radicals. Cinnamon also has an excellent anti-inflammatory effect that actively fights against body infections and successfully repairs damaged tissue. The use of cinnamon in cuisines reduces stomach-bloating problem. Adding cinnamon to food ensures the proper functioning of insulin hormone to regulate metabolic activities and decrease the chances of insulin resistance in our body.

Chillies: Chillies are found in the cuisines of almost every household. Red and green chillies are an important source of vitamin C. Presence of capsaicin in chillies gives a spicy touch to the food. Apart from weight loss, chillies also help in regulating blood pressure. Chillies have zero calories and are fully loaded with vitamins. It also has anti-oxidants to fight against free radicals. It enhances the metabolic rate of our body when consumed in optimum amount. Chillies also reduce the blood cholesterol level and help in reducing the chances of heart diseases.

Garlic: Garlic belongs to the allium family, which contains an important compound called allicin. Doctors often recommend eating garlic cloves especially to those having heart-related problems (Kaefer and Milner 2008). Due to its medicinal properties and strong taste, garlic is one of the most common spices used in various cuisines. Garlic fulfils many nutritional demands at it is rich in manganese, vitamin C, vitamin B6, fibre, selenium, calcium, iron and potassium. It is also beneficial to cure common cold (Bozin et al. 2008).

Turmeric: Turmeric is one of the essential spices, which has significant antibiotic properties. It helps in curing skin-related problems like eczema. Drinking milk with half a tablespoon of turmeric powder mixed in it helps in curing joint pain, ulcers and healing wound. Turmeric boosts up brain functioning and reduces the chances of Alzheimer's disease. Curcumin compound present in turmeric acts as a source of natural anti-inflammatory and minimizes the chances of heart stroke. It also helps in controlling the growth of cancer cells. Turmeric intake in food is also recommended to arthritis patients. It strongly improves the immune system and is helpful to provide relief from acute depression (Chattopadhyay et al. 2004).

Cloves: Cloves are grown widely in Southern states of India like Karnataka, Kerala and Tamil Nadu. It is known and is useful for its antiseptic, antimicrobial and antifungal properties. Cloves are an important spice rich in omega-3 fatty acids, fibre, minerals and vitamins. Due to its antimicrobial properties, it cures mouth ulcers and other oral problems like toothaches. It is recommended for a diabetic patient to maintain the blood sugar level. Cloves act as a medicinal curing agent for any skin-related problems like acne. It also helps in regulating blood circulation, maintains proper digestion, provides relief from cold and cough and respiratory-related problems. The presence of Eugenolin cloves has the property to reduce cancerous cells (Bhowmik et al. 2012).

Cumin: Cumin water helps in digestion. It is best for curing skin-related problems, respiratory problems and sleeping disorders. Cumin oil is an excellent source of antiseptic and antibacterial properties. Cumin water also aids in irritable bowel syndrome (IBS). For curing allergies, black cumin is quite helpful (Fatima et al. 2018).

Coriander: Coriander is also known by the name ‘cilantro’ in Western countries and ‘dhaniya’ in India. Coriander seeds have good amount of fibre and manganese. Leaves of coriander have high content of vitamin C, vitamin K and protein. It boosts the immunity and is an excellent source for good eyesight. Minor amounts of phosphorous, potassium, thiamine and calcium are also present in coriander.

Fennel Seeds: Fennel seeds are consumed after meals, as it a rich source of fibre and as a mouth freshener. Despite being low in calories, fennel seeds are considered as powerhouse of nutrition. It contains vitamin C, calcium, iron, magnesium, manganese and potassium. Polyphenol antioxidants present in fennel seeds act as an anti-inflammatory agents that have a positive impact on our health. It also reduces the risk of heart diseases and has anti-bacterial properties. It boosts up prolactin content of blood, which enhances the milk secretion of breast-feeding women.

Ginger: Ginger is widely used to cure cold and cough. An important compound called gingerol helps in curing digestion and nausea-related problems. It acts as a catalyst for improving joint pain and reducing menstrual pain. Ginger keeps bad cholesterol level and blood sugar level of our body in check.

11 Research and Analysis of Spices

Research practices on spices like ginger, turmeric, cardamom, pepper and garlic started from the 1950s. Research Institutes and centres were set up in Karnataka, Kerala, Assam, Maharashtra and Punjab States of India. Initial research activities were carried out on three major spices, namely, ginger, turmeric and cardamom. To stretch the R&D activities, research on other spices like nutmeg and cloves were included in the next 5-year plan. Apex Organisation of Agriculture, Indian Council of Agriculture Research (ICAR) focused on the need to start the detailed research on different spices in the fifth 5-year plan. Organisations like ICAR, Spice Board of India and various State Agriculture Universities played a significant role in providing a platform for different spice-relevant research activities.

For conducting research activities on particular spice like cardamom, in the year 1986, ICAR collaborated with cardamom research centre of Central Plantation Crops Research Institute (CPCRI) located at Appangala, Karnataka as National Research Centre of Spices, which now commonly known as Indian Institute of Spices Research (IISR). IISR strictly follows mandates to conduct successful research activities regarding the cultivation of spices, enhancing its productivity, making spice production profitable to farmers etc. Some of the important mandates for carrying out research on various spices are mentioned below:

- Systematic approach regarding the production of spices with sustainable development with efficient use of split application of fertilizers, sprinkle irrigation method and weed management practices for surplus spice productivity (Singh and Solanki 2015).
- Developing improved varieties of spices to gain maximum productivity, good quality and drought-resistant varieties.
- Collecting and conservation of germplasm of spices for economical aspect.
- Identification of pathogens, diseases and insects that has an adverse impact on spice production.
- Ensuring environmental food safety in spice production food chain and its protection from harmful chemicals and microbial attack (Szekacs et al. 2018)
- Forecasting the possibility of a decline in spice productivity due to weather conditions, insects, pests or any diseases much in advance and its mitigation strategies.
- Value addition in the harvested spices so that producer can get maximum profit.
- Conducting seminars, workshops and training programmes to create awareness among spice-growing farmers and also knowing the field data/ground report regarding sowing dates, cultivation or management practices, varieties that can adapt to climate change (Raziya 2018) and harvesting time of various spices.
- Developing weather and crop-based module expertise system.
- Developing several statistical modelling techniques.
- Detailed study regarding medicinal and nutraceuticals application of spices.
- An analysis is carried out regarding proper pre/ post-processing, marketing of spices.
- Assuring quality and quantity of planting materials.
- Detailed study regarding different cultivars of spices and the impact of current and forecasted weather on spices.

12 Conclusion

Spices have significant importance for cooking as well as for herbal medication across the world. It is widely used in different cuisines to add flavour and aroma to foods. One cannot deny the fact that spices have great demand in the world market, as it has several antimicrobial properties to enhance the food quality against the harmful pathogens and bacteria that can be harmful to human health. Research and analysis show that a systematic approach regarding the production of spices with sustainable development is very important along with rationalized value addition in spices. A detailed study on forest spices indicates that excess in afforestation activities can decline the major cultivars of spices. Spices like turmeric, nutmeg, bay leaf, ginger, garlic, coriander, cumin seeds, fennel seeds, cloves, cardamom etc. play a significant role in curing various health-related issues like controlling blood sugar level, anti-inflammatory agents, boost digestive system, curing joint pain, ulcers, healing wound, respiratory problems, cold and cough etc. Therefore, cultivation of spices and their trading will always have a wider future perspective because of its endless demand in the world market. In forthcoming years, forecasting the possibility of a decline in spice productivity due to weather and climate change, insects, pests or any diseases much in advance and its mitigation strategies using modelling techniques can help spice-growing farmers, policy makers and industrialists in the decision-making at various stages of socio-economic planning and trade. Sustainable development is also a major step, which adds to the rational development of spice production in the coming years.

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Ganoderma lucidum: King of Mushroom

Mustafa Nadhim Owaid

Contents

1 Introduction

Macrofungi are redundant resources of a wide variety of interesting natural products and novel compounds with many bioactivities (Lorenzen and Anke 1998). Higher fungi can decompose substrates such as sawdust and form biomass by secreting enzymes and hence cleaning nature (Martins 2017). *Ganoderma lucidum* is one of the basidiomycetes (white rot macrofungi) species that belongs to the family of Polyporaceae (Ganodermaceae). The common name of G. lucidum is Lingzhi in Chinese and Reishi in Japanese (Yang and Liau 1998). It is a source of many types of polysaccharides, ganoderic acid (Fang and Zhong 2002; Wagner et al. 2003), and triterpenoids (Ma et al. 2011). It is considered one of the most known traditional Chinese medicinal herbs, which is used as a remarkable drug and healthy fresh or dried food for more than 2000 years (Sanodiya et al. 2009).

Ganoderma lucidum is a macrofungi species that grows on dead and deciduous trees. *G. lucidum* is an important natural source of myco-compounds that are used to treat different diseases for numerous years. It has many bioactive components,

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including polysaccharides and triterpenes, and thus it is used in the treatment of cancer and the regulation of the human immune system. Recently, this mushroom has been used as an eco-friendly reducing agent in the green mycosynthesis of metallic nanoparticles. Moreover, *G. lucidum* was used in pharmacological application, especially as antidiabetic, antihypertensive, cardioprotective, hepatoprotective, antioxidant, immune-modulatory, and anticancer agent.

2 Cultivation of *Ganoderma Lucidum*

This mushroom has limited growth by nature and is in demand for its use in critical therapeutic emergencies, so growing in stationary liquid media, by submerged cultivation, or on the solid substrate has become necessary to meet the increasing demands of the international market (Sanodiya et al. 2009). Tree sawdusts are used to cultivate *G. lucidum* globally, such as sawdust of *Carpinus betulus* (hornbeam) with tea wastes and wheat bran (Peksen and Yakupoglu 2009); poplar sawdust; Turkey oak sawdust; black pine sawdust; beech sawdust with wheat bran (Maszlavér 2008); sawdust of *Swietenia mahagoni*, *Tectona grandis*, *Dipterocarpus turbinatus*, *Michelia champaca*, and *Gmelina arborea* with rice bran or wheat bran (Roy et al. 2015); sawdust of oak, poplar, and beech with bran of rice, wheat, and corn (Erkel 2009); and combination of 79% of various sawdust (rubber tree, acacia tree, eucalyptus tree, long-zeim tree, mixed tree sawdust, and Korean oak tree sawdust) with 20% rice bran, 1% $CaCO_3$, and 60–65% H_2O (Chang et al. 2007). Figure 1 shows stages of artificial cultivation of *G. lucidum* in farms.

3 Nutritional Values of *Ganoderma Lucidum*

3.1 Bioactive Compounds

G. lucidum contains different chemical compounds, involving several types of polysaccharides and more than 119 kinds of triterpenes (Hsieh and Yang 2004). About 29 triterpenoids are present in its spores like ganoderic acid (types E, δ, H, D, A, ξ, C_1, ε, C_6, η, G, and C_2) as in Fig. 2, ganopsoreric acid B, ganoderic acid γ, ganodermanontriol, ganosporelactone A, ganosporelactone B, β, θ, lucidumol A, ganoderiol F, lucidumol B, ganodermanondiol, ganolucidic acid A, ganolucidic acid D, lucidenic acid SP1, methyl ganoderate A, and methyl ganoderate B (Ma et al. 2011). Parts of *G. lucidum* have therapeutic potential, such as basidiocarps, spores, and mycelia which contain approximately 400 various bioactive compounds used in the pharmacological field like polysaccharides, amino acids/proteins, peptides, triterpenoids, steroids, sterols, fatty acids, nucleotides, and trace elements (Sanodiya et al. 2009).

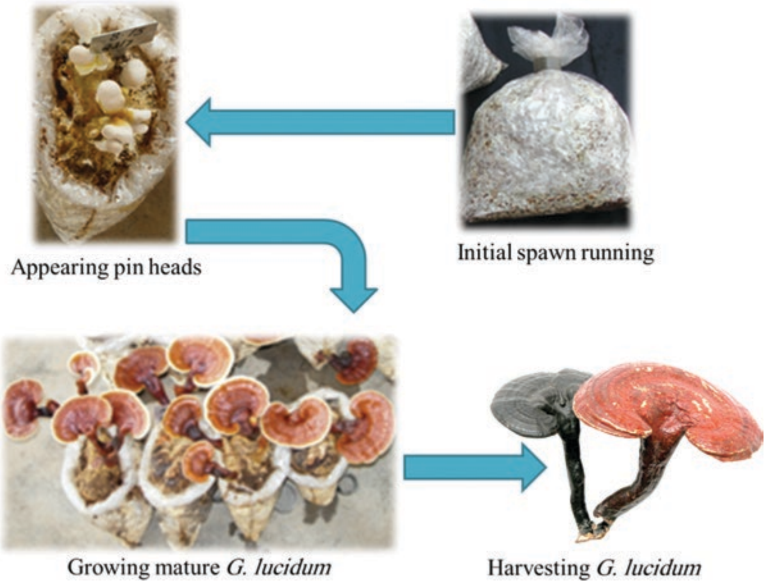
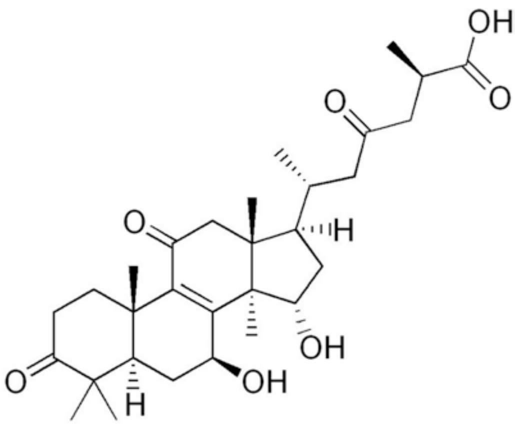


Fig. 1 Stages of artificial cultivation of *Ganoderma lucidum*

Fig. 2 Ganoderic acid isolated from *Ganoderma lucidum*



3.2 Medical Benefits of Ganoderma Lucidum

Ganoderma lucidum possesses many properties, including immunomodulation, anti-inflammatory, antibacterial, anti-atherosclerotic, chemopreventive, analgesic, anticancer, radio- and chemoprotective, antiviral (anti-HIV), sleep-promoting, anti-fibrotic, hypolipidemic, hepatoprotective, antiherpetic, antiaging, hypoglycemic, antidiabetic, anti-angiogenic, anti-androgenic, estrogenic activity, antioxidative, and radical-scavenging and antiulcer properties (Sanodiya et al. 2009). However,

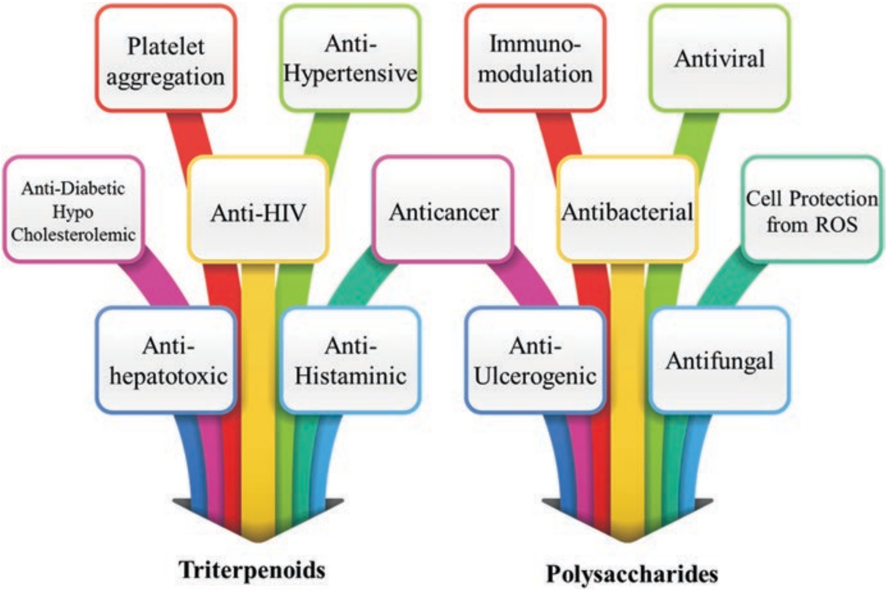


Fig. 3 Biomedical applications of triterpenoids and polysaccharides of *G. lucidum*

some of the main biomedical applications of triterpenoids and polysaccharides of *Ganoderma lucidum* are listed in Fig. 3.

3.2.1 Antibacterial Activity

Fungal antimicrobials are used for the treatment of infectious diseases, while simultaneously reducing various side effects often related to synthetic antibiotics (Naveenkumar et al. 2018). *G. lucidum* is active against many Gram-positive and/or negative bacteria (Sanodiya et al. 2009) like *Escherichia coli*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Streptococcus mutans*, and *Salmonella typhi*. *G. lucidum* fruit bodies exhibited potential antibacterial activities toward these bacterial species. The aqueous extract (200mg) of this fungus showed best zone of inhibition of 31 mm toward *S. aureus* and *S. typhi,* while the concentration of 50 mg showed only 10mm (zone of inhibition) against *E. coli* (Sridhar et al. 2011). Also, *G. lucidum* extracts exhibited potential activity against multidrug resistant *S. aureus* (Prasad and Wesely 2008).

The antibacterial efficacy of different solvent extracts of this mushroom (40μg/ml) was investigated against some bacterial species like *Escherichia coli* (MTCC443), *Staphylococcus aureus* (MTCC737), *Bacillus subtilis* (MTCC1789), *Salmonella typhi* (MTCC 531), *Pseudomonas aeruginosa* (MTCC 779), and *Klebsiella pneumoniae* (MTCC2405). The acetone extract showed best antimicrobial activity and reached 31.60 mm, whereas the minimum inhibition zone was observed with *K. pneumoniae* (Quereshi et al. 2010). Besides, *G. lucidum* extracts exhibited antibacterial efficacy toward *Pseudomonas, E. coli, S. aureus, Enterococcus, Bacillus,* and *Serratia* (David et al. 2012).

However, many strains involving *Bacillus anthracis* ATCC 6603, *Bacillus cereus* ATCC 27348, *Bacillus subtilis* ATCC 6633, *Micrococcus luteus* ATCC 9341, and *Staphylococcus aureus* ATCC 25923, *Escherichia coli* ATCC 25922, *Klebsiella oxytoca* ATCC 8724, *Klebsiella pneumoniae* ATCC 10031, *Proteus vulgaris* ATCC 27853, *Salmonella tompson* ATCC 10256, *Salmonella typhi* ATCC 6229, *Salmonella typhimurium* ATCC 14028, *Serratia marcescens* ATCC 27117 (Yoon et al. 1994), *Pseudomonas syringae* IMI 347448 (ATCC 19310), and *Bacillus subtilis* IMI 347329 (Ofodile et al. 2005) were applied in this field. Recently, this mushroom was also active to inhibit the growth of *Bacillus cereus*, *Listeria monocytogenes, Micrococcus flavus Enterobacter cloacae, Salmonella typhimurium* (Heleno et al. 2013), *Staphylococcus aureus*, MRSA, *Enterococcus faecalis*, *Acinetobacter baumannii*, *E. coli*, and *P. aeruginosa* (Bal 2019).

3.2.2 Antifungal Activity

G. lucidum has antifungal activity against many fungal species, including *Penicillium*, *Aspergillus*, *Aspergillus flavus*, *Aspergillus niger*, *Fumigatous*, and *Mucour indicus*. The methanolic extract (200 mg) exhibited the best antifungal efficacy and reached 30 mm (zone of inhibition) against *Mucor indicus*, while the minimum zone of inhibition was 3 mm toward *Aspergillus flavus* with the concentration of 50 mg (Sridhar et al. 2011).

Also, this mushroom showed antifungal and anticandidal activity against *Cladosporium herbarum* (Ofodile et al. 2005), *Candida albicans*, *Aspergillus niger*, *Aspergillus ochreus* (Roy et al. 2016), *Candida tropicalis, Candida glabrata, C. albicans, Candida lusitaniae, Candida parapsilosis, Candida kefyr, Candida krusei, Candida dubliniensis, Candida guilliermondi* (Naveen Kumar et al. 2017), *Candida albicans, Candida krusei,* and *Candida glabrata* (Bal 2019).

Recently, the crude aqueous and ethanolic extracts of *Ganoderma lucidum* have been investigated for their antifungal efficacy against pathogenic yeasts and fungi, namely *Candida albicans*, *Aspergillus niger*, *Cryptococcus neoformans*, *Penicillium marneffei*, *Microsporum canis*, and *Trichophyton rubrum*. The result showed ethanolic extract had high inhibitory action against the studied fungus when compared to aqueous extract. In both ethanolic and aqueous extracts, the maximum inhibition activity was observed against *Candida albicans* followed by *T. rubrum, M. canis, A. niger, P. marneffei,* and *C. neoformans*, respectively (Naveenkumar et al. 2018).

3.2.3 Antiviral Activity

Some bioactive compounds isolated from *Ganoderma lucidum* have showed inhibitory impacts toward HIV-1 protease and HIV-1 efficacy (El-Mekkawy et al. 1998) involving ganolucidic acid A, lucidumol B, ganoderic acid β and C, ganodermanontriol, and ganodermanondiol. Recently, *Ganoderma lucidum* has been used to treat patients with Coronavirus (COVID-19) (Obaid AL-Jumaili et al. 2020) and to inhibit the Dengue virus NS2B-NS3 protease (Bharadwaj et al. 2019).

3.2.4 Antioxidant and Anticancer Activities

Oxidative stress is the main contributor that leads to increased cancer risks. Free radicals and ROS (reactive oxygen species) are generated as by-products of the metabolic processes, including bioenergetics electron transfer, redox enzymes, and exposure to many toxic chemicals (Dreher and Junod 1996). Thus, *G. lucidum* is considered one of the most antioxidant agents used against ROS to protect animal cells from damages (Samarakoon et al. 2013; Bal 2019; Shaher et al. 2020) and to treat Alzheimer's Disease (Yu et al. 2020).

The bioactive components of *G. lucidum* like triterpenes, polysaccharides I, II, III, IV, peptides, and polysaccharide peptide exhibited antiaging roles, and ganoderic acid C1 could pursue life span elongation or associated efficacies (Wang et al. 2017). Generally, polysaccharides of this mushroom inhibit human hepatocarcinoma cells (Liu et al. 2012) and have immunomodulatory, proapoptotic, antiproliferative, anti-angiogenic, and antimetastatic effects (Sohretoglu and Huang 2018). Recently, it has been used as a radioprotector (González et al. 2020).

The isolated drugs from this mushroom showed inhibition and lethal effects such as antiangiogenesis, inhibition of tumor growth, and antimetastasis against different cancers in humans such as leukemia, lung, hepatoma, breast, prostate, bladder, colon, cervix uteri, and sarcoma (Yuen and Gohel 2005). *Ganoderma lucidum* showed anticancer activity against oral cancer cells HSC-3, melanoma cells M21, human lung cancer cells CH27 (You et al. 2012), prostate cancer cell migration (Zhao et al. 2018), osteosarcoma MG63 and U2-OS cells (Zhang et al. 2019), porcine epithelial cell line (Liang et al. 2019), and PC-3 prostate cancer cells (Jiang et al. 2004; Wang et al. 2020).

4 Mycosynthesis of Metallic Nanoparticles from *Ganoderma Lucidum*

The literature review has shown that research in metallic nanoparticle synthesis uses mycelia filtrates or fruitbodies extracts of mushrooms rather than their isolated organic compounds (Owaid and Ibraheem 2017). The formation process of metallic nanoparticles from organic substrates is considered a new science that relates to the field of green chemistry. The natural resources involve some medicinal plants and herbs (Seetharaman et al. 2017; Chandra et al. 2020), seaweeds (Narendrakumar et al. 2020), edible and medicinal macrofungi (Rabeea et al. 2020), and bacteria (Jafari et al. 2018), Also, for example, the AuNP (gold nanoparticle) has miscellaneous biological and medical applications (Dheyab et al. 2020).

Only a small group of publication has been done on mycoreduce ions of Au by myco-compounds isolated from mushrooms like Schizophyllan from fruiting bodies of *Schizophyllum commune*(Bae et al. 2007), glucan (polysaccharides) from *P. florida* oyster mushroom(Sen et al. 2013), and laccase (proteins) from another oyster mushroom (*P. ostreatus*) (El-Batal et al. 2015). However, most of the researches in the current aspect used different mushroom crude extracts obtained from fruiting bodies and mycelia to mycosynthesize Au NPs (Owaid and Ibraheem 2017), like *P. florida* (Bhat et al. 2013), *Volvariella volvacea* (Philip 2009), *Grifola frondosa* (Vetchinkina et al. 2013), *P. sapidus* oyster mushroom (Sarkar et al. 2013), *Pleurotus cornucopiae* (Owaid et al. 2017), *Hericium erinaceus* (Raman et al. 2015), *Agaricus bisporus* (Eskandari-Nojehdehi et al. 2016; Eskandari-Nojedehi et al. 2018), *Flammulina velutipes* (Narayanan et al. 2015; Rabeea et al. 2020), and *L. edodes* shiitake mushroom (Owaid et al. 2019). Besides, AgNPs (silver nanoparticles) have been made from some species of *Ganoderma* such as *G. neo-japonicum* (Gurunathan et al. 2013), *G. lucidum* (Aygün et al. 2020), *G. applanatum* (Dandapat et al. 2019; Jogaiah et al. 2019), and *Ganoderma sessiliforme* (Mohanta et al. 2018), and *G. lucidum* has been used to mycosynthesize extracellular (Kumar et al. 2017) and intracellular Au nanoparticles (Vetchinkina et al. 2013).

The biosources were depleted, as industrial waste, particularly dyes, was not adequately treated, and this poses a severe environmental threat due to the toxicity of the dye, which is hard to analyze (Nandhini et al. 2019). However, the conventional approaches to industrial dye removal in aqueous solutions like water are not successful. Nevertheless, bacteria, some agrowastes (Nallapan Maniyam et al. 2020), some Actinomycetes (Saipreethi and Manian 2019), and enzymes of basidiomycota (Cardoso et al. 2018) have great capability to decolorize Azo dyes, but NPs biosynthesized using green approaches were important for treating wastewater. Besides, all metallic NPs made from plants showed a good role in the removal of methylene blue dyes (Anchan et al. 2019; Ganesh et al. 2019). Also, 18.70-nm crystals of AuNPs have been synthesized from phenols of *Ganoderma lucidum* which showed rapid MB dye removal (Abdul-Hadi et al. 2020). Besides, mycosynthesized Au NPs from some mushrooms have antioxidant, anticancer, and catalytic efficacy (Owaid and Ibraheem 2017). In brief, the use of mushroom in the mycosynthesis process of NPs is very significant (Owaid 2019) due to the huge amount of mushroom products such as mycelia, fruiting bodies, and metabolites that decrease the cost of the synthesis and rise the eco-friendly aspect (Owaid and Ibraheem 2017). Further, the synthesis of *Ganoderma lucidum*–based nanoparticles and their applications are illustrated in Fig. 4.

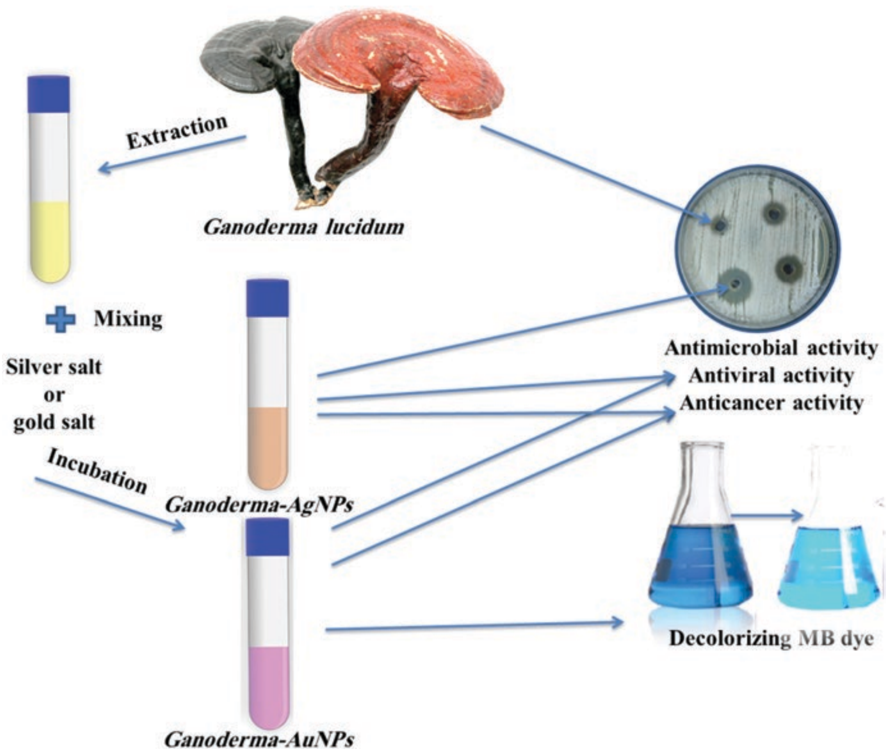


Fig. 4 Synthesis of *Ganoderma lucidum* nanoparticles and its applications

5 Conclusion

G. lucidum is an important natural source of myco-compounds that are used to treat different diseases for numerous years. It has many bioactive components, including polysaccharides and triterpenes; thus, it is used in the treatment of cancer and the regulation of the human immune system. Recently, this mushroom has been used as an eco-friendly reducing agent in the green mycosynthesis of metallic nanoparticles. Moreover, *G. lucidum* was used in pharmacological application, especially as antidiabetic, antihypertensive, antiviral, cardioprotective, hepatoprotective, antioxidant, immune-modulatory, and anticancer agent.

