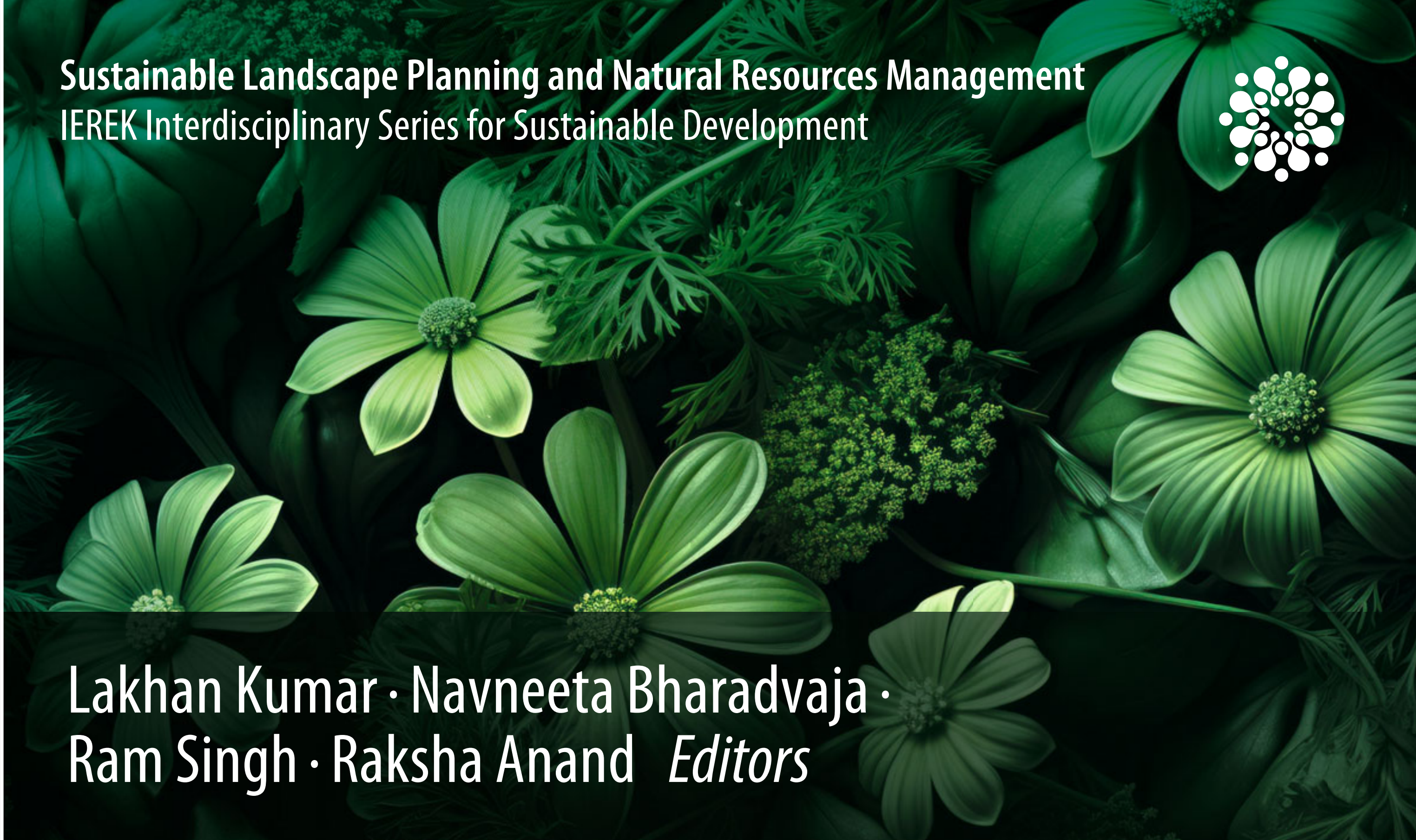
Sustainable Landscape Planning and Natural Resources Management
IEREK Interdisciplinary Series for Sustainable Development



Lakhan Kumar · Navneeta Bharadvaja ·
Ram Singh · Raksha Anand *Editors*

Medicinal and Aromatic Plants

Current Research Status, Value-Addition to Their Waste, and Agro-Industrial Potential

Vol I

IEREK
RESEARCH & KNOWLEDGE ENRICHMENT

Springer

Sustainable Landscape Planning and Natural Resources Management

IEREK Interdisciplinary Series for Sustainable Development

Sustainable Landscape Planning and Natural Resources Management (SLNR) is a peer-reviewed book series that presents groundbreaking research through the intersection of two main areas that of which are ‘Sustainable Landscape Planning’ and ‘Natural Resources Management’. The series initially covers a wide range of academic disciplines in sustainability, including landscape ecology, green urbanism, urban regeneration, land restoration and renaturation, energy management, and nature conservation. Moreover, it also incorporates the latest developments and research in engineering topics that contribute to more sustainable cities, such as Geosciences, infrastructure, civil engineering, geology, mining, water, and natural resources conservation and management.

By showcasing methods for discovering, managing, and employing natural resources, the series aims to provide approaches that enable the responsible use of these resources. Ultimately, the SLNR series is committed to advancing the United Nations’ Sustainable Development Goals for 2030.

The wide range of topics covered in this series are primarily related to sustainable development, involving durable infrastructure projects, civil engineering, urban regeneration, the built, sustainability, climate change mitigation, energy management, geosciences, geology, and the future of cities, all of which depend on the availability of natural resources and effective wealth management. The series also features conceptual and empirical contributions from various interrelated fields of earth science, with an emphasis on the era of new discovery. It focuses on providing practical solutions to ensure sustainable development and provides new case studies that offer concrete examples of how to manage natural resources effectively.

The series encompasses the best research papers from various international conferences organized by IEREK conferences, also accepts proposals from other international conferences, including interdisciplinary contributions. It exhibits innovative approaches and highlights how they can best support both economic and sustainable development through the responsible use of natural resources and global, local, and individual activities for the welfare of all societies on Earth.

The SLNR series is a valuable source for experts in government, international organizations, consultancies, industry, business sectors, and academics. Published in cooperation with IEREK, the Springer SLNR series displays important new research in various sectors, delivering valuable insights and practical solutions to the complex challenges of sustainable development for the readers.

Lakhan Kumar · Navneeta Bharadvaja ·
Ram Singh · Raksha Anand
Editors

Medicinal and Aromatic Plants

Current Research Status, Value-Addition to Their Waste, and Agro-Industrial Potential (Vol I)

Springer

Editors
Lakhan Kumar
Department of Biotechnology
Delhi Technological University
New Delhi, India

Navneeta Bharadvaja
Department of Biotechnology
Delhi Technological University
New Delhi, India

Ram Singh
Department of Applied Chemistry
Delhi Technological University
New Delhi, India

Raksha Anand
Department of Biotechnology
Delhi Technological University
New Delhi, India

ISSN 2948-1910 ISSN 2948-1929 (electronic)
Sustainable Landscape Planning and Natural Resources Management
ISBN 978-3-031-60116-3 ISBN 978-3-031-60117-0 (eBook)
https://doi.org/10.1007/978-3-031-60117-0

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Contents

Biologically Active Compounds from Medicinal and Aromatic Plants for Industrial Applications

Sevinç Yeşilyurt, Muazzez Gürgan, and Mehmet Sertkahya

Abstract

Medicinal and aromatic plants or MAPs can be defined as plants containing compounds with medicinal and aromatic properties that can have a positive effect on the human or animal body. In addition, medicinal and aromatic plants are known to contain biologically active compounds. Bioactive components obtained from these plants can be used in various industrial applications. These plants are effectively used in several fields such as health protection, nutritional supplements, essential oils, inks, paints, lubricants, cosmetics, plastics, and nutrition. Essential oils have a wide range of uses in the pharmaceutical, food, feed, and other sectors. In addition, oils from various aromatic plants are also used as lubricants. Another application of medicinal and aromatic plants is fabric coloring. The extracts of these plants are used to color fabrics as a natural and environmentally friendly alternative, while their flowers, leaves, or roots are used to make perfumes in the cosmetics industry. They can also be used as natural packaging materials in the food industry to extend shelf life. Medicinal aromatic plants have increased interest in the industry by offering economically and environmentally sustainable alternatives. This chapter aims to identify and examine the various uses of compounds derived from medicinal aromatic plants.

S. Yeşilyurt (✉) · M. Sertkahya
Department of Soil Science and Plant Nutrition, Tekirdağ Namık Kemal University, Tekirdağ, Türkiye
e-mail: sevincyesilyurt1@gmail.com; sadiloglu@nku.edu.tr

M. Sertkahya
e-mail: mehmetsertkahya@gmail.com

M. Gürgan
Department of Biology, Tekirdağ Namık Kemal University, Tekirdağ, Türkiye
e-mail: mgurgan@nku.edu.tr

Keywords

Medicinal and aromatic plants · Essential oils · Inks and dyes · Lubricants · Perfumes · Cosmetics · Plastics

1 Introduction

1.1 Medicinal Aromatic Plants and Their Classification Hey

Plants may convert the water, minerals, and some elements they absorb from the soil into some compounds to incorporate into their metabolism. They are active compounds such as essential oils, alkaloids, tannins, and bitter substances. These compounds are not only beneficial for plants, but also for humans, and they enhance the immune system and support organ systems in the human body. Hence, they positively affect some tissues and organs in humans (Samarth et al., 2017). Despite the fast advancements in modern medicine, humans did not give up natural remedies. Moreover, the side effects of synthetic medications and the worries about the chemicals drive people to use medicinal plants instead.

