Chapter

Herbal Drugs Forensic

Shalvi Agrawal and Astha Pandey

Abstract

Due to pandemic Covid-19, suddenly the vast population is drawn towards herbal drug treatment in India. In India, Ayurveda is practised to a greater extent as it does not have any side effects or other major effects. They are also added in many nutraceutical products like Chyawanprash, honey, etc. There are a lot of medicinal floras sold in the market in the form of small twigs, pieces of roots, stems or leaves of which decoction is made and consumed. The consumers are unaware of the authenticity of these crude drugs that lead to the deterioration in their health owing to the consumption of inferior quality of products or their substitute or the illicit bioadulterants which look like any other common plant part. The herbal drugs could also be in the form of tablet, powder, etc. which might be adulterated with look-alike plant products. Thus, a new branch of **Forensic Science,** i.e. **Herbal Drugs Forensic** which deals with identification of fake herbal product by various techniques which might be chemical or biological in nature has come up. In fact, the analytical methods for the testing of various bioconstituents need to be standardized and validated. Thus to prevent herbal drug fraud, it has become necessary to develop the methods for their detection through an emerging field of Forensic Science, i.e. Herbal Drugs Forensic.

Keywords: adulteration, authenticity, fraud, herbal drugs, herbal drugs forensic, identification, standardization

1. Introduction: Ayurveda - the science of healing

> *'The great thing about Ayurveda is that its treatments always yield side benefits, not side effects.'—Shubhra Krishan*

Ayurveda is an age old science that deals with the sacred knowledge of healing and longevity. The word Ayurveda is derived from two words that is 'Ayuh' which means 'life' and 'veda' which means 'science or knowledge'. Thus, Ayurveda itself defines its meaning as the science or knowledge of life. Not only a science, but Ayurveda is a tradition that originated in India and is practised since then.

In other words, Ayurveda is not only taking herbal preparation and waiting for it to give results but encouraging all of us to be an active participant in the journey of healing. This process involves learning about our relationship with the nature and elements and their unique combinations they form known as *doshas*.

The practice of Ayurveda dates back to over five thousand years, during the *Vedic* period of ancient India [1]. The tradition was kept alive by the *vaidyas* and *acharyas* (those who practise Ayurveda) till India got independence in 1947. After independence, Ayurveda saw a resurge in India and emerged as a major healthcare system. Not only in India, but in different parts of the world like China, Europe,

Middle East, etc., Ayurveda has been practised since long as the alternative medicine system was not in reach of major population [2].

Along with Ayurveda, practice of Yoga and eastern spiritualism flourished towards the western world in twentieth century.

1.1 The positive side of Ayurvedic medicine

The most important advantage associated with ayurvedic medicines is that it gives no side- effects even if it does not cause any good to health. This property of Ayurvedic medicines makes it most popular among all systems of medicine. The practice of Ayurveda is as easy for the new practitioners as it is for the age old [3]. It does not work on the symptoms of the disease rather works on the root cause to treat the ailment permanently. That is why the practice of Ayurveda requires patience.

1.2 Ayurveda and the current pandemic

Antibiotics resistance across the world is already a problem, especially if Covid-19 deepens as a syndemic in populations with antibiotic resistance [4, 5]. To fight with such a situation, Indian Ayurvedic system of healing can play a vital role. Also, against such a syndemic, there should be something that can act synergistically. For such a synergy, a combination of drugs can prove in a most effective manner that can not only help in fighting against such a syndemic but can also play an efficient role in boosting the immunity and acting as a line of defense against any such future epidemic.

2. Forensic botany and herbal drugs forensics

The study of plants and their role in criminal investigations is referred as 'Forensic botany' [6, 7].

Forensic Botany not only involves the examination of botanical evidences present near the victim or at crime scene but also involves the detection of any unwanted material present in the herbal drugs. Though this part is untouched in forensic botany and is considered differently under Ayurveda but whenever and wherever any illegal, intentional or unintentional substitution or adulteration in trade of natural/authentic product comes, forensic science has always a crucial role to play.

A fundamental Ayurvedic philosophy is that 'food is medicine and medicine is food'. According to an Ayurvedic proverb 'When diet is wrong, medicine is of no use; when diet is correct, medicine is of no need'.

Food, the fundamental for the sustenance of life is not unblemished from various malfeasances owing to the adulteration and falsification of food commodity. Not only food but the drugs also are no safer enough to be completely relied upon. The food and the herbal drugs (prepared from the medicinal flora having one or more bioactive constituents) market offer a huge income due to growing population, their needs, consumerism and marketism. The various food products and herbal drugs available in the market are carrying lot of adulterants and counterfeits that are almost impossible for a common man to detect [8–14]. **Herbal drugs forensic** is a branch of forensics and a multidisciplinary science that not only answers the questions as to 'what' and 'how much' related to drug safety and quality issues but also investigates the sources, fate, implications and possibilities related to adulteration, falsification, counterfeiting and substitution in nutraceuticals (the drugs or herbal supplements consumed for extra nutrient intake that is not fulfilled by routine diet) and herbal medicinal drugs.