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Health-Promoting Benefits, Value-Added Products, and Other Uses of Banana

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Contents

Abbreviations

ABPC	Activated banana peel carbon
BPE	Banana peel extract
BPP	Banana peel powder
DW	Dry weight
FRP	Fiber-rich powder
FW	Fresh weight
GI	Glycemic index

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HPLC High-pressure liquid chromatography
RBF Raw banana flour
SSF Solid-state fermentation
VOC Volatile organic compound
WBS Waste banana stem

1 Introduction

Bananas are monocotyledons and belong to the family Musaceae. They are tree-like perennial herbs, 2–9 m tall, with an underground rhizome or corm, a pseudostem composed of leaf sheaths, and a terminal crown of leaves through which an inflorescence emerges (Seymour 1993). Bananas are broadly classified into dessert and cooking types. Dessert types are eaten raw when ripe, while cooking (starchy) bananas are boiled, fried, brewed, powdered, or roasted before consumption. Plantains are the best known among the cooking bananas and form about one-third of total banana production (Nayar 2010). They are grown all over the tropics and, to some extent, in the subtropics, with 37% in South and Southeast Asia and the Pacific, 30% in tropical Africa, 26% in Central and South America and the Caribbean, and about 7% elsewhere (Nayar 2010). It is grown up in more than 130 nations, usually in the tropics and subtropics, and has a South-East Asian base of origin (Singh et al. 2016). They are predominantly produced in Asia, Latin America, and Africa. The biggest producers of bananas are India, which produced 29 million tonnes, and China at 11 million tonnes per year. Philippines, Ecuador, and Brazil are other courtiers with the highest production of bananas in the world.

Bananas are the most valuable fruits on the world market, next to rice, wheat, and maize (Singh et al. 2016). Aurore et al. (2009) stated that banana, after coffee, grains, sugar, and cocoa, is the fifth rural food crop in terms of world trade. FAOSTAT (2019) suggested that world driving banana makers are India, China, Indonesia, Ecuador, and the Philippines. According to the latest FAO insights, Asia is the largest banana producer, accounting for 54.4% of the world's banana production, with an average banana consumption of 12 kg per capita (FAOSTAT 2017). The majority of the bananas are consumed in the nations where they are produced, and just 20% are sent out to different nations. Ecuador is the largest exporter of bananas, and the United States is the largest importing country in the world (FAOSTAT 2014).

Banana plants have different uses, for example, in the application of food, animal feed, drug, wrapping, the plants have a great contribution (Vu et al. 2018). Banana leaves are suitable lignocellulosic resources and have a range of uses in banana-growing areas, from feed to bundling materials for various food products and also as a covering material (Subagyo and Chafidz 2018). The current chapter is focused on the application of bananas in food, health care, waste utilization, and some industrial applications.

2 Bioactive Compounds in Banana

Plants are important sources of common items that keep up human well-being by contributing toward cell reinforcement exercises (Karuppiah and Mustaffa 2013). As per Lara et al. (2020), phenolic compounds, vitamins, carotenoids, volatile, and organic acids are the essential phytochemicals found in fruits and vegetables that are associated with human well-being. Banana is not only the source of starch, fibers, minerals (magnesium, calcium, potassium, phosphorus, and manganese), and vitamin B_6, but they also contain different bioactive compounds such as carotenoids, biogenic amines, phenolics, and phytosterols (Siddiq et al. 2020).

2.1 Phenolic Compounds

Polyphenols are considered complex groups of compounds with a phenolic ring in their structure. They can be defined based on the number of phenol rings they contain and the components underlying those rings (Siddiq et al. 2020). In banana pulp and peel, numerous phenolic compounds have been identified, such as catechin, gallic acid, epicatechin, tannins, and anthocyanins (Singh et al. 2016). Mattila et al. (2006) reported about 7 mg/100 g phenolic acids in bananas. Further, using the Folin-Ciocalteu reagent, other studies have also detected the presence of these phenolic compounds in bananas (Sulaiman et al. 2011). Kandasamy and Aradhya (2014) have reported that the banana rhizomes are extraordinarily rich in phenolics, ranging from 2.11 to 234.6 mg GAE/g, and are also used as food in Southern parts of India, and have restorative properties. Numerous phenolics have been found as essential constituents in bananas, such as ferulic, salicylic, sinapic, gallic, vanillic, para hydroxybenzoic, syringic, gentisic, and para coumaric acids (Russell et al. 2009). Among these phenolics, ferulic acid substance was the most noteworthy (69% of cinnamic acids). Some phenolic compounds using HPLC have been detected in bananas from Tenerife and Ecuador (Méndez et al. 2003). Tsamo et al. (2015) have studied banana pulp and strip from nine plantain cultivars and two dessert banana cultivars. The authors suggested that hydroxycinnamic subsidiaries, such as ferulic acid-hexoside, were the important ones (4.4–85.1 μg/g DW) in plantain pulp, and rutin was the most concentrated flavonol glycoside (242.2–618.7 μg/g DW) in the peel of plantain cultivars. Total phenolic and mineral content were determined in pulp and peel from eight bananas (*Musa* spp.) cultivars from Malaysia. Chloroform extract of dried peels of Mas cultivar shown maximum DPPH activity. It was also concluded that banana peel has higher nutrient value than pulp. Also, potassium, phosphorus, magnesium, and sodium were the essential components present in both the peel and the pulp (Sulaiman et al. 2011). In the dissolvable cell wall fractions of the fruit pulp, tannins, and flavonoids (gallocatechin, catechin, and epicatechin) have also been identified (Bennett et al. 2010).

2.2 Flavonoids

The main groups of flavonoids known in bananas include flavonols such as quercetin, myricetin, kaempferol, and cyaniding. Flavonoids are protective scavengers responsible for aging and diverse diseases against oxygen-derived free radicals and reactive oxygen species (ROS). Leucocyanidin has been detected in the watery extract of unripe plantain pulp (Lewis et al. 1999). Gallocatechin was extracted from the peel and pulp using HPLC, which showed pulp was less (29.6 mg/100 g DW) abundant in gallocatechin than peel (158 mg/100 g DW). The phenolic compounds present in banana fruit (total flavonoids, anthocyanins, and flavonol aglycones, such as kaempferol quercetin and myricetin) have been determined by Kevers et al. (2007). Bioactive compounds present in 29 banana pulp samples (9 diploids, 13 triploids, and 7 tetraploids) were collected from Active Germplasm Bank of Embrapa Cassava & Fruits (Brazil) by Borges et al. (2014). Results revealed a great diversity in the content of bioactive compounds (phenolic and carotenoids). The composition of bioactive compounds of phenolics, flavonoids, tannins, and carotenoids found in candi banana ethanol and ethyl acetate extracts was analyzed by Laeliocattleya et al. (2018) which revealed that in the ethanol extract, the content of phenolics, flavonoids, tannins, and carotenoids was greater compared to ethyl acetate extract.

2.3 Carotenoids

Various plant species have nearly 600 distinct carotenoids with medicinal benefits due to their novel physiological capabilities (Sidhu and Zafar 2018). In plants and animals, carotenoids are responsible for several vivid colors in nature (Siddiq et al. 2020). In general, carotenoids are analyzed for their role in reducing the risk of infections, basically many cancers and eye sicknesses (Singh et al. 2016). Van Den Berg et al. (2000) noticed that the isoprenoid biosynthetic pathway gives carotenoids, in which its primary function is as cancer prevention agents and frill pigments for light harvesting in plants. Subagio et al. (1996) used column chromatography and HPLC to determine the major carotenoids in banana peel and found that α-carotene, β-carotene, lutein, neoxanthin, violaxanthin, auroxanthin, isolutein, β-cryptoxanthin, and α-cryptoxanthin as the major carotenoids. Ekesa et al. (2015) evaluated the overall carotenoid content of seven banana cultivars, and it varied from 7760 to 10,633 μg/100 g FW. High levels of β-carotene carotenoids have been reported in the different species of banana (Englberger et al. 2003). Other reports are also available which showed the presence of α-carotene, β-carotene, and β-cryptoxanthine in banana (Wall 2006; Englberger et al. 2010). Indian banana varieties were picked and analyzed for presence of β-carotene and suggested the karpooravalli banana had a high content of β-carotene (143.12 μg/100 g) with maximum carotenoid collection in the unpalatable portion (68 μg/g DW) (Arora et al. 2008).

However, the content of bioactive compound such as carotenoids and phenolic compounds vary in the different species of *Musa* spp. (Borges et al. 2014).

2.4 Organic (biogenic) Amines

Biogenic amines are nitrogenous compounds that are formed by ketone and aldehyde amination or by amino acid decarboxylation. Banana pulp and peel contain multiple biogenic amines. For example, dopamine, serotonin, and norepinephrine are some amines found in banana peel and pulp. The feelings of well-being and bliss are given by serotonin. In common fruits and vegetables, physiologically dynamic biogenic amines were investigated, and biogenic amines such as serotonin, dopamine, and norepinephrine from banana fruits were identified (Singh et al. 2016). Kanazawa and Sakakibara (2000) identified that in peel dopamine ranged from 80 to 560 mg/100 g and from 2.5 to 10 mg for mash of commercially matured banana *M. cavendish*. Dopamine concentration was 42, 54, and 5.5 μg/g in the pulp of yellow banana (*M. acuminata*), red banana (*M. sapientum*), and plantains (Feldman et al. 1987), respectively. Dopamine is a catecholamine produced by the elimination of a carboxyl group from L-DOPA (l-3,4-dihydroxyphenylalanine) that functions like a human brain and body neurotransmitter with an impact on our state of mind, reasoning abilities, and passionate power. Bapat et al. (2000) and Romphophak et al. (2005) identified substantial quantities of catecholamine and its precursor, L-DOPA, in bananas. The presence of a lot of dopamine and L-DOPA in the peel part has been noted, and several bioactive compounds have been identified, including banana peel catecholamines. As the extraction time improved from 1 to 120 minutes at 25 °C using methanolic extracts, the authors found that the dopamine content was substantially increased. It has been reported that due to banana fruit maturation, the concentration of L-DOPA and tyramine was increased (Romphophak et al. 2005).

2.5 Phytosterols

In their major impacts on human well-being, such as lowering serum cholesterol and reducing its ingestion in the digestive tract, phytosterols are naturally occurring plant sterols used as additives in valuable foods (Marangoni and Poli 2010). Quilez et al. (2003) revealed that phytosterols have anticancer activity and act as immune system modulators. A detailed analysis of banana peel sterol constituents was carried out, and new sterol, (24S)-14 a, 24-dimethyl-9 a 19-cyclo-5 alpha-cholest-25-en-3β-ol, was identified using chemical and spectroscopic techniques (Akihisa et al. 1986). Knapp and Nicholas (1969), Akihisa et al. (1986), and Oliveira et al. (2006) showed remarkable concentrations of phytosterols in banana fruit. Further, β-sitosterol, stigmasterol, campesterol, cycloeucalenol, cycloartenol, and

24-methylene cycloartanol present in banana peels were noted by Knapp and Nicholas (1969). Steryl glucosides, namely, stigmasteryl 3-β-D-glucopyranoside, campesteryl 3-β-D-glucopyranoside, and sitosteryl 3-β-D-glucopyranoside, have been identified in dichloromethane extracts of Dwarf Cavendish banana (Oliveira et al. 2006). Oliveira et al. (2008) analyzed the chemical composition of Dwarf Cavendish fruit lipophilic extracts of banana peels and showed that high sterol content denoted between 49–71% of the overall lipophilic extract with 31-norcyclolaudenone and cycloeucalenone as the main components. Phytosterols, such as campesterol, cycloartenol, stigmasterol, cycloeucalenone, cycloeucalenol, and β-Sitosterol, are found in banana (Villaverde et al. 2013), and these compounds were found in the unripe peel of ten banana cultivars belonging to the *M. acuminata* and *M. balbisiana* species with values in the range of 2.8–12.4 g/kg DW among different cultivars. The chemical composition of the ready pulp lipophilic extract of banana fruits of various *Musa* spp. was analyzed using GC-MS, and phytosterol was detected in the range of 11.1–28.0% of the total lipophilic components (Vilela et al. 2014). Marangoni and Poli (2010) reported that in patients seeking a substantial reduction in plasma LDL cholesterol levels, normal consumption of up to 3 g/day phytosterols is healthy and has hypocholesterolemic action. These compounds interact with the solubilization of cholesterol in the intestine because of their structural similarities with cholesterol, thus reducing its absorption.

3 Uses of Banana

3.1 Food and Related Products

Banana fruit is very nutritious and contains 75% moisture, 23% sugar, 1% protein, and 0.5% fat; thus, it has incredible health benefits and is a good source of calories (Singh et al. 2018). Ogazi (1996) explained the nutritional composition of plantain and banana. The primary carbohydrate in green fruit is starch, and this contains certain important minerals that are necessary for the proper functioning of the human body and include large quantities of vitamin C and carotene that help to regenerate the immune system. Aurore et al. (2009) have demonstrated that bananas are the possible raw material for the food and nonfood processing sectors. Bananas have been conveniently processed for many value-added items, including flour, puree, chips, beer, dried banana blossoms, jelly, wine, vinegar, sauce, banana peeling sauce/paste, and banana peeling vinegar (Emaga et al. 2007). Further, various uses of bananas are summarized and shown in Fig. 1.

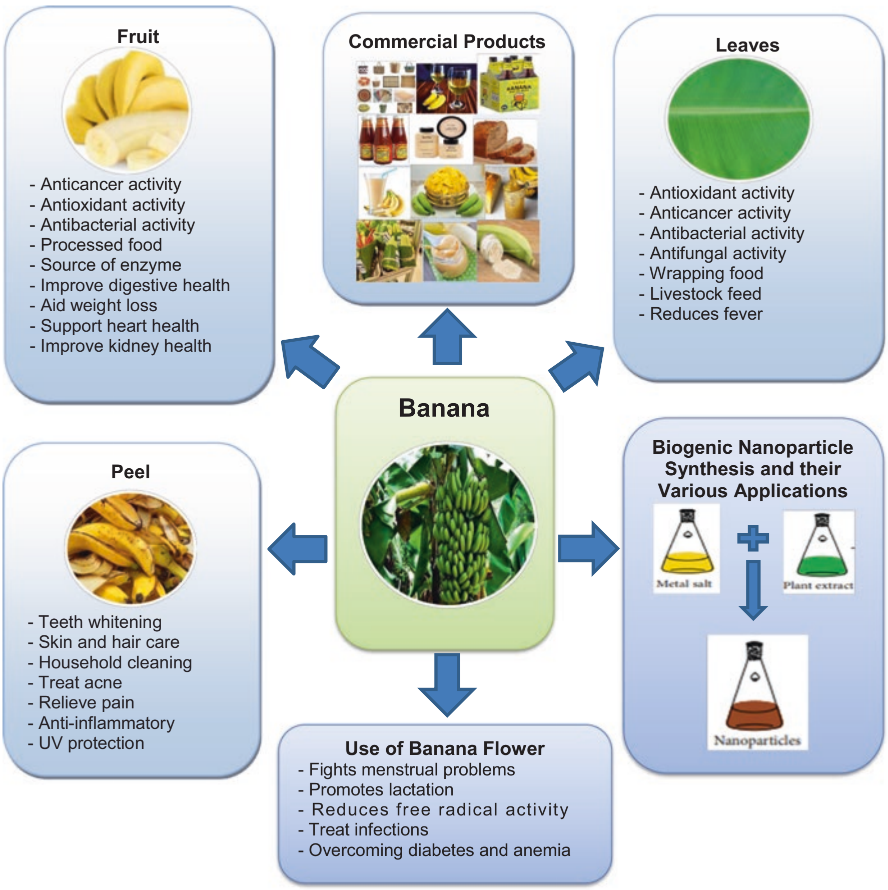

Fig. 1 Potential uses of banana

3.1.1 Banana Flour

Banana flour is an outstanding choice to build usage of bananas, to decrease post-harvest losses, and to keep up the dietary benefit of fresh bananas. Green and Cavendish's bananas have been used to produce banana pulp and peel flour. The green/unripe banana flour showed high dietary fiber and total starch content (Alkarkhi et al. 2011). The authors tested many physicochemical characteristics, such as total soluble solids, pH, water holding capacity, oil holding capacity color values, back extrusion force, and viscosity, and all the statistical analyses showed that physicochemical properties of flour prepared from pulp and peel of green and ripe banana were different from each other (Alkarkhi et al. 2011). Additionally, green banana flour is a source of antioxidant substances (Agama-Acevedo et al. 2012). Menezes et al. (2011) also analyzed unripe banana flour composition and dietary benefit which revealed that banana flour has high levels of dietary fiber and low accessible starch and dissolvable sugar content. Green banana flour, however, demonstrated mild antioxidant activity. Additionally, Bezerra et al. (2013) examined the composition of unripe banana flour. The result showed that fiber content in unpeeled banana flour was higher. However, the lipid and ash content in peeled banana flour was higher. Compared to the peeled banana flour, unpeeled banana flour has a darker hue and a more astringent taste. High amounts of potassium, calcium, iron, and sugars are present in ripe banana flour, which helps to increase blood circulation, and unripe banana flour is rich in resistant starch and dietary fiber which helps in colon health (Pragati et al. 2014). Physicochemical properties (unripe and ripe) of banana pulp flour during the storage of 60 days at ambient conditions were analyzed. Unripe banana flour has a greater water absorption capacity than ripe banana flour (Pragati et al. 2014). By liquefaction of raw banana flour, Rodríguez-Ambriz et al. (2008) developed a fiber-rich powder and measured its chemical composition, water and oil retaining ability, and antioxidant capacity. The demand for banana flour in baking is increasing worldwide (Sarifudin et al. 2020). The maturity stage and dietary characteristics are the key variables in the production of banana flour. Mateljan (2007) revealed that the sugar content of bananas makes them perfect for banana flour preparation.

3.1.2 Banana Powder

Banana powder is found in different kinds of food products as an added substance and fixings (Atchison et al. 2010; Minggong et al. 2019). Yang et al. (2007) confirmed the outstanding health profile of banana powder. Different carbohydrates, minerals (potassium, magnesium, manganese, calcium, chlorine, and phosphorus), and vitamins are abundant in banana powder. Dadzie and Orjeda (1998) observed that sweet bananas contain 75% more water than the water (66%) that is found in cooking bananas and plantain. There are many reports which showed that banana powder has a wide number of application (Orsuwan et al. 2016, 2017; Horie et al. 2020: Biernacka et al. 2020).

3.1.3 Banana Chips

Banana chips are mostly a traditional chow meal in America, Europe, China, and Japan. Banana chips have an incomparable taste and smell (Zhang et al. 2008). The characteristics of banana chips through baking and frying were considered, and their nutritive worth and adequacy were assessed (Abd Elmoneim et al. 2014). Food products like banana chips are sources of minerals including potassium and phosphorus, and their method of preparation of chips is quick, environmentally clean, and straightforward and can be produced at the family level (Zhang et al. 2008; Abd Elmoneim et al. 2014). Banana crispy chips are worldwide characterized by high quality, very popular foods, and their ingredients, texture, and color. They are low destined, high nutritional, but low caloric diets. The demand and consumption of banana crisp chips are increasing day by day independently. Vacuum drying is the most commonly used technique for processing bananas into crisp chips (Zhu 2000; Wen 2002; Zhang et al. 2008).

3.1.4 Banana Jam and Puree

Banana jam can be processed as easily as other fruits (Aurore et al. 2009; Patel et al. 2015; Fibrianto et al. 2020). Aurore et al. (2009) have shown that ripened bananas with a sweet taste, fine flavor, and texture are better suited for jam production. In another study, mixed jam was prepared from banana, watermelon, and pineapple. A result showed that the minerals and vitamin composition of mixed fruit jam were nutritionally rich and better than commercial jam (control) (Awolu et al. 2018). Banana puree is the source of high dietary fiber and helpful in lowering heart risk. Banana puree is used for baby foods such as juices, baked foods, jams, jellies, sugar goods, and sauces (Singh et al. 2018; Shandilya and Siddiq 2020).

3.1.5 Banana Wine and Beer

From the beginning of human civilization, wine has been produced by various fruits. Recently, attention has been given to fruits like banana and orange for the preparation of wine (Tamrakar et al. 2020). Each year, large amounts of bananas are discarded. This is a major loss of an organic product. Alternatively, bananas can also be utilized for ethanol production (Hammond et al. 1996). Bananas have a high amount of sugar content that makes them an appropriate substrate for the preparation of wine. Banana beer is an alcoholic beverage usually produced by fermenting mashed bananas (Pauline et al. 2017; Kubo 2016). Fermentation of banana juice was carried out in the presence of yeast to obtain wine. To minimize the contaminations, it has been suggested that particular attention is required for quality wine production and process. Kiribhaga et al. (2020) studied the biochemical changes in banana wine during storage with different varieties of banana. The result showed that wine from Poovan variety had the highest overall acceptability throughout the storage period. Obiekezie et al. (2020) examined the production, preservation, and shelf-life of wine production from banana which showed that banana is a good substrate for wine production.

3.2 Health Care

Bananas are ideal sources of fiber, carbohydrates, minerals (potassium, calcium, and magnesium), and vitamins (A, B_6, C, and D) (Aurore et al. 2009). Potassium increases muscle power, takes care of muscle functioning, stops muscle spasms, regulates blood pressure, and decreases the risk of stroke (Susanti and Resti 2019;

Jayedi et al. 2019). Vitamins maintain the body's health in a variety of areas, such as teeth, bones, soft tissue, and muscles within the human body and support the immune system of the body, brain health, heart health, and even the absorption of calcium by the body (Holick 1996; Uwitonze et al. 2020; Crescioli 2020; Lewis et al. 2019). In addition to banana fruit as alternative medicine, the banana plant peels, leaves, stem, root, twig, and sap were used as components of traditional medicines to treat cough, fever, asthma, diarrhea, indigestion, and skin diseases as components of conventional medicines (Siddiq et al. 2020). Some of the possible health benefits of bananas are explained Table 1.

3.2.1 Brain Health Improvement

Bananas are good sources of vitamin B_6, which is used for mental function improvement. The US National Library of Medicine reported that deficiency of vitamin B_6 causes confusion, depression, and peripheral neuropathy (Malouf and Evans 2003). Glucose is consumed by the cells in our brain as food. Since our brain is unable to hold glucose, we must supply it daily (Pellerin 2010). Banana fiber steadily release their sugars through the bloodstream, and our body uses this sugar more commonly than refined sugar, and this provides our brain a steady source of glucose (Asadi 2006). Potassium likewise keeps up the levels of oxygen in regularized brain cells. Banana manganese is known to avoid neurological disorders such as seizures and Alzheimer's (Takeda 2003). Levine and Coull (2002) revealed that people with poor intake of potassium may be 1.5 times more likely to suffer a stroke.

3.2.2 Heart Health Improvement

For appropriate contraction and extension, the heart is a smooth muscle regulated by potassium (Haddy et al. 2006). Owing to the presence of assorted potassium ion channels in the heart, bananas are very important for a healthy heart (Khan et al. 2013). Very low potassium levels will also stop the working of the heart. Intake of more potassium combined with physical exercise and a balanced diet is used to maintain cardiac well-being and also to decrease the impact of sodium, consistent with the American Heart Association (American Heart Association 2017). Consuming massive doses of sodium allows our body to absorb water and increase blood pressure. Potassium is then used to decrease this water retention, showing a beneficial effect on blood pressure and even enhances renal function and helps wash the salt out of the body (Doyle and Glass 2010).

Table 1 Uses of banana in different sectors

Plant parts	Responsible compound present	Uses	Key references
Fruit	Fiber, elements (K, Ca, Mg, P, Se, Fe), and vitamins (A, B2, B6, C, E)	Baby food	Barthakur and Arnold (1990)
Peel	Tryptophan, iron, potassium, and serotonin	Prevent depression, anemia, and blood pressure	Schimelpfening (2020)
Peel	Phenolic compounds	Strong antioxidant	Rebello et al. (2014)
Flowers	Phenolic and carotenoids	Antimicrobial	Jahan et al. (2010)
Flowers	Phenolic	Reduce the blood sugar levels	Bhaskar et al. (2011)
Leaves	--	Biodegradable food packaging	Jeenusha and Amritkuma (2020)
Flowers	Phenolics compounds	Antioxidant activity and stabilize the free radicals formed	China et al. (2011)
Pulp	Phenolic compounds	Reduced lipid oxidation of plasma and lipoprotein	Yin et al. (2008)
Flower	–	Treating excessive menstrual bleeding	Agarwal (2019)
Peel	Caffeic acid	Dietary antioxidant	Aziz et al. (1998)
Fruits	Potassium	To lose weight	Gomez (2020)
Leaves	Phenolic	Antioxidant activity	Karuppiah and Mustaffa (2013)
Fruit	Dietary fiber	To decrease the colorectal cancer risk	Le Marchand et al. (1997)
Peel	Phenolic compounds	Antimicrobial activity	Mordi et al. (2016)
Fruit	Potassium	Cardiovascular Protection	Szalay (2017)
Peel	Carbohydrate	Production of wine	Preys et al. (2006)
Pulp	Dietary fiber	cholesterol-lowering	Horigome et al. (1992)
Peel	potassium and nitrogen	organic fertilizer	Kalemelawa et al. (2012)
Stem	Phenolic	Helps to kill tuberculosis bacteria	Connolly et al. (2007)
Peel	Carbohydrate	Bioethanol	Meena et al. (2015)
Peel	Potassium, natural oils, carbohydrates, and vitamins	Hair Care	Bose (2020)
Peel	Cellulose	Bio-substrate	Oberoi et al. (2011)
Flowers	Flavonoid	Antioxidants and anti-hyperglycemic	Marikkar et al. (2016)
Peel	Major nutritional components	Livestock feed	Ahnwange (2008)
Roots and seeds	Phenolics	Treat digestive disorders	Bahmani et al. (2014)
Peel	Leucocyanidin (flavonoid)	Antacid effects against stomach ulcers	Imam and Akter (2011)

(continued)

Table 1 (continued)

Stem	High potassium	To dissolve the stones in the kidney	Vanitha and Vyshnavi (2020)
Peel	Glycosides, alkaloids, saponins, tannins, and flavonoids	Antibacterial activity	Ehiowemwenguan et al. (2014)
Peel	Carbohydrates	Production of lactic acid	Umesh and Preethi (2014)
Peel	Starch	Production of amylase	Jadhav et al. (2013)
Peel	Carbohydrates	Production of wine vinegar	Byarugaba-Bazirake et al. (2014)

3.2.3 Bone Health Improvement

For bone health and structure, potassium and magnesium present in bananas are essential (Kumar et al. 2012). Silicon in bananas can also contribute to the health of the bones (Sripanyakorn et al. 2005). It is important to remember that when the body is acidic, the bones receive a warning to neutralize the acid, and the bones try to do this by breaking down to remove the alkali (Agrawal and Sinha 2017). Zhu et al. (2009) examined the use of potassium supplementation in older women to increase bone density to decrease the risk of osteoporosis. Weaver (2013) linked the intake of potassium to the prevention of bone loss due to age.

3.2.4 Support to Treat Diarrhea, Hangovers, and Anemia

According to the US National Library of Medicine, bananas help in the treatment of diarrhea by substituting the lost electrolyte (potassium). To recover quickly from diarrhea, there is one prescribed diet i.e., bananas, rice, applesauce, and toast (BRAT). For infants and children with disturbed stomachs, BRAT is especially helpful to give the stomach some relief by reducing the amount of stool produced (Duro and Duggan 2007). Since iron helps to combat anemia, vitamin C and copper in bananas facilitate the appropriate absorption of iron (Kumar et al. 2012).

3.2.5 Digestive Health Improvement

Bananas are rich in fiber that is both insoluble and soluble. Insoluble fiber brings bulk to our food, helps to move smoothly, and helps you feel complete after a meal as well (Chuwa et al. 2020). The second (soluble) fiber enhances our digestive well-being and decreases fat and starch intake, maintaining our blood sugar levels at a stable amount. Banana fruit is additionally a rich source of fructo-oligosaccharides that are used more efficiently than other probiotics to feed helpful bacteria in the gut and boost gut health (Kurtoglu and Yildiz 2011). Leucocyanid in bananas aids to increase the thickness of the stomach's mucous membrane, offering extra ulcer protection. (Kumar et al. 2012).