The terms "medicinal" and "aromatic" are often used together for these herbs. The general definition is that plants have bioactive compounds with medicinal and aromatic characteristics, which can have positive effects on human and animal bodies (Samarth et al., 2017). Medicinal and aromatic plants (MAPs) are plants used to inhibit diseases, protect health, and cure diseases. The bioactive compounds are known to be used in various industrial applications. Hence, they are consumed for nutrition, cosmetics, personal care, incense, and religious rituals, as well as in the food, pharmaceutical, and perfume industries (Petrovska, 2012). The spectrum of active ingredients of MAPs is quite wide.

L. Kumar et al. (eds.), *Medicinal and Aromatic Plants*, Sustainable Landscape Planning and Natural Resources Management,
https://doi.org/10.1007/978-3-031-60117-0_1

There is still no standardized classification, yet MAPs can be classified according to their families, active ingredients, consumption aims, and pharmaceutical effects (Yener & Cömert, 2022).

1.2 Biological Active Compounds

Phytochemicals are usually split up as primer and secondary metabolites; proteins and nucleic acids are not considered in this classification. Primary metabolites are carbohydrates, oils and fats, and proteins, which are vital for the basic metabolic functions of plants. However, secondary metabolites are compounds with various chemical structures, found in low amounts and not vital for plant life (Oskay & Oskay, 2009). Stem and leaves of the majority of MAPs are found to be rich in secondary metabolites with different physiological activities. The secondary metabolites in these plants are classified into three classes- phenolic compounds, terpenoids/terpenes, and alkaloids (Aftab & Hakeem, 2021). The secondary metabolites most often encountered in MAPs are alkaloids, essential oils, glycosides, steroids, saponins, flavonoids, tannins, phenols, pigmentary substances, and resins; more than 30 thousand kinds of them have been defined in plants. Moreover, polyphenols, kinin, flavanols/flavonoids, polypeptides, or their substituted oxygen derivatives are also found in MAPs. Some of these compounds may have synergistic effects and can enhance the biological activities of one another (Perumalla & Hettiarachchy, 2011). The relationship between primary and secondary metabolites is schematized in Fig. 1.

1.2.1 Alkaloids

Alkaloids are compounds that have nitrogen and usually rings in their structure, have alkaline characteristics, and have strong physiological effects. They are obtained from plants. These compounds are usually found in salt form with minerals and organic acids and rarely in free form in plant cells (Badri et al., 2019).

Alkaloids can medicinally be effective when consumed right but can cause severe damage when misused. For instance, morphine obtained from *Papaver somniferum*, cocaine from the coca plant, nicotine from tobacco, and theobromine from the cacao plant are alkaloids that can be addictive (Bhambhani et al., 2021).

1.2.2 Terpenoids (Terpenes)

They are the basic constituents of essential oil and are made up of 5 C isoprene. The isoprene unit counts make the terpenes have different structures, such as monoterpene, sesquiterpene, diterpene, triterpene, and tetraterpene. Monoterpene and sesquiterpene structures are intensively found in essential oils. Monoterpenoids are usually responsible for the scent and taste of a plant. Sesquiterpenes are known for their antimicrobial and antitumoral effects. Diterpenoids are found in resins, and gibberellin, a plant growth hormone, is a well-known diterpene. Cucurbitacin, quassinoid, and limonoids are among the ecologically important triterpenoids as they form the basis of defense against herbivores and insects. For example, azadirachtin obtained from *Azadirachta indica* is one of the most powerful insecticides. Carotenoids are formed from tetraterpenoids, and they make up the colors yellow, orange, red, and purple in plants. They have a wide commercial market for food, feed, pharmaceuticals, and cosmetics (Mukherjee, 2019).

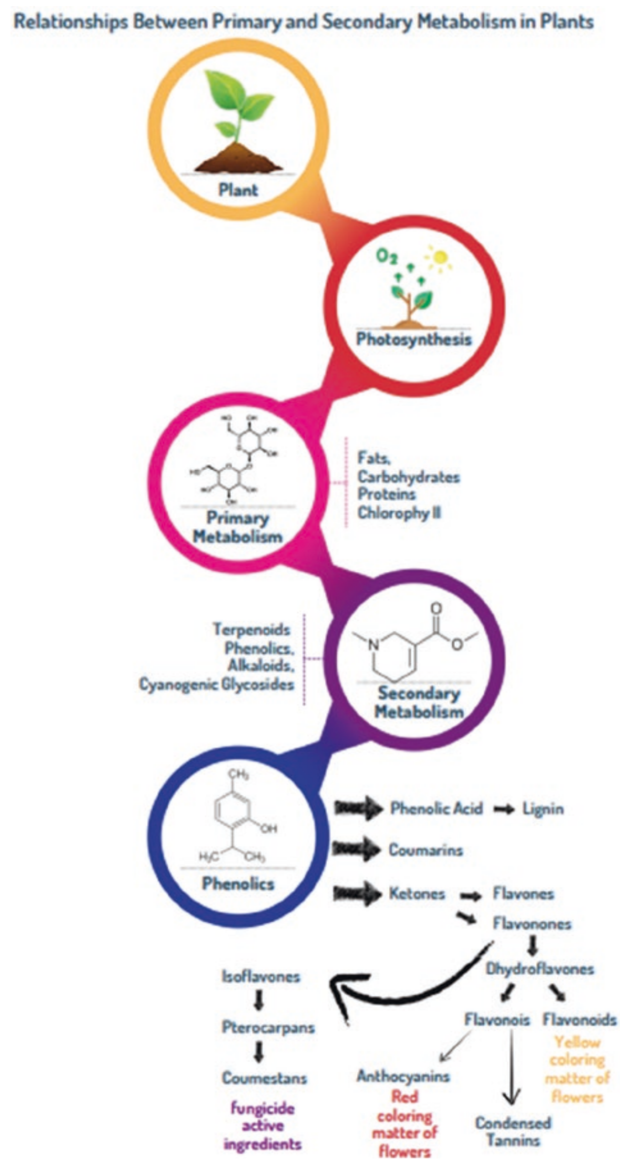


Fig. 1 Relationship between primary and secondary metabolites in plants

1.2.3 Phenolics

Phenolics are compounds having one or more hydroxyl group in their aromatic ring (Tiring et al., 2021). They play critic roles in plant growth, development, pollination, and defense. Plants with high phenolic content have antioxidant characteristics and are hence important for preventing cardiovascular diseases, cancer, inflammations, and mutations in human cells (Karakaya, 2004). Benzoquinones, phenolic acids, acetophenones, anthraquinones, flavonoids, lignin, flavonols, and tannins are among the well-known phenolics. Flavonoids contain flavones, flavonones, flavonols, and anthocyanins, and play a role in the formation of color, protect cells from free radicals, and also attract insects for pollination. Tea leaves are sources of phenolics on their catechin and theaflavin contents. Artichoke contains sinarin, which enhances hepatocyte renewal. Silymarin, another flavonoid found in thistle seeds, is also used in liver treatment (Gillessen & Schmidt, 2020).

Essential oils obtained from plants do not contain only one compound, but tens or hundreds of different constituents. Rose oil, for example, contains more than a hundred compounds, but citronellol, neral, and geraniol are three important ones (Yuca et al., 2023). Fennel and anise are rich in anetol; thyme species are rich in carvacrol. Lavender is rich in linalyl acetate, mint in menthol, and melissa in neral. Medical sage has a high content of thujone, and marjoram is known to have thymol (Swamy et al., 2016).

1.3 Industrial Importance of Biological Active Compounds

MAPs have been used in a large spectrum of industrial sectors, such as pharmaceuticals, personal care products, cosmetics, and organic food (Riaz et al., 2021). Growing concerns about synthetic additives led to the use of MAPs, their extracts, and essential oils in the pharmaceutical, food, and feed industries (Sacchetti et al., 2005). The use of synthetic medications increased with increased population. However, the tendency to use plant-based products also increased due to concerns about the side effects of medications. Several pharmaceutical companies apply for patents on MAPs and products obtained from them. Around 40% of the medications produced in the last 20 years are based on formulations derived from natural sources (Riaz et al., 2021).

Moreover, demand for plant products for other industrial applications increase worldwide. For instance, they can be used in non-alcoholic beverages, confectioneries, etc., in the food industry. They are also desirable for perfumes, skin and hair care products, and aromatherapy products in the cosmetics industry. Mint, a well-known MAP, is used in various areas, from cosmetics to the food industry, from agriculture to the textile industry, thanks to its antimicrobial, antidiabetic, antioxidant, anti-inflammatory, antitumor, and pesticide activities (Zhang et al., 2022).

2 Industrial Use of MAPs and Bioactive Compounds from Plants

Maps have a potential to be used in a wide area of applications in industry. The bioactive compounds of these plants are valuable for the cosmetics, food, pharmaceutical, and perfume industries. For example, essential oils from lavender, mint, and rosemary are used for aroma and therapeutic purposes in cosmetics. Moreover, the antioxidant, antimicrobial, or anti-inflammatory properties of plant bioactive compounds can be used to develop new medications in the pharmaceutical industry. The extracts of these plants are preferred for various formulations thanks to the increased demand for natural and organic products. An example is lavender oil, which is preferred in cosmetics and shampoos due to its antioxidant properties (Zuzarte et al., 2013). Rosemary extracts attract attention due to their antioxidant and anti-inflammatory characteristics. They can be effective in the processes of new medications and antioxidant supplements (Alizadeh et al., 2016).

2.1 Essential Oils

Plants produce two types of oils: Fixed oils and essential oils. Fixed oils are comprised of fatty acids and glycerol esters. Essential oils, on the other hand, are a chemical mixture of volatile organic compounds and various metabolites. These oils form the taste and scent, i.e. the essence of the plant. Essential oils are actually part of the immune system and the defense system against environmental threats (Buchbauer et al., 1993).