3. Trade in herbal drugs

According to National Medicinal Plant Board (NMPB) Report, India's domestic herbal industry (since India being a major exporter of herbal raw drugs) has around 8610 licensed herbal units, thousands of cottage level unregulated herbal units and millions of folk healers and household level users of thousands of herbal raw drugs. Also, the trade web that channelizes various herbal raw drugs from the supply to the end users is very complex. Thus, to have a better understanding of the Market and trade of the sector, we need to focus on demand and supply chains of the medicinal plants. The demand and supply chain of medicinal plants in the country is itself very complex.

Presently, medicinal plants are marketed and traded through Mandis and other wholesale markets in India with numerous intermediaries in between. Trade is rather opaque and information on prices, arrivals and other trends are difficult for farmers/growers to access. NMPB has been initiating many steps in order to fill this gap.

Another major gap between the demand and supply has emerged due to the commercialization of the production of classical Ayurveda, Siddha and Unani (ASU) formulations that require large quantities of wild harvested, cultivated or imported herbal raw drugs. This has resulted into thriving trade in raw drugs. Because of this, knowledge about the annual consumption levels of the herbal raw drug, the trends in their usage and their trade value is important so that the resources can be managed to ensure sustainable supplies to the herbal drug industry, folk users and growing global markets [15].

3.1 Demand and supply position of medicinal plants

India has very strong traditional health care practices that are represented by the classical systems of medicine like Ayurveda, Siddha, Unani, and Swa-rigpa. Besides these traditional heath care practices, there exists a very diverse area-specific and community-specific folk healthcare practices. Both the Indian classical system of medicine and the folk health care systems are highly dependent on the raw herbal drug material derived from a diverse species of medicinal plants, which is estimated to be about 6500 in number [16].

NMPB, during 2001–2002, commissioned a study through Centre for Research, Planning and Action (CERPA) to understand annual trade levels of selected 162 medicinal plant species. The NMPB, then in 2006–2007 commissioned a national study that was carried out by Foundation for Revitalisation of Local Health Traditions (FRLHT) to assess demand and supply of medicinal plants in India which for the first time highlighted various drawbacks in the herbal drug sector and added more to the existing knowledge and understanding of the subject related to the diversity of raw drugs in trade, their botanical correlation, volume of annually trade drugs, their supply sources and others [16].

Figure 1 below shows various Industrial uses of Medicinal Plants [17]. Each of these groups can contain a wide range of products like herbal medicinal products, food supplements or dietary supplements, foodstuffs, Cosmetics, etc.

Countries where the highest uses of traditional medicines are practiced include [18]:

- United Arab Emirates (100%)
- China (100%)
- India (70%)

- Pakistan (70%)
- African countries (70–80%)

A major percentage of raw drugs are used in making plant extracts. This is carried out either by the end product manufacturers or by extract companies. In addition to this, there is an exorbitant demand in developed countries for plant based products including health supplements, herbal health drinks, herbal cosmetics and various other health and personal care products. The current worth of the global market for herbal products is estimated around US$60 billion per year with a growth rate of 7% [16].

In India, trade in medicinal plants accounts for a turnover of Rs. 2300 crores of ayurvedic and herbal products with a contribution of about Rs. 1200 crores of over-the-counter products. Currently Covid-19 pandemic has opened door to explore more in the ayurvedic treasures. This would help in enabling rapid access of these herbal drugs into developed country markets as well as in Indian market [16].

There are major challenges in tapping the substantial potential for utilizing medicinal, aromatic and natural dyes plants (MADPs) nationally in India, as well as in export markets. At the forefront of these problems is ensuring consistent and acceptable quality which always suffers against making money out of it. As this tradition has now moved to industries which was earlier a part of a local community's culture and health practices, quality is not manageable and has suffered a