3.2.6 Anticancer Activity

Yellow skin bananas with dark spots are found eight times more effective than the green skin type in fighting against the cancer cells due to the presence of a substance called TNF (Tumor Necrosis Factor) (Ha 2018). The anticancer activity of *M. paradisiaca* flower extract was evaluated on the cervical cancer cell line HeLa by MTT assay, and the result showed that ethanol extract had significant cytotoxicity with an IC50 of 20 μg/mL (Nadumane and Timsina 2014). Nendran banana (banana variety found in Kerala, India) is used as a fruit and a vegetable. Extract peel of Nendran banana was tested for antitumor activity against MCF-7 breast cell lines and found that aqueous methanol extract of Nendran peel has a potent cytotoxic activity which is due to the presence of high flavonoid content in peel extract (Durgadevi et al. 2019). Cancer treatments like chemotherapy and radiation have many side effects, which can be minimized by eating proper food and drink. Banana fruit helps a lot for those recovering from cancer, as it is an important source of many nutrients. Pectin and potassium present in bananas help in recovering from diarrhea caused by cancer treatments (www.healthline.com). Also, studies showed that pectin helped in the reduction of growth of colon cancer cells (Olano-Martin et al. 2003; Tan et al. 2018).

3.2.7 Good for Diabetes

Carbohydrates increase blood sugar levels faster than other nutrients. So, understanding the carbohydrates in the diet is important for diabetics. In bananas, the carbohydrates are in the form of sugar, fiber, and starch. To delay the digestion and absorption of carbohydrates, fibers are used (Lattimer and Haub 2010). This also controls the level of blood sugar and eliminates an increase in blood sugar. Another important aspect to remember is the glycemic load, which is centered on the glycemic index. Depending on their age, bananas have a GI ranging from 42 to 62; this means they have a low glycemic load and could also not be detrimental to diabetics (Liu and Willett 2002; Brouns et al. 2005). Cressey et al. (2014) reported that in patients with type 2 diabetes, daily intake of bananas can raise blood glucose levels.

3.2.8 Immune System Improvement

By defending cells from destruction during chemical reactions, copper in bananas enhances immunity and is also an essential component of enzymes that metabolize iron (Nile and Park 2014). For the immune system, iron is also crucial. The banana fruit contains vitamin C that stimulates white blood cell development. Folate is another essential nutrient found in bananas that required cytokine synthesis, which is the protein that controls the immune response. Potassium and magnesium in bananas also increase the functioning of the immune system (Kumar et al. 2012).

3.2.9 Hair and Skin Care

Banana is used for skin and hair beauty treatment. In bananas, calcium, potassium, natural oils, nutrients, carbohydrates, and vitamins help to smooth the hair, maintain the natural elasticity of the hair, and avoid split ends and breakage. Bananas are also used to recover the dampness lost and repair damaged, dull, and dry skin. Bananas are a rich source of nutrients and antioxidants that help to keep the skin youthful and prevent wrinkles. Nutrients like vitamin A, zinc, and manganese are anti-inflammatory. Accordingly, rubbing a banana peel on our face treats acne (Kumar et al. 2012).

3.2.10 Water Purification or Treatment

The banana fruit causes a large amount of waste and its unsafe damping produces greenhouse gas. The use of banana waste-derived adsorbent for water purification had significant advantages as it has low cost and easily available. Lead and copper ions were removed from water using grounded banana peel by Castro et al. (2011). Banana peel and stem (after activating with sodium hydroxide and formalin) were used for removal of Cu(II) ion present in textile industry effluent (Hasanah et al. 2012). This study showed removal efficiency of 89.01% with pH of Cu(II) ions solution 4.0 and contact time of 12 h. In another study of banana peel, carbon peel was utilized to remove the heavy metal Cu^{2+}, $Pb^{2+,}$ Cd^{2+}, and Cr^{6+} ions (Li et al. 2016). Sathasivam and Haris (2010) used banana trunk fibers for the removal of Fe(II), Cu(II), Cd(II), and Zn(II) from aqueous solution and found that the adsorption capacity of banana trunk fibers depends on pH of the solution and initial metal ion concentration. Banana peels' activated carbon was used for the removal of Cd (II) from an aqueous solution, and in a solution of 20 mg/ L, the percentage of removal of Cd(II) ions was found to be 98.35% (Mohammad et al. 2015).

3.2.11 Banana Waste Product Utilization

Banana plants produce a huge amount of waste that can be converted into different useful products. Different reports say differently about the volumes of waste generated. According to one report, the volume of waste generated is almost double when compared to the weight of banana produced by (Kamdem et al. 2013), while other reports say total waste generated (1.5 ton of leaves and 2.5 ton of pseudostem) is four times when compared of banana fruit (Sellin et al. 2013).

3.2.12 Banana as a Source of Nutraceutical and Bioactive Compounds

Banana by-products contain compounds with nutraceutical properties and are used in the pharmaceutical industry. Polyphenolic compounds such as gallocatechin, caffeic acid, cinnamic acid, and catechin have various functions including antimicrobial, antioxidative, neuroprotective, chemopreventive, anticancer, and antiproliferative activities (Shan et al. 2008; Chye and Sim 2009). Jenshi et al. (2011) found that owing to their antioxidant, anti-inflammatory, antiviral, and anticarcinogenic properties, banana inflorescences are abundant in anthocyanins that are essential constituents in human nutrition.

3.2.13 Livestock Feeds

Banana by-products are one of the possible raw materials for feedstock processing in most banana-producing countries (Padam et al. 2014). Ahnwange (2008) stated that banana peels have a significant amount of carbohydrate, protein, fiber, and essential minerals like potassium, calcium, manganese, sodium, and iron; due to this, banana peels serve as a raw material in feed production. Microbial fermentation raises the nutritional value of banana waste to produce feedstock of high nutritional content from low levels (Hong et al. 2004).

3.2.14 Paper Production

Another possible application of banana by-products is in paper manufacture (Padam et al. 2014). Cordeiro et al. (2005) observed that *M. acuminata* Collap pseudostem can be used either on its own or in conjunction with other popular pulps for pulp and paper production. Goswami et al. (2005) have shown that banana pseudostem pulp from *M. paradisiaca* provides a better tensile index, burst index, tear resistance, and oil resistance when joined with bamboo mash in the manufacture of oil-free paper. Ogunsile et al. (2006) also compared the consistency and yield of the pulp produced from various varieties of banana by-products. The authors reported that 34–49% of pulp is provided by the leaves, pseudostem, and fruit stalk, and the yield was strongly affected by the pulping parameters such as pH, temperature, and pulping time. Jacob and Prema (2008) observed that banana-based papers have a very low potential for water absorption, making them more resistant to water and tougher than wood-pulp paper.

3.2.15 Renewable Fuel

Energy has a crucial role in the growth of any nation. The trend of using greener and more renewable fuels has been growing around the world to eventually decrease and substitute nonrenewable energy sources because of the environmental problem of burning fossil fuels (Hill et al. 2006). Gebregergs et al. (2016) studied the use of banana peels as a raw material for the manufacture of bioethanol using *Saccharomyces cerevisiae* yeast. Also, Guerrero et al. (2018) study the use of banana peel as raw material for bioethanol production, and saccharification and fermentation conditions were optimized. Kwon et al. (2020) explored the production of syngas (fuel) by banana peel pyrolysis and the use of CO_2 as the raw material.

3.2.16 Biofertilizers and Organic Fertilizers

Banana peel has a high content of potassium (40% of the fruit content) and can be used in the garden as fertilizer. It provides the nutrients that plants need to flourish and also acts as pest repellent (Haider 2013; Hulbert 2014). Doran et al. (2005) reported that the use of banana waste as agricultural fertilizers and biofertilizers has been dramatically increased by incorporating biotechnological approaches. Converting banana waste by solid-state fermentation into biofertilizers and using it as a banana farming nutrient greatly raises plant biomass, increases fruit production, and decreases the mortality of planted suckers (Phirke and Kothari 2005). Nano-fertilizer was prepared from banana peel and was tested on tomato and fenugreek crops. The germination percentage of tomato crop after 7 days was increased from 14% (control without nano) to 97% while 25–93.14% (Hussein et al. 2019). Another study showed that poultry manure and banana waste were effective biofertilizers and good for the growth of banana crops.

3.2.17 Banana Fiber for Fashion and Textiles

Banana fiber is a natural fiber that is durable and biodegradable and manufactured from the pseudostems of banana trees. It comprises natural gums fused by thick-walled cellular tissue and consisting predominantly of cellulose, hemicellulose, and lignin (Doshi 2017). Banana fiber is commonly used to produce wall drilling cords, ropes, and cordages for power transfer, fishing nets, banana papers, handicrafts, and products for textiles and packaging (Vigneswaran et al. 2015). Banana fiber is one of the existing earth-friendly alternative fabrics in the textile industry, owing to the harmful impacts of synthetic petroleum-based fibers and increasing awareness of resource-intensive natural fabrics pursuing alternative fibers (Ottman 2011). Vigneswaran et al. (2015) found that there are many beneficial physical and chemical properties of banana fiber, making it a very good raw material for the textile and packaging industries. Banana fibers have higher tensile strength, thermal resistance, UV resistance than cotton, and soundproof properties in the form of fibers and nano-fibrillated cellulose films making many textile products favorable (Priyadarshana et al. 2020a, b).

3.2.18 Biogenic Synthesis of Nanoparticle Using Banana

Nanoparticles (NPs) are gaining importance in every field of life due to their versatile applications (Husen and Siddiqi 2014a, b). Several scholars have shown keen interest in the green synthesis of NPs from plants and their applications (Husen et al. 2019; Bachheti et al. 2019; Husen 2020a, b, c; Bachheti et al. 2020a, b, c). Reports are available on the green synthesis of NPs from bananas. For instance, banana peel extract was utilized for the synthesis of palladium NPs and was characterized by using UV–Vis, FTIR, SEM-EDS, XRD, and DLS. The size of synthesized NPs was found to be 50 nm in size. FTIR analysis showed the presence of carboxyl, amine, and hydroxyl groups in the banana extract (Bankar et al. 2010). In another study, mesoporous silica NPs were prepared using banana peel ash and tested for adsorption of methyl orange and phenol from an aqueous solution. In this experiment, the optimum pH was 5 and 3 for the removal of phenol and methyl orange, respectively (Mohamad et al. 2019). Very recently, different concentration of $AgNO_3$ solution (0.125; 0.1; 0.075 and 0.05 M) was mixed with banana peel extract to prepare silver NPs at a temperature of 50 °C. The synthesized NPs were characterized by UV-Vis, FTIR, and SEM. It was noticed that 0.1 M $AgNO_3$ concentration gave the highest absorbance in UV-Vis spectrometer (Pratikno et al. 2021). Banana peel crude extract was used as a reducing agent for the synthesis zinc oxide NPs. The shape of synthesized zinc oxide NPs had shown rod-like or sheet-like structures. These particles had shown antibacterial activity and anticancer activity (Ruangtong et al. 2020).

4 Conclusion

Banana and their wastes, such as peels, leaves, flowers, and stems, are rich sources of many nutrients and bioactive compounds of functional significance. They contain polyphenols, flavonoids, carotenoids, phytosterols, minerals, vitamins, carbohydrates, amino acids, pectin, and dietary fibers. Because of their functionality, bananas and their waste products have shown potential uses in the food and pharmaceutical industry, water purification of plants, and cattle feed formulation. Banana has several health advantages such as the treatment of cough, headache, asthma, diarrhea, indigestion, skin diseases. It also promotes immune system, mental health, and cardiac health; calcium absorption by the body; and reduces cholesterol. Banana wastes, such as peels, pseudostems, inflorescence, leaves, fruit stalk (floral stalk/rachis), and rhizome, function in various food and non-food applications. Waste products obtained from bananas have been utilized in water treatment, nanoparticle synthesis, and textile industries. Interestingly, it has been noticed that banana fiber is one of the existing earth-friendly alternative fabrics in the textile industry, owing to the harmful impacts of synthetic petroleum-based fibers. To explore more in terms of industrial application, many wild species of bananas also need to be examined and commercialized. In the future, research is also required in the area of pest and disease control, nutrition improvement, genomics, and low-cost micropropagation of bananas. Also, there are a large number of publications on the application of banana waste as bio-absorbent that are accessible, but still, there is no commercial process available in the market, so there all necessitated more intensive research works.

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Forest-based Plants in Beautification and Their Medicinal Significance

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1 Introduction

Trees are the silent ambassadors of life. Ironically, it was climate change that brought our focus on the trees. Ever since there has been a paradigm shift in the utilization and promotion of non-timber forest products (NTFPs). NTFPs have significantly affected the general well-being, conservation strategies, and livelihood of forest communities. Product commercialization, namely nuts, fruits, fibre, resins, oils, fats, medicines etc. has further contributed to an escalated market value of forest resources (Nautiyal et al. 2002; Marshall et al. 2003; Borai and Husen 2003; Joshi et al. 2003). The forest plant species have been well documented for their use as therapeutic agents (Nautiyal et al. 2002; Andel 2006). These products have been in use in the traditional systems of healing since time immemorial. Herbal renaissance, aided by a boom in the cosmetic and nutraceutical industry, has furthered the harvesting of forest resources for medicinal/cosmetic/nutraceutical product preparations. Most of the raw material is still collected from the wild leading to a potential threat to their existence. Besides, various ornamentally important plants are found in the forests. The floriculture industry has metamorphosed into one of the most prominent and fast-growing global enterprises. To cater to the industrial demand, there is an increased focus on exotic varieties and new hybrids while the natural plant's wealth is yet to be prudently harnessed for its ornamental and medicinal value.

India, with biodiversity hot spots in four phytogeographical regions, namely IHR (Indian Himalayan range), Western Ghats, North East India and Andaman and Nicobar Islands, represents about 12% of the global floral diversity. This diversity needs to be discreetly exploited for medicinal and ornamental use. Of the different plant species that can be utilized for the aforesaid purpose, seed pod plants need a special mention. In these plants, the fruit grows into a pod that contains the seeds of the plant. The flowers and distinctive fruits are characteristic features of the big plant family – Fabaceae. The seeds (legumes) are well known as sources of a wide range of phytochemicals accounting for their tremendous medicinal potential. The broad Orchidaceae family also includes the stunning orchid plants that occupy the top position in the global floriculture trade owing to their magnificent floral beauty, with some of the members also exhibiting medicinal properties. The present chapter is an attempt to highlight the significance of forest-based plant species for embellishment in native gardening and utilization in therapeutics.

2 Native Gardening and Landscaping

Indigenous flora of a region is the natural flora of a specific region (Joshi et al. 2019). A native garden or natural landscape is a creation where native plants are allowed to grow, primarily to conserve biodiversity. The focus is on the utilization of local and endemic plant species (trees, shrubs, herbs and grasses) that have been growing in the wild for several years in a particular geographical zone. In native gardening and landscaping, these plants are selected for the decoration of public and private places. While in native gardening, the plants are grown in private and public gardens as potted plants, climbers, shrubs etc., in natural landscaping, these species are grown on a tract of land in a manner that a prolific scenic beauty is created (Thakur and Sharma 2005; Thakur et al. 2009).

2.1 Benefits of Native Gardening/Landscaping

Native plants (trees/herbs/shrubs) are home to the wildlife hence forming the backbone of the ecosystem. Native gardening aims at the aesthetic growing of native plants that serve several purposes. One important contribution of native gardening is the conservation of biodiversity. The endemic varieties of plants and pollinators flourish in these gardens/landscapes, helping in the conservation of biodiversity and strengthening the ecosystem. Native gardening or landscaping epitomizes beautification with minimal investments. Being native to the geographical zone, the plants require little or no maintenance creating an urban green zone with nominal expenditure. The hardiness, easy-to-care property, better tolerance and improved resistance of the native species make the gardens an overall profitable venture (Thakur 2012). Besides, they also help in creating public awareness for the biodiversity of the region and the need for conservation. Local populations become aware of the ornamental and medicinal values of the native plant species. Access and benefit-sharing further facilitate in commercial utilization of these species by the locals while still maintaining them in the gardens. Overall, native gardening assists in conservation, promotion of floriculture, sustainable development of local populations and value addition to the local flora.

2.2 National and International Scenario

Native gardening has gained much popularity in Western countries. An exemplary example has been set by Australia. The country has around 25,000 native plant taxa most of which occur naturally in the Western region of Australia. Many of these plants have exceptional ornamental and medicinal values. However, it was reported that only a limited number was being utilized for home gardening or landscaping. Consequently, they initiated domestication of their native wildflowers like Kangaroo Paw (*Anigozanthos*), Banksia, rice flower etc., resulting in a drastic escalation of annual sales (Growns and Webb 2012). Besides, concerted efforts were done to create novel native plants with improved traits and better adaptability to the Australian climate which would be used for landscaping and native gardening. In Brazilian Pampa, a detailed evaluation of local plant species was done for their use in floral art and landscaping (Stumpf et al. 2012). The study identified 250 ornamentally important endemic species for the purpose. Other countries like the United Kingdom, South America, Sri Lanka, Ethiopia, and several European nations have kept their best foot forward in this direction. India is yet to embark on a full-fledged native plants movement. The Indian flora is rich with a variety of seed pod species of medicinal and ornamental significance. These species need encouragement, care and an approach like the Make in India and can be selected for dual purposes: landscaping features, which include flower beds, ground cover, hedges, shrubberies, avenue trees etc., and preparation of herbal drugs.

2.3 Challenges and Approach

With ever-increasing anthropogenic activities on natural forests, the plant wealth of the country is under severe pressure. Besides, illegal trading poses a potential risk to the plant species, particularly the ornamental varieties. The loss is completely irreparable. To add to the woes, even gardening and landscaping have been focussed on the usage of exotic species that becomes invasive, competing with and degrading the habitats of the native species. It has become the call of the hour to shift our focus to native plant species rather than exotic varieties of ornamentals. In this context, there is an urgent need for the following:

- documentation of native ornamental plant species with medicinal values
- ornamental plant characterization
- validation of medicinal/ therapeutic values of these species
- improvement of genetic characters
- adoption of latest propagation and production technologies
- domestication of the priority species
- species evaluation for commercialization
- public awareness and participation of local populations in species conservation and utilization

3 Plants with Medicinal and Beautification Value

In this chapter, some important seedpod-bearing plants are being discussed that have the potential to be utilized for decorative purposes (Table 1) as well as harnessed for curative properties.

Table 1 Role of plants in beautification

Species name	Use in beautification
Albizia lebbeck	Specimen tree, avenue tree plantation
Abrus precatorius	Decoration of trees, herbs and shrubs
Acacia spp. (*A. sinuata, A. ferrugenea, A. nilotica*)	Scenic artificial fencing or walls
Bauhinia spp. *(B. variegata* and *B. purpurea)*	Winter colour in garden, avenue plantation, specimen tree, group plantations
Butea monosperma	Specimen trees, rockeries, group plantation
Caesalpinia pulcherrima	Shrubbery borders, flower fencing
Cassia fistula	Specimen tree, avenue tree plantation
Clitoria ternatea	Potted plants, decoration of fences and walls
Crotolaria spp.	Border plantation, corner plantings
Dalbergia sissoo	Avenue plantation
Desmodium spp.	Specimen shrub, mass plantations
Erythrina spp. *(E. variegata, E. indica*)	Specimen tree, avenue plantation, hedges, rockeries, fencing/support for vines and climbers
Indigofera pulchella	Specimens, avenue shrubs, mass plantations
Peltophorum pterocarpum	Specimen tree, avenue plantation, street tree, cut flower/dry flower decoration
Pongamia pinnata	Avenue tree, street tree, plantation on banks of canals or streams
Saraca indica	Decoration of homes, parks
Tamarindus indica	Decoration of home gardens, parks, bonsai for indoor décor
Orchids	Potted plants, hanging baskets, over the tree branches plantations

3.1 Albizia spp.

The genus *Albizia* includes shrubs and tree species that are native to Asian and African regions (Parrotta 2002). Of the different species, *Albizia lebbeck* is a medicinally and ornamentally important species. Commonly known as Indian siris or East Indian walnut, the tree is distributed in most of the regions of the country. The tree attains a height of about 15 m and bears beautiful white aromatic flowers. The tree is also ecologically significant, as it is an efficient nitrogen fixer and soil binder helping in increasing soil fertility and preventing soil erosion (Gabhane et al. 1995). The leaves of the tree can also be used as green manure due to their nitrogen-rich composition (Tilander 1993). The seeds, leaves and bark of the tree are used in folk remedies to treat ophthalmic and dermal infections (Ganguli and Bhatt 1993). The pods and roots of the tree yield saponin that is reported to have spermicidal activity while leaves, seeds, pods and bark have anticancer activity (Desai and Joshi 2019). Besides, the tree also provides red-coloured resin (that can be substituted for gum-arabic), and the bark can be used to make soaps (Pal et al. 1995). The flowers are major bee attractants and play a significant role in pollination biology. The sweet-tasting flowers can also be used to make a variety of honey (Gupta 1993). *A. lebbeck* trees are usually planted on roadsides and often in home gardens by landscaping enthusiasts, shade tree in tea and coffee plantations and as rapid growing cover for other plants in coastal areas. They can be effectively used in landscaping for specimens and avenue tree plantation, and plant parts can be utilized in herbal preparations.

3.2 Abrus precatorius

Commonly known as "Bead vine" (vernacular name: Gunja), *Abrus precatorius* (L.) is a perennial, woody climber that grows in abundance in the Indian subcontinent. The plant is well known for its therapeutic properties. In the traditional Indian system of medicine, *A. precatorius* leaf juice is used to cure ulcers; paste of seeds is used to treat stomach ache (application with ghee/ butter), joint pain (consumption with milk) and baldness (application with honey); leaf powder is used for urine infection treatment and root and leaf powder is used to cure eye infections. Besides, the seed tea leaves are used to treat common cold and cough, while oil is also known to have aphrodisiac property. The immunostimulatory, immunomodulatory, anti-inflammatory, antidiabetic, anti-malarial, antiviral and anti-epileptic properties of the plant are attributed to a wide range of active chemical ingredients, namely alkaloids, triterpenes and flavanoids (Garaniya and Bapodra 2014; Balachandran and Rajendiran 2015). The plant bears attractive pink flowers and can be used to decorate trees, herbs and shrubs in gardens and public places.

3.3 Acacia spp.

Acacia genus comprises plants mainly found in the warm and drier regions of the world. The native species of *Acacia* are thorny shrubs and trees. Acacias are well known for their usage as fuel, fodder, gum, tannins and timber. Native species like *A. sinuata* are also valued for their saponins in soap and detergent preparations. Flowers of *A. ferrugenea* emit a beautiful fragrance and are used in perfume making. The wood of Acacias is also used in preparing local agricultural implements due to its strength, besides being used for furniture making. The gum obtained from the tree is of special importance, as it is extensively used in preparing confectionery items, medicines, and in the paper and textile industry. Acacias have been well documented for their therapeutic uses. Active ingredients like steroids, kaempferol, niloticane, isoquercitin androstene, gallic acid, catechin etc. have been reported from different species (Mutai et al. 2004; Eldeen et al. 2010; Singh et al. 2010). *A. nilotica*, in particular, has been documented for its use in different home remedies for treating ulcers, dysentery, diarrhoea, tuberculosis and leprosy has been an important (Kumari 2013). The species has also been used in the development of bird sanctuaries in otherwise declared wastelands. Acacias can be employed for the beautification of home gardens and landscaping as they have a picturesque effect. The thorny bark of the trees prevents unchecked barging in of animals and people. Consequently, *Acacia* species can be used as a cheaper, ecologically beneficial and appealing substitute for artificial fencing or walls.

3.4 *Bauhinia spp.*

The *Bauhinia* group has more than 200 species (liana, shrubs and trees) that are found in the tropical and temperate regions (Connor 2001; Wang et al. 2014). *Bauhinia* spp. have been acknowledged for their large, flashy blooms, foliage and medicinal value in different parts of the world (Connor 2001). In India, *Bauhinia* spp. are distributed in most of the regions from north to south. *Bauhinia variegata* and *B. purpurea* are two important species that have varied usage. *B. variegata* bears differently hued flowers ranging from white to shades of pink and purple. *B. purpurea* flowers are more of purplish shade (light pink to bright pink-purplish) leading to it is commonly called ‘The Purple Orchid Tree’. The flowers in both cases are extremely prolific in appearance with an enchanting fragrance. *B. variegata* (commonly known as kachnar in India) has been popular in Ayurvedic, Homeopathic and Unani system of medicine. Chemical constituents like octacosanol, hentriacontane, β-sitasterol, lupeol stigmasterol and many amino acids account for its antimicrobial, anticancer, antidiabetic, antigoitre, haemagglutination and hepatoprotective activities (Singh et al. 2012; Shahana et al. 2017; Khare et al. 2017). *B. purpurea* is also known to be used for its antidysenteric, antidiarrhoeal, febrifugal properties, preparation of dyes (Contu 2012), equipment used in agriculture and as fuelwood (Connor 2001; Orwa et al. 2009). Both species can be used for native gardening and landscaping as winter colour in the garden, avenue plantation, specimen tree and group plantations.

3.5 *Butea monosperma*

Butea monosperma, also known as Bastard teak and ‘Flame of the forest’, is a slow-growing, medium-sized multipurpose tree. The tree is widely distributed in the Indian subcontinent where it is known by vernacular names dhak, palash and tesu. The tree is considered sacred in Hindu mythology. The medicinal and therapeutic properties of the tree are well known in the traditional medicine system (Jhade et al. 2009; Tiwari et al. 2019). Stem juice and leaves have excellent astringent properties. The leaves are also known to have diuretic, astringent and aphrodisiac properties (Gupta et al. 1970). The gum obtained from the bark (butea gum) is known as ‘kamarkas’ and commonly used as a food ingredient and in the leather industry. The flowers are used to prepare red/orange dye which also has insecticidal activity. The species is associated with a wide range of pharmacological properties like hepatoprotective, anti-inflammatroy, antimicrobial, antidiabetic, antigiardiasis, anti-infertility, antidiarrhoeal etc. (Burli and Khade 2007). The tree has resplendent orange-coloured blooms accounting for its ornamental value for beautification as specimen trees and also for rockeries and group plantation in large landscaping.

3.6 Caesalpinia pulcherrima

Caesalpinia pulcherrima (L.) is a small shrub that attains an average height of around 3 m. Commonly known as Peacock flower or Red bird of paradise, it bears strikingly radiant flowers in racemes that are around 20 m long with brilliant red, orange or yellow petals. *C. pulcherrima* has been in cultivation for long as an ornamental specimen and in avenue plantation. Flashy flowers are excellent pollinator attractants. The prickly branches assist in its usage as shrubbery borders and 'flower fencing'. Besides being popular as an ornamental, *C. pulcherrima* is also used for treating gastrointestinal infections, dysentery, diarrhoea and other stomach and uterine-related ailments. It is also reported to have antipyrexic, antioxidant, anti-asthmatic, antiviral, antibacterial, antimalarial, insecticidal, anticatarrhic and immunomodulatory properties (Chiang et al. 2003; Patel et al. 2010; Chew et al. 2011; Sharma and Rajani 2011; Vivek et al. 2013; Khan et al. 2018). The species needs to be judiciously utilized for its ornamental and medicinal properties.

3.7 Cassia fistula

Cassia fistula (L.) is an evergreen tree known for its dazzling yellow flowers, aroma and medicinal use. In India, it is commonly known as 'Amaltas' and grows in the regions of Himalayan and sub-Himalayan tracts, Eastern states, Deccan plateau and Southern India. In folk remedies, the plant parts are used in treating abdominal and throat tumours, carcinomas and uterine abscesses (Duke 1983). Studies have confirmed their antimicrobial and laxative properties (Kumar et al. 2006; Senthilkumar et al. 2006; Danish et al. 2011; Kamath and Kizhedath 2019). The wood is also used in making agricultural implements. Owing to their attractive appearance, *C. fistula* trees can be used as a specimen and avenue tree plantation for beautification of available areas.

3.8 Clitoria ternatea

Clitoria ternatea (L.) (common name Butterfly Bean) is a legume that has been widely used as a livestock feed. It is grown as a crop for ground cover, green manure and hay production (Gomez and Kalamani 2003). The significant features of this species are rapid rate of regeneration, tolerance to drought, adaptability to heavy clay soil, increasing soil fertility and high-quality palatability, leading to it being identified as species capable of natural grassland improvement (Staples 1992). The species is also used for culinary purposes in different parts of the world. *C. ternatea* has been used in the Siddha medicines to cure fever, eye infections, leucorrhoea and worm infestations. *C. ternatea* has been reported to possess antibacterial, insecticidal, antipyretic and muscle-relaxing properties (Mukherjee et al. 2008). The roots of the plants are also known to have antiasthmatic activity (Chauhan et al. 2012). The extract from the flower is reported to act as an antioxidant, anti-inflammatory and antidepressant agent (Karel et al. 2018). *C. ternatea* can be grown to screen unpleasant areas, as potted plants, over fences, walls and trellis.

3.9 Crotolaria spp.

The *Crotolaria* genus is spread across the tropical and sub-tropical regions of the globe. In India, it is majorly concentrated in the Western Ghats region with around 50% of the total *Crotolaria* species in the country being endemic to Peninsular India (Rather et al. 2018). The genus includes herbs and shrubs and rarely trees. The *Crotolaria* species are a known source of manure, fodder and fibre. *C. retusa* has been reported to have ethnomedicinal use in treating syphilis and malaria (Rouamba et al. 2018). The species with showy flowers can be used for ornamental purposes in native gardens, along borders, and in corner plantings.