These oils are usually obtained from nonwoody and aromatic parts of the plant, especially flowers, leaves, fruit peels, or roots, via steam distillation or hydro distillation (Dorman & Deans, 2000). They are volatile liquids that are non-soluble in water but highly soluble in organic solvents. The oils with scent reflect the essence of the plants or their active compounds. Essential oils represent around 17% of the global aroma and scent sector (Riaz et al., 2021). Rose, jasmine, and mint can be given as examples of plants to obtain essential oils.

MAPs, and especially essential oils and their compounds, are known to have antibacterial, antiviral, antifungal, antiparasitic, and insecticide activities (Basile et al., 2006). Moreover, essential oils can have hypolipidemic, antioxidant, and anti-toxigenic activities, and contribute to odor control and mitigation of ammonium and methane in ruminants (Botsoglou et al., 2004; Varel, 2002).

Essential oils contribute to various industrial additives. They are auxiliary compounds for products of cosmetics, medical products, soap, perfumery, ice cream, and disinfectants (Riaz et al., 2021). The use of essential oils to prevent nutrient deficiencies and inhibit pests as insecticides and plant growth promoters indicate new fascinating and unexplored research areas (Bose et al., 2001).

There have been studies to obtain essential oils from around three thousand aromatic plants. However, essential oils from approximately 300 plants are available on the market around the world. Around 50 of them are demanded extensively in industry and trade, but only two dozen have regular and large-scale use (Basak et al., 2018). Some of these plants are reviewed in the following sessions.

2.1.1 Lemongrass (*Cymbopogon Citratus*)

Lemongrass is a tropical, perennial plant producing an essential oil which contains 70–90% sitral. Lemon grass oil, usually known as Cochin oil in the world market, is widely used in China, India, and Japan. The leaves of this plant are used to sweeten tea, food, and beverages and also to provide a nice scent in bath water. Lemon grass oil also has a repellent effect on flies and mosquitos (Bose et al., 2001; Narayan & Maheshwar, 2017). Besides the nice scent, antibacterial and cleaning effects help to fight against fungal/bacterial infections and bad body odor (Narayan & Maheshwar, 2017). Compounds like myrcene, citronella, citronellol, and geraniol, which enhance the aroma, play important roles in food and non-food industries with their potential to protect and enhance products.

2.1.2 Palmarosa (*Cymbopogon Martinii*)

Palmarosa is a long-lived plant that has a rose-like scent. There are two kinds of palmarosa: Rosha grass offers a high-quality oil to be used in perfumery for rosa and tobacco notes. This oil is important in soap production due to its geraniol content which is stable against alkalinity.

Gingergrass oil, on the other hand, offers a lower quality oil to be used in perfumery (Bose et al., 2001). This oil is used for perfumery, cosmetics, and even to hinder the pesticide scents, and used in anti-mosquito products. This oil, used in tobacco products, food, and non-alcoholic products, is also used in medicine against back pain, skin diseases, and gall bladder problems. Moreover, it takes attention due to its aphrodisiac effect (Rao et al., 2005).

2.1.3 Vetiver

Vetiver is a perennial grass with a nice scented oil in its roots. Vetiver oil is considered as one of the high-quality aromatic oils in the world. It is used in perfumery, aromatizing cosmetics, and soaps to stabilize more volatile compounds (Bose et al., 2001). High cellulose, hemicellulose, and lignin content make this plant an ideal raw material for bioethanol production. Moreover, this plant can be used to remediate heavy metals from agricultural lands (Dousset et al., 2016). Moreover, being an efficient carbon-holding material, it can serve to downgrade climate change (Rao et al., 2005). Although it is well known, the use of it is not globally widespread, having a market in India and Thailand (Lavania, 2008).

2.1.4 Mints

Mints have been cultivated all over the world and mint aroma is known as its commercial value. Mint essential oil contains carveol, dihydrocarvon, and dihydrocarvil acetate and is frequently used in taste and scent industries. Mint essential oil attracts great interest not only in conventional uses but also in medicine, agriculture, food, and beverages due to its antimicrobial, antioxidant, pesticide, anti-tumor, antidiabetic, and anti-inflammatory effects (Zhang et al., 2022). Mint essential oil, l-menthol crystal, essential of without menthol, and other monoterpenes are included in the mint plant. It has a large market share: global menthol mint essential oil is more than 20,000 tons a year (Srivastava et al., 2002).

2.1.5 Basil

Basils are an important MAP group belonging to the Lamiaceae family, growing in various regions of the world, from Italy to Haiti, from Guatemala to India (Bose et al., 2001). *Ocimum basilicum* L, among various *Ocimum* species, is widely cultivated for essential oil production for use in perfumery, cosmetics, and other industries.

2.1.6 Patchouli

Patchouli essential oil is a perfect stabilizer for mixed, heavy perfumes with its significant, intense, and alluring notes (Bose et al., 2001). It is obtained from *Pogostemon cablin* Benth, belonging to the Lamiaceae family. It is very important for aromatherapy, perfumery, cosmetics, food aroma, and fume production (Ramya et al., 2013). The main ingredients of the oil are patchuliol (tricyclic sesquiterpenes) and several sesquiterpenes (Jain et al., 2022).

2.1.7 Rosemary

Rosemary is a perennial, Mediterranean plant belonging to Lamiaceae family. The essential oil of rosemary is used in soap, detergent, air fresheners, etc. (Bose et al., 2001). It is a source for at least 140 different compounds, such as rosmarinic acid, carnosic acid, ursolic acid, oleanolic acid, flavonoids, and phenolic acids. It has antibacterial, antifungal, antioxidant, hepatoprotective, and insecticide properties due to its high phenolic content (Alizadeh et al., 2016). The oil contributes to the shelf life of cosmetics and has a high potential for topical (Aziz et al., 2022).

2.1.8 Clary Sage

Clary sage (*Salvia sclarea* L.) is a perennial plant with xerophytic characteristics belong to Lamiaceae family and has a strong aroma, well known in traditional medicine. Essential oil plant has economic value in the scent and taste industries, pharmaceutical, food, cosmetics industries, and agriculture (Cai et al., 2006). Oil of the plant is used to produce alcoholic and non-alcoholic beverages, ice creams, confectionary and bakery products (Bose et al., 2001). Clary sage essential oil has anti-inflammatory, antimicrobial, antioxidant, and antidiabetic properties and has been used in food packaging and wound dressings (Hans et al., 2023).

2.1.9 Thyme

Thyme is a continuously green, perennial plant with a strong fresh scent of essential oil, which is evaluated in perfumery, soap and detergent production, food processing, and pharmaceutical preparation (Bose et al., 2001). The thyme essential oil is one of the 10 most frequently used aromatic oils in the world. Thyme belongs to the Lamiaceae family. It contains carvacrol and thymol in the essential oil (Tuğlu et al., 2021).

2.1.10 Celery

Celery (*Apium graveolens* L.) is a widespread plant from Sweden to Egypt. The distillation of seeds reveals a volatile oil to be used as an aroma and essence in the pharmaceutical industry (Bose et al., 2001). It has a high commercial value. It can also be used as a food sweetener. The essential oil contains limonen and selinen (Sowbhagya, 2014). The seeds are used in soups, salad dressing, sausages, vegetable stock, and pickles as flavor enhancers. Moreover, seed oil emulsions are considered as homemade medication against nausea, colic pain, and bloating (Malhotra, 2006).

2.1.11 Lavender

Lavender is a MAP belonging to the Lamiaceae family used to obtain high-quality volatile oil for perfumery, cosmetics, and the pharmaceutical industry and for medicine due to its antioxidant, antimutagenic, anti-inflammatory, and analgesic properties (Silva et al., 2017). The plant generally contains phenolic acids and flavonoids. Basically, it has antioxidant, antibacterial, antifungal, anticholinesterase, antidepressant, spasmolytic and sedative properties (Dobros et al., 2022). Their oil is used in the food industry as aromatizers in food, beverages, and confectionery. Moreover, it is preferred for soap and perfumes to provide a nice aroma (Zuzarte et al., 2013).

2.1.12 Citrus

Citrus is a group of plants from Rutaceae family, *Citrus* genus. The most common species are orange, lemon, mandarin, lime, pummelo, bitter orange, and grapefruit. These plants are rich in bioactive chemicals such as vitamin C, carotenoids, flavonoids, alkaloids, terpenes, etc. (Gök et al., 2012). Secondary metabolites such as alkaloids, coumarins, limonoids, flavonoids, carotenoids, and essential oils contribute to the pharmacological properties of citrus. These pharmacological agents contribute to health by being antioxidant, anti-inflammatory, anticancer, neuroprotective, and cardioprotective (Das et al., 2018). 80% of them are used in the food industry to produce juice, jelly, marmalades, etc. (Khan et al., 2021). Moreover, wastes from processing citrus have the potential to be used for biogas production (Wikandari et al., 2014).

2.2 MAPs in Dye Industry

The interest in natural dyes is increasing due to the increased awareness of sustainability and environmental problems. Natural dyes and pigments are obtained from plants, insects, some animals, and minerals (Islam et al., 2024). Plants, besides creating elegant colors, can have antibacterial, antioxidant, anti-inflammatory and anti-ultraviolet effects thanks to polyphenols, flavonoids, and anthocyanins they possess (Gong et al., 2019). Many MAPs can be used as dye material in the dye industry. For example, chlorophyll is a common pigment in plants responsible for the green color. Although plants are usually green, they can have flowers and leaves with various colors, such as white, pink, yellow, and red. Non-green plants can also use natural sunlight and use colors in the visible spectrum to produce chlorophylls, and different colors occur in plants (MacDavid & Aebisher, 2014). Textiles have been painted using flower petals and plant roots both in the past and in our era (Domka et al., 2019). Natural dyes are quite important in textile industry to inhibit water pollution, sustaining raw materials and processed products (Bechtold et al., 2009).