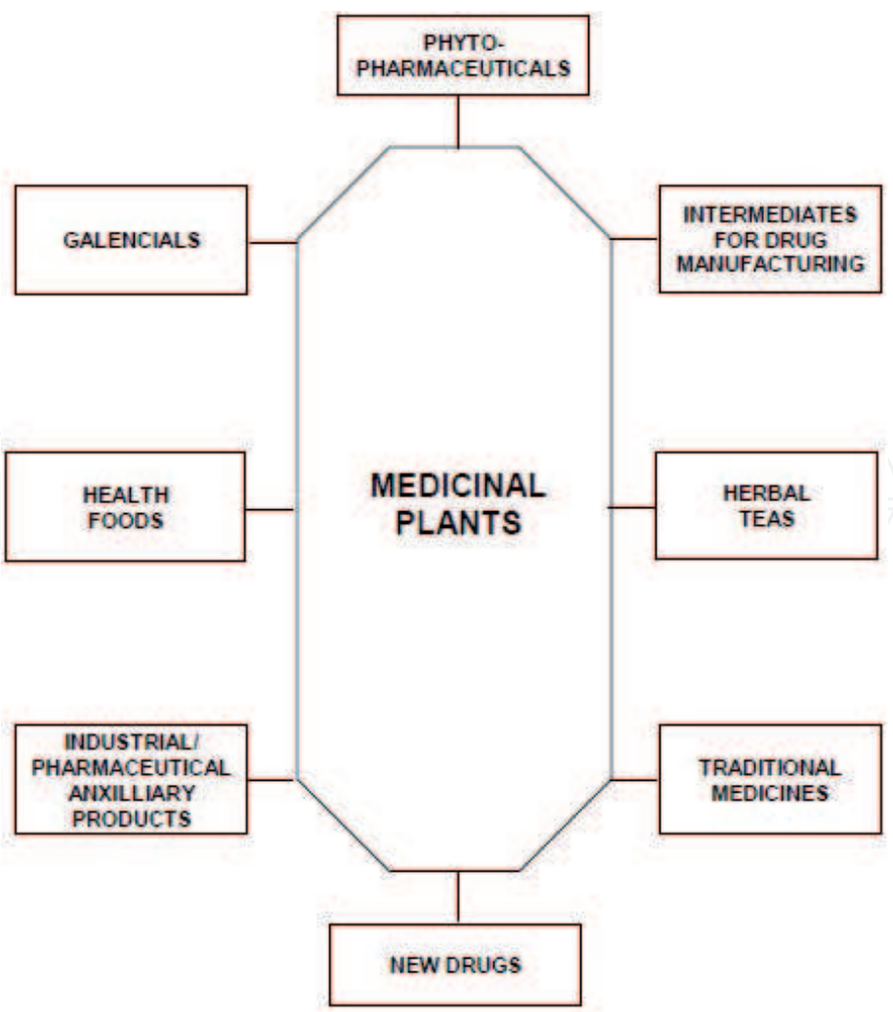

Figure 1.
Industrial uses of medicinal plants. Source: De Silva [17].

lot. In case of medicinal plants, quality means the correct identity of the medicinal herb, purity of the composition and safety and efficacy of the final drug. However, quality standardization of MADPs suffers a lot of challenges as:

- Firstly, unlike allopathic drugs that are composed of a single or a fixed number of chemical compounds that are easy to be standardized, plants have a diverse range of phytoconstituents contributing to their bioactivity and it is very difficult to isolate, purify and standardize that bioactive compound.

- Secondly, bioactivity is not constant but varies according to time (day, season, constellar position) and to region (arid, marshy).

- Thirdly, there are also differences in the bioactivity exists depending on the way a plant has been collected, processed and stored [16].

There are many more factors that contribute to the varied behavior of plant based drugs besides the ones stated above. Phytoconstituents that are responsible for the specific medicinal properties of a plant are not present in uniform quality or quantity under different edaphic (soil) conditions. The medicinal and toxic property of a plant may also vary according to the kind of processing through which it had undergone. Traditional, ancient systems of medicine used to take care of all these parameters and thus it had specific recommendations and procedures as to how a plant should be collected and processed in order to get its optimum efficacy.

Currently, there are modern analytical techniques like chromatography, spectroscopy and bioassay methods that can be used to determine the chemical profile of the selected medicinal plants and can compare their bioactivity and efficacy in treating one or the other disease [16].

Note: Information in the above paragraph has been taken from the country studies prepared for the Workshop on Medicinal Plants held in Bangalore, India, 22–26 July 2004.