3.10 Dalbergia sissoo

Dalbergia sissoo L. (Indian rosewood, Sheesham) is a horticulturally important perennial tree that is primarily valued for its timber. The tree is also used as fuelwood, fodder and ornamental tree. The wood is highly priced for its durability, smoothness and finishing and is widely used for furniture making (Lowry and Seebeck 1997) and its fibres in paper making. The sawdust from wood is employed in heavy metal remediation (Habib-ur-Rehman et al. 2006). Folk medicines have been utilizing *D. sissoo* in treating skin, blood, stomach, eye and inhalational diseases. It is also known to have anti-inflammatory, analgesic, antihelmintic, antipyretic, antioxidant, antidiabetic, expectorant, aphrodisiac and insecticidal properties (Asif and Kumar 2009; Kaur et al. 2011; Kharkwal et al. 2012; Pund et al. 2012; Bharath et al. 2013; Bhattacharya et al. 2014). The tree is usually planted as a shelterbelt, shade tree and windbreak. It bears fragrant flowers and can be used for landscaping as an avenue plantation

3.11 Desmodium spp.

Desmodium genus includes more than 250 species growing in the tropical and subtropical regions. Several species of the group are used as forages and in forestry as shade plants and to check weed growth (Khan et al. 2001; Gu et al. 2007). They have been used in traditional medicines to treat liver, kidney and stomach diseases, ulcers, eye infections, abscesses, acne and general pains in body parts (Allen and Allen 1981; Ngondya et al. 2016). India is home to about 60 *Desmodium species,* which are commonly called as the 'Indian telegraph'. The beauty of pink/purple-coloured flower accounts for its usage as a specimen shrub and mass plantations.

3.12 Erythrina spp.

Erythrina is a pantropical genus of Fabaceae. *E. variegata* (Indian coral tree) and *E. indica* are two common Indian species that can be exploited as ornamental trees (Adema 1996). These are thorny deciduous trees with an average height ranging from 80 to 90 ft. Thick clusters of rich red or crimson-coloured flowers are a characteristic feature of the species. The striking red blooms present an enthralling image when they appear on the leafless dry branches (Thakur 2012). Some cultivars also have white flowers and known as 'Alba'. The flowers attract the avian fauna and insects like wasps, butterflies and bees. The trees can be used for specimen, avenue plantations, rockeries, fencing and support for vines and climbers. They can also be planted as hedges around gardens. Besides, the tree species have been used to prepare medicines for stomach, liver infections, in antiabortion and malaria treatment (Baidya et al. 1995).

3.13 Indigofera spp.

Indigofera is a large genus that includes more than 700 species distributed in the tropical and subtropical regions of the world (du Puy et al. 2002). The genus is primarily valued for the dye 'indigo' sourced by the member species. Besides, pharmacological and phytochemical investigations have revealed that the genus is rich in several chemically active components that have potential therapeutic value (Rehman et al. 2017). *Indigofera tinctoria* is known to yield the 'true indigo dye'. However, plant-derived indigos have been widely replaced by commercial, synthetically manufactured indigo dyes. The species is reportedly used for the preparation of traditional medicines to treat epilepsy, neural disorders, bronchial asthma, liver ailments, urine infections, ulcers and sores (Lemmens and Wulijarni-Soetjipto 1991). The tree leaves are also used as herbal tea. *I. pulchella* is another medicinally important species that is used in folk medicines to treat lung and stomach infections (Khare

2007). The trees bear beautiful pink or violet blooms and can be used for beautification as specimens, avenue shrubs and for mass plantations.

3.14 *Peltophorum pterocarpum*

Peltophorum pterocarpum (DC.) Backer ex Heyne is a deciduous tree species that bears resplendent orangish-yellow flowers. It is also used as fodder, fuelwood and timber. The tannin from the tree is used as a dye for paintings and tanning leather. Folk remedies have been widely using the plants in treating muscular pains, worm infections, bruises, sores, intestinal infections and childbirth pain. It is also used as an astringent and tooth powder. The medicinal properties are due to the presence of a wide range of phytochemicals, namely terpenoids, flavonoids, phenolics, aliphatic alcohols, fatty acids, steroids and amino acids. The fast-growing tree also helps in land reclamation by being an efficient nitrogen fixer. The dense crown of the tree accounts for its usage as a shelterbelt. The flowers are brilliant yellow and are fragrant, presenting a prolific scenic beauty of the land (Thakur et al. 2011). They are major bee attractants hence playing a significant role in biodiversity conservation (Ramanujam et al. 1993). They are also employed as cut flowers and for dry-flower making (Jash et al. 2013). The tree can be used as a specimen for large landscaping, namely for the beautification of large parks, gardens, as an avenue tree and as street trees.

3.15 *Pongamia pinnata*

Also known as *Millettia pinnata* (L.), it is a medium-sized tree or glabrous shrub that is characterized either as evergreen or as briefly deciduous. The tree is found in tropical regions with a humid climate and is valued for its multipurpose benefits. Commonly known as ‘Indian beech’, *P. pinnata* flowers are rich in nectar and serve as a food source for honey bees. The tree is utilized as a source of fuelwood, fibre (for paper/rope making), wood for making furniture and agricultural equipments, tannins and oils. The seed oil is largely commercialized for use as varnish, pain-binder, lubricant and in making soaps. The plant parts are largely used for preparing drugs for the treatment of liver and stomach infection, skin diseases, bronchitis, rheumatoid arthritis, herpes infection, nematode infestation, diabetes, spleen enlargement, haemorrhoids, ulcers sores, cough and cold (Usharani et al. 2019). The tree can be used for plantation as an ornamental tree in homes and parks, avenue tree, plantation on roadsides, banks of canals or streams and as windbreaks.

3.16 *Saraca indica*

Saraca indica (common name Ashoka) is an evergreen tree species with an average height of 24 m and 35 cm width. The tree holds special importance in Hindu and Buddhist mythology. The bark plays a significant role in Ayurveda and is often associated with the treatment of reproductive system ailments in females, namely bleeding in uterine tissue, fibroids, haemorrhoids, menstrual cramps and stimulation of ovarian tissue. It is also shown to have antioxidant and anticancerous activity (Yadav et al. 2015). The bark extract also helps in the regulation of the circulatory system, renal flow and neural stimulations. The tree bears flowers in clusters of orange-yellow hues, becoming red before wilting and are a treat for the eyes (Baranwal and Devi 2016). Besides, they are known to be effective in the treatment of diabetes. Although the tree is often planted in places of worship, it can be judiciously used for the embellishment of homes, parks and gardens. Plantation at public places will ensure the cleanliness of the area, as the public would maintain sanitation near this revered tree.

3.17 *Tamarindus indica*

Tamarindus indica, commonly called tamarind, is a tree growing in tropical and semi-arid regions. It is widely grown in different parts of India and valued for its fruit which is rich in minerals and vitamins. The tender pods are relished as vegetable/pickles. Ripe fruit is sweet and sour and enjoys an international market as syrup, sauce, processed food, and in preparations of confectionaries, condiments, beverages. Tamarinds have been acknowledged in the Ayurvedic system of medicine in treating liver ailments, throat infections, digestion-related issues and problems of male infertility. Tamarind is also used as a cosmetic preparation for improving hair quality on the scalp and treating acne. The leaves have been reported to be a source of several active metabolites like alkaloids, glycosides, flavanoids, steroids and tannins (Dhasade et al. 2018). It has been scientifically proven to have anti-inflammatory, antiobesity, antidiabetic antifungal and anticancer properties. The wood is used in preparing gunpowder and leaves, and fruits are employed for dye preparation (Van der Stege et al. 2011; Paull and Duarte 2012). The species can be widely used for ornamental plantation in gardens, homes and even as bonsai for indoor decoration.

3.18 *Orchids*

One of the largest plant families is Orchidaceae (around 800 genera) which includes the monocots-Orchids. Orchids may be epiphytic, lithophytic or saprophytic and their seeds are borne in pods (Jalal et al. 2008). Orchids are flowers of exceptional splendor and priced heavily for their wide array of colours, patterns, beauty, fragrance and longevity. In India, congenial geographical location and appropriate climatic conditions have proven to be a boon for the growth of a variety of orchid species, and they have also shown several applications in the traditional system of medicine (Husen and Rahman 2003; Husen and Faisal 2005). Many of these orchids are also valued for their medicinal properties. They are rich in alkaloids, flavonoids, glycosides, carbohydrates and other phytochemical contents. Some indigenous people of eastern Himalaya extensively use the beautiful *Vanda coerulea* and *Dendrobium nobile* for eye disease, and the whole plant of *Paphiopedilum insigne* is said to be useful for stomach troubles such as amoebic dysentery. *Aerides multiflora* is known to have antibacterial property and is commonly used in treating cuts and wounds. *Rhyncostylis retusa* is another orchid that is used in folk remedies to cure rheumatism. Some orchids like *Cymbidium elegans*, *Cypripedium pubescens* and *Epipactis latifolia* are used in local medicine for the treatment of nervous disorders. Nevertheless, orchids are mostly valued as ornamentals. They occupy the top position in the global floriculture trade as potted plants and cut flowers which has been increasing by leaps and bounds. Countries like Thailand, Malaysia, Singapore, the Philippines, Sri Lanka and Indonesia have established their orchid industries. Indian orchid industry is still in its native stage. To aggravate the scenario, a majority of the orchid business depended on exotic hybrids. The native orchid species have taken a back seat when it comes to commercialization. The picture is grave in India where several ornamentally and medicinally active native orchid species, namely *Cattleya*, *Cymbidium, Dendrobium, Phalaenopsis, Paphiopedilium, Aerides, Habenaria*, *Rhyncostylis and Vanda* have fallen prey to ignorance (Lal et al. 2019). There is a need to identify and utilize these orchid species in native gardening as potted plants, hanging baskets and plantation as over the tree branches, adding an unparalleled mystique to the garden and parks. The flowers can be further used for cut flower decoration. This will aid in orchid conservation and its potential being harnessed by the local populations.

4 Conclusion

Despite unprecedented advancements in science and technology, the human race is still dependent on the forests to suffice its essential needs, be it food, timber, flowers or medicines. Over the centuries, man has focussed on the floral heritage to nurture for his common good. However, pandora's box has much more to offer. Several wild species are only marginally utilized, while many others are waiting to be explored for their medicinal and ornamental value. There is a tremendous scope of domestication and commercialization of these plant varieties. Thus, an intensive effort is suggested for sustainable utilization and management of native plant species for beautification and therapeutic purposes.

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Food, Fodder and Fuelwoods from Forest

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1 Introduction

India is rich in terms of biodiversity and counted in the top ten wealthy nations that contain wood forests. Altogether, India and the other nine countries namely Russia, Brazil, China, Australia, the US, Argentina, Indonesia and Congo, account for almost 67% of the total forest cover around the world (FAO 2010). India is considered as one of the mega biodiversity nations in the world due to favourable climatic, ecological and phytogeographical conditions that create a foundation for various ethnic plant diversity to expand. Rich biodiversity expansion starts from the north in Ladakh lined with dry alpine forests to the south in Kerala with tropical moist rain forests and the west, the thorny forests penned by desert tract to the eastern part of the country surrounded with lush green plants in the wet evergreen forests (MOEF 2019). In India, the forest is a principal part of rural trade and a prime environmental reserve. The forests in India can be categorized into many types such as temperate, mixed temperate (deciduous and conifers forest), Taiga (consist of pines trees), tropical and sub-tropical forests. But mainly Indian forests are classified into six types of groups only such as montane temperate, dry tropical, moist tropical, montane subtropical, alpine and subalpine. India is a vastly pressured land, having 16% of the world's human population and 15% of the livestock population, although it occupies 2.47% of the world's topographical area and only 1% of the world's forest. The pressure exerted by the humans and cattle population is further exacerbated due to the monsoonal pattern of rain, as nearly 90% of the country receives rainfall varying from 2 to 6 months, and the remaining 6–10 months are dry.

India is historically an agricultural country and mainly depends on wood resources. This dependence has led to the destruction of forest resources adversely in the past few years. The main percentage of the population stays in a rural area where they are mainly dependent on fuelwood. Evidences have shown that some parts of the country that are transformed into desertification were earlier verdant land (Rai and Chakrabarti 1996). Humanity faces the big challenge of nourishing the population that is increasing at a faster rate and also fulfilling the energy needs of the people without exhausting the natural resources of the earth as enunciated by the United Nations General Assembly in 2015 and designed some goals known as Sustainable Development Goals (SDGs) or Global Goals (UN 2015). Each goal of SDGs has some targets and indicators to achieve a healthier and more sustainable future for everyone. Food and nutrition are the central targets for SDGs to achieve good health and well-being of one and all. The prolonged increase in the global population at a faster rate and simultaneously, the demand for food has also been increasing especially since the rise in the animal source food will be observed more in the developing countries (Alexandratos and Bruinsma 2012).

Globally, India stands at 10th position in the forest-rich country. The forest in India is increasing at a rate of 0.20% every year from 1999 to 2000. But from 2000 to 2010 there was only a 0.7% annual increase in the forest cover (FAO 2010). FAO (2010) estimated that Indian forest cover has reached just about 68 (Mh) million hectares that is almost 22% of the country's area. In the year 2018, the State forest report clearly showed that India's total forest and tree cover has increased to 24.3% even so in just 1-year of span the total forest area has exhibited a sudden rise up to 24.56% in the year 2019 (Ghosh 2018; Aggarwal 2020). The forest has an indispensable role in food security for millions of household people around the world to be contingent on food and fodder.

Although forest food does not provide a complete diet still, they play a principal role in the food supply. The edibles that we are getting from the forest are nutritionally essential and traditionally used as a staple food. The earth has a diverse ecosystem as well as different types of woodland and culture, which is related through the progression, which has produced different varieties of the food system that associate with the number of trees and forest (Berkes et al. 2000; Altieri 2002). The forest and trees are mainly based on the constructed traditional erudition, the different applications and technologies of the community, which are evolved and improved through various experiments as well as adaptation to change environ situations and societal needs for past many generations (Galloway-McLean 2010; Colfer 2012; Parrotta and Trosper 2012; Anderson 2013). In the early days, traditional knowledge of forest and innovation techniques by farmers played a major role in the expansion of extremely diverse, rich as well as sustainable food-producing systems inside and outer forests area (Posey 1999; Kuhnlein et al. 2009; Turner et al. 2011).

Presently, a large portion of the population mainly depends on forests for their livelihood. The forest is said to be a rich source of energy, housing, food, timber, fodder, firewood, oil and fats; and apart from it, also employs a large section of the rural community (Joshi et al. 2003; Borai and Husen 2003; Husen and Nautiyal 2004; Husen 2013). There is an increase in the demand for forest products and services in the country with a rise in rapid economic growth, industrialization and population. The prime role of the forest is to maintain the ecological balance of the ecosystem, food security, conservation of biodiversity, protection of water and soil resources, withstand against desertification and sustainable development that has been extensively accepted. This chapter illustrates different wild edible food, fodder and fuelwood plant species that have countless utilization and importance as natural resources for the livestock population and livelihood in India and other parts of the world.

2 Forest – A Store House of Edible Food Varieties

In this modern era, people are uneducated about traditional food. The knowledge of folkloric food with farmers and nomadic tribes is of great significance and these are the peoples who had to sustain their lives in famine scarcity of food from ancient times (Deshpande et al. 2019). There is a great importance of plants in the human diet since ancient times. The wild varieties of food are not cultivated nor domesticated, but they add up in the special group. These wild plants grow in the forests and farmlands where they are reaped by the local communities as sources of food (Harisha 2019). There are nearly more than 20,000 edible plant species whose different edible parts such as leaves, fruit, flowers, roots, stem, seeds, shoot etc are used in various forms. But only fewer plant species, less than 20 species only provide 90% of the food. Though, there are very few plant edible species in the world that are appetizing and also have good nutritional value (Abbasi et al. 2015).

In the present era of modernized food style, genetically modified crops and different hybrid varieties are designed for commercial advantage rather than for the nutritional and quality of food. There should be an alternative to achieve proper human requirements for nutrition and health. Some of the wild food varieties signify the wild antecedent of modern crops, so it is essential to preserve and use sustainably for a healthier future. There is an extensive increase in the global population but at the same time the area under the agricultural cultivation remains similar and on the other hand, it is declining at a faster rate due to a drastic increase in urbanization and industrialization.

There are some of the wild food varieties, which can be grown to fulfil our food demand in the coming future. These wild varieties grow in diverse seasons in the cultivated and wastelands deprived of the least care such as fertilizer and irrigation. The health and nutrition crisis in the near future will be fulfilled by these wild foods for staying healthy and nutritionally fit life (Deshpande et al. 2019). India has the largest agricultural land for food. Rao et al. (2018) stated that the food diet in India is diversified and rural people consume a more different variety of cereals and staple food as compared to the urban community. The locally reaped wild edible plant species provide food as well as a source of income for the native people staying in rural areas and are of great importance in ensuring food security globally. Wild edible plant varieties are an essential source of food but also make a remarkable contribution to the peoples in the form of nutrition throughout the year as nutrient derived from the plant sources are good for health (Ogle et al. 2003). Some of the wild edible food sources from the various countries have been described in the following subheadings and illustrated in Fig. 1a–h.

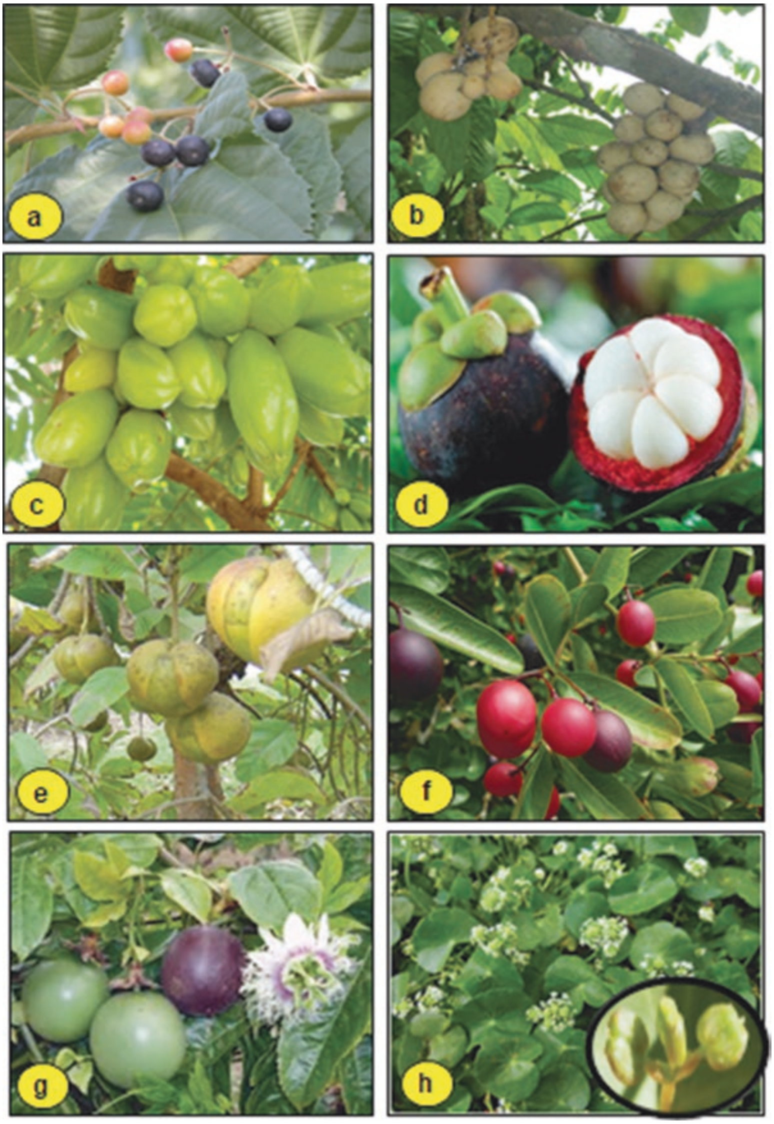

Fig. 1 Some of the forest-based food plants: (**a**) *Grewia asiatica*, (**b**) *Lansium parasiticum*, (**c**) *Averrhoa bilimbi*, (**d**) *Garcinia mangostana*, (**e**) *Dallenia indica*, (**f**) *Carissa carandas*, (**g**) *Passiflora edulis* and (**h**) *Centella asiatica*

2.1 Averrhoa Bilimbi L.

A. bilimbi (also known as bilimbi, cucumber tree or tree sorrel) belongs to the family of Oxalidaceae. The plant is a long-lived tree that reaches up to a height of 5–10 m, trunk short, leaves branched up to 12–20 m in length and pointed on the tip. Leaves are small, fragrant, 5-petalled flowers, yellowish-green or purplish marked with dark-purple, are borne in small, hairy panicles. The star fruit is ellipsoid, obovoid or nearly cylindrical, faintly five-sided, 4-0 cm long; capped by a thin. The fruit is crunchy when unripe and generally turns from bright-green to yellowish-green, ivory or white as it gets ripe and falls to the ground. The outer skin is glossy, very thin, soft and tender and the flesh green, jelly-like, juicy and extremely acid.

2.1.1 Geographical Distribution

A. bilimbi generally originated in the Moluccas, throughout Indonesia but is widely seen in Myanmar, the Philippines, Maldives, Sri Lanka, Bangladesh, Malaysia and common in other south Asian countries. The species are now cultivated in other parts of the world including Africa (Seychelles, Zanzibar Island and Tanzania), North America (El Salvador, Cuba, Costa Rica, Mexico, Jamaica, Haiti, Nicaragua, Panama, Puerto Rico, Trinidad and Tobago, United States- Florida), Oceania (Australia- Queensland, Fiji, French Polynesia, Guam, Northern Mariana Islands, Papua New Guinea), South America (Brazil, Rio de Janeiro, Colombia, Ecuador, Guyana, Suriname, Venezuela). In India, this plant is typically found in gardens but this has gone wild and found growing in the warm regions of south India.

2.1.2 Nutritionally and Medicinal Properties

Bilimbi has good energy value containing carbohydrate; protein; total fat; dietary fibres; vitamin C; vitamin E; sodium; potassium; calcium; magnesium; phosphorus; zinc and, small amounts of beta-carotene in the fruit pulp. In some countries like the Philippines, bilimbi leaves paste is used to cure swelling, itches, rheumatism, skin eruptions and leaf eruption is also beneficial as a birth tonic. In Malaysia, the leaves are useful as a fermented or fresh form in the treatment of venereal diseases. In French Guiana, fruits are used to make syrup that is very effective in the treatment of inflammatory conditions. In India, the fruit is useful in folk medicine for the cure of obesity in some villages of Thiruvananthapuram. The fruit juice of this plant is quite effective against high cholesterol

2.1.3 Other Benefits

The fruit raw juice of this plant is very effective against the remover of spots and stains on clothes. The fruits work as caustic used in the orange colour dye preparation for silk materials (Subhadrabandhu 2001).

2.2 *Bauhinia Variegata L.*

B. variegata (also known as the orchid tree or mountain ebony) is a large-sized tree and belongs to Fabaceae, family. Bark is dark brown, smooth; branches when young they are grey puberulent, later become glabrous. Leaves are rather longer than broadly ovate, sub-leathery, abaxially almost glabrous, primary veins 8–12, secondary veins protruding, base shallowly to deeply cordate. Flower buds are smooth, fusiform, sub-sessile. Petals are white or pink or purplish spots, obovate. Seeds are nearly 12–15, compressed and suborbicular.

2.2.1 Geographical Distribution

B. variegata is native to temperate and tropical regions of China and the Indian subcontinent *such as* India, Nepal, Bhutan and Pakistan. The other southeastern Asia countries are Myanmar, Laos, Thailand and Vietnam. The species introduced as well as found cultivated and naturalized in tropical America, Africa, the West Indies and several islands in the Indian and the Pacific Ocean (USDA, ARS, National Genetic Resources Program 2014). In India, *B. variegata* is also used as a fodder tree.

2.2.2 Nutritional and Medicinal Properties

The leaves are highly nutritious as well as edible and contain crude protein, fibre, nitrogen-free extract, calcium and phosphate (Gupta 1993). The plant has medicinal properties that are effective for both humans as well as livestock. *B. variegata flowers are* useful as a laxative for proper bowel movement and bark is used as an astringent as well as tonic to treat diarrhoea. In the case of livestock, the leaves are said to be useful for retention of pregnancy (Singh 1989; Hocking 1993; Singh et al. 2012).

2.2.3 Other Benefits

In the tropical and subtropical regions of the world, it is planted as an ornamental tree in the gardens, parks and homes as it is eye-catching when its flowers bloom which has tempting fragrance and splendidness. *B. variegata* various parts are edible such as fruits, pods, leaves and exudates consumed by humans as a vegetable, chutneys and pickles (Gurbaksh 1989). In India, Nepal and Pakistan, it is locally known as Kachnar the edible flower buds of this tree and extensively used as an ingredient in many subcontinents recipes as it has scrumptious taste. The kachnar is a good source of food as it is used traditionally in curry that is prepared using chicken. The *B. variegata* tree also works as watershed protection in its natural area, the sub-Himalayan regions that are prone to soil erosion mainly during the rainy seasons.

2.3 Carissa Carandas L.

C. carandas (also known as jasmine flowered carrisa, carandas plum or Christ thorn) is a flowering shrub in the family of Apocynaceae. The plant is about 1.5–2 m long, dichotomously branched. Leaves are long 1–3 in., glossy, very dark green, spines large. This plant leaf and stem has one of the main characteristics whenever it gets injured, then a white milky like sap comes out. Flowers are small, fragrant, white, stalk rose colour. Fruits are small, purple to black, size variate, some fruits 3.5 in. in diameter with very less seeds, occur in clusters and sometimes resemble just like a large purple grape.

2.3.1 Geographical Distribution

The plant is native to India and Bangladesh. The species is introduced to most of the South Asian countries in plain and scrub forests of Sri Lanka, Nepal, Afghanistan, Pakistan, Myanmar, Malaysia, Malaya, Mauritius, Philippines, Java, Puerto Rico, Taiwan, Thailand, Trinidad and Tobago and Vietnam. Generally, the plant flourishes well in those Indian regions that have high temperatures thus, it is found lavishly in the Western Ghats, some parts of eastern and northern India.

2.3.2 Nutritional and Medicinal Properties

The fruit of this plant has good caloric energy and essential nutrition content like carbohydrate, protein, fat, dietary fibres, vitamin C, E, sodium, potassium, calcium, magnesium, phosphorus, zinc and small amounts of beta-carotene. The fruits have effective medicinal properties and can be helpful for the treatment of skin infections, acidity, anaemia, fresh and infected wounds, urinary problems and diabetic ulcers, stomach pain, biliousness and constipation. The leaves are in the medication for earache, fevers and syphilitic pain.

2.3.3 Other Benefits

The plant is known to be a drought-tolerant plant that can flourish well in a wide range of soil as its roots are heavily branched, making it valuable for stabilizing eroding slopes. It produces berry-sized fruits that are usually used as a condiment in Indian pickles, spices, jelly, jams and syrups.

2.4 *Celtis Australis L. (Food)*

C. australis (also commonly known as the European nettle tree, Mediterranean hackberry or honeyberry) is a middle-sized deciduous tree, attains a height of 25 m, sometimes increase 10 m more in the colder climatic conditions. It belongs to the family of Ulmaceae. The bark is bluish-grey or brown, smooth, nearly clumsy or elephantine. Leaves are alternate, ovate, narrow, shape toothed, rugose above and oblique at the base, dark grey to dark green throughout the year and fade out in the autumn. Flowers are small, green, either single or form a small cluster. Fruits are berry-like drupe and dark-purple in colour.

2.4.1 Geographical Distribution

C. australis is native to Southern Europe (Romania and Balkan Peninsula), North Africa (Algeria, Libya, Egypt, Morocco, Tunisia, Sudan and Western Sahara) and Asia minor (Anatolia). In India, *C. australis* occurs in the Western Himalayan regions and also reported in Nepal.

2.4.2 Nutritional and Medicinal Properties

European hackberry fruit contained protein, dietary fibres, insoluble, soluble fibres and vitamins. The leaves and mesocarp contained several minerals such as K, Ca, Mn, Fe, Ni, P, S etc. The leaves and fruit are having great medicinal properties as they are used as astringent, stomachic and lenitive. The extract of leaves and fruit is also used for the treatment of amenorrhoea, colic, inter-menstrual and heavy menstrual bleeding. Even this extract form is also beneficial for curing dysentery, peptic ulcers and diarrhoea. It has been seen that if the fruit is used before fully ripe, then it is considered more effective for medicinal use.

2.4.3 Other Benefits

C. australis is planted extensively in the Indian subcontinent as an ornamental tree. The bark is used to obtain a yellow colour dye. The wood is strong, tough durable and used by turners as well as it also used to make agricultural tools. The shoots are very flexible and useful as walking sticks.