Several plants are used to obtain different colors from black to yellow. The most radiant yellow is obtained from turmeric, and other plants such as woodwax, venetian sumac, dyer's mignonette can be used to obtain yellow dye (Colombini et al., 2007). Yellow dye can also be obtained from the leaves of *Adhatoda vasica nees,* jackfruit, flowers of *Crocus sativus* L., chamomile, *Tagetes erecta* L. or *Nyctanthes arbortristis* L., seed and flower of *Cassia auriculata* L. Red color can be obtained from the flowers of *Carthamus tinctorious* L., *Tagetes erecta* L., while purple can be obtained from the root of *Galium aparine* L., onion peel or leaves and flowers of rosemary. Some fruits might yield black color, such as *Acanthophonax trifoliatum* L. and *Garcinia mangostana* L. Brown, on the other hand, can be obtained from leaves and barks of plants like *Azadirachta indica A., Acacia catechu*, and oak trees (Islam et al., 2024). Tea plants can be used to dye textile, which makes textiles antibacterial and antioxidant (Cheng et al., 2019; Ren et al., 2019). Carotenoids in plants give a red-yellow color. Other pigment compounds include orellin, bixin, annatto, mordan, and lawone (Arık et al., 2020).

2.3 Use of MAPs in Perfumery Sector

Perfumes are a combination of natural essential oils or synthetic organic compounds in order to modify the scent experience. There are more than three thousand commercial products in the fragrance industry. Perfumery is not only an industry, but also an art of combining natural, herbal, animal, and synthetic aromas (Aftab & Hakeem, 2021). Perfumes are generally produced by adding pure ethyl alcohol to animal, herbal or synthetic essences with the help of stabilizers (Sikora et al., 2018). Perfume raw materials can be natural or synthetic. Natural essences are obtained from plants via extraction or distillation. Flowers, leaves, roots, resins, seeds, and whole plants can be used to obtain fragrance (Fratér et al., 1998). The flowers of jasmine, rose, lilac, narcissus, violet or gardenia can be used to obtain essence. In some cases, both flowers and fruits, like lemon and orange, can be used.

There is detailed information about 500 out of 1500 aromatic plant species used for perfume production. Only 50 of them are used to obtain essential oils (Riaz et al., 2021). The basic plants to be used to obtain essential oils for the perfume industry are as follows:

- *Aromatic plants*: Lavender, melissa, sage, rosemary, thyme, marjoram, vanilla, clove, etc.
- *Flowers:* Rose, jasmine, clove, orange flower, narcissus, violet, hyacinth, etc.
- *Citrus:* Orange, lemon, mandarin, bergamot
- *Grains and seeds:* Anise, dill, cumin
- *Balsam and resins*: Camphor, myrrh, galbanum
- *Bark and roots*: Cinnamon, ginger, rotan, vetiver, angelica
- *Forest trees:* Birch, cedar, cypress, pine, sandal tree, laurel, patchouli
- *Other aromas:* Tobacco, chamomile, cudweed, vervain (Aftab & Hakeem, 2021)

Natural essences are basically formed from alcohols, esters, phenols, aldehydes, ketones, acids, and hydrocarbons. Essential oils are natural mixtures of 20–60 different chemical compounds (Bakkali et al., 2008). Terpenoids form the constituents of natural fragrances in plants. For example, menthol offers refreshing scents, linalyl acetate represents fruit and flower scents, carvone carries a mint scent, citronellol, and esters form rose scent, and dihidromyrcenol offers citrus and flower scents. On the whole, secondary metabolites of the plants used in fragrance industry may form the basis of the fragrances. For example, carvacrol, timol, and simen are present in thyme (*Origanum vulgare*); menthol, menton, 1,8-sineol, and mentofuran in mint (*Mentha piperita*); sitral, neral and mirsen in lemon grass (*Cymbopogon citratus*); alpha-bisabolol, bisabolol oxide B, (E)-beta-farnesen, alpha-bisabolon okside sinnamaldehide and sinnamil acetate in chamomile (*Matricaria chamomilla*); benzyl alcohol, linalool, benzyl acetate, jasmon and geraniol in jasmine (*Jasminum* spp.) (Aftab & Hakeem, 2021).

2.4 Use of MAPs in Cosmetics

The demand for natural and organic products is on the rise. Flavonoids, among the important active compounds of MAPs, have positive effects on skin health (Ren et al., 2003). Moreover, plants contain various minerals such as Ca, Fe, Mn, Zn, etc., which are vital for our bodies (Başgel & Erdemoğlu, 2006). Plant-based raw materials are especially preferred in cream formulations, and there are several MAPs used in the cosmetics industry. For instance, flowers of calendula (*Calendula officinalis*) are used in creams, shampoos, toothpastes, baby oils, etc. Leaves and roots of comfrey (*Symphytum officinale*) are used in medicinal ointments and in skin and hair care products. Licorice root (*Glycyrrhiza glabra*) can be used as a skin lightener and stain remover, while anthers of St. John's wort (*Prunella vulgaris*) can be used against hair loss (Göktaş & Gıdık, 2019). Grape seed oil is used in antiaging cosmetics since resveratrol found in black grape peels is a strong antioxidant (Bazter, 2008). Tea contains polyphenol compounds rich in tannins and catechins. The extracts of green tea were reported to be resulted from the flavonoids found in tea leaves (Çelik, 2006).

2.5 Use of MAPs in Plastic Production

Avoiding chemicals are not only beneficial for human health but also for the environment. That is why alternatives to plastics, which cause a huge pollution problem, are of interest. Plant-based biodegradable polymers can be carbon–neutral polymer sources and environmentally friendly alternatives to petroleum-based plastics as long as they are produced as added-value byproducts or produced from noon-food plants grown on marginal fields (such as *Panicum virgatum* L.) (Mooney, 2009). Bioplastics have many advantages: They are biodegradable, produced from renewable sources, recyclable, compostable, and burnable without toxic byproducts. These make them a perfect alternative to traditional plastic products (Reddy et al., 2013). Gavril et al. (2019) developed an antioxidant-active packaging material by adding antioxidants obtained from MAPs (sage and lemon) to the polylactic acid matrix. Such research is significant in terms of designing environmentally friendly antioxidant-active packaging materials. Reshmy et al. (2021) conducted a study on the formation of biodegradable biofilms using pure nanocellulose obtained from peels of jak fruit via an environmentally friendly method and combining this nanocellulose with different plasticizers and *Boswellia serrata* filling material. The results of the study revealed enhanced surface morphology by the usage of nanocellulose, which forms more stabilized hydrogen bonds between plasticizers and filling material during the formation of biofilms. Since these biofilms are biodegradable and compostable, they can be used instead of petroleum-based plastics.

2.6 Other Industrial Applications

The antimicrobial, fungicide, and bactericidal characteristics of MAPs make them to be preferred as preservers in meat preparation, canned products, and fresh vegetables (Davidson et al., 2005). MAPs have been used to develop successful alternatives to decrease antimicrobial use in animal feed. A lot of plants have been used as nutraceuticals and daily nutrition and they are marketed as tablets or soft capsules (Burdock, 2010).

There has been research on the use of MAPs as landscapes. Bozkurt (2019) resulted that plants like *Berberis vulgaris* L., *Sambucus nigra* L., *and Crataegus pontica* C. Koch can be used in landscaping due to their leaf, flower, and fruit characteristics and their usability as live fences. Arslan and Ekren (2018) determined the places to use MAPs in landscaping as collection gardens, therapy gardens, botanical gardens, pots, roof and terrace gardens, and hiking trails.

The use of MAPs was evaluated for the textile industry. Varona et al. (2013) studies the antimicrobial effect of microencapsulation of lavender (*Lavandula hybrida*) against three pathogenic bacteria and resulted that this process led the continuum of antimicrobial activity of the plant. Dadalioglu and Akdemir Evrendilek (2004) showed that *Origanum minutiflorum*, *Laurus nobilis*, *Lavandula stoechas* L., and *Foeniculum vulgare* extracts showed strong antibacterial activity on textiles. El-Molla and El-Ghorab (2022) showed that polyester textile processed with lavender, thyme, and clove showed antibacterial activity against *Staphylococcus aureus* and *Escherichia coli,* and the strong scent of the textile did not last long. They suggested that MAPs can be used to produce antibacterial textile products. Asbahani et al. (2014) applied an environmentally friendly microencapsulation procedure using *Thymus leptobotrys* essential oil and gum Arabic and integrated the essential oil microcapsules into cotton textile fibers. They showed that the processed textile had strong antifungal activity against *Aspergillus niger*. The antifungal activity lasted very long, and hence, this was suggested to be used in hygienic applications such as in the medicinal and food industries.

2.6.1 MAPs in Energy Production

Continuously increasing population, industrialization, urbanization, and unconscious use of fossil fuels have depleted the natural sources and caused environmental pollution. Biofuels are suggested to be the solution to this problem since they are considered to be the energy source of the future. Biomass resulting from the processes where MAPs are used for industrial purposes such as fruits, roots, leaves, flowers, etc., can be evaluated for biofuel production (Saha & Basak, 2020). The waste biomass is any biological material resulting from the production process that was not produced for purpose (Olofsson & Börjesson, 2018).

Evaluation of the biomass resulting from aromatic industries is critical since this will lead to economic, environmental, and social benefits (Saha & Basak, 2020). Although no certain information about the waste biomass of MAPs has been reported, significant amount of residual biomass can be produced from MAPs, since the essential oil content is less than 5% of the plant, and significant soil waste results from processes of MAPs (Saha & Basak, 2020). Around 200,000 tons of solid waste/year is supposed to remain after essential oil extraction from plants (Sayed Ahmad et al., 2018). This waste biomass is rich in polyphenols and some other bioactive compounds. This waste can be evaluated for the production of value-added products such as biogas, compost, biochar, biofuels, and biopesticides etc. (Gómez et al., 2017). Some of the plants used for biofuel production are jojoba, sunflower, rapeseed, madwort and mole bean (Khan et al., 2023). Moreover, plants can be useful for solar energy production. Green color obtained from the extracts of malabar spinach and red cabbage were shown to absorb green light and reflect red and blue light, and they were suggested to contribute to developing multicolor solar cells to be used in agri-voltaic systems (Mejica et al., 2020).