4. Constraints to the development of trade

While developing countries like India has huge potential in the marketing and trade of herbal drugs owing to their ancient knowledge and experience with the Ayurveda but they face a number of challenges and limitations that need to be addressed to meet the growing demands in the developed country markets [16].

a. **Quality assurance:** the herbal drugs need to be consistent in quality and should be free from contaminants. Unwanted ingredients like dirt, soil particles, plant parts, or any other chemical adulterant need to be addressed before final packaging and trade of the herbal product.

b. **Consistent volume:** the herbal drugs that are high in demand must be available in consistent volume so that there should be no pressure on natural resources and no exploitation of biodiversity occurs.

c. **Strict regulatory laws:** to regulate the collection, processing, storage, manufacturing and trade in herbal products, there should be strict norms laid by the concerned authority at local, national and international level.

d. **Pre- and post-harvesting practises:** the herbal plants that are harvested for the use in different products need to be monitored and their pre- and

post-harvesting practices must be standardized so that a consistent quality can be met. Also, as we discussed earlier, quality and quantity of bioactive components are impacted depending upon pre- and post-harvesting practices.

e. **Lack of proper knowledge:** lack of proper knowledge in the species and variety of the plants many a times create confusion. There is limited knowledge of the herbs' medicinal properties beyond traditional knowledge and belief. This restricts the use and marketability of the plants. Common man/consumers are unaware of these scientific terms and blindly trust the manufacturer or brand in this regard.

f. **Lack of database/data repository:** there must be a herbal drug repository and related database of all the medicinal plants found in the country, their availability, flowering season, abundance, medicinal properties, toxicity, etc. so that exploitation of natural resources can be stopped and endangered species of plants can be protected.

g. **Lack of access to latest technology:** developing countries/Poor countries often lack in accessing latest technologies for the quality assessment of the herbal drugs which results in compromising with the quality and efficacy of the drugs.

h. **Research and development:** often developing countries use a very less proportion of their Gross Domestic Product (GDP) in research and development. In case of herbal drugs, research and development is the foremost requirement as the drugs are sourced from natural product and the environment in which these plants grow is ever changing with lot of mutations occurring resulting in change of bioactivity of phytoconstituents.

i. **Intellectual property rights (IPR):** plants cannot be protected under IPR as they have been used in traditional medicines for centuries. Any new discovery with a herbal drug that show its effectiveness in treating certain ailment can be patented. A therapy which is new for one region can be a part of regular practice for the other region of the world. Thus, everything cannot be patented. The plants can only be registered based on their availability in one or the other region and their status in the wild. Also, there is very little knowledge of the whole IPR field in the developing countries and the access to it is still lower. These issues are currently under discussion, debate and negotiation on a broader scale in the World Trade Organization (WTO).

j. **Deliberate malpractices:** beside lack of knowledge, there is sometimes deliberate adulteration and substitution in herbal drugs to make more money. Always the end users pay a cost of these malpractices and sometimes suffer due to inferior quality of the products which many a times produce side-effects.

A detailed review on the various malpractices in herbal drugs is discussed below.

4.1 Types of illegal/malpractices

Deliberate malpractices can be broadly classified into two categories-**adulteration** and **substitution**. The term '**adulteration**' can be defined as 'admixturing or substituting original or genuine drug with inferior, defective or otherwise useless or harmful substance'. Adulteration in simple words is the debasement of an article [19]. The drugs may be adulterated with substandard commercial varieties or with superficially similar inferior drugs or

with artificially manufactured substance or with same exhausted drug or with synthetic chemicals to enhance natural character or with any other harmful adulterant. The drugs which are in powdered form are frequently adulterated as identification of adulterant becomes very difficult in powdered form of drugs. According to World Health Organization's (WHO) publication on quality standards for medicinal plant materials, any batch of raw herbal drug which has more than 5% of any other plant part, even of the same plant say, stem in leaf drugs, should be strictly rejected never the less if they are derived from the authentic plant.

Substitution may be defined as a process of replacing partially or completely an authentic herbal drug with its different species or with different plant part or with any other material that have similar morphology or functional property so that the substitution may be difficult to detect.

4.1.1 Types of adulteration and substitution

a. *Adulteration with inferior commercial varieties* [20, 21]: they are added due to similarity in morphology; for example, black pepper (*Piper nigrum*) adulterated by papaya seeds.

b. *Adulteration by artificially manufactured substitutes* [20, 21]: the artificially manufactured substance resembles the original drug. This method is used for the costlier drugs. For example, artificial invert sugar or cane sugar is added to Honey.

c. *Adulteration by exhausted drugs* [20, 21]: when the drug is devoid of medicinally active substance as it has been extracted already and then is used to make the herbal product, such substitution comes under this category. Mainly volatile oil containing drugs like clove, coriander, fennel, caraway are adulterated by this method. As it is devoid of colour and taste due to extraction, natural colour and taste is balanced with additives and synthetic chemicals, e.g. Clove, Fennel, etc.

d. *Adulteration by addition of heavy metals* [20, 21]: many a times due to non-standardized or sub-standardized processing of raw herbal drugs, many harmful pollutants from the soil and environment get added to the final product, e.g. pieces of limestone in asafoetida, lead in pieces of opium.

e. *Adulteration by synthetic principles* [20, 21]: synthetic chemicals are used to enhance natural colour, fragrance and taste of the exhausted