2.5 Centella Asiatica (L.) Urban

C. asiatica (also known as Indian pennywort or Asiatic pennywort) belongs to the family Apiaceae and it is an herb plant, which grows in swampy areas in different parts of the world. Stems are slender, creeping stolons, green to reddish-green in colour, connecting plants to each other. Leaves are orbicular–reniform 3–5 cm across, crenate or sub-entire. The flowers are white or crimson in colour, sessile, small, rounded brunch near the surface of the soil. Each flower is partly enclosed in two green bracts. The fruit is 3–4 cm long, densely reticulate distinguishing it from species of hydrocotyle which have smooth, ribbed or warty fruit. Roots consist of rhizomes, growing vertically down, creamish in colour, covered with root hairs.

2.5.1 Geographical Distribution

C. asiatica is native across much of tropical regions of the world like Africa, Asia, Australia, South America and some islands in the Pacific (USDA, ARS, National Genetic Resources Program 2014). The species is introduced to other countries also like Russia, Hawaii, Norway, American Samoa, Lord Howe Island, French Polynesia, Ecuador, Marshall Islands, Georgia, Cambodia and the Chagos Archipelago. This perennial plant is growing in some swampy areas of India.

2.5.2 Nutritional and Medicinal Properties

This perennial plant is rich in anti-oxidants containing beta-carotene and B-complex vitamins, dietary fibre, protein and small quantities of niacin, riboflavin, thiamine and ascorbic acid. The plant is clinically efficient in dermatitis, skin irritation, stomach complaints and the crushed leaves' paste is also helpful in wounds and cuts.

2.5.3 Other Benefits

The leaves are used as a salad in Aceh (Western part of Indonesia), although in Thailand and Vietnam the leaves are used for preparing a drink or eat in raw form in salads or cold rolls. In India, the leaves and young shoots are consumed as a vegetable and used in various Indian regional cuisines.

2.6 *Dillenia Indica L.*

D. indica (also known as elephant apple) is an evergreen tree that attains a height of 25–65 ft and belongs to the Dilleniaceae family. Plant bark is smooth, reddish-brown, when exocarp formed into thin hard scales or red-brown feeble flakes inside forms with good deep red lines, branches solid, delicate and hairy. Leaves are oblanceolate, sometimes narrow elliptic, seems like more or less V-shaped in transverse section, base cuneate or acute, margins found to be serrate or subentire, dentate, strigose mostly present beneath the veins. Flowers are solitary, found near shoots of older branches, whitish to creamish. Fruits are pseudocarps indehiscent, sepals enlarged thick, subglobose, yellow to green when ripe up. Fruiting carpels, seeds reniform, compressed, reddish-brown colour to black, spiked with hairs on the margins.

2.6.1 Geographical Distribution

The species is native to China and other Asian countries like India, Bangladesh, Borneo, Nepal, Cambodia, Indonesia, Malaysia, Sri-Lanka, Java, Laos, Philippines, Sumatera and Vietnam. It is an exotic species in Cuba, Ecuador, Mauritius, Gulf of Guinea, reunion, Trinidad and Tobago and Windward. In India, it is found in the moist and evergreen forests of the sub-Himalayan tract from Kumaon and Garhwal to eastwards Assam and West Bengal and southern regions.

2.6.2 Nutritional and Medicinal Properties

Being the wild form, it also has essential nutrient content protein, carbohydrates, total fat, dietary fibre, ash, calcium, phosphorus and vitamin. *D. indica* is a very useful species in the Ayurveda and Siddha for the treatment of various disorders. Its bark, leaves, fruit juice and crushed fruit are very effective for the cold, cough, fever, stomach and diarrhoea. The bark and leaves are mainly used as both laxative and astringent. The fruit juice also works as a cooling beverage for toning the nervous system. Even this mixture when added with water and sugar becomes a cooling beverage and works as a cardio tonic (Barua et al. 2018).

2.6.3 Other Benefits

The mucilage known as liquid extraction that is found in the fruit is mostly very useful for washing hair as a shampoo and works as a good enhancer for the growth of hairs. Fruits are eaten in raw and in cooked form. In the eastern part of India (Assam), it is cooked with fish, and is one of the famous local dishes called 'Mashor tenga'. In some areas, it is prepared with dal during the summer season. Besides these, this edible fruit is also used in pickles and jams etc.

2.7 *Ficus Auriculata Lour.*

F. auriculata (also known as Roxburgh fig) is a moderate-sized tree attaining a height of 5–10 m and belongs to the family of Moraceae. The bark is grey, warty and young shoots are hallowed. Leaves are big, rounded or ovate, cordate or round base, entire or toothed. Male flowers have large sepals and female flowers are two to three lobed. Receptacle is wide, depressed, covered with yellow pubescence, purple–orange when ripe.

2.7.1 Geographical Distribution

F. auriculata is native to Asian countries including India, Cambodia, Bangladesh, Nepal, South- Central China, Southeast China, Hainan, Laos, Myanmar, Malaya, Pakistan, Tibet, Thailand, Vietnam and also cultivated in South America in Brazil. In India, it occurs in the sub-Himalayan tract.

2.7.2 Nutritional and Medicinal Properties

The plant's edible fruit contains nutrients such as crude protein, fibre, carbohydrates, minerals, potassium, phosphorus and calcium. The fruit has medicinal properties also as it can be used for diuretic, regulation of the digestive system as well as a laxative. In north-eastern India, the leaves are used to cure diabetes and dysentery. The latex from the stem is extensively used for wounds, cuts, diarrhoea (Pant et al. 2009).

2.7.3 Other Benefits

The ethnic Himalayan people use the plant parts as food, fodder and medicines. Leaves are used extensively as fodder for livestock populations in the foothills of Nepal and India. The fruits are used to make jelly and jams; and also, unripe fruits are used as a vegetable (Thingbaijam et al. 2012).

2.8 *Garcinia Mangostana L.*

G. mangostana (also commonly known as purple mangosteen) belongs to the family of Clusiaceae and it is a tropical evergreen tree that is about 25–30 cm long. Twigs are found to be roughly wrinkled 4-angled, stout, deep dark yellowish-brown or pale brown. Petiole stout, finely transversely striate, angled, to 3 cm long. Fruits are greenish-yellow turning pinkish-red and finally to purplish-black, ovoid or pear-shaped, ellipsoid or globose, to 3–6 cm across, tipped with the black, sessile or protruding stigma of four- to eight-lobed, wedge-shaped or square bundles, surface rugose or smooth, fused in the middle, usually the number of lobes or bundles equalling the number of ovules; and seeds with white, gelatinous and edible aril.

2.8.1 Geographical Distribution

The mangosteen is naturally occurring throughout the tropics of southeast Asia and it is endemic to Malay Peninsula, Thailand, Vietnam, Myanmar, Cambodia and the Maluku Islands (Archipelago in Indonesia). The species can thrive in warm, humid, or tropical regions and also has wide climatic availability in Central America-Honduras South America–Brazil, India and Oceania–Australia) (Obolskiy et al. 2009). In India, this edible fruit species is found growing extensively in the semi-wild state of Gujarat, Maharashtra, coastal areas of Karnataka, Goa, Thiruvananthapuram-Kerala, Andaman & Nicobar Islands, Assam (Khasi, Jantia hills), West Bengal and 'Malabar' region of southern India.

2.8.2 Nutritional and Medicinal Properties

Mangosteen has great nutritional energy values as it contains dietary fibres, protein, vitamins (thiamine, riboflavin, pantothenic acid, folate, vitamin C) and minerals (calcium, iron, manganese, potassium and zinc). The plant also has effective medicinal properties that are used to treat wounds, dysentery, gastrointestinal problem, skin and urinary tract infection.

2.8.3 Other Benefits

In Ghana, the twigs of Mangosteen are used as chew sticks. In Thailand, the wood is used to make spears and cabinetry. In China, this plant fruit peel is also used to tan leather.

2.9 Grewia Asiatica L.

G. asiatica (Indian phalsa) plant is a small shrub tree that generally grows to 4 m tall and belongs to the Malvaceae family. Leaves are broad, heart-shaped or ovate, alternate, deciduous, thick, pointed apex, oblique base, measure up to 20 × 15 cm in length and width, coarsely uneven, light to whitish blush underside. Flowers are small, bright orange to yellow colour, narrow in thick cymes, leaf axils during late spring. Fruits are small, round drupes, purple, cherry red or crimson colour when gets ripen up. Fruits ripen gradually on bushes during the summer month (Yadav 1999).

2.9.1 Geographical Distribution

Phalsa is native to Eastern Asian countries such as India, Sri Lanka, Pakistan, Bangladesh and Nepal. It grows quite well in tropical as well as subtropical regions of South Asia includes the Luzon region of the Philippines, Cambodia, Laos, north and south part of Thailand, Vietnam and it is also cultivated in some parts of the United States (Khan et al. 2019). In India, the species has its wide distribution and commercially grown in different states.

2.9.2 Nutritional and Medicinal Properties

The phalsa fruit is very rich in minerals and vitamins such as iron, potassium, calcium, phosphorus, magnesium and vitamin C. Its bark is helpful in the treatment of various diseases such as pain, diarrhoea arthritis and rheumatism. Leaves also have an antibiotic effect that helps to cure eczema, cuts and several other skin infections. Fruits are said to be very useful for the treatment of blood, heart and liver disorders, asthma, cough, anorexia, stomatitis, spermatorrhoea, diarrhoea throat, tuberculosis and sexual debility troubles (Mishra et al. 2012).

2.9.3 Other Benefits

The fibre extracted from the bark is used to make rope. The refining sugar and its brew can be used as a demulcent. The root is said to be used by Santhal tribal in the treatment of rheumatisms. The leaves are very helpful and can be used as an application to pustular eruptions. The woods are white-yellow colour flexible, fine-grained and are used to make baskets.

2.10 *Lansium Parasiticum (Osbeck) Sahni & Bennet*

L. parasiticum (also known as langsat, longkong or duku) belongs to the Meliaceae family and the average height is about 30 m. Leaves are pinnate, compound odd-numbered, with thin hair, 6–9 buds at intervals. Buds are long to elliptical, 9–21 cm and 5–10 cm in size; stem measure 5–10 mm. Fruits are elliptical, ovoid or round, measuring 2–7 cm and 1.5–5 cm in size; look more like small potatoes, and grown in clusters shape similar to grapes.

2.10.1 Geographical Distribution

The langsat mainly originated in western Malaysia. Its variety is found growing in both wild as well as cultivated forms through the Archipelago. The fruit is quite popular on the island of Luzon in the Philippines and, its tree is helpful in reforestation purposes of hilly areas. It is grown too much in southern Thailand and Vietnam. The fruit was introduced to other parts of the countries including Hawaii, Cambodia, India, Sri Lanka, Myanmar, Laos, Trinidad and Tobago, Micronesia, Seychelles and Surinam. In India, it is luxuriantly grown in the Nilgiris and other humid areas of South India, as well as fruits, which are plentiful on local markets.

2.10.2 Nutritional and Medicinal Properties

L. parasiticum is one of the nutritionally rich fruit and abundant in vital elements such as carbohydrates, proteins, dietary fibre, vitamins and minerals. They are rich in terms of vitamin A, thiamine and riboflavin, these are essential elements for body functions. The seeds are known to be antimalarial. The fruit is also helpful in the problem of the digestive tract and the fibre present in the fruit is proven to be good for gut health. The bark of the tree has antispasmodic properties and can be efficiently used to treat dysentery and diarrhoea.

2.10.3 Other Benefits

L. parasiticum is mainly cultivated as a fruit is eaten in raw form and it is also used as a syrup (Verheij and Coronel 1997). The wood is also beneficial as it is thick, hard, heavy, tough, which is used in the construction of houses in the rural areas. In the Philippines, the dry skin of the fruit is useful as an insect repellent (Heyne 1987).

2.11 Passiflora Edulis Sims

P. edulis (also known as purple passion fruit, black passion fruit, passion fruit, purple granadilla, sour passion fruit or yellow passion fruit) belongs to the family of Passifloraceae. The plant is a perennial vine, leaves are usually tendril borne in leaf axils, base cordate, margin subentire to ciliate, apex acute, red or purple hue when young. Flowers are 5–7.5 cm wide at each node, axillary solitary and hermaphrodite. The fruit is a berry, subglobose, 4 cm across, spherical or ovoid. The outside colour of fruit dark purple with fine white to light yellow. Fruits with purple colour are small, while yellow fruits are bigger. Berries have black seeds and each seed is surrounded by a membranous sac filled with pulpy juice.

2.11.1 Geographical Distribution

The plant is native to Southern Brazil through Paraguay and Northern Argentina. It has a unique taste that is appealing, musky, guava-like sweet and its fruit is cultivated commercially in India, Brazil, China, Caribbean, north-western South America, Hawaii, Indonesia, Thailand, Vietnam, southern Florida, Australia, southeast Africa, Israel and Europe. This climbing plant is found in different parts of India.

2.11.2 Nutritional and Medicinal Properties

The raw passion fruit has a higher content of nutritional values including water, carbohydrate, protein, fat, dietary fibres, niacin, riboflavin, vitamin C, K, iron, potassium, calcium, phosphorus, magnesium and a small amount of beta-carotene. The plant is known to be a stimulant, tonic and also have antioxidants properties. Its flowers are generally used for the treatment of nervous disorders, insomnia, bronchial conditions, arthritis, asthma, gastrointestinal disorders and menopausal symptoms.

2.11.3 Other Benefits

The ripe fruit is used to make aromatic pulp which is consumed in raw form, juice, syrup, or used as sauces. The passion fruit has a diversity of uses in different parts of the world such as Australia, Brazil, New Zealand, Colombia, Mexico, Paraguay, Hawaii, Philippines, Puerto Rico and Indonesia etc. In India (the government of Andhra Pradesh started growing passion fruit in the forest of Chintapalli (Vizag) for the local community and entire region fulfilment as a fruit is eaten raw, sprinkled with sugar and juice.

3 Forest Constitutes an Important Source of Fodder

India has varied climatic and environmental conditions that cannot be defined precisely. Inside a particular region, there are large variations that occur due to altitude, topography, edaphic and ecological conditions and patterns. Therefore, there are different types of fodder species that include leaf litter from trees, herbs, shrubs and grasses that are used widely as fodder resources in our country. As livestock mainly relies on fodder from the wild. There is a large variation in the climatic, topographic, altitude and socio-economic conditions that vary in the concentration of livestock in different areas for the several grass species, which define the grassland productivity both quantitatively and quantitatively wise (Whyte 1968).

The leaf litter from trees constitutes an important feed resource in many parts of the country. The tree litter produces nutritious fodder for livestock and provides about 50–90% of feed fodder demand during winter periods (Negi 1977). The leaf fodder available from the forest generally depends on the type of forest, amount of growing to the total growing stock, forest density, harvesting practices of leaf fodder etc. Grass and grazing constitute another important source of fodder in India (Pokhriyal et al. 1992). The grass species used as fodder are received from the natural grasslands occurring in the forest area, uncultivated land (grazing land, permanent pasture land, cultural wasteland and miscellaneous tree and crops). The leaf fodder from the tree is comprehended to very rich in nutritional value like crude protein, fibre, nitrogen-free extract, calcium, phosphorus, etc. compared to grasses or green fodder species (Sen and Ray 1971).

The tree, grasses, shrubs, herbs species of fodder resources are collected and assembled from the different ecological regions of India such as alpine, temperate, tropical, sub-tropical and difficult areas (coastal, island, arid or semi-arid, saline and wetland area (Dalvi and Ghosh 1981)). The fodder production falls due to the shortage of dry and green fodder. Mainly the green fodder or the concentrates are agricultural residues used as fodder such as straw of cereals (wheat, barley, maize and paddy, etc.). In India, the fodder deficit in phrases of green, dry and concentrates within side the 12 months in 2015, which become 26 MT (million tonnes), 21MT and 34MT, and this shortfall probably to growth with the aid of using 40MT, 21MT and 38MT by the year 2025, respectively (Parmar and Misra 2020). Some of the fodder species noticed from the various country have been described in the following subheadings and illustrated in Fig. 2a–h.

3.1 Aegle Marmelos (L.) Correa

A. marmelos (commonly known as Japanese bitter orange, Indian bael, Indian bael tree, stone apple or golden apple) is a deciduous tree up to 10–12 m tall and belongs to Rutacae family. Its branches are cylindrical, slightly angled, spines axillary, solitary, straight, sharp. The bark is pale brown and greyish. Leaves are trifoliate, pale

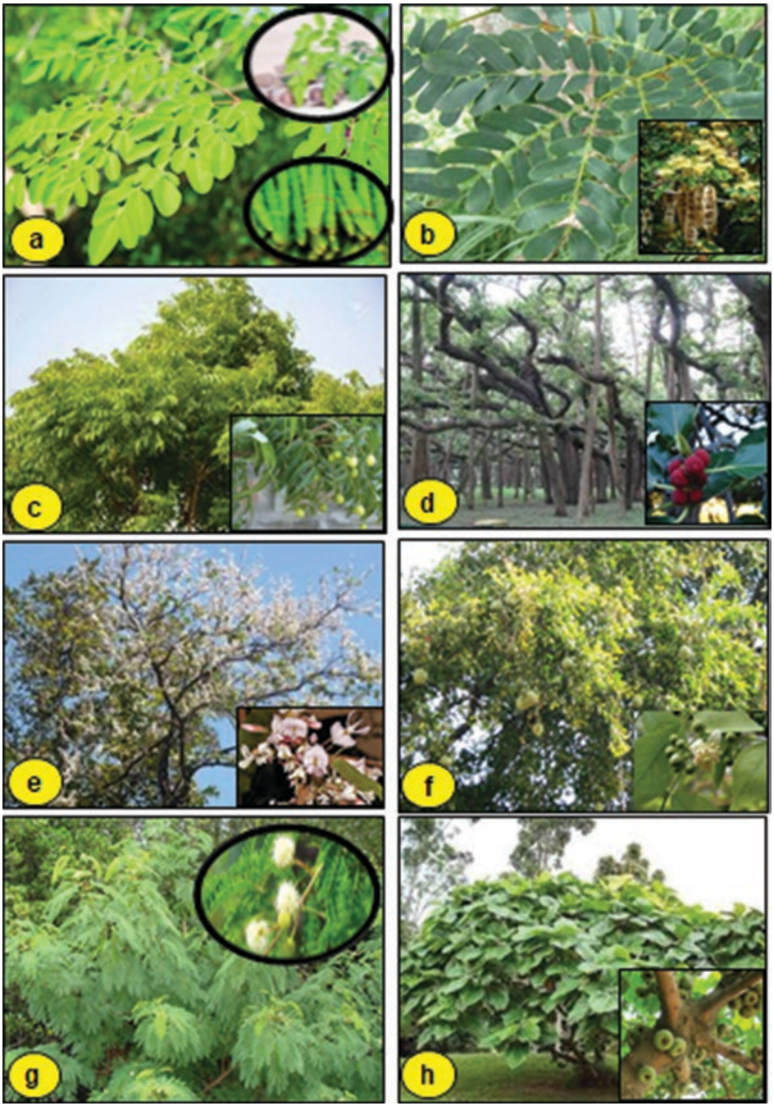

Fig. 2 Some of the fodder -based food plants: (**a**) *Moringa olifera*, (**b**) *Albizia lebbeck*, (**c**) *Azadirachta indica*, (**d**) *Ficus benghalensis*, (**e**) Ougeinia oojeinensis, (**f**) Aegle marmelos, (**g**) Leucaena leucocephala and (**h**) Ficus auriculata

green, alternate, dimorphic, glabrous; leaflet sub-sessile, ovate, elliptic, oblique at base, shallow at the margin, tapering at the apex. Flowers are bisexual, greenish-white to yellow. Fruits are oval-shaped and have a thin, hard woody shell, with a soft rind.

3.1.1 Geographical Distribution

Bael is extensively found growing in the dry forest in the Indian peninsula, Sri Lanka, Bangladesh and Pakistan. It has spread in southeast Asia (particularly northern Malaysia, Thailand, northern Luzon and eastern Java) and some of the parts of the tropics. In India, it is a very old cultivated tree and found throughout the different phytogeographical regions except for Arunachal Pradesh, Himachal Pradesh, Sikkim, Jammu and Kashmir.

3.1.2 Nutritional and Medicinal Properties

A. marmelos leaves contain protein, carbohydrate, dietary fibre, vitamin B6, thiamine (B1), riboflavin and sodium. The plant leaf, seed, root, fruit all parts are used in preparing a number of traditional medicines, which cure ailments such as colitis, flatulence, oedema, bleeding, haemorrhoids, scurvy and fever (Kaur and Kalia 2017; Panda 2002). The ripe fruit is used with milk and sugar as a laxative. The unripe fruit or roasted is used in dysentery and diarrhoea. The dried fruit is used as a hot drink known as 'Bel tea' which is good for heart problems (Baliga 2013; Bhat 2020).

3.1.3 Other Benefits

Bael is the holy plant in the Hindu culture as its fruit and trifoliate leaf are one of the important ingredients used for worshiping Lord Shiva and Goddess Durga (Streep 2003; Bakhru 1995). The fruit is eaten as fresh or dried form and can be made in candy or toffee etc. It can also serve as sharbat called 'bael pana'. The leaves and smaller shoots can be used in salad preparation. Its fruit also serves the purpose of food and can be eaten safely. It is eaten fresh or after converting into candy. Leaves of *A. marmelos* contain many essential oils that are extracted from it for commercial use (Panda 2002).

3.2 Albizia Lebbeck (L.) Benth.

Deciduous trees attaining a 25 m height and belong to Fabaceae family. *A. lebbeck* is commonly known as lebbeck, lebbek tree, flea tree, frywood, koko, white siris or woman's tongue. Its bark is thick, surface yellowish-brown, deeply fissured, rough and exfoliating in irregular semi brittle scales. Leaves are bipinnate, alternate, 20 40 pairs, stipulate, obliquely cordate, tapering into a sharp point from a broad base. Flowers are bisexual, yellowish-white, globose heads, slightly tingled, fascicles or arranged in terminal and red in axillary panicles; peduncle slender, pubescent, sessile. Fruits are in a pod, flat, strap-shaped reddish to brown, wavy along the margin, shortly stalked, apices round or tapering, slightly bullate over the seeds; and seeds are ovate and dull brown.

3.2.1 Geographical Distribution

A. lebbeck is native to India, north-eastern Thailand, some parts of Malaysia, eastern islands of Indonesia and north Queensland (Lowry et al. 1994). This woody species is native to Asian countries such as Bhutan, Nepal, Sri Lanka, India, China, Indonesia, Bangladesh etc. and other regions or countries are Africa, South Africa, North America, South America and Oceania.

3.2.2 Nutritional and Medicinal Properties

East Indian walnut tree has good nutrition value content protein, carbohydrate, calcium, phosphorus and minerals. *A. lebbeck* contain some active components such as quercetin, polyphenols, isoquercetin, saponins and these trends to give a strong impact on the hormonal and nervous system in the human body (Kokila et al. 2013). In India, the plant is beneficial in serval diseases such as the bark powder is helpful in boils and dysentery treatment, leaves for night blindness, roots can be useful for spongy and ulcerated gums, and seeds are good for the treatment of piles, gonorrhoea and diarrhoea (Duke 2008).

3.2.3 Other Benefits

The plant is very useful for feeding fodder for cattle, goats, sheep and elephants. The wood can be used for several purposes such as construction, furniture and agricultural implements. The light-coloured honey is made from flowers (Gupta 1993).

3.3 Azadirachta Indica A. Juss.

Also known as neem, it is a large tree that attains a height of 15–25 m with a dense rounded crown and belongs to the family Meliaceae. They are deep-rooted, usually evergreen with wide branches and approximately are 15–20 m tall except in very dry localities. *A. indica* is known for its drought resistance and has a dark grey bark. Leaves are imparipinnate, green to dark green, leaflets sub-opposite, lanceolate or ovate, unequal sided. Flowers are white, scented, arranged in axillary panicles. Fruits are drupe, smooth, ovoid, greenish to yellow when ripe; and have only one seed.

3.3.1 Geographical Distribution

A. indica is considered to be native to dry areas of India, Afghanistan, Pakistan, Sri Lanka, Bangladesh, Myanmar and China. It is also cultivated and naturalized in other Asian countries like Thailand and Indonesia. Recently, the plant is seen to be in other parts of the world such as the Caribbean, Singapore, Peninsular Malaysia, Saudi Arabia, Philippines, Australia, tropical Africa and Central and South America. Neem is indigenous to India and occurs throughout the country but more often grows in the drier states of the country. It is one of the commonly planted along the roadside avenue tree and shade-loving tree for the farmers (Kumar and Navaratnam 2013; Sengottayan 2013).

3.3.2 Nutritional and Medicinal Properties

The principal nutritional value constituents are protein, carbohydrates, minerals, calcium, phosphorus, vitamin C, carotene etc. It is being used as a medicinal plant in Ayurveda and has magical medicinal properties. Its fruits, leaves, flowers stem, roots and bark are widely (Thakurta et al. 2007). The leaves are used from the traditional time for skin diseases and also come in the various external application form of ointment. Leave juice is administrated with salt to treat intestinal worms. A hot brew made of leaves is useful in increased swollen glands, sprains etc. The fruits act as a cleansing and an emollient and beneficial in the control of urinary tract diseases, piles and intestinal worms (Von Carlowitz 1991). Neem also has anti-bacterial, anti-fungal and anti-viral constituents in it (Sidhu et al. 2004).

3.3.3 Other Benefits

Leaves are used as fodder, green manure and mulch and act as well-fed fodder for terrestrial animals. Even leaves are used as a pot herb and mixed with vegetables in the preparation of curries and soups. Its shoots and flowers are consumed as a vegetable. It is the main constituent in NPM (Non-Pesticide Management) (Sundararaj et al. 1995). Neem oil can prevent the effect of termite and soap is also manufactured from the oil. (Srivastava et al. 2002; Brahmachari 2004). Juice of plant is beneficial as an ingredient in wall plaster.

3.4 Ficus Benghalensis L.

F. benghalensis (also known as Indian banyan, banyan tree, banyan fig or East Indian fig) is a large evergreen to deciduous tree up to 20–25 m tall and belongs to the Moraceae family; having a wide leafy crown throwing numerous aerial roots from branches. Trunk massive, fluted, bark grey, smooth, young softly white puberulous. Leaves stout, hairy petiole, ovate or elliptic, entire, obtuse, rounded at the base. Male flower numerous, crowded. Female flower with shorter perianth, sessile. Figs are globose, hairy; receptacle, at the fruiting stage, enlarges like in a fig fruit and is orange-red in colour.

3.4.1 Geographical Distribution

F. benghalensis is known to be native to tropical Asia countries like India, Myanmar, southern China, Thailand, Pakistan, Nepal, Israel and Malaysia. It is also cultivated in many tropical regions of the world including the Western part of Africa, North America - United States, Bahamas, Jamaica Oceania-Australia, Northern Mariana Islands, Papua New Guinea, French Polynesia (USDA, ARS, National Genetic Resources Program 2014). Bayan tree also is known as the National tree and indigenous to India having its distribution throughout the country. The species is mostly distributed from tropical to warm temperate regions (Stevens 2020).

3.4.2 Nutritional and Medicinal Properties

F. benghalensis leaves contain crude protein, carbohydrate, fat, fibres, vitamin C, E and minerals as a rich nutrition content. It has been used for preparing medicines since Ayurveda times in the treatment of diarrhoea, dysentery, diabetes and piles (Gabhe et al. 2006). The milky latex is used for treating pains and is applied externally in rheumatism and lumbago (Edlin and Nimmo 1978).

3.4.3 Other Benefits

The banyan tree is mostly planted as an ornamental plant. Leaves are lopped for fodder and woods are a good source for fuelwoods. The tree is important for the conservation of soil, timber and pulp paper. Fruits are used as food mainly during scarcity times (PROTA 2017).

3.5 Grewia Optiva J.R. Drumm. ex Burret

G. optiva is a moderate-sized tree attaining a height of 12–15 m and belongs to the Tiliaceae family. The bark is whitish, thick, roughish, small woody scale peeling off. Leaves are broadly ovate-lanceolate, acuminate, closely serrated, scabrous above, pubescent below. Branches are spreading, divaricate young shoots, rough. Flower petals are white or yellow. The leaves are opposite, petiolated with blades tomentose on both sides, rough, ovate to broadly ovate. Fruits are drupe, fleshy, dark green to olive green, then black when ripe, rough with scattered stiff white hairs.

3.5.1 Geographical Distribution

G. optiva (also known as Bhimal) is native to India, Nepal, Bhutan and Pakistan and the plant grows in a subtropical climate. In India, *G. optiva* occurs in the northern part including the Himalayan range.

3.5.2 Nutritional and Medicinal Properties

The leaves of *G. optiva* contain protein, crude fibre, calcium, nitrogen-free extract and phosphorus. The plant is mostly used in Ayurveda medication as leaves are used in eruptions. The bark extract is useful for indigestion and gastric glitches. It also beneficial during childbirth and its fruits cure fever. The bark is also an effective medication for cattle as a fresh part of the bark is used as a bandage on fracture and its paste as plaster.

3.5.3 Other Benefits

It is an important plant for agroforestry in hilly areas. The leaves make excellent fodder for the cattle population. The bark sap is used as shampoo and branches are useful to make ropes. In India and Nepal, *G. optiva* is commonly used for fodder, wood and fuel.