2.6.2 MAPs in Agricultural Applications

MAPs can also be employed in agricultural applications. One of them is the fight against pests. Plants use secondary metabolites such as esters, ketones, essential oils, etc., in the defense against pests and mites (Traboulsi et al., 2005). Neurotoxicity, regulation of pest growth, deformation of wax layers of insect cuticles, inhibition of digestive enzymes, and inhibition of glutathione-S-transferase are among the action mechanisms of essential oils. Extracts of *Foeniculum vulgare* Mill (fennel) were found to have high toxicity on larvae of *Culex pipiens* molestus, and also, terpineol and 1,8-cineol were determined to be the most effective compounds against mosquito bites (Park & Tak, 2016).

Sujatha (2010) determined that root extracts of vetiver had insecticidal effects on *Tribolium castaneum* and suggested that vetiver could be used as an economic and ecologically suitable insecticidal. Gillij et al. (2008) obtained essential oils from 12 different MAPs and showed that most of them successfully repelled mosquitos for 90 min.

Jbilou et al. (2023) suggested *Origanum vulgare* L. as a candidate for pest control in agriculture upon its insecticidal, antiviral, antibacterial, and antifungal characteristics. Industrial cannabis (*Cannabis sativa* L.) flowers secrete cannabinoids and volatile terpenes, which act against plant-eating insects. Benelli et al. (2018) tested the essential oils obtained from cannabis inflorescence to be used as insecticides. The results revealed high toxicity in *Myzus persicae* (peach-potato flea), Musca domestica (housefly), and *Spodoptera littoralis* (tobacco moth). This essential oil was also shown to be harmless on non-target invertebrates. Moreover, combined planting of MAPs plays an essential role in vegetable cultivation by protecting vegetables from pests, increasing storage period, and enhancing quality during transfer. Essential oils of aromatic plants protect against nematodes in soil. Combined planting decreases the pH and nitrogen of soil and enhances organic nitrogen and water content (Dikir, 2022). Furthermore, MAPs can be used to remediate soil contamination by heavy metals. Growing MAPs on heavy metal-contaminated soil resulted in economic products without heavy metal content since heavy metals were shown not to transfer to essential oil (Zheljazkov et al., 2008). The results suggested that some MAPs can have a good phytoremediation potential, and hence, they can be cultivated on polluted soils.

3 Conclusion

This chapter reviewed the biological active compounds found in MAPs for the usage in various industrial applications such as ink, dye, perfume, cosmetics, plastics and even energy production. The bioactive compounds have important roles in many industries.

- *Essential oils* in plants are invaluable for perfumery, cosmetics, aromatherapy, and pharmaceutical industries.
- *Inks and dyes* obtained from MAPs can be used in the textile industry as well as printing houses.
- *Plastics* can be produced using bioactive compounds contained in the MAPS and have significant roles in today's world to fight against pollution and climate change.

MAPs and their bioactive compounds are invaluable as natural sources with their industrial applications and use for therapeutic purposes. Ongoing research enlightens new plant species, new bioactive compounds, and their applicability for human and environmental benefits. New potentials of bioactive compounds produced as secondary metabolites by MAPs are only to be explored.

References

Aftab, T., & Hakeem, K. R. (2021). *Medicinal and aromatic plants: Healthcare and industrial applications.* Springer Nature.

Alizadeh, L., Nayebzadeh, K., & Mohammadi, A. (2016). A comparative study on the in vitro antioxidant activity of tocopherol and extracts from rosemary and *Ferulago angulata* on oil oxidation during deep frying of potato slices. *Journal of Food Science and Technology, 53*, 611–620.

Arık, B., Dikkal, İ, & Karacan, S. (2020). Evaluation of the dyeing and fastness properties of wool fabrics treated by chitosan in different molecular weights and dyed with mint. *Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi, 26*(7), 1186–1192.

Arslan, M., & Ekren, E. (2018). Mythos and opportunities of usage in landscape architecture of some medicinal and aromatic plants naturally growing in Turkey. *Mersin Üniversitesi Tıp Fakültesi Lokman Hekim Tıp Tarihi ve Folklorik Tıp Dergisi, 8*(3), 172–184.

Asbahani, A. E., Addi, E. H., Miladi, K., Bitar, A., Casabianca, H., Mousadik, A. E., & Elaissari, A. (2014). Preparation of medical cotton textile activated by *Thymus leptobotrys* essential oil colloidal particles: Evaluation of antifungal properties. *Journal of Colloid Science and Biotechnology, 3*(3), 253–261.

Aziz, E., Batool, R., Akhtar, W., Shahzad, T., Malik, A., Shah, M. A., & Thiruvengadam, M. (2022). Rosemary species: A review of phytochemicals, bioactivities and industrial applications. *South African Journal of Botany, 151*, 3–18.

Badri, S., Basu, V. R., Chandra, K., & Anasuya, D. (2019). A review on pharmacological activities of alkaloids. *World Journal of Current Medical Pharmaceutical Research, 1*(6), 230–234.

Bakkali, F., Averbeck, S., Averbeck, D., & Idaomar, M. (2008). Biological effects of essential oils–a review. *Food and Chemical Toxicology, 46*(2), 446–475.

Basak, B. B., Saha, A., Chinchmalatpure, A., & Manivel, P. (2018). Prospect of aromatic grass cultivation in salt affected soils of semi-arid region in India. *Indian Farming, 68*, 20–23.

Basile, A., Senatore, F., Gargano, R., Sorbo, S., Del Pezzo, M., Lavitola, A., & Vuotto, M. L. (2006). Antibacterial and antioxidant activities in *Sideritis italica* (Miller) Greuter et Burdet essential oils. *Journal of Ethnopharmacology, 107*(2), 240–248.

Başgel, S., & Erdemoğlu, S. B. (2006). Determination of mineral and trace elements in some medicinal herbs and their infusions consumed in Turkey. *Science of the Total Environment, 359*, 82–89.

Bechtold, T., Mahmud-Ali, A., & Komboonchoo, S. (2009). Sustainable dyes from agrifood chain co-products. In K. W. Walden, G. K. Moates, & C. B. Faulds (Eds.), *Total Food* (pp. 211–218). RSC Publishing.

Benelli, G., Pavela, R., Petrelli, R., Cappellacci, L., Santini, G., Fiorini, D., & Maggi, F. (2018). The essential oil from industrial hemp (*Cannabis sativa* L.) by-products as an effective tool for insect pest management in organic crops. *Industrial Crops and Products, 122*, 308–315.

Bhambhani, S., Kondhare, K. R., & Giri, A. P. (2021). Diversity in chemical structures and biological properties of plant alkaloids. *Molecules, 3*, *26*(11), 3374

Botsoglou, N. A., Christaki, E., Florou-Paneri, P., Giannenas, I., Papageorgiou, G., & Spais, A. B. (2004). The effect of a mixture of herbal essential oils or α-tocopheryl acetate on performance parameters and oxidation of body lipid in broilers. *South African Journal of Animal Science, 34*(1), 52–61.

Bose, T. K., Kabir, J., Das, P., & Joy, P. P. (2001). *Tropical horticulture* (Vol. 2). Naya Prokash.

Bozkurt, S. G. (2019). Determination of usage possibilities of some medicinal and aromatic plants grown In Gürün (Sivas)-Tohma river valley in landscape architecture. *Bartın Orman Fakültesi Dergisi, 21*(1), 66–80.

Buchbauer, G., Jirovetz, L., Jager, W., Plank, C., & Dietrich, H. (1993). Fragrance compounds and essential oils with sedative effects upon inhalation. *Journal of Pharmaceutical Sciences, 82*(6), 660–664.

Burdock, G. A. (2010). *Fenaroli's handbook of flavor ingredients*. CRC Press.

Cai, J., Lin, P., Zhu, X., & Su, Q. (2006). Comparative analysis of clary sage (*S. sclarea* L.) oil volatiles by GC–FTIR and GC–MS. *Food Chemistry*, *99*(2), 401–407.

Cheng, T.-H., Liu, Z.-J., Yang, J.-Y., Huang, Y.-Z., Tang, R.-C., & Qiao, Y.-F. (2019). Extraction of functional dyes from tea stem waste in alkaline medium and their application for simultaneous coloration and flame retardant and bioactive functionalization of silk. *ACS Sustain Chemistry Engineering, 7*, 18405–18413. https://doi.org/10.1021/acssuschemeng.9b04094

Colombini, M. P., Andreotti, A., Baraldi, C., Degano, I., & ve Łucejko, J. J. (2007). Colour fading in textiles: A model study on the decomposition of natural dyes. *Microchemical Journal, 85,* 174–182.

Çelik, F. (2006). Tea (*Camellia sinensis*); composition, the preventive effects on health and consumption: Review. *Turkiye Klinikleri Journal Medical Science, 26*, 642–648.

Dadalioglu, I., & Akdemir Evrendilek, G. (2004). Chemical compositions and antibacterial effects of essential oils of Turkish oregano (*Origanum minutiflorum*), bay laurel (*Laurus nobilis*), Spanish lavender (*Lavandula stoechas* l.), and fennel (*Foeniculum vulgare*) on common foodborne pathogens. *Journal of Agricultural and Food Chemistry, 52*(26), 8255–8260.

Das, M., Kundu, D., Singh, J., Rastogi, A., Mukherjee, G., & Chatterjee, A. (2018). Rejuvenation of metabolic cascades for controlling aging through bioactive compounds: a review. *Journal Nutrition Food Science Forecast, 1*(1), 1003.