3.6 Leucaena Leucocephala (Lam.) de Wit

They are also commonly known as ipil-ipil, white popinac, false koa, horse tamarind coffee bush, jumbie-bean, hedge acacia, lead tree, wild tamarind or jumpy-bean. A small tree up to 2–15 m tall and belongs to the Fabaceae family. Its bark is greyish-brown, vertical fissures; upright angular branching. Leaves are bipinnate, linear, leaflet 10–12, oblong, base oblique. Flowers are dense globular clusters and white in colour. Pods are dark brown, thin, straight, flat, apex triangular. The fruits are elongated flattened, initially green, turn brown or reddish-brown mature. Seeds are 10–15 and slightly oblique.

3.6.1 Geographical Distribution

L. leucocephala originated from Mexico and introduced to other regions of the world as it has an extensive distribution in Asia, Africa, North America, South America, Europe and Oceania. This species extensively cultivated as a fodder plant throughout India as it is a fast-growing tree.

3.6.2 Nutritional and Medicinal Properties

The leaf contains crude protein, fibre, nitrogen, calcium, phosphorus, potassium, magnesium and carotene as nutritional content. *L. leucocephala* is known to have an excellent medicinal property that helps to control stomach diseases, and most of the time it is also useful as an alternative complementary treatment for diabetes. The extracts of leaf and seeds show antidiabetic and antioxidant activities and it also inhibit raising the blood glucose as well as lipids levels (Zayed et al. 2018).

3.6.3 Other Benefits

It is a good forage tree known from tropics to sub-tropic areas and recommended foliage for livestock animals as well as wildlife. It leaves provide excellent food as it has amino acid composition. In Mexico, it is one of the nutriments (Casas and Caballero 1996). The seeds and unripe pods are useful as food material in some parts of Asia (Indonesia, Thailand, Philippines and Vietnam) (Jones et al. 1997). The leaf litter is utilized as a fertilizer to maintain over crops that are widely used by the farmers in Central America, Indonesia and the Philippines (Dijkman 1950).

3.7 Moringa Olifera Lam.

M. oleifera is a middle-sized soft fast-growing deciduous tree with thick corky bark, thick, roots punget attaining a height of 11–12 m and belongs to the family of Moringaceae. *M. oleifera* is also commonly known as a behen tree, ben-oil tree, bridal veil, cabbage tree, clarifier tree, drumstick tree (as it is long, slender and triangular seed pod shape), mother's best friend, neverdie, west Indian ben, horseradish tree (as roots taste is like horseradish) and benzolive tree (oil obtained from its seeds). Its leaves are compound, 3 pinnate, leaflet obovate or elliptic with pale green leaflets when young, become darker when older and yellow at the fall period. Flowers small, whitish, honey scented in an axillary panicle. Fruit is a capsule, trigonous. Seeds are wringed at an angle.

3.7.1 Geographical Distribution

M. oleifera mainly has its distribution in the tropics and subtropics regions and found cultivated in Africa, Asia and North, Central and South America, the Caribbean and Oceania (Godino et al. 2017; PROTA 2017). India is the only country where this perennial plant is common to proposed distribution (Vogt 1996). It is mainly found in the wild in the hilly lowland areas of North-Western and South India.

3.7.2 Nutritionally and Medicinal Properties

Moringa plant is very nutritious and mainly all parts are edible such as immature seed pods known as 'drumsticks' and have their uses on the region-wise bases. The leaves are one of the most nutritious parts of this plant containing significant rich sources of protein, vitamins B, C, A, K and manganese, micronutrients and also including carotene and ascorbic acid.

Medicinally this broadleaved plant is very useful in the treatment of various chronic diseases in pharmaceuticals as well as traditional and folklore medicines. It is known to have anti-bacterial, anti-inflammatory, analgesic and anti-tumour effects. On the other hand, *M. oleifera* extracts have significant results in curing many ailments such as rheumatism, diabetes, anaemia, scurvy, mouth sores, skin disorders, venomous bites and heart problems. After grinding the dried leaves, its powder is stored for a longer duration so that it can be added in flavouring or as a health supplement, and also used in the preparation of capsule and tablet (Ambrose et al. 2016).

3.7.3 Other Benefits

In African countries, leaves are used for adding flavours and meat preparations. The dried leaves and pod herbs can be used as a tea of soup and porridge preparations. The seed produces a seed husk is a rich source of high-quality activated carbon, which is produced by stream pyrolysis (Warhurst et al. 1997). The leaf extract also has great potential as it can enhance the growth of various agricultural species such as sugarcane, coffee and soybean. The bark can also be used in the preparation of fibre for the rope as it is a good source of tannin (Heuzé et al. 2019). *M. oleifera* has a great ability to absorb carbon dioxide so it makes this perennial plant a significant source for the mitigation of environmental climatic conditions (Amaglo et al. 2017). The species with multiple benefits can also be used in reforestation programs as suggested by Caceres et al. (1991).

3.8 Ougeinia Oojeinensis (Roxb). Hochr.

O. oojeinensis (also known as desmodium tree) is middle-sized deciduous tree up to 6–12 m tall and belongs to the Fabaceae family. Trunk short and recurved; leaves pinnately, trifoliate, large, lateral leaf opposite, ovate, glabrous above. Flowers are densely fascicled racemes, white. Pods are linear, oblong, flat, light brown, two or more seeded. Seeds are compressed and reniform.

3.8.1 Geographical Distribution

The tree is generally found growing few Asian countries such as Nepal, Bhutan, Pakistan and native plants to India. It is a tree of the subtropical climate and grows in the sub–Himalayan tract and outer Himalayan valley, Central India, Western Peninsula areas.

3.8.2 Nutritional and Medicinal Properties

Its leaves contain total digestible nutrient content, calcium, magnesium and nitrogen as nutrient content. *O. oojeinensis* is used for burning syndrome, skin disease, urinary disorder, obesity, anti-inflammatory, anti-spasmodic and anti-hypertensive activity (Velmurugan et al. 2011). It is used for the treatment of jaundice, diarrhoea, dysentery, diabetes, verminosis, leprosy, leucoderma, haemorrhages, fevers, ulcers etc. (Samyal et al. 2013). Medicinally plant has great importance as it is certainly no wonder that it is known in the Indian traditional circle in pharmacognostical, pharmacological and ethno-medicine.

3.8.3 Other Benefits

Sandan is good fodder for the livestock animals. The bark fibres are used for making ropes. Transparent material like astringent gum is obtained from cuts in the trunk. The wood is a light brown or red-brown colour that is tough, elastic and durable that can beneficial in many ways.

3.9 Terminalia Alata Heyne ex Roth (Fodder)

T. alata (also commonly known as silver-grey wood) is a large deciduous tree that attains a height of 25 m and belongs to the Combretaceae family. Bark is distinct, rough grey, deeply cracked oblong segments. Leaves are alternate, oblong-elliptic or obovate, coriaceous, glabrous above, tomentose below, apex acute and entire margin. Flowers are dull yellow, or greenish-yellow, small and bisexual. Fruit with broad 5-winged having crenulated margins.

3.9.1 Geographical Distribution

T. alata is indigenous to India, Nepal, Myanmar and Thailand.

3.9.2 Nutritional and Medicinal Properties

The leaves, especially in the young stage, are rich in crude protein and calcium and they are not very nutritious and can substitute only as straw or hay in animal diet. The bark is known to be very essential for curing diuretic, cardiotonic, styptic conditions. It is very useful in the treatment of fractures, diarrhoea, ulcers, bronchitis, boils and fever.

3.9.3 Other Benefits

The leaves are used as fodder in Nepal. The wood is dark brown which is valuable and can be used for commercial purposes in the south Asian countries for making furniture, house building, tool handlers etc., as fuel is mostly required during an emergency due to having a great ability to burn when it is wet.

3.10 Toona Ciliata M. Roem.

T. ciliata (also commonly known as red cedar, toon or toona) is a tall tree reaching up to 15–25 m with a dense spreading crown and belongs to Meliaceae. Bark is thin, dark grey, which is smooth up to middle age. Leaves are compound, pinnate, lanceolate, acuminate, pubescent below, margin usually wavy, base acute and sparsely hairy. The flower is large, cream coloured, densely or branched panicles, separate male and female flower. Fruit is capsule, oblong, dehiscent, dark brown. Seeds are dark brown, with membranous wings on either end.

3.10.1 Geographical Distribution

T. ciliate is native to south and Southeast Asian countries which ranges from Pakistan, western China, Indonesia, Nepal, India, Malaysia, Thailand, Myanmar, Sri Lanka, Philippines and Vietnam. The species is also introduced to Africa, North America, Oceania including Australia and Islands of the western Pacific Ocean, South America (Argentina, Brazil, Paraguay and Peru).

3.10.2 Nutritional and Medicinal Properties

The leaves contain crude protein and fibre that are a good source of nutrition. It is known to be used in folk medicines as the bark is used to cure several ailments such as haemorrhage, blood disorders, leprosy Chronic dysentery for infants, useful as an external application for wounds and ulcers.

3.10.3 Other Benefits

The wood is considered as high value and used for construction purposes for making high-grade furniture, musical instruments. The flowers yield yellowish and reddish colour dyes used in tropical Asian countries to dye the silk fabric. The leaves are mainly lopped as fodder in India and also seen as ornamental and roadside trees throughout Asia and tropical African countries.

4 Forest as a Source of Fuel Wood in Attaining the Energy Needs

The land is a restricted resource that provides cooking fuel to the rural population. Mainly population residing in the developing countries rely on firewood for cooking that is a traditional method and will remain significant always (Husen and Nautiyal 2004; Anríquez and Stloukal 2008; Husen 2013; Mohan 2017). The collection of firewood useful part is done from the forest trees that are grown on farmlands, homesteads and land outside areas of the forest. The total earth land area of the agricultural land accounts for 37% and 31% of a forest.

This percentage shows the intensity of global agricultural land increase and a gradual decrease in forest area (World Bank 2018). The rural communities in India generally sustain their lives by farming and cultivate crops and different breeds for livestock household purposes (Bisht et al. 2014). The maximum total energy is exhaust by the household that is usually used for cooking, and the remaining is helpful for lighting and heating purpose (Ranjan and Singh 2017). The prime source of fuelwood is acquired from the forests or the open spaces areas. Approximately, three billion of wood were reaped globally from the forest land and out of which only 50% is utilized as fuelwood resources (FAO 2015). The domestic household sector is one of the most protuberant energy end consumers in rural areas, and cooking is the largest end-use accounting as the highest of the household energy.

The dependency of fuelwood in the rural community is mainly due to the poor connectivity with the urban areas of the country, improper socio-economic conditions, high price and limited supply, the commercial energy forms very less amount of total energy, which comprises of kerosene and electricity (Bhatt and Sachan 2004; Kumar 2005). The massive growth of the populace and declining forest areas has led to the depletion of fuelwood sources around localities of the rural areas which causes fuelwood shortfall. This makes a straight influence on the rural people such as high fuelwood prices, collection time for fuelwood that has led their life risk to maintain their primary human needs (Arnold et al. 2003). Fuelwood has remained one of the useful components of rural domestic energy so below there are mentioned some of the tree and grasses species used as fuelwood resources (Bhat et al. 2016). Wood has remained one of the important sources of fuel used by different communities as well as tourism sectors in the Himalayan region which is the main reason for the continuous harm and destruction of forest resources (Chettri et al. 2002; Bhat et al. 2016). Some of the important fuelwood species found around have been described in the following subheadings and illustrated in Fig. 3a–h.

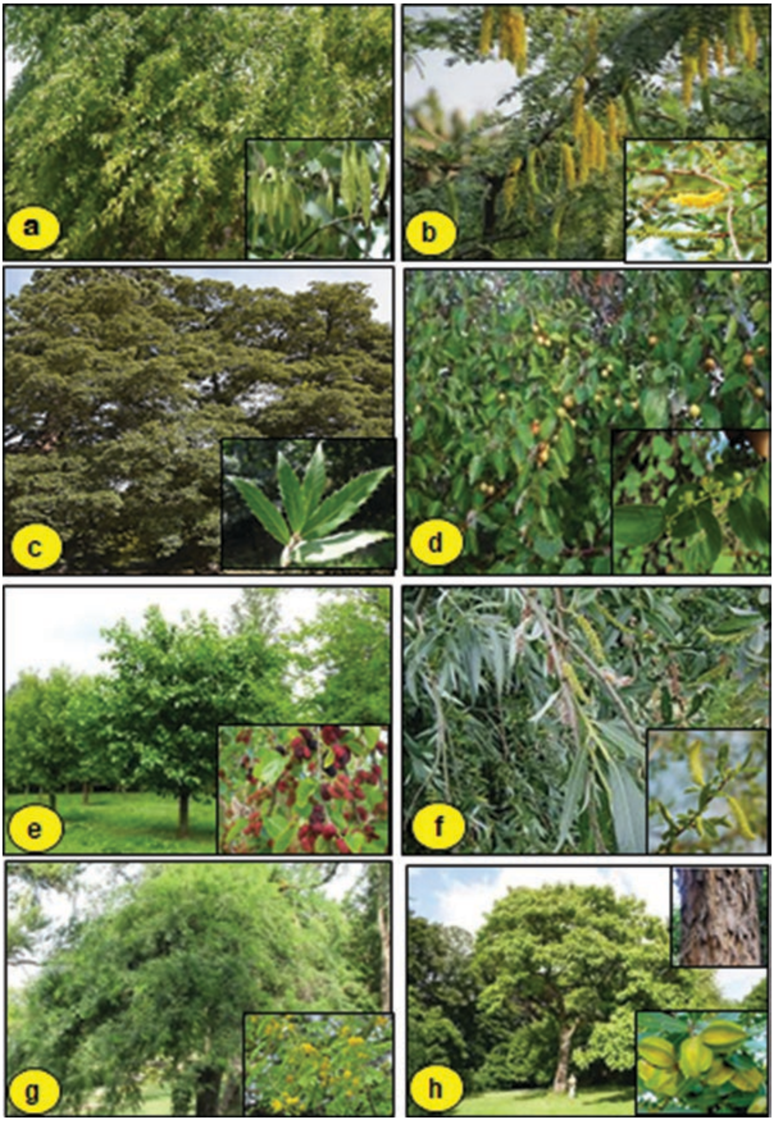

Fig. 3 Some of the forest-based fuel-wood plants (**a**) *Dalbergia sissoo*, (**b**) *Prosopis cineraria*, (**c**) *Quercus leucotrichophora*, (**d**) *Ziziphus mauritiana*, (**e**) *Morus alba*, (**f**) *Salix alba*, (**g**) *Acacia nilotica* and (**h**) *Terminalia arjuna*

4.1 Acacia Nilotica (Linn.) Willd. Ex. Del

A. nilotica is also known as Arabic gumtree, blackthorn, babul acacia, Egyptian thorn, Egyptian mimosa, prickly mimosa, prickly acacia, scented-pod acacia or scented thorn; and belongs to Fabaceae family. *A. nilotica* is medium-sized tree attainting a height of 5–20 m, evergreen in the habitat with dense stems and branches. Its stems are dark to black coloured. The leaves are bipinnate, pinnate, long thorns at the base of each leaf and flowers are globular heads with bright golden yellow colour.

4.1.1 Geographical Distribution

The Babul species is dispersed throughout tropical and warm temperate countries of the world. The species is native to Africa and some of the Asian countries (India, Bangladesh, Pakistan, Iran, Oman, United Arab Emirates, Syria, Yemen). The species also shows its distribution in other countries of the world as it was introduced to Africa- Mauritius; Asia – China, Nepal, Myanmar, Indonesia, Sri Lanka, Vietnam; North and South America and Oceania. In India, the species is growing extensively in the western parts of the Indo-Gangetic plains, semi-arid regions of Deccan Plateau and Eastern Himalayas.

4.1.2 Nutritional and Medicinal Properties

The nutritive value of *A. nilotica* mature fruit are rich in crude protein and show some trace of essential mineral particularly zinc, iron, potassium and copper. The bark, root, gum, leaves and flowers have been found uses for skin diseases, diarrhoea, dysentery, cough, diabetes, eczema, wound healing, burning sensation and as an astringent, demulcent and anti-asthmatic etc. It shows antibacterial, anti-inflammatory, anti-diabetic and anti-cancer properties (Uguru et al. 2014).

4.1.3 Other Benefits

A. nilotica provides fuel, fodder, gum, tannin and timber. It also acts as a powerful astringent. In India, its branches are commonly cut and used for fodder; whereas, pods are the best useful material for the fed supplement.

4.2 *Dalbergia Sissoo* Roxb.

D. sissoo (also known as Indian Dalbergia, India teakwood, Bombay blackwood, Himalaya raintree, Indian rosewood) is a medium to large deciduous tree attaining a height up to 30 m and belongs to the Fabaceae family. Bark is thin and grey in colour; leaves are imparipinnate; pinnately compound leaflets four to five broadly ovate or rhomboid, glabrous and leathery. Flowers are pale white consist of whitish to pink and fragrant nearly and in clusters (Sheikh 1989). Pods are oblong, flat and thin, one seed and narrow at the base. Seeds are found to be kidney-shaped, pale brown, brown to brownish-black, reniform and compressed.

4.2.1 Geographical Distribution

The plant is native to India, Afghanistan, Bhutan, Bangladesh and Pakistan and introduced, to other countries such as Asia (Malaysia, Indonesia – Java and Sumatra, some parts of China, Sri Lanka and Thailand), Southern, Central and Eastern Africa, North America – USA, South America – Paraguay, Oceania – Western and Southern Australia, Queensland, New Caledonia. It is indigenous to India and occurs in the entire sub-Himalayan, Shivalik range and the Indo–Gangetic plains.

4.2.2 Nutritional and Medicinal Properties

The young leaves are more nutritious than the older leaves, and the composition is crude protein and fibre, nitrogen-free exact, fat, carbohydrate, calcium and phosphorus. The shisham tree is used in Ayurveda and helps to cure various diseases as it is an important medicinal plant (Lal and Sanjay 2012; Bhattacharya et al. 2014). The leaves are quite beneficial for curing eye pain, swelling, gynaecological disorders, diarrhoea, painful urination etc. Bark powder in gonorrhoea, pain in the body, leprosy and sciatica (Shah et al. 2010; Al-Snafi 2017). As the plant has excellent medicinal importance and it is extensively grown and used for a longer duration as an antipyretic, anti-diabetic, anti-inflammatory, anti-oxidant, analgesic and antimicrobial agent (Hajare et al. 2000; Asif and Kumar 2009).

4.2.3 Other Benefits

Shisham is known to be an excellent fuelwood tree as it burns like charcoal and has average calorific value. It has extensive use as timber for making furniture as the wood is hard, heavy, durable, and further, woods are very useful in all types of construction work. The tree twigs chewed as a toothbrush in Asia, Pakistan and Africa. The wood yields oil which is light brown, highly viscous and becomes solid as it cools down just like a Vaseline – suitable as a lubricant for heavy load machinery. It also enriches the soil due to the presence of nitrogen fixing bacteria present in its roots and leaf litters helps to improve the soil quality.

4.3 Morus Alba Linn.

M. alba (commonly known as white mulberry, mulberry or white mulberry) is a moderate-sized deciduous tree 10–12 m high and belongs to the family Moraceae. with a short lifespan. Leaves are alternate, simple, wide broadly ovate and are shiny green in colour, bark is light brown to grey and smooth. The flower mainly blossoms with young leaves, male and female flowers usually appear on separate or on the same tree. Fruits are 3–4 cm long, ovoid or subglobose, green-yellow when young, red at maturity, black when ripe with short live plant and old trees becomes hallow.

4.3.1 Geographical Distribution

It is native to northern China, Bhutan, Japan, India, Korea, Malaysia, Myanmar, Nepal, United States, Europe and naturalized in different regions of India.

4.3.2 Nutritional and Medicinal Properties

The fruit has high nutritional value water, total fat, carbohydrate, protein, dietary fibres, potassium, calcium, iron, vitamin A thiamine, riboflavin, nicotinic acid and ascorbic acid. Its leaves are also taken to treat fever, sore and inflamed eyes, sore throats, headaches, dizziness and vertigo. Its fruit is useful to prevent premature greying of the hair and to treat dizziness, ringing in the ears, blurred vision and insomnia. The plant also shows pharmacological activities including anti-diabetic, anti-microbial, anti-mutagenic, anti-oxidant, anti-cancer, anxiolytic, anthelmintic, anti-stress, immunomodulatory, hypo-cholesterolemic, nephron-protective and hepato-protective (Sanghi and Mushtaq 2017).

4.3.3 Other Benefits

It is widely used as fodder to feed animals and invertebrate food for silkworms. It is widely used in agroforestry, erosion control. It is also used as fuel and for manufacturing wood-based materials. In Asia, southern Europe and the southern part of the United States, *M. alba* has been utilized for windbreaks, in arranging, and their low water prerequisites and protection from pruning makes them appropriate for use as a road tree. In India, the wood is utilized for cabinet purposes and sporting things (Sánchez 2002).

4.4 *Prosopis Cineraria (L.) Druce*

P. cineraria (also known as Spunge tree) is a small or medium-sized evergreen tree and belongs to the Fabaceae family. Branches are armed with short straight nearly compressed, while older are broad conical base. Leaves are bipinnate; 7–12 pairs, oblong, apex usually mucronate with a rounded base. Flowers are creamy white, pods slender, pendulous, cylindric and smooth (Khatri et al. 2010).

4.4.1 Geographical Distribution

It is native to arid regions of western Asia and the Indian subcontinent, Afghanistan, Bahrain, Iran, Oman, Pakistan, Saudi Arabia, the United Arab Emirates and Yemen. In India, it occurs in dry and arid regions.

4.4.2 Nutritional and Medicinal Properties

Leaves contained crude fibre, carbohydrates, sucrose, calcium and phosphorous. The pods provide protein, iron, vitamins A and C and other micro minerals. The plant has high medicinal value as its bark is said to treat ailments such as leprosy, dysentery, bronchitis, asthma, leucoderma, piles, muscular tremors, asthma, rheumatism and inflammations. The smoke of the burnt leaves is very helpful to treat eye inflammations. Leaf paste is applied on boils and blisters, including mouth ulcers in livestock, and leaf infusion on open sores on the skin pharmacological activities like analgesic, anti-oxidant, anti-pyretic, anti-hyperglycaemic, nootropic, anti-hyper cholesterolemic, anthelmintic, anti-tumour, antibacterial, anti-fungal, anti-viral and anti-cancer activities have been reported from different plant extracts (Preeti et al. 2015; Malik and Kalidhar 2007; Pareek et al. 2015).

4.4.3 Other Benefits

It is excellent fuelwood with high calorific value and makes high-quality charcoal. The wood is hard, strong and tough; used for house building, doors and windows. Unripe pods are used to prepare curries and pickles. The pods and leaves are good fodder for camels, goats and donkeys in the aired regions. It is the national tree of the United Arab Emirates, where it is known as Ghaf.

4.5 *Quercus Leucotrichophora A. Camus*

Oak (commonly known as banj) is a moderate to evergreen tree attainting about 20 m height and belongs to the Fagaceae family. Bark dark grey with cracks and fissured. Leaves are oblong to ovate, acuminate, tough and coriaceous. Male spikes slender, frequently interrupted, female spikes are axillary, sessile. Fruit is solitary, acorn or oak nut usually in the same year.

4.5.1 Geographical Distribution

Q. leucotrichophora is found in Nepal, Myanmar, Pakistan, Sri Lanka and Indigenous to India. Ban oak occupies extensive areas of the Western Himalayas. It is mainly found in outer foothills and avoids dry valley.

4.5.2 Nutritional and Medicinal Properties

The leaves of the plant contain crude protein and fibres, carbohydrates, calcium, phosphorus, nitrogen-free extract. Most parts of the plant are used in medicinal The seeds, bark, leaves, fruits and resins are variably used in treating a wide range of diseases such as urinary infection, toothache, piles, astringent, chronic diarrhoea, stomach ache, gonorrhoea, asthma, dysentery and treatment of haemorrhage.

4.5.3 Other Benefits

The major use of ban oak is for firewood and charcoal due to its high calorific value. Its leaves are used as cattle fodder. Leaf litter is rich in nitrogen and makes an excellent compost fertilizer. The timber is hard and strong and used for agricultural implements. The long-lived ban forest has immense importance for soil conservation as well as flood preservation.

4.6 *Salix Alba Linn.*

S. alba (also known as white willow or Indian willow) is also known as cricket bat willow or white willow and belongs to the Salicaceae family. It is a large deciduous tree10–30 m tall, ascending branches, green and brown bark, spreading crown, leaves covered with silky hairs on both surfaces. It has flowers which grow in ament in early spring. Generally, the plant is found to be having a short lifespan.

4.6.1 Geographical Distribution

The White willow is native to Europe, Western and Central Asia. In western part is found in the southern region around the Mediterranean basin that includes North Africa (Morocco and Algeria part). On the north, it ranges from the British Isles, then the Netherlands and also covering eastern Baltic coast such as Latvia and Lithuania (Isebrands and Richardson 2014). The species is exotic in India and cultivated in Western Himalayas in Kashmir and Kullu valley. *S. alba* also reported from the dry temperate zones of the country Lahaul (Himachal Pradesh) and Ladakh at high altitudes.

4.6.2 Nutritional and Medicinal Properties

The plant contains total fats, iron, carbohydrates, phosphorus and protein which are good sources of nutrition. Its bark can relieve pain in osteoarthritis due to the availability of salicylic acid. *S. alba* helps cure several diseases such as dyspepsia, fever, headache, joints pain, febrifuge, gout, rheumatism, arthritis and immune disorder. It also shows anti-inflammatory, anti-diarrhoeal, analgesic, anti-fertility and anti-ulcer properties.

4.6.3 Other Benefits

The species are known to be as good fuel, and the stem is used in the making of baskets. Wood is useful for making cricket bats as well as produces charcoal that helps in the manufacturing of gun powder. It is planted extensively along with the other willow species for soil conservation and land reclamation in the catchment area. The species is beneficial in critical areas as it helps to mitigate erosion, and it is a more efficient plant for controlling erosion, modify the bank of waterways as well as in the restoration of ecosystem and phytoremediation (Ball et al. 2005).

4.7 Terminalia Arjuna Bedd.

This plant is commonly known as arjuna tree, tropical almond, white murdah or Malabar almond; and belongs to the Combretaceae family. The evergreen tree about 20–25 m in height, the bark is grey and leaves green from above and brown from below. It contains pale yellow colour flowers on it which grow in the month of March and June. It is whose new leaves appear in the hot season. Its fruit is drupe which is 2.5 cm long and oval in shape.

4.7.1 Geographical Distribution

T. arjuna is native to India and Sri Lanka apart from it has been planted as an ornamental and roadside tree throughout Bangladesh, China, Cuba, Ghana, Indonesia, Kenya, Malaysia, Mauritius, Nepal, Pakistan and Thailand. In India, it is luxury flourishes across the river bank.

4.7.2 Nutritional and Medicinal Properties

This evergreen tree has enormous nutritional and medicinal importance. Its bark powder extract is enriched with calcium, magnesium, potassium and iron. Arjuna is one of the most widely accepted medicinal plants in the indigenous system for the treatment of several serious diseases. This plant is very beneficial as a good safety outline when it is mixed in combination with other conventional drugs. Its leaves and twigs are a significant part and supportive to make drugs in Ayurveda and for therapy of malignant growth, ulcer of mouth, rankles, dermatological, gynaecological, heart infections and urinary problems (Garg et al. 2017).

4.7.3 Other Benefits

It is widely used as timber, fodder for livestock and planted for raising silkworms. It helps in controlling erosion and pollution. Its flowers have religious value. *T. arjuna* is one of the finest avenues and shade trees as it has beautiful foliage. In some areas, leaves are fed by tassar silkworms. It also yields rayon-grade pulp that is mixed with other hardwoods for various purposes (Prakash and Hocking 1986).

4.8 Zizphyus Mauritiana Lam.

Z. mauritiana (also known as Chinese fig, Chinese date, cottony jujube, Chinese jujube, Indian jujube, Indian cherry, dessert apple, Indian date, Indian plum or Malay jujube) is small to moderate-sized, thorny, almost evergreen sensitive tree up to 12–15 m of dry regions and belongs to Rhamnaceae family. Leaves are orbicular to round, basally 3-nerved, grey to glabrous above, rust-tomentose below. Flowers are borne in axillary cymes, small, green to yellow. Fruit is a drupe, oblong-globose with rounded apex yellow or orange when ripe, seeds 1 or 2, compressed. This tree can tolerate very humid to hot and dry temperatures. It can prefer fairly light, deep soils, but it can be grown on marginal land, alkaline, saline or slightly acid, light or heavy and drought-susceptible or occasionally waterlogged soils.

4.8.1 Geographical Distribution

Z. mauritiana is considered a native of Central and South Asia and China and introduced to Africa, Europe, North and South America, Oceania, South-east Asia and Middle East countries. In India, ber is found throughout the hotter, drier parts either wild, semi-wild, or cultivated in the Deccan, the Gangetic Plains and sub-Himalayas hills.

4.8.2 Nutritionally and Medicinal Properties

It contains high nutritive value including vitamin C, minerals, calcium, phosphorus, iron and carotene. Besides, it also possesses some quantity of proteins, fat and carbohydrates. Medicinally the plant has anti-cancerous, antidote, expectorant, refrigerant and sedative. They are used to purify blood and aid digestion. Also used to treat chronic fatigue, loss of appetite, diarrhoea, pharyngitis, bronchitis, anaemia, irritability and hysteria, dyspepsia and ulcers.

4.8.3 Other Benefits

Z. mauritiana makes an excellent fuelwood and first-grade charcoal. Its wood is hard, fine-grained and strong which is used for house construction, oil crushers, toys etc. The fruit is very delicious and can be eaten also fresh or prepared as a drink. The bark is used to produce brown, grey and reddish dyes. Fruits are eaten fresh and pickle is made from the dried form. Leaves are fed by the tassar silkworms. The tree is likewise utilized for live fencing around houses, and the branches thorny that can be utilized as dead fencing to discourage cattle (Gupta 1993).

5 Conclusion

Forests are an excellent source for the survival of all living beings. The sustainable use of the forest is generally associated with land resources that one of the complicated issues that include society requirements and cultural values as well as the socio-economic status of the people. Wild plants have played a key role for humanity as they can be used as food, fodder, fibre, fuels and has many medicinal benefits. They have been used since ancient times in various forms such as medicines, food, fodder, fibre, fuels and many more. The wild edible varieties are one of the important foods, which ensure livelihood safety for numerous communities as well as families throughout the world. The rural community is mainly dependent on the forest for fuelwood for attaining their energy needs. They are also a major part of the rural community and extensive harvesting is leading to deforestation. Some of the forest-based tree species are commonly used for all purposes, for instance, *Ficus* spp., *Grewia optiva, Moringa olifera, Morus alba* etc. Several countries around the world are characterized by an immense diversity in climate, topography, flora, fauna, land use and socioeconomic conditions. However, in this twenty-first century, countries around the world have experienced remarkable land-use and land-cover changes including deforestation, cropland changes and urban expansion. Thus, forest conservation should be one of the major parts of society, as they are the storehouse of biodiversity. Wild herbs, shrubs and trees are known to increase the capacity of agricultural systems of the world. They represent a huge amount of genetic diversity, thus at the same time, germplasm conservation is also required in different climatic zones. Additionally, awareness about the major food, fodder and fuelwood species among the local communities is also required. It has been noticed that most of the fodder and fuelwood tree species are under stress because of unplanned or unscientific lopping. Furthermore, it has been noticed that the improvement and preservation of life especially in the third world will largely depend on the presence of forest. Therefore, to meet this critical requirement of food, fodder and fuelwood tree species, and to reduce the pressure on natural forests stand, there is a strong need to screen the fast-growing food, fodder and fuelwood tree species around the world.

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Fiber from Forest and Their Importance in Modern Time

Surendra Pratap Singh

Contents

1 Introduction

Forests currently cover 4 billion ha or 31% of Earth's landmass (Huang 2019). In North America and most other developed regions, wood at present constitutes mostly the fibrous raw material used for pulp, paper, paperboard, and reconstituted panel board. However, forest loss is a main causal agent of biodiversity huge loss that is anticipated to continue due to the constantly growing human population (FAO and UNEP 2020). Global forest area declined by 13 million ha/annum in the last decade, however, during the same period, the area of planted forests increased by about 5 million ha/annum (Ramage et al. 2017). This expansion of plantation forests is primarily driven by global demands for bioenergy, fir, wood, and wood

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fiber (Hillring 2006). Although, these plantations do not support the same biodiversity as natural forests (Didham 2011).

It has been predicted that the industries using wood and or wood fiber may face a common problem for the future due to the increasing demand for raw material. For instance, the demand for wood-based and wood-derived products is expected to double in North America; and on a worldwide basis, projections indicate that demand will grow at an even faster rate (Didham 2011). Consequently, there will be severe competition for raw materials among the forest-based industries, especially the major ones, namely pulp and paper, lumber, plywood, and particleboard (Ke et al. 2019). In many areas, the normal wood supply will not match demand, and adjustments will have to be made in the kinds and qualities of wood and fiber to be used. Competition and cost will compel the utilization of lower quality trees and wood that was formerly wasted. Thus, the management of wood resources has become a complex problem requiring a broad knowledge of many interrelated factors. The fiber supplies of the future for the pulp and paper industries will be affected not only by domestic and world requirements but also by competitive demands within the forest-based industries themselves. Although technological innovations will undoubtedly play an important role in improving fiber utilization, these gains may be countered by governmental regulations and environmental pressures (Seppälä et al. 2019).

As the natural stands were being depleted, the forest industry, government, and university scientists began researching, developing, and applying methods—similar to those used successfully in farming domesticated agricultural crops to grow select forest tree species on plantations. Thus, technologies were developed for genetic improvement, planting and managing forest tree plantations for a sustainable supply of wood and fiber. The use of forest plantations as a sustainable source of wood for conversion into products was a paradigm shift in the industry. Table 1 compares the advantages and disadvantages of using plantations or natural forests for wood production. This shift from harvesting wood from natural forests and relying on the natural forests to regenerate themselves to planting forest trees in managed plantations is impacting many characters of the forest industry.

It has been estimated that of the roughly 150,000 plant species in the world. There are above 20,000 species of woody plants (Saw et al. 2009). Only a few are of commercial value today, but as the demand for wood is rapidly increasing new species are taken into consideration, both in the forests, which today are considered as commercially available, and in the potentially available areas, such as most of the tropical forests. Tables 2 and 3 give a survey of the most common wood species for pulping or natural fiber composite manufacturing and their origin (Ilvessalo-Pfäffli 1995a; Parham and Gray 1982). Some annual species are also used as raw materials for pulping, such as bamboo and Sabai grass in India, esparto grass from Spain and North Africa, reed and cereal straws in various countries, e.g., Holland, and flax straw and bagasse in America (Sridach 2010; Laftah and Wan Abdul Rahman 2016).

Wood used for natural fiber or pulp is obtained from seed plants. In the wood products trade and the pulp and paper industry, these plants are categorized as softwoods and hardwoods. However, the names are apparently adequate for commercial

Table 1 A comparison of using native forests or plantations for wood production

Native forest		Plantation	
Advantage	Disadvantage	Advantage	Disadvantage
Ecosystem less susceptible to disease outbreaks	Wood and fiber properties more variable	Improved uniformity of wood and fiber properties	More risk of disease outbreaks
Greater fire risk in some ecosystems	–	Reduced risk of fire	–
Higher wood quality in slow-growing older trees	Long rotations	Research and development, faster shorter rotations	Potential for reduced wood quality
Lower ecological impacts	Larger land area needed for supply	Smaller land areas needed or supply	Greater ecological impacts
Minimal management costs	Higher harvesting costs	Lower harvest costs, greater returns per unit land area	Higher establishment and maintenance costs
Mixed species Heterogeneous	Slow growth	Fast growth, uniformity	Single species

purposes. Other colloquial designations for these types of plants include conifers versus broadleaf trees or evergreen versus deciduous trees. From an anatomical view, softwoods and hardwoods can be called nonporous and porous woods, respectively. Forest fiber or pulpwood trees described in this chapter are largely those indigenous to the United States and Canada. Other woods discussed include some types commonly used in Europe and Scandinavia as well as some species grown on plantations in other temperate or tropical locations.

2 Overview of Plant Fiber Diversity

Plant can be identified to the species level by the form and architecture of their twigs, bark, leaves, flowers, and fruit. Nature offers a large diversity of plant fibers, which are generally classified according to their location within plants. An overview of plant fibers is given in Fig. 1. The plant-based fibers are divided into two categories depending on their origin within the plant.

2.1 Non-wood Fiber

Agro-based or non-wood fibers are derived from selected tissues of various monocotyledonous and dicotyledonous plants and categorized botanically bast (stem) fibers, leaf fibers, and seed hair fibers (Ashori 2006). Cotton fibers are obtained from the seed hairs of cotton capsules. The fiber bundles of flax, hemp, and kenaf are obtained from the bark of the stalk and are therefore called bast fibers. Coir fiber

Table 2 Hardwood plant species

Common name	Botanical name	Origin
Alder	*Alnus glutinosa* Gaertn.	Europe
American aspen	*Populus tremuloides* Michx.	North America
American beech	*Fagus grandifolia* Ehrh.	Eastern North America
American red or sweet gum	*Liquidambar styraciftua* L.	Southern North America
Basswood	*Tilia americana* L.	North America
Black gum	*Nyssa silvatica* Marsh.	Southern North America
Eastern Cottonwood	*Populus deltoides*	Western North America
Cucumber magnolia	*Magnolia acuminata* L.	Southern North America
Elm	*Ulmus glabara* Huds.	Europe, Asia
European ash	*Fraxinus excelsior* L.	Europe, India
European aspen	*Populus tremula* L.	Europe
European beech	*Fagus sylvatica* L.	Europe
European birch	*Betula pubescens* Ehrh.	Europe
European oak	*Quercus robur* L.	Europe
European poplar	*Populus nigra* L.	Europe
Japanese birch	*Betula japonica*	Japan
Jarrah	*Eucalyptus marginata* Sm.	Australia
Mountain ash (giant gum)	*Eucalyptus regnans* F. v. M.	Australia
Mulberry	*Morus nigra* L.	Asia
Paper (White) birch	*Betula papyrifera* Marsh.	Eastern North America
Poplar hybrid	*Populus X euramericana*	Europe
Red alder	*Alnus rubra* Bong.	Western Europe North America
Red oak	*Quercus borealis* Michx.	North America
Silver birch	*Betula verrucosa* Ehrh.	Europe
Southern blue gum	*Eucalyptus globulus* Labill.	Australia, planted in Mediterranean areas
Sugar maple	*Acer saccharum* Marsh.	Eastern North America
Sycamore	*Acer pseudoplatanus* L.	Europe, Asia, North America
Sydney blue gum	*Eucalyptus saligna* Sm.	Australia, planted in South Africa and Brazil
Tasmanian oak	*Eucalyptus gigantea* Hook	Australia
Tuart	*Eucalyptus gomphocephala* A.DC.	Australia, planted in Morocco
Tupelo gum	*Nyssa aquatica* L.	Southern North America
White ash	*Fraxinus americana* L.	North America
White elm	*Ulmus americana* L.	North America

bundles are obtained from the fibrous hull of the coconut. Being rich in lignin and course in fiber bundle width, they are resistant to bending and are therefore classified as hard fibers (El-Sayed et al. 2020). Non-wood is also classified by means of production; such as wheat straw, rice straw and sugar cane bagasse, and so on.

Table 3 Softwood plant species

Common name	Botanical name	Origin
Alpine fir	*Abies lasiocarpa* (Hook.) Nutt	Western North America
Bald cypress	*Taxodiunn distíchunn* Rich.	Western North America
Balsam fir	*Abies balsamea* Mill.	North-eastern North America
Black spruce	*Picea mariana* B.S. et P.	North-eastern North America
Douglas fir	*Pseudotsuga taxifolia* Britt.	Western North America
Eastern hemlock	*Tsuga canadensis* Carr.	Eastern North America
Engelmann spruce	*Picea engelmannii*(Parry)Engolm.	Western North America
European larch	*Larix decidua* Mill.	Europe
European silver fir	*Abies alba* Mill.	Europe (continental)
Grand fir	*Abies grandis* Lindl.	Western North America
Jackpine	*Pinus banksiana* Lamb.	North-eastern North America
Japanese larch	*Larix eptolepis* Gord.	Japan
Loblolly pine	*Pinus taeda* L.	Southern North America
Longleaf pine	*Pinus palustris* Mill.	Western North America
Noble fir	*Abies procera* Rehd.	Western North America
Pacific silver fir	*Abies amabilis* Loud.	Western North America
Patula pine	*Pinus patula* Schiede ex Schltdl. & Cham.	North America, planted in South Africa
Ponderosa pine	*Pinus ponderosa* Dougl.	Western North America
Red pine	*Pinus resinosa* Ait.	Eastern North America Europe
Red spruce	*Picea rubens* Sarg.	North-eastern North America
Scots pine	*Pinus silvestris* L.	Europe
Shortleaf pine	*Pinus echinata* Mill.	North-eastern North America
Siberian larch	*Larix sibirica* Lebed.	Russia, Siberia
Sitka spruce	*Picea sitchensis* (Bong.) Carr.	Western North America
Tamarack	*Larix laricina* K. Koch.	North-eastern North America
Western hemlock	*Tsuga heterophylla* Surg.	Western North America
Western larch	Larix occidentalis Nutt.	Western North America
Western red cedar	*Thuja plicata* D. Don.	Western North America
Western white fir	*Abies concolor* Lindl. & Gord.	Western North America
White cedar	*Thuja orcidentalis* L.	North America
Yellow pine	*Pinus strobus* L.	Southern North America
Alpine fir	*Abies lasiocarpa* (Hook.) Nutt	Western North America

2.2 Wood Fiber

Anatomically, wood is the secondary xylem of a plant. There are two categories of wood based on their source. They are softwood and hardwood. The wood of gymnosperm is called softwood. The softwood is mainly composed of wood rays (parenchyma) and tracheids. The wood of dicot Angiosperm is called hardwood. Hardwood

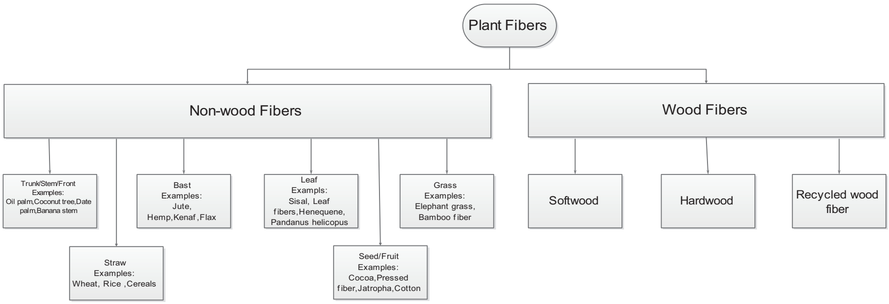

Fig. 1 Classification of natural fibers

contains plenty of wood fibers (libriform fibers and fiber tracheids). The fiber material for cellulose fiber insulation material is obtained from waste newsprint by means of a mechanical process, which is why these fibers are also called recycled cellulose fibers.

3 Morphology, Ultrastructure, and Chemistry of Forest Plant Fibers

Trees are the giants of kingdom Plantae, i.e., plants, because of their large size and age, and the unique rigid wooden structure of stem and branches. To be able to fully utilize wood, we need to understand the morphology, anatomy, and chemistry behind the building blocks and constituents of wood. Basic knowledge of the structure and chemical composition of wood will help in choosing the right tree species for specific end uses. The main part of the tree which is used for non-timber products such as, pulp and paper, composite materials, etc., is the trunk. The trunk consists of three main parts*:* bark, cambium, and xylem or wood. It has three major physiological functions, to transport water and mineral salts from root to crown, to store some reserve food, and to carry the crown aloft, and it is constructed accordingly (Mencuccini et al. 2013).

In the core of the wood is the pith, and in older trunks, the wood is of denser structure in the inner parts, the heartwood, than in the outer sapwood (Pinto et al. 2004). Between the bark and the wood is a layer of thin-walled living cells called the cambium, in which most growth in the thickness of bark and wood arises by cell division. Bark can be further divided into inner living bark(phloem) and outer dead bark (rhytidome). Stems, branches, and roots also grow by elongation. This is accomplished through the activity of terminal growing points called apical meristem. These are housed in the bud system of the crown and beneath protective caps in the roots. Terminal growth is closely coordinated with the addition of growth rings by the vascular cambium (which can be termed a lateral meristem). However, since stems elongate only at their tips, this situation results in a tree form in which the number of growth rings in a given cross section becomes fewer and fewer along the vertical axis of the stem. Thus, a tree stem is analogous to a stack of inverted hollow cones, each cone representing the wood added to the stem during one growing season as a cambial cell divides, one of the daughter cells remains a cambial cell, whereas the other forms a phloem cell or a xylem cell, depending on which side it was split off. Most of the xylem cells are longitudinal and are formed from the cambium in concentric layers outside the older wood. In springtime when growth is rapid, cells with thin walls and wide cavities are formed, whereas towards the fall growth is slower, producing cells with thicker walls and narrow cavities. The former wood cells are called springwood, or earlywood, the later summerwood, or latewood, and a year's growth is, especially in softwoods, easily seen and is called a growth ring. The Scandinavian softwoods have a growth season of 3–4 months; a growth ring contains some 20–50 fairly concentric layers of cells, which means that the cambium on average splits off 2–3 layers a week. The growth rings vary in thickness from 0.1 to 10 mm, according to climate, soil, age of the tree, species, etc. (Wodzicki 2001). A thin growth ring often means dense wood. Therefore, density variations are frequent both within a stand and within one single trunk.

3.1 Classification, Functions, and Occurrence

Wood tissue, known technically as xylem, is formed through the activity of a circumferential sheath of cells at the wood/bark interface called the vascular cambium. Wood cells are produced to the inside and bark cells to the outside. Several different types of cells, with different functions, are formed from the cambium. There are four main elements: fibers, tracheids, parenchyma cells, and vessel elements.

The parenchyma cells serve as storage and transport cells for food and water. The fibers are supporting elements, giving rigidity to the wood structure. The tracheids and the vessels function as water conductors, and also give mechanical support to the structure. There are several forms of gradations between libriform fibers, which have only mechanical functions, and the tracheids, which have well-developed conductive functions. The intermediate elements are called fiber tracheids (Thomas 1977).

All wood contains parenchyma cells, but need not contain all the other types of structural elements. In softwoods, the tracheids dominate, with few if any libriform fibers and no vessels, whereas tracheids are limited in hardwoods, and the corresponding functions instead are performed by the more specialized libriform fibers and vessels. This difference is due to the more pronounced need for rapid water transport in the case of hardwoods, which develop their leaf crowns during a very short period in springtime. Table 4 gives the approximate relative proportions of different structural elements in some technically important natural fibers (Smook 1982; Ilvessalo-Pfäffli 1995a, b, c).

Table 4 Fiber dimensions of some woody plant species

Common name	Botanical name	Length, mm		Width, µm		Wall thickness, µm		Wall fraction, %
		Average	Range	Average	Range	Average	Range	Average
Angelique	*Dicorynia paraensis*	1.39	0.6–2.3	22	10–40	4.5	–	39
Aspen	*Populus tremula*	0.95	0.50–1.35	21	–	4.3	–	39
Balsa tree	*Ochroma lagopus*	1.30	–	40	19–55	1.5	–	9
Blue gum	*Eucalyptus globulus*	0.99	0.6–1.4	19	–	5.9	–	64
Bullet wood	*Manilkara bidentata*	1.33	0.4–2.0	22	10–40	9.2	–	84
Courbaril	*Hymenaea courbaril*	1.12	0.4–1.9	20	10–30	4.5	–	45
Determa	*Ocotea rubra*	1.89	0.6–2.8	34	10–60	9.6	–	56
European ash	*Fraxinus excelsior*	1.05	0.49–1.61	16	10–29	7.5	2.4–6	48
European beech	*Fagus silvatica*	1.30	0.40–2.30	29	25–35	5.2	2.5–15	59
European birch	*Betula verrucosa*	1.25	0.56–2.00	18	10–29	3.7	2.4–7.2	42
European lime	*Tilia vulgaris*	1.00	0.45–1.80	28	17–37	4.7	2.9–5.7	35
European oak	*Quercus robur*	1.10	0.40–1.90	21	10–35	6	2.5–10	55
Frijolillo	*Pseudosamanea guachapele*	0.92	0.3–1.5	22	10–40	3.8	–	35
Greenheart	*Ocotea rodiaei*	1.04	0.4–1.6	26	10–40	7.5	–	58
Guyacan	*Tabebuia guyacan*	0.95	0.4–1.5	16	10–30	5	–	63
Kakeralli	*Eucalyptus sagotiana*	1.59	0.8–2.4	19	10–30	7.3	–	77
Kaneelhart	*Licaria cayennensis*	1.54	0.9–2.3	21	10–40	7.7	–	73
Laurel blanco	*Cordia alliodora*	1.34	0.3–2.4	27	10–60	3.5	–	26
Mahogany	*Swietenia macrophylla*	1.42	0.7–2.3	28	10–60	3.3	–	24
Mangrove	*Rhizophora mangle*	1.74	1.21–2.56	25	16–29	11	6.3–13	87
Murray red gum	*Eucalyptus camaldulensis*	0.97	0.5–1.4	17	–	3.6	–	44

(continued)

Table 4 (continued)

Common name	Botanical name	Length, mm		Width, μm		Wall thickness, μm		Wall fraction, %
		Average	Range	Average	Range	Average	Range	Average
Tauari	*Cordia alliodora*	1.49	0.6–2.3	23	10–40	3.3	–	30
Teak	*Tectona grandis*	1.29	0.6–2.0	30	20–50	6	–	40
Tuart	*Eucalyptus gomphocephala*	1.06	0.7–1.4	19	–	7.4	–	80
Umbrella tree	*Musanga smithii*	1.44	0.77–2.25	43	32–58	1.5	–	9
Willow	*Salix*	0.73	0.43–1.05	20	13–37	2.4	–	26

3.2 Softwood Anatomy

The wood volume in softwoods is composed of mainly two different cells: ray cells (5–10%) and longitudinal tracheids (90–95%). The longitudinal tracheids give mechanical support and in the conduction of water and nutrients from the roots. At maturity, fibers are dead, hollow with a central cavity or lumen, and aligned in radial rows.

The other major cell type in softwoods is the parenchyma cell. These are short, brick-like elements, often thin-walled, which are arranged in vertical or horizontal series. Parenchyma is often living, even in mature wood tissue, and functions largely as a storage site for gums, starch, resin, tannins, latex, and other extraneous materials. They are also a repository for most of the wood inorganics, including both crystalline and amorphous deposits. They serve a similar function in hardwoods.

Longitudinal or axial parenchyma is sparse in most softwood and abundant in only a few species. However, horizontal parenchyma is prevalent in all species, forming thin ribbons of tissue along the stem radius. These ribbons are called rays. In some species, the ray tissue also contains cells known as ray tracheids. These cells are dead at maturity and have some wall markings similar to those in longitudinal tracheids, but ray tracheids are not fibrous cells. They are similar in size to parenchyma and are also arranged in a horizontal series. Since they occur in some species and not in others, they are of some diagnostic value in wood identification. The wood of all pines, spruces, larches, and Douglas firs contain normal longitudinal and horizontal resin ducts. These are tube-like cavities lined with specialized secreting parenchyma called epithelial cells.

As in other cells, the dimensions of the tracheids vary depending on genetic factors and growth conditions. Variations exist among different species and individuals as well as between different parts of the stem and within one and the same growth ring. The fiber length in the stem increases from the pith toward the cambium and reaches a maximum at the middle of the bole. Tracheids in the latewood or narrow annual rings are usually longer and narrower than those formed more rapidly. The tangential width of the fibers varies only slightly but large differences exist in the radial direction between earlywood and latewood tracheids.

3.3 Hardwood Anatomy

Hardwoods contain several cell types, specialized for different functions. The supporting tissue consists mainly of libriform cells, the storage tissue of ray parenchyma cells, and the conducting tissue of vessels with large cavities (Thomas 1977). In addition, hardwood contains hybrids of the above-mentioned cells, which are classified as fiber tracheids. Although the term fiber is frequently used for any kind of wood cells, it more specifically denotes the supporting tissue, including both libriform cells and fiber tracheids. In birch, these cells constitute 65–70% of the stem volume.

Libriform cells are elongated, thick-walled cells with small cavities containing some simple pits. The dimensions of birch libriform fibers are 14–40 μm (width), 3–4 μm (cell wall thickness), and 0.8–1.6 mm or on an average 1.1–1.2 mm (length). In some tropical hardwood species, the libriform fibers' average length may reach up to 4 mm. Vessels are composed of thin-walled and rather short (0.3–0.6 mm) and wide (30–130 μm) elements, which are placed on top of one another to form a long tube. The ends have disappeared more or less completely. The channels thus formed, which might be several meters in length, are capable of a more effective water transport than the softwood tracheids. This is needed especially in the spring during the leafing. In diffuse-porous woods (maple, birch, and aspen) the vessels are evenly distributed across the annual ring. The vessels are larger and more numerous in the earlywood portion in ring-porous woods, such as elm, ash, and oak. In aspen and birch, the vessels amount to about 25% of the wood volume. Several different pores are present in the walls of the vessels. These differences together with other structural features are of great help in the identification of pulp fibers. Besides the usual vessels, some hardwoods contain cells similar to softwood tracheids or small vessels. Their walls are mostly bordered pits. Hardwood rays consist exclusively of parenchyma cells. The ray width varies in the tangential direction. In aspen wood, the rays form one row, in oak wood and birch wood 1–30 and 1–3 rows, respectively. The height varies from one up to several hundred tiers. The rays account for 5–30% of the stem volume.

3.4 Fiber Dimensions

Wood is of plant origin, and therefore variability in structure and dimensions. On the basis of their different shapes, wood cells can be divided into two broad categories known generally as prosenchyma cells and parenchyma cells. The softwood consists of tracheids, which are fibrous in form; these prosenchyma cells are termed as fibers. The tracheids and libriform fibers, after being split off from the cambium, extend longitudinally. These are stretched to a length of approximately fifty to a hundred times their diameter. The length of the softwood tracheids varies from 1 to 11 mm and is usually 2–5 mm in the commercially important species. The hardwood libriform fibers are shorter, about 1–2 mm. The vessel elements are very often wide and short, with thin walls. Their diameter may be as small as 0.02 mm and sometimes as large as 0.5 mm, and their length shows similar variations. The parenchyma cells are generally small, 0.02–0.2 mm (Smook 1982; Clayton et al. 1993). It is observed that the average length of softwood tracheids is always much greater than that of hardwood libriform fibers, so, softwoods are preferred for pulp manufacturing. The fiber dimensions (i.e., lumen width and wall thicknesses) are also important as the fiber length. Table 4 gives the results of extensive investigations on the length and wall thickness of tracheids and libriform fibers for a large number of species, including tropical woods (Smook 1982; Przybysz et al. 2018; Ilvessalo-Pfäffli 1995a, b, c; Kyrklund 1976). It is seen that dimensions vary considerably within each sample (Reme and Helle 1998). However, the average width of softwood tracheids is about 40 μm or twice that of the libriform fibers of most hardwoods as the average length of the tracheids is about three times that of the libriform fibers, the latter are generally less fine. The wall thickness varies especially for the softwood tracheids, because of the occurrence of springwood and summerwood fibers. The average wall thickness varies widely in different species. The wood species has been shown to be a very significant factor for the fiber dimensions. Other important variables are the age of the tree, the trunk height, the growing conditions, the proportions of springwood and summerwood, etc. An early work on Scot's pine made the following generalizations: at any height of the trunk, the fiber length increases from the center outwards to a maximum and then remains constant; at any growth ring the fiber length increases up the trunk to a maximum and then decreases. Subsequent work has disclosed many exceptions to these rules and shown the great variability of the material with a large number of influential factors, but on the whole, the generalizations have been confirmed. The fiber length in any one tree also varies a little according to its position from the ground. In most trees, the longest fiber is found in wood at from 3 to 6 m from the ground; above 6 m or below 3 m the fiber is found to be progressively shorter. The average fiber length at various heights from the ground has been found; in a white spruce tree about 100 years old (Hale 1969; Ilvessalo-Pfäffli 1995a, b, c). A similar type of variation occurs in all species of tree. In a horizontal direction, the variation in the length of fiber may be expected in any tree at any height from the ground. An often-cited investigation on a white spruce trunk, 106 years old showed a variation in average fiber length at one meter from the ground was 0.9 mm in the first growth rings, 2.3 mm in the 30th annual ring, 3.1 mm in 59th annual ring, and around 3.8 mm in 106th annual ring (Hale 1969). Within a growth ring, fiber length generally increases somewhat from springwood to summerwood, only about 10% in the case of softwoods, whereas in some hardwoods larger differences occur, in some eucalyptus species up to 50–100 %, difference. The increase in fiber length during the juvenile period is of industrial importance, since increasing forest areas consist of plantations on short rotation periods, from 6 to 20 years, and because of the increasing use of thinning of pulpwood.

3.5 Reaction Wood

The shape of cells, particularly of tracheids and fibers, is influenced not only by seasonal change but also by mechanical force. In all trees, there is some wood tissue that is anatomically and/or chemically dissimilar to the typical or so-called normal wood produced in straight, vertically erect stems. Such tissue is often referred to as abnormal wood, but it is perhaps more appropriately termed reaction wood because it develops as a result of the tree responding to certain stimuli (Sinnott 1952). More specifically, reaction wood is often concentrated in stems and branches as a means by which to achieve and maintain a preferred orientation. In other cases, it assists the tree in gaining a more suitable exposure to light (Donaldson and Singh 2016).

In softwood the fibers in the pressure zone (on the lower side) become shorter, the fiber walls thicker and more heavily lignified, and the structure stiffer, denser, and darker. Characteristic are the round cross sections of the tracheids, leaving intercellular space. This type of wood is called compression wood and is present in all trees, although it is most frequent in those growing under hard climatic conditions (Wimmer and Johansson 2014).