Davidson, P. M., Sofos, J. N., & Branen, A. L. (2005). *Antimicrobials in food*. CRC Press.

Dikir, W. (2022). Role of intercropping some aromatic and medicinal plants with fruit vegetables crops, a review. *Global Academic Journal Agriculture Biosciences, 4*, 22–30.

Dobros, N., Zawada, K. D., & Paradowska, K. (2022). Phytochemical profiling, antioxidant and anti-inflammatory activity of plants belonging to the *Lavandula* Genus. *Molecules, 28*(1), 256.

Dorman, H. J. D., & Deans, S. G. (2000). Antimicrobial agents from plants: Antibacterial activity of plant volatile oil. *Journal of Applied Microbiology, 88*, 308–316.

Dousset, S., Abaga, N. O. Z., & Billet, D. (2016). Vetiver grass and micropollutant leaching through structured soil columns under outdoor conditions. *Pedosphere, 26*(4), 522–532.

El-Molla, M. M., & El-Ghorab, A. H. (2022). Extraction of eco-friendly essential oils and their utilization in finishing polyester fabrics for fragrant and medical textiles. *Journal ofEngineered Fibers and Fabrics, 17*, 15589250221104476.

Fratér, G., Bajgrowicz, J. A., & Kraft, P. (1998). Fragrance chemistry. *Tetrahedron, 54*, 7633–7703.

Gillessen, A., & Schmidt, H. H. (2020). Silymarin as supportive treatment in liver diseases: A narrative review. *Advances in Therapy, 37*(4), 1279–1301.

Gillij, Y. G., Gleiser, R. M., & Zygadlo, J. A. (2008). Mosquito repellent activity of essential oils of aromatic plants growing in Argentina. *Bioresource Technology, 99*(7), 2507–2515.

Gómez, L. D., Amalfitano, C., Andolfi, A., Simister, R., Somma, S., Ercolano, M. R., & Caruso, G. (2017). Valorising faba bean residual biomass: Effect of farming system and planting time on the potential for biofuel production. *Biomass and Bioenergy, 107*, 227–232.

Gong, K., Pan, Y., Rather, L. J., Wang, W., Zhou, Q., Zhang, T., & Li, Q. (2019). Natural pigment during flora leaf senescence and its application in dyeing and UV protection finish of silk and wool – a case study of *Cinnamomum camphora*. *Dyes Pigments, 166*, 114–121. https://doi.org/10.1016/j.dyepig.2019.03.037

Göktaş, Ö., & Gıdık, B. (2019). Uses of medicinal and aromatic plants. *Bayburt Üniversitesi Fen Bilimleri Dergisi, 2*(1), 145–151.

Gavril, G. L., Wrona, M., Bertella, A., Świeca, M., Râpă, M., Salafranca, J., & Nerín, C. (2019). Influence of medicinal and aromatic plants into risk assessment of a new bioactive packaging based on polylactic acid (PLA). *Food and Chemical Toxicology, 132*, 110662.

Hans, M., Nayik, G. A., & Salaria, A. (2023). *Clary sage essential oil. In essential oils* (pp. 459–478). Academic Press.

Jain, P. L., Patel, S. R., & Desai, M. A. (2022). Patchouli oil: An overview on extraction method, composition and biological activities. *Journal of Essential Oil Research, 34*(1), 1–11.

Jbilou, R., Matteo, R., Bakrim, A., Bouayad, N., & Rharrabe, K. (2023). Potential use of *Origanum vulgare* in agricultural pest management control: a systematic review. *Journal of Plant Diseases and Protection*, 1–17.

Islam, S. R., Alam, M. K., Alassod, A., Ahmed, T., Yousif, A. H., Rashid, M. M., & Mia, R. (2024). Natural dyes and pigments as a source of medicine. In *Renewable dyes and pigments* (pp. 177–232). Elsevier.

Karakaya, S. (2004). Bioavailability of phenolic compounds. *Critical Reviews in Food Science and Nutrition, 44*(6), 453–464.

Khan, U. M., Sameen, A., Aadil, R. M., Shahid, M., Sezen, S., Zarrabi, A., & Butnariu, M. (2021). *Citrus* genus and its waste utilization: A review on health-promoting activities and industrial application. *Evidence-Based Complementary and Alternative Medicine, 2021*, 1–17.

Khan, E., Ozaltin, K., Spagnuolo, D., Bernal-Ballen, A., Piskunov, M. V., & Di Martino, A. (2023). Biodiesel from rapeseed and sunflower oil: Effect of the transesterification conditions and oxidation stability. *Energies, 16*(2), 657.

Lavania, U. C. (2008). Vetiver in India: historical perspective and prospective for development of specific genotypes for environmental or industrial application. In P. Truong (Ed.), *Proceedings of 1st Indian Vetiver Workshop–Vetiver System for Environment Protection and National Disaster Management, Cochin, India* (pp. 40–47).

MacDavid, K., & Aebisher, D. (2014). A Review of sunlight induced cellular DNA damage. *American Journal of Cancer Therapy and Pharmacology, 2*(1), 48–55.

Malhotra, S. K. (2006). Celery. In *Handbook of herbs and spices* (pp. 317–336). Woodhead Publishing.

Mejica, G. F. C., Unpaprom, Y., & Ramaraj, R. (2020). *Anthocynain pigment evaluation and development of multicolored natural dye from malabar spinach and red cabbage as a potential dye sensitizer for dye-sensitize solar cell.* In *Conference: Proceedings of the 13th seminar on science and technology*.

Mooney, B. P. (2009). The second green revolution? Production of plant-based biodegradable plastics. *Biochemical Journal, 418*(2), 219–232.

Mukherjee, P. K. (2019). *Quality control and evaluation of herbal drugs: Evaluating natural products and traditional medicine*. Elsevier.

Narayan, P., & Maheshwari, R. K. (2017). Astonishing *Cymbopogon citratus* (Lemongrass) for healthcare prakash. *Research Journal Chemical & Environmental Science, 5*(5), 84–90.

Olofsson, J., & Börjesson, P. (2018). Residual biomass as resource–Life-cycle environmental impact of wastes in circular resource systems. *Journal of Cleaner Production, 196*, 997–1006.

Oskay, D., & Oskay, M. (2009). Biotechnological importance of plant secondary metabolites. *Ecological Life Sciences, 4*(2), 31–41.

Park, Y. L., & Tak, J. H. (2016). Essential oils for arthropod pest management in agricultural production systems. In *Essential oils in food preservation, flavor and safety* (pp. 61–70). Academic Press.

Perumalla, A. V. S., & Hettiarachchy, N. S. (2011). Green tea and grape seed extracts—Potential applications in food safety and quality. *Food Research International, 44*(4), 827–839.

Petrovska, B. B. (2012). Historical review of medicinal plants' usage. *Pharmacognosy Reviews, 6*(11), 1–5.

Ramya, H. G., Palanimuthu, V., & Rachna, S. (2013). An introduction to patchouli (*Pogostemon cablin* Benth.)–A medicinal and aromatic plant: It's importance to mankind. *Agricultural Engineering International: CIGR Journal*, *15*(2), 243–250.

Rao, B. R., Kaul, P. N., Syamasundar, K. V., & Ramesh, S. (2005). Chemical profiles of primary and secondary essential oils of palmarosa (*Cymbopogon martinii* (Roxb.) Wats var. motia Burk.). *Industrial Crops and Products, 21*(1), 121–127.

Reddy, R. L., Reddy, V. S., & Gupta, G. A. (2013). Study of bio-plastics as green and sustainable alternative to plastics. *International Journal of Emerging Technology and Advanced Engineering, 3*(5), 76–81.

Ren, Y., Fu, R., Fang, K., Chen, W., Hao, L., Xie, R., & Shi, Z. (2019). Dyeing cotton with tea extract based on in-situ polymerization: An innovative mechanism of coloring cellulose fibers by industrial crop pigments. *Industrial Crops and Products, 142*, 111863.

Ren, W., Qiao, Z., Wang, H., Zhu, L., & Zhang, L. (2003). Flavonoids: Promising anticancer agents. *Medicinal Research Reviews, 23*, 519–534.

Reshmy, R., Philip, E., Vaisakh, P. H., Raj, S., Paul, S. A., Madhavan, A., & Pandey, A. (2021). Development of an eco-friendly biodegradable plastic from jack fruit peel cellulose with different plasticizers and *Boswellia serrata* as filler. *Science of the Total Environment, 767*, 144285.

Riaz, U., Iqbal, S., Sohail, M. I., Samreen, T., Ashraf, M., Akmal, F., & Akhter, R. M. (2021). A comprehensive review on emerging importance and economical potential of medicinal and aromatic plants (MAPs) in current scenario. *Pakistan Journal of Agricultural Research, 34*(2), 381–392.

Sacchetti, G., Maietti, S., Muzzoli, M., Scaglianti, M., Manfredini, S., Radice, M., & Bruni, R. (2005). Comparative evaluation of 11 essential oils of different origin as functional antioxidants, antiradicals and antimicrobials in foods. *Food Chemistry, 91*, 621–632.

Saha, A., & Basak, B. B. (2020). Scope of value addition and utilization of residual biomass from medicinal and aromatic plants. *Industrial Crops and Products, 145*, 111979.

Samarth, R. M., Samarth, M., & Matsumoto, Y. (2017). Medicinally important aromatic plants with radioprotective activity. *Future Science OA 3*(4), FSO247.

Sayed Ahmad, B., Talou, T., Straumite, E., Sabovics, M., Kruma, Z., Saad, Z., & Merah, O. (2018). Protein bread fortification with cumin and caraway seeds and by-product flour. *Foods, 7*(3), 28.

Sikora, E., Małgorzata, M., Wolinska Kennard, K., & Lason, E. (2018). Nanoemulsions as a form of perfumery products. *Cosmetics, 5*(4), 63.

Silva, S. M., Luz, J. M. Q., Nogueira, P. A. M., Blank, A. F., Sampaio, T. S., Pinto, J. A. O., & Junior, A. W. (2017). Organomineral fertilization effects on biomass and essential oil of lavender (*Lavandula dentata* L.). *Industrial Crops and Products, 103*, 133–140.

Sowbhagya, H. B. (2014). Chemistry, technology, and nutraceutical functions of celery *(Apium graveolens* L.): An overview. *Critical Reviews in Food Science and Nutrition, 54*(3), 389–398.

Srivastava, R. K., Singh, A. K., Kalra, A., Tomar, V. K. S., Bansal, R. P., Patra, D. D., & Kumar, S. (2002). Characteristics of menthol mint *Mentha arvensis* cultivated on industrial scale in the Indo-Gangetic plains. *Industrial Crops and Products, 15*(3), 189–198.

Sujatha, S. (2010). Essential oil and its insecticidal activity of medicinal aromatic plant *Vetiveria zizanioides* (L.) against the red flour beetle *Tribolium castaneum* (Herbst). *Asian Journal of Agricultural Sciences, 2*(3), 84–88.

Swamy, M. K., Akhtar, M. S., & Sinniah, U. R. (2016). Antimicrobial properties of plant essential oils against human pathogens and their mode of action: An updated review. *Evidence Based Complement Alternative Medicine, 2016*, 3012462.

Tiring, G., Satar, S., & Özkaya, O. (2021). Secondary metabolites. *Bursa Uludağ Üniversitesi Ziraat Fakültesi Dergisi, 35*(1), 203–215.

Traboulsi, A. F., El-Haj, S., Tueni, M., Taoubi, K., Nader, N. A., & Mrad, A. (2005). Repellency and toxicity of aromatic plant extracts against the mosquito *Culex pipiens molestus* (Diptera: Culicidae). *Pest Management Science: Formerly Pesticide Science, 61*(6), 597–604.

Tuğlu, Ü., Baydar, H., & Erbaş, S. (2021). Influence of distillation methods, times and fractions on essential oil contents and compounds in Turkish Oregano (*Origanum onites* L.). *Journal of the Institute of Science and Technology, 11*(4), 3195–3202.

Varel, V. H. (2002). Livestock manure odor abatement with plant-derived oils and nitrogen conservation with urease inhibitors: A review. *Journal of Animal Science*, *80*(E-suppl_2), E1-E7.

Varona, S., Rodríguez Rojo, S., Martín, Á., Cocero, M. J., Serra, A. T., Crespo, T., & Duarte, C. M. M. (2013). Antimicrobial activity of lavandin essential oil formulations against three pathogenic food-borne bacteria. *Industrial Crops and Products, 42*(1), 243–250.

Wikandari, R., Millati, R., Cahyanto, M. N., & Taherzadeh, M. J. (2014). Biogas production from citrus waste by membrane bioreactor. *Membranes (Basel)., 4*(3), 596–607.

Yener, O., & Cömert, M. (2022). Medicinal and aromatic plants in artvin regional gastronomy. *Aydın Gastronomy, 6*(1), 29–38.

Yuca, H., Tekman, E., Civaş, A., & Karakaya, S. (2023). Comparison of essential oils and secretion structures of *Rosa damascena* Mill. Grown in Iğdır and Isparta (Turkey). *Sakarya University Journal of Science, 27*(3), 523–529.

Zhang, L. L., Chen, Y., Li, Z. J., Li, X., & Fan, G. (2022). Bioactive properties of the aromatic molecules of spearmint (Mentha spicata L.) essential oil: A review. *Food & Function, 13*(6), 3110–3132.

Zheljazkov, V. D., Craker, L. E., Xing, B., Nielsen, N. E., & Wilcox, A. (2008). Aromatic plant production on metal contaminated soils. *Science of the Total Environment, 395*(2–3), 51–62.

Zuzarte, M., Gonçalves, M. J., Cavaleiro, C., Cruz, M. T., Benzarti, A., Marongiu, B., & Salgueiro, L. (2013). Antifungal and anti-inflammatory potential of Lavandula stoechas and Thymus herba-barona essential oils. *Industrial Crops and Products, 44*, 97–103.

In-vitro Propagation to Conserve Medicinally Important Plants: Insight, Procedures, and Opportunities

V Samridha and Saket Chandra

Abstract

The utilization of plant tissue culture for the purpose of identifying and isolating bioactive phytocompounds has a wide range of industrial applications. The utilization of this technology offers prospective advantages across various sectors, encompassing the food, pharmaceutical, and cosmetics industries. India is known for its herbal remedies and has stood as an epitome of harnessing medicinal plants for ethnomedicinal benefits. The sudden loss of the majority of endemic medicinal plants is the stiff challenge that the world is facing today. A recent estimate has declared an alarming count of more than 90% of medicinal plant species as being threatened, with the majority nearing extinction. The use of the micropropagation technique for large-scale production of plantlets and preservation of germplasm is an essential requirement that must be pursued to establish an efficient in vitro regeneration strategy for medicinal plants. *In-vitro* propagation ensures a conserved environment for plant propagation and maintains disease-free plants. Micropropagation stands as a promising innovation that ensures a better tomorrow for endangered plants. Several protocols are developed worldwide to conserve flora and enhance its value. This chapter focuses on the in vitro propagation efforts to conserve medicinally important plants.

Keywords

In vitro regeneration · Medicinal plants · Herbal remedies · Endemic · Plant tissue culture

V. Samridha · S. Chandra (✉)
Department of Bioscience and Engineering, National Institute of Technology, Calicut, Kozhikode, Kerala 673601, India
e-mail: saketchandra@nitc.ac.in

1 Introduction

The term "medicinal" is used to describe a plant that signifies or possesses one or more compounds that positively regulate the physiological functions of diseased mammals. Humans have utilized such plants for their beneficial effects on health. These medicinal plants have long been used as safe and effective option in preventive medicine globally, originating from ancient practices, this method continues to hold importance in contemporary pharmacological preparations. Both an entire plant and its individual components can possess therapeutic properties (Sharma & Pandey, 2013). Medicinal plants contain secondary metabolites also often referred to as bioactive compounds like carotenoids, coumarins, polyphenols, alkaloids, terpenoids, flavonoids and lignin, etc., several plant species proved to be effective ailments for diseases like common cold, cancer, cardiovascular disorders, diabetes, Alzheimer's disease, asthma, Gaucher's disease, and infectious illnesses (Seca & Pinto, 2019). These phytochemicals have a broad range of bioactivities, including anti-inflammatory, anti-tumor, antimicrobial, antipruritic, antidermatitic, anti-neurodegenerative and antioxidant activities that often offer treatments with fewer side effects compared to synthetic drugs, making them a preferred choice in healthcare systems globally (Nasim et al., 2022). Given the growing global need for herbal medical products, nutraceuticals, and natural products for primary healthcare, the importance of medicinal plants has significantly risen. Besides their medicinal attributes, these plants embody cultural heritage, especially in a country like India, where the botanical diversity profounds a connection between communities and natural environment (Chanda & Ramachandra, 2019). Indigenous tribes have extensively depended on the therapeutic benefits of plants. For instance, *Chlorophytum tuberosum,* or Safed Musli, has been utilized for its properties including antitumor, anti-inflammatory, hypolipidemic, and much more. *Acorus calamus,* also known as Sweet flag, is known to cure various respiratory

L. Kumar et al. (eds.), *Medicinal and Aromatic Plants*, Sustainable Landscape Planning and Natural Resources Management,
https://doi.org/10.1007/978-3-031-60117-0_2

and digestive tract disorders. The tribal community harness *Bacopa monnieri,* popularly known as Brahmi, for memory boosting and to improving cognitive abilities. These plant remedies reflect the relevance of traditional medicine as remedies for numerous health conditions. However, plants face ominous threat of extinction in their natural habitats-driven by habitat degradation, overharvesting, and climate change. *Aconitum heterophyllum, Cinnamomum wightii, Jatropha nana, Nilgirianthus ciliates, Santalum album* constitute a few endangered species that require immediate attention for conservation (Gowthami et al., 2021). Conservation of natural flora of medical importance thereby rose to be a necessity. From ancient times, various civilizations developed methods to preserve plants, by adopting techniques like domestication and cultivation (Chen et al., 2016). Many traditional cultural beliefs revered specific plants and forests as sacred, contributing essentially to preservation of plant diversity (Chanda & Ramachandra, 2019). As time progressed, threats to the natural habitats intensified and consequently, the urgency to develop effective preservation methods for plants became imperative. Conventional plant propagation methods practised alone, will not meet the definitive requirements of conserving, and thereby preserving a superior variant of the plant. In 1902, Gottlieb Haberlandt, on addressing the German Academy of Science, proposed the possibility of generating artificial embryos from vegetative plant parts, utilizing their totipotency. His contributions laid an intact foundation for modern day *in-vitro* propagation or plant tissue culture. Haberlandt was later honoured with the title of 'Father of Plant Tissue Culture' (Thorpe, 2007). Later, in 1934, Roger Gautheret, practically established the first true plant tissue culture using cambial tissue derived from *Acer pseudoplatanus* (Gautheret, 1983). Since then, the world witnessed several advancements in the field of plant tissue culture, which now stands up to the modern techniques of micropropagation, somatic embryogenesis, and de novo organogenesis (Thorpe, 2007). *In-vitro* propagation, commonly known as tissue culture or micropropagation, represents a revolution in plant science, replacing the traditional methods of plant propagation and conservation. Unlike conventional methods, *in-vitro* propagation involves the growth of plant cells, tissues, or organs in a precisely controlled environment. This technique holds immense potential for reproducing numerous plant species, including those at risk of extinction, with precision, in short duration. *In-vitro* propagation not only facilitates the conservation of endangered species but also ensures sustainable utilization. It enables the production of uniform, disease-free plant material, providing a reliable supply for pharmaceutical, agricultural, and research purposes.