In hardwoods, reaction wood tissue is called tension wood and, in contrast to compression wood, is common on the upper sides of branches and leaning stems. In many hardwood species, they show an additional characteristic cell wall layer compared with regular fibers. This so-called G-layer can be regarded as the operative part of the tension wood fiber, although many hardwood species can bend their organs without its formation. The G-layer can fill the whole lumen of the tension wood fiber and consists of almost pure cellulose, oriented parallel to the axial direction with comparatively high crystallinity, and some xyloglucan, as well as traces of monolignols or syringyl units (Jonasson et al. 2020). Both abnormalities are also called reaction wood and affect pulping, having inferior fibers and giving a lower pulp yield than normal wood.

3.6 Density

Wood density or specific gravity is of importance in the wood industry. Density determines, to a considerable degree, the amount of fiber contained in a given volume, e.g., a cord of round wood, a truckload of chips, or a digester charge. Wood density or specific gravity is commonly defined as the dry weight divided by green or wet volume. In the metric system, this is expressed as g/cm^3. Since wood is a porous material, it consists of a void volume and a solid fraction or cell wall substance. The solid fraction itself may vary somewhat in density, but to a much less degree than does the bulk density. Obviously, the bulk density is greatly influenced by the proportion of void volume.

The density of a wood substance is about 1.53 and shows little variation with species, type of growth, or chemical composition. As the porosity of the wood varies very much with the proportions of different structural elements and their type, the density variations of dry wood are great, from 0.04 in the case of the pith tree (*Aeschynomene*) or0.1for balsa wood (*Ochroma*), to 1.42 for axemaster (*Krugiodendron*)wood. The volumetric proportion of wood substance in these woods is 3.9% and 93% respectively. The commercial pulpwoods have densities in the range 0.3–0.6, or 20–40% of their volume occupied by wood substance. The remaining 60–80% of the volume is void spaces, the lumina of the fibers as well as vessels and ducts. If this volume is filled with water, the wood becomes heavier. Also, the wood substance itself adsorbs water whereby it adds to both its weight and volume. Obviously, some definitions have to be made. Apart from the density of the actual wood substance, which is of theoretical interest, the density of wet wood often determines the transportation costs for a volume unit of pulpwood, whereas the density of dry wood determines the amount of wood substance obtained from a volume unit. As the shrinkage of wood on drying is around 10–15% and as the volume of green (living or freshly felled) wet wood is usually measured when the pulpwood is bought, the density of interest, in this case, should be defined as oven-dry weight per volume of greenwood. This magnitude is called the basic density of the wood. The values are averages, and there are large variations, not only for different species, but also for trees of the same species, within one single trunk at varying height and distance from the center, and within a growth ring. The densities for 2000 different samples of spruce with an average density of 0.45 ranged from 0.3 to 0.6 and similar results were obtained for others.

It is well recognized that wide differences exist in the bulk density of wood samples taken from various parts of a tree and trees of the same species grown under different climatic conditions. The fibers of summerwood (latewood) have thicker walls than do springwood fibers, and hence, have greater specific gravity. Core wood or juvenile wood produced by young trees generally has a lower density than mature wood produced in later years. Despite these differences in density within a wood species, it is also well recognized that average wood density is species-dependent to a considerable degree and hence, various woods may be classified in a general way as heavy, medium, and light. Those species of softwoods that normally have a large proportion of summerwood (southern pine), tend to be heavy; those species with little summerwood (spruce and fir) are light.

3.7 Characteristics of Plant Fiber

Natural plant fibers are cell walls that occur in stem and leaf parts. The plant fibers are exceedingly difficult to define chemically, because it is a complex heterogeneous product of nature made up of interpenetrating components, largely of high molecular weight. The principal components generally are c1assified as cellulose, lignin, hemicellulose, and solvent-soluble substances (extractives) (Kollmann and Cote Jr 1968). The chemical composition of wood varies somewhat from country to country depending upon the soil, the climate, age, the length of the growing season, etc. The chemistry and structure of fibers determine their characteristics, functionalities, and processing efficiencies (Khalil et al. 2010).

The primary organic compounds, which eventually buildup the wood substance are produced in the leaves by photosynthesis from water and CO_2 in the presence of chlorophyll and light (Saxena et al. 2011). The chemical composition of natural fibers varies from species to species. The structure and chemical composition of the plant fibers are fairly complicated (see Fig. 2). The major polysaccharide component of wood is called cellulose, and the rest is a mixture of shorter chain polysaccharides called "hemicelluloses." These components taken together make up the fraction termed "holocellulose," which is, in effect, the total polysaccharide portion of extractive-free wood.

Cellulose is a linear polymer of glucose (Barnette et al. 2011). In its simplest form, cellulose is a linear carbohydrate polymer of β-1,4-linked glucose units. However, the basic repeating unit of cellulose is the dimer cellobiose, which comprises two glucose units bound by the β-1,4 linkage as well as intermolecular hydrogen bonds. Cellulose is the major component of cell walls of wood fibers and yields theoretically only the monosaccharide sugar D-glucose on hydrolysis (i.e., it is a polymer of D-glucose). Experimentally, cellulose is isolated from wood in an impure state, since it is associated with closely related polymers of mannose and xylose. Cellulose has a high molecular weight and a highly crystalline material.

Lignin comprises 23–33% of softwoods, but only 16–25% of hardwoods. It occurs in the wood largely as an intercellular material. Lignin fills the space between

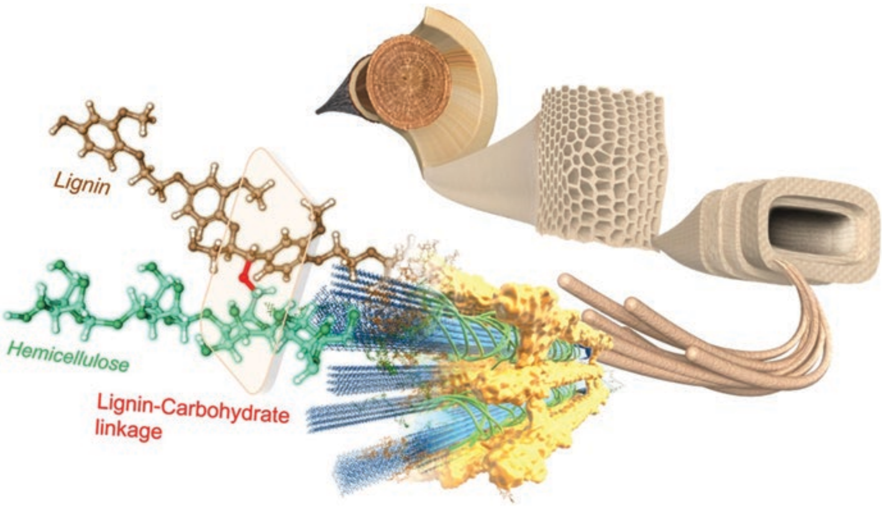

Fig. 2 A three-dimensional view of the lignin–carbohydrate complex (LCC) in the wood cell wall (adopted from Nishimura et al. 2018)

the polysaccharide fibers, cementing them together. Lignin is an amorphous, highly polymerized product, which is insoluble in water, but soluble in hot NaOH (especially in presence of Na_2S) or sodium sulfite solutions, alcohol, or dioxane. The principal feature of the chemical structure of lignin is the presence of methoxyl (–OCH_3) groups, but the proportion of those present appears to vary according to the origin of lignin. Thus, hardwood has a methoxy group content that is about 50% greater than that of softwood, but there are also variations between different woods in these two classes. Indicating that such difference can serve to distinguish different types of wood. The order of basic building units is as follows: Syringyl > guaiacyl > p-hydroxyphenyl. The lignin also contains 1-(4-hydroxy-3-methoxyphenyl)-3 hydroxypropane-1-one structures. Other chemical groups known to be present in the native lignin are carbonyl groups, alcoholic, and phenolic hydroxyl groups. The function of lignin in a plant is to form the middle lamella and to cement the fiber together by means of an intercellular layer surrounding them. In this, it is associated with certain polyuronoids. Thus, the outer layer of the wood fiber contains a relatively large proportion of lignin, whilst the inner or primary wall contains more cellulose; the remainder of the fiber is free from lignin. The lignin contents of sapwood and spring are greater than those of corresponding heartwood and summerwood respectively; the cellulose contents are correspondingly less (Hedges and Mann 1979).

The hemicelluloses are a mixture of low molecular weight polysaccharides polymers, which are closely associated in plant tissues with cellulose. The polymeric units are built up from simple sugar molecules and amorphous in nature. The hemicelluloses yield more than one type of sugar on acid cleavage. Also, the relative amounts of these sugars vary markedly with species. Hardwoods contain an average of 20–30% hemicelluloses with xylose as the major sugar. The smaller amounts of arabinose, mannose, and sugar acid are also attached to the main polymer chain. Softwoods contain an average of 15–20% hemicelluloses, with mannose as the major sugar unit. The sugar acid, arabinose, and xylose are again present at lower levels. The hemicelluloses play a significant role in fiber-to-fiber bonding in the paper manufacturing. The component sugars of hemicellulose are of potential interest for conversion into various chemical products (Pauly et al. 2013; Ebringerová 2005). When wood is subdivided into wood meal and extracted with such neutral solvents as cold water, alcohol, benzene, ether, and acetone generally 3–10% of the wood substance dissolves. This fraction, termed "extractives," is composed of an astonishingly, wide variety of materials that generally are not considered a part of the cell wall (Yang et al. 2003). The organic compounds present, although no one species has all, including low molecular weight carbohydrates, terpenes, aromatic and aliphatic acids, alcohols, tannins, color substances, proteins, phlobaphenes, lignans, alkaloids, and soluble lignins. In addition, less than 0.5% of wood is composed of inorganic salts (e.g., calcium oxalate), which are not generally extractable and appear as ash upon co1nbustion of wood. Small amounts of other non-cell-wall substances such as starch, pectins, and proteins are not generally extractable either. Thus, to include all non-cell-wall components of wood, the term "extraneous materials" is used, regardless of whether or not the materials are soluble in solvents. The extraneous compounds of wood are of much greater importance than is indicated by their small concentration. They are the source of many wood by-products, lend wood its resistance to insects and decay, and give wood its odor, taste, and color (Sajc et al. 2000).

Plant material is burned in a furnace, with remaining mineral materials determined gravimetrically as the ash content. The ash in softwood and hardwood plant fibers is less than 2%, but substantially higher levels in grasses such as rice and wheat straw. These higher levels in grasses are probably due to silica (SiO_2) content, which is deposited in grass cuticle as silica bodies and trichomes and other features of leaves (Torri et al. 2016; Stern et al. 2003).

3.8 Engineering Properties of Plant Fiber

The physical and mechanical properties of plant fibers vary considerably and depending on the growth conditions, fiber type, structural and chemical composition. Some of the natural variability of plant fiber properties comes from the adaptational growth of plants, with the consequence that the within-plant variation in fiber properties is as large as the between-plant variations in fiber properties. Plants utilize various concepts to adjust the mechanical performance of their fibers and thereby the macroscopic properties of their organs. For instance, trees change the orientation of cellulose fibrils in the cell walls to adjust mechanical properties (Lichtenegger et al. 1999), which can be followed during the ontogeny of the organism. Young trees form so-called juvenile wood fibers, which possess cell walls with a rather large MFA (Sarén et al. 2004). By making their wood flexible, young trees support the strategy of reducing the impact of wind loads by streamlining. In contrast, mature trees build wood fibers with rather small microfibril angles in their cell walls, which make the adult wood stiff and help to withstand wind loads. The mechanical data of the different fiber types from different sources clearly show why there are crucial concerns about the large variation in mechanical properties of plant fibers when it comes to technical utilization. The mechanical properties show large variability both within and between fiber types. This variation can be partly explained by natural variation, but it is also due to technical factors (Machado et al. 2019).

4 Applications of Forest-Based Natural Fibers

Forest fibers of various origins are processed using different procedures. Owing to different mechanical and physical properties, natural fibers are suitable for a variety of applications. A wide range of products has already been developed to date. The areas of application include the use of raw fibers in the sealing of pipes (e.g., hemp), as a filling material for seat upholstery (e.g., coir fibers), life preservers (e.g., kapok),

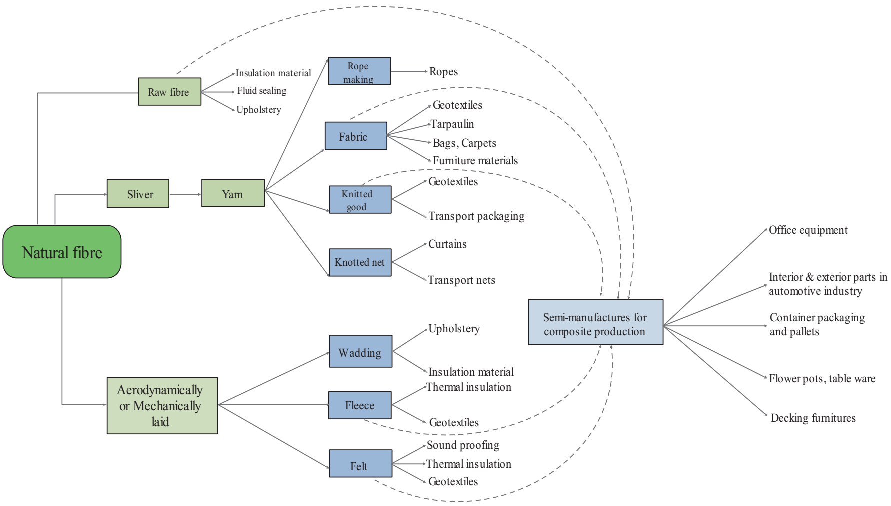

Fig. 3 Different uses of natural fibers in technical applications

technical textiles, transport packaging, and geotextiles through to complex construction materials used in the automotive and furniture industries and materials used as reinforcement in cement. An overview of the different application areas of natural fibers is shown in Fig. 3, involving various technical uses. Ropes are produced predominantly from flax and jute. Fabrics, knitted goods, and knotted nets can be produced from yarns, and wadding, fleeces, and felts are produced by the aerodynamic or mechanical laying of fibers.

4.1 Insulating Materials Made from Natural Fibers

Insulating materials made from natural fibers provide good summer heat accumulation properties and winter heat insulation, as well as good sound absorption. In addition, these insulating materials have a high sorption capacity providing a climate balance between the living space and surrounding areas. Nevertheless, they are naturally flammable, and the use of flame inhibitors such as borates is often essential. Therefore, these insulating materials cannot as yet be used in areas demanding high fire standards (Korjenic et al. 2016).

A wide range of insulation materials made from natural fibers is already being produced for different application areas. An example is given in Fig. 3. Insulating fleeces and felts, panel absorbers, blowing insulation, pouring insulation, impact sound insulation materials and ceiling panels are used for thermal insulation and acoustic soundproofing.

Insulating boards are also offered as fitted products. Nevertheless, they are substantially more pressure resistant and only slightly compressible compared with insulating fleeces. On account of these characteristics, they are ideally suited as facade insulation. In applications in wooden constructions, the insulating board follows the shrinking of wood very poorly in comparison with insulating fleeces and should only be used in constructions with negligible or no shrinking. Softwood fibers or poplar wood planning chips of up to 500 mm in length (often used as wooden fill fibers with a diameter of 0.08–0.3 mm) are primarily processed into insulating boards. The wooden rests are frayed out and mixed with water to a wooden mash. The mash is then fed through long sieves and role pressings for draining and forming. In a dry procedure, the components are mixed, dispersed, and hot-formed. The insulating qualities can vary according to density and application area. In addition, thermal insulating boards are also suitable to use as acoustic sound.

For blowing insulation materials, recycled paper and cellulose fibers are primarily used. Special machines are required for the blowing of insulation materials such as wood and cotton fibers to fill the hollows in cavities. Boundary materials for the delineation of the blowing pressure must be well secured. Owing to the blowing pressure, the fibers behave like compressed wadding. The fibers become caught up together against the boundary material. Insulating materials that are to be poured are produced from recycled paper, cellulose fibers, wood chips, cotton, and shives from hemp plant stalks. The hollow cavity to be insulated is dammed, and then the insulating material is poured in to fill it. Darning wadding from hemp, flax, wool, or cotton is used for the insulation of joints, for example in windows, where it is stuffed into the hollow cavities (Pfundstein et al. 2012).

4.2 Specialty Papers

Specialty papers are of considerable interest to the paper industry. Paper is the generic term for a felted sheet of plant fibers in which its thickness is invariably minute compared with its width and length. Where the sheet has been altered significantly with the addition of non-fibrous materials, either by admixture into the felted fibers or by application of coatings or films to the fibrous web, the product is considered a specialty paper (Biermann 1996). The specialty paper industry is very complex, diverse, and multifaceted. This report addresses the need to understand the existing and future trends of the industry. Although there are hundreds of specialty grades, their combined volume only accounts for a few percent of the entire paper industry. Specialty papers tend to be higher value-added products that are more financially attractive to the manufacturer. As the needs of our society become more complex, the varieties of such papers become correspondingly more numerous and more sophisticated. The growth of these papers in various fields such as communication, reprography, graphic arts, packaging, and functional industrial applications attests to their importance in filling real needs (Zule et al. 2012).

4.2.1 Decorative Papers

Many specialty papers have some functional characteristics but are basically utilized for their decorative values. Such papers are wallpapers, display papers, lampshade stocks, and paper drapes. Other decorative papers should also possess some functional characteristics: those used for table cloths, napkins, and shelf papers. These sheets are utilized in the home and in business as expendable products that have a predicated life span and then are replaced by new material. These papers are generally printed in bright colors and fancy patterns and maybe coated are or specially treated according to their use requirements (Yang et al. 2012).

Several types of decorative papers produced by the specialty converting industry do not fit into any of the other larger groups of classification. Such papers are used in one or more specific applications and are manufactured by a special technique or by using a type of material that is not common to the rest of the industry. Such papers are luminescent coated and printed papers, metallic coated papers, mica-coated papers, dull-coated papers, decalcomania or transfers, flock-coated or velour papers, marbled papers.

4.2.2 Abrasive Papers

Abrasive papers are adhesive coated and covered with suitable grades of grit to provide sandpapers or emery papers for sanding, polishing, rubbing down or surface finishing wood, metal, and glass. The abrasive base is made in standard weights (typically 110–140 g/m^2) for individual abrasive manufacturers and most use unbleached kraft, although some colors may be required (Mercer and Hutchings 1989). The main requirements are flatness, tensile strength tear resistance, flexibility, and porosity. Abrasive papers are divided into three categories, as follows:

1. Heavyweight for applications such as higher quality disks, belts, and other demanding applications (40%)
2. Latex saturated qualities for industrial applications (40%)
3. Lightweight sandpapers for DIY and other, less demanding applications (20%).

Good quality paper-based abrasive continues to gain some business, although this is largely at the expense of textiles. However, overall demand for abrasive papers is affected by improving industry techniques for smoother surface finishing of metals and wood, which require less and less surface grading.

4.2.3 Safety Papers

Safety papers are special papers treated to make visible any attempts to alter the writing or printing on them. They can be produced by the addition of certain chemicals in the beater when the paper is being made, by surface treatment or coating, or by the printing or embossing an overall design on the surface with sensitive inks.

Safety papers are papers that have been made or treated so that their identity can be verified by some easy visual or chemical means to prevent counterfeiting (Choi et al. 2010).

4.2.4 Banknote Papers

Banknote papers are based on the use of short red and blue silk fibers that were incorporated into the sheet when it was manufactured on the paper machine. These silk fibers are visible to the naked eye because they differ from the cellulosic fibers from which the paper is fabricated. Identifiable paper was also proposed in which the mark of identification comprised fibers that fluoresce under ultraviolet light. In the printing of currency notes that precaution is taken to discourage the counterfeiting of stamps by incorporating into the paper structure fluorescent cellulosic fibers invisible in ordinary light but visible under the influence of ultraviolet light (Otsuka and Miyashita 2003).

In connection with the printing of subsequent currency notes, the technical division of the Government Printing Office engaged in research to develop an identifiable paper that would distinguish genuine from counterfeit ration coupons by means other than the use of fluorescent fibers.

It was found that ferric chloride-treated fibers incorporated into the structure of the paper to the extent of 0.5% would remain colorless and invisible in the sheet until treated with certain reagents, such as potassium ferrocyanide and orthophosphoric acid. They then become visible and individually identifiable by acquiring a distinctive and permanent blue color.

These fibers presented several advantages not obtainable with silk or fluorescent fibers. One advantage is that they are invisible within the paper structure and do not reveal their presence to counterfeiters. Another advantage is that they are basically identical in composition with the untreated fibers of the entire sheet of paper.

4.2.5 Gummed, Specialty Tapes, and Labels

The manufacture of gummed paper is one of the major converting processes. The base paper is bought in the form of rolls from the paper manufacturer and the adhesive is applied at the gumming plant. The basic function of the industry is to supply adhesives in a more useful and economical form than in the uncertain and wasteful manner of the olden days. The old glue pot and mucilage have to be controlled given the way adhesives are applied to the proper paper, which is selected according to its specific use. Gummed papers are used for labels, stickers, sealing tape for corrugated shipping cases and packages, stay for corners of set-up boxes, veneer, and tape tablet binding (Reiling 1969).

Gummed flat-label paper is used for all types of stamps, label of innumerable types, pennants, posters, seals, window stickers, and many other such common items. Certain types of resinous materials are used for labels, and their development has been rapid. Their use at present is generally limited to special cases because of cost, but the water-insoluble adhesives will probably become increasingly popular (Stephen 1937).

Sealing tape is made in three categories, light, medium, and heavyweight. Lightweight sealing tape is designed generally for lightweight bundles and bags, such as those put out by retail stores. Medium-weight tapes are employed most extensively for sealing the flaps of corrugated or fiber cartons. Heavyweight tapes are designed for heavier packages and cartons. Stay tape is employed for the corner sealing of "set up" boxes.

4.2.6 Electrical Paper

Electrical papers are used in specialty applications such as separator tissues for transformers and capacitors, cable insulation, and battery separators (Emsley and Stevens 1994). Paper is a good insulator but in most electrical applications it has to be reinforced with resins to meet full functionality. The following are key requirements for electrical papers:

1. High resistivity
2. Water and moisture repellence
3. High flexural strength
4. High-temperature resistance.

Electrically conductive cable traditionally contained paper wrap. Most cable containing electrical wiring (mains, household goods, or telephone) now has only plastic insulation, but there is still widespread use of paper insulators in cable for TV aerials. Batteries use specialty papers to separate the anode and cathode chemicals. Impregnated paper is a traditional low-cost application in all markets. Transformers and capacitors have paper separators of various grades to act as electrical insulators. Paper is traditional in this market as it is a proven technology (Prevost and Oommen 2006).

4.2.7 Release Papers

Many raw materials and articles of commerce are either permanently tacky or have some tendency to stick to other surfaces at some stage of their manufacture or storage. When this happens, it is usually necessary to cover the surface of the product at least temporarily until the tackiness is gone or until the product is ready to be used. For these purposes, the so-called releasing papers are almost always employed. A release paper may therefore be defined as a web, composed at least partially of cellulose fibers, which shows low enough adhesion to some other material so that it may be removed easily without damage to either the paper or the product (Mascheroni et al. 2011).

A surprising number of products can stick to other surfaces. Unless some precaution is taken, all frozen meats and many frozen pastries and vegetables will stick to the container. Candies, pastries and breads, candied fruits, and many cereals will also stick to many surfaces. In the industrial world, almost all rubber and plastics, all adhesives, natural and modified wood rosins, asphalts, concrete, and paints, can adhere to other surfaces. In most of the above-named cases, there are many separate uses for releasing papers, each with its list of performance requirements. Three general classes of release papers or boards are considered:

1. Those that release by a smooth, impenetrable surface only.
2. Those that release by transferring a layer of coating or treatment to the tacky surface.
3. Papers that are chemically treated to reduce adhesion but that do not contaminate the product.

Ordinary paper has almost no valuable traits for releasing purposes.

4.2.8 Filtration Paper

Filter papers are traditionally used for filtering oil, air, and fuel in vehicle engines. Most paper filters have a pleated construction to maximize surface area in a confined space and are impregnated with a polymer binder that has a low melting point. Paper is popular, traditional, and inexpensive, but has reached its technical limit in under-bonnet systems, due to higher temperatures and inaccessible environments, and is now used selectively, not universally. Non-woven polyester and fiber–glass have made strong inroads into the engine filtration segment, reducing growth prospects for paper. Converters report strong growth in the number and size of filtration systems, particularly low-temperature air conditioners and cabin filter systems. Filter specifications vary by depth of material, the density of fiber mat, number of pleats for porosity and surface area, absorbency, and lifespan (Jain et al. 2018). Papers are invariably resin impregnated and low-melt polymer bonded. Additives are usually flame-retardants, with embossing of specifications and coloring.

4.2.9 Grease-Resistant and Greaseproof Papers

The development of sheets resistant to the passage of "grease" presents a problem almost diametrically opposite to that posed by water-resistant papers. Grease is hydrophobic and is a common term for anything from heavy motor oil to light machine oil containing special penetrants, and extending to chocolate, peanut butter, and lard (Sheng et al. 2019). Cellulose itself is a good grease-resistant barrier because of its hydrophilic character, so grease or oil penetrates a sheet of paper through the interstices between the individual fibers or along the fibers themselves by capillary action and not through the cellulose. If the sheet can be so altered that there are no interstitial spaces as in the case of glassine and parchment, it will be resistant to the passage of grease or oil. The use of cellophane, or regenerated cellulose film, also illustrates this point. If a film, foil, a coating, or a laminate is used to produce the barrier, it should be insoluble in the specific grease or oil being tested. If a coating or laminate is used, it should be applied to a smooth base sheet, because any voids or apertures in the film may permit transmission and any fibers that protrude through the surface may act as wicks and pass the oil or grease through the film to the opposite side (Schur 1942).

Three types of requirements can be distinguished:

(a) Resistance to training and absorption in the sheet by a film of grease or oil under negligible pressure.
(b) Resistance to penetration of grease or oil through the sheet under substantial pressure for a given period.
(c) Absolute resistance to any penetration of grease or oil over long periods and under substantial pressure.

When selecting a sheet for a certain application one should study the test methods that will be applied to the sheet and also its use requirements.

4.3 Composites of Natural Fibers

Natural fibers are just as able as petrochemical-based fibers to be processed into composites with a polymer matrix in different production procedures. The classical fiber composite construction makes it possible to generate highly loaded structures with variable fiber orientation and directional characteristics (Kuranska and Prociak 2012). The automotive industry is currently taking a leading role in the processing of natural fiber–reinforced composites. Semi-finished parts are made predominantly for the automotive interior, such as indoor panels or instrument boards. Moreover, automotive manufacturers have also started to use natural fiber–reinforced plastics for exterior uses for car body components. Examples are the underbody paneling of the Daimler A class, gear encapsulation in an urban bus, a prototype of the middle section between the headlights above the bumper of a passenger bus, the spare wheel cover of the Toyota RAUM, as well as the bonnet, boot lid, and roof of the Bio-Concept car. The aircraft construction industry, which demands the highest requirements of mechanical and fire prevention characteristics, is also anxious to use natural fibers in airplane interiors. At the moment, market entry is still prevented by the failure to meet high fire standards. Nevertheless, the past demonstrates that it is in principle possible to use natural fibers in aircraft construction. As early as the 1920s and 1930s the first composites in aircraft construction were made from natural fibers to realize lighter components for primary structures in the airplane.

5 Conclusion

Plant-based fiber has been shown special interest by engineers, technologists, industrial and manufacturers for its huge potential for application in different engineering usefulness such as defense, railway, building construction, packaging, automotive, etc. As with plant cell walls generally, natural fibers have a complex structure and chemistry that impart characteristic features. These features have been recognized and put to use for mankind for many years in diverse industrial applications. Not to be ignored is the need to expand the chemical knowledge of all parts of the fiber plants that may improve the economic benefits of natural fibers through co-products. It seems clear that the application of natural fiber–reinforced composites can do much to reduce the environmental burden of our materials' usage by replacing fossil-based materials directly (or by reducing the processing energy required), by reducing the fuel consumption of vehicles incorporating these materials or by replacing materials with a higher environmental impact. Plant fiber–reinforced composites have found commercial application in the construction and automotive industries, and it seems highly probable that they are now well enough established to stay. In the automotive sector, developments are already underway to combine natural fibers with matrix polymers derived from renewable resources. These developments will continue to improve the environmental profile of these materials and so extend their utility. One way in which the application areas for natural fiber–reinforced composites could be extended would be if the performance of the composites were to be improved to give them potential as true structural materials. The future for these materials looks promising, and, with advances in the materials science and technology of these materials, new application areas will undoubtedly be found. The most promising applications may well be those where light mass (relative to glass fiber–reinforced plastics) and 'green' credentials are most advantageous. It is also probable that the current environmental concerns will remain with us and, if anything, will become more acute and provide an ever-stronger driving force for the development of 'greener' materials. The future need for natural fibers of all kinds is projected to increase both in historic uses and in new applications, possibly replacing and reducing the use of petroleum-based fibers. A better understanding of the chemistry of the fibers, and how the chemical molecules are arranged, will result in more efficient processing, improved standards for quality, and new and advanced applications.

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