2 Importance of Medicinal Plants

Since times immemorial, the medicinal benefits of plants have been harnessed and are still relevant. Many phytochemicals are recognized for their potential pharmacologic activity and are being used as ailments worldwide. The first ever recorded evidence of the usage of plants for ailments comes from a 5,000-year-old Sumerian clay slab from Nagpur, India (Petrovska, 2012). The slab describes 12 drug recipes prepared from the usage of over 250 plants, including poppy (*Papaver somniferum*), henbane (*Hyoscyamus niger*), and mandrake (*Mandragora officinarum*). 'Pen T Sao', an ancient book from China, depicts 365 drugs derived from plants (Petrovska, 2012). Further, Hippocrates, known as the 'Father of Medicine,' illustrated about 300 plant species and derived their medicinal properties. Also, the father of Botany, Theophrast, extensively examined and classified more than 500 plants of medicinal importance. In India, the Vedas and other scriptures emphasize the role of medicinal plants in treating diseases, maintaining a healthy lifestyle, and for aesthetic and ornamental purposes (Petrovska, 2012).

Herbal remedies are increasingly being embraced and recognized in modern healthcare practices. One of the primary factors contributing to this acknowledgment is the detrimental side effects induced by the majority of commercially accessible synthetic medications. Medicines produced from plants typically provide a synergistic effect, assisting the body in activating its own healing mechanisms. Instead of focusing solely on the primary symptom, herbal medications aim to assist the body holistically, ultimately resulting in the cure of the disease. Thus, it eliminates the 'risk' of depending on synthetic drugs. This century is witnessing increased scientific research and clinical trials on medicinal plants, not limited to pharmaceuticals, but also for cosmetics and nutraceuticals (Krasteva et al., 2021). Furthermore, being closely connected to cultural and traditional beliefs, these are being widely accepted by a greater part of society.

With over 50,000 species, more than one-tenth of plant biodiversity worldwide is being utilized in the healthcare industry. Two-thirds of the total biodiversity resides in tropical regions (Sharma & Pandey, 2013). China possesses the highest number of medicinal plants with a count of 11,146, while India ranks second with 7500 species of medicinal plants, followed by tropical countries like South Africa, Columbia, and the United States. The Indian subcontinent alone is home to 44% of the total medicinal plant species (Chen et al., 2016). The legacy of India is rich in traditional medicinal practices like Ayurveda, Unani, and Siddha. In India, several generations of the country have sustained this valuable knowledge of herbal remedies, which efficiently continues to be practiced even today. These plants, which are deeply rooted in our cultural and religious rituals, have gained huge attention on a global scale for their potential pharmaceutical applications (Sharma & Pandey, 2013).

3 Factors Related to the Rarity and Reasons to Conserve Medicinal Plants

Medicinal plants are one of the most highly valuable resources in our world. Despite being in high demand, numerous medicinal plants face threats all over the country, resulting in a major loss of resources and biodiversity. The natural or background extinction rate refers to the standard extinction rate in the biological history of the Earth, especially the pre-human era, revealed by fossil studies. As per reports, at least one medicinal plant is becoming being extinct, every two years (Pimm et al., 1995). According to the International Union for Conservation of Nature (IUCN) red list, over 15,000 plant species are endangered, and out of them, over 5,000 species are critically endangered. The threat to the existence of plants stems from both natural and anthropogenic reasons. Habitat loss and fragmentation due to urbanization is a major concern. More forest areas and natural habitats are being destroyed, giving rise to a major risk in biodiversity conservation (Sharma & Pandey, 2013). Climate change exacerbates the situation by modifying temperature and precipitation patterns, ultimately resulting in extreme climatic conditions that impair plant life. This is more concerning in the case of endemic plant species. Natural calamities like flooding drought, etc. can be very detrimental for endemic flora (Sharma & Pandey, 2013). The invasion of exotic species of plants and animals also affects the ecological balance of an ecosystem and threatens the existence of these endemic plant species.

The popularity of plant-derived commercial products drives the global industries to harvest more plants, leading to a major loss in biodiversity. The indiscriminate harvesting and exploiting of plants by pharma companies without any sustainability measures are further worsening the situation. Therefore, the conservation of medicinal plants is important. The objective of conservation is to save plants in a manner that allows for their utilization and the harnessing of benefits while ensuring sustainability and the preservation of biodiversity. (Krasteva et al., 2021; Sharma & Pandey, 2013).

4 Conservation Strategies for Medicinal Plants

Conservation of medicinal plants can be achieved either by in-situ or *ex-situ* methods (Table 1). In situ conservation aims to conserve wild flora within their natural habitat. Natural reserves, wildlife sanctuaries, and indigenous forests are the methods for in situ conservation of plants. Here, rather than a species, the ecosystem as a whole is being protected. This approach protects flora and fauna from over-exploitation, habitat degradation, and foreign species invasion (Chen et al., 2016). On the other hand, ex-situ conservation complements in situ conservation methods by providing the ideal in vitro growth conditions for the plant. This approach is extremely advantageous for plants that are encountering peril in their native habitat. Hence, a controlled in vitro laboratory environment provides a promising alternative for slow-growing and sparsely populated plants (Sun et al., 2022). For these endangered plant species, the application of in vitro propagation is highly beneficial and is one of the popular approaches. Therefore, ex situ conservation, particularly in vitro culture, not only allows for the production of medical bioactive components in large quantities but also ensures the sustainable exploitation of plants.

5 In vitro Propagation as a Means of Conserving Medicinal Plants

In vitro propagation of plants is an integral procedure, whereby the cell, tissue, or organ of the target plant is isolated aseptically and propagated in artificial culture media of known composition. The media for plant tissue culture is generally formulated by optimizing the ideal ratios of all the nutrient constituents, thereby enabling a specialized growth condition for the plant. The technique is used to produce clones of the donor plant that meet the essential characteristics (Chen et al., 2016). Moreover, the donor or the mother plants are also manipulated genetically; for example, gene editing tools like Zinc Finger Nuclease and CRISPR Cas9 can induce the expression of a gene by targeting the promoter (Shahzad et al., 2017). The principle of totipotency endows any plant cell, tissue, or organ, with the ability to develop into a complete plant by regeneration. As a result, many clonal plantlets can be generated, which retain the characteristics of the donor plant in *in-vitro* conditions (Table 2).

Table 1 Comparison of in situ and ex-situ methods of conservation

Aspect	In-situ conservation of plants	Ex-situ conservation of plants
Method	Preserves flora within their natural habitat	Preserves flora outside their natural habitat
Location of preservation	Natural ecosystems like wildlife sanctuaries, national parks and protected ethnic forests	Controlled laboratory environment like seed banks, botanical gardens, arboreta, tissue culture laboratories
Objective and scope	Protects entire ecosystems and associated biodiversity, rather than focusing on a specific genera or species	Focuses on conserving individual species or genetic diversity by providing ideal conditions in vitro
Advantages	• Allows to continue natural evolutionary processes and maintain genetic adaptability to changing environmental conditions • Preserves complex ecological relationships • Minimizes genetic drift and founder effects	• Offer more targeted protection for rare and critically endangered species • Protects against threats like habitat loss, natural disasters, and poaching • Enables research, education, breeding programs and ecosystem restoration • Act as a backup for plant diversity that could be lost in natural habitats, thereby preventing extinction
Limitations	• More susceptible to large-scale threats like climate change and natural calamities • Challenges in managing foreign species invasion and anthropogenic actions • May not be feasible for species requiring highly specific habitat conditions • Can be challenging in monitoring plants in inaccessible remote areas	• Disrupts natural interactions and evolutionary processes • Possibility to lead to loss of genetic diversity and genetic bottlenecks • Requires significant resources and expertise man-power for management • Reintroduction to natural habitats can be challenging
Diversity	Preserves natural genetic diversity within populations	Preserves genetic diversity across populations
Human intervention	Minimal human intervention and relies on natural processes	Demands active human intervention in the form of skilled labour
Threat mitigation	Addresses threats including pollution and habitat destruction	Protects against threats like habitat loss and extinction
Long-term sustainability	Depends on effective habitat protection and management	Requires ongoing financial support for proper maintenance

6 Basic Procedure for in vitro Propagation of Plants

In vitro plant propagation aims to produce clonal copies of the mother plant, utilizing the property of totipotency. Specific culture media that meet the nutritional requirements of the plant species are used to propagate the plant under controlled environmental conditions. The basic procedure for *in-vitro* propagation of plants involves five major stages as illustrated in Fig. 1:

i. Stage 0: Selection of explant source
ii. Stage 1: Establishment of explant
iii. Stage 2: Multiplication of explants
iv. Stage 3: Rooting of explants
v. Stage 4: Acclimatization

It was Murashige who first described the stages of in vitro propagation of plants in detail. The stages apply to all the plant species being cultured, but specific alterations are made based on the plant species to be grown and the explant being utilized (Chokheli et al., 2020).

Stage 0: Selection of explant source:

The success of plant tissue culture lies in the selection of a proper source for the explant in the pre-propagation stage. Usually, the mother plant considered is maintained in conditions offering minimal chances of microbial contamination. Greenhouses, glass chambers, and plastic tunnels are used to store the donor or the mother plant, and they are ensured to be aseptic by treating them regularly with fungicides and insecticides. Culture indexing of explants derived is done to preserve them disease-free. It is been found that the best stage to isolate the explant is when the donor plant is in its active growth phase. If explants are derived from plants under dormant conditions, the dormant stage should be halted by refrigerating or soaking the tissue in GA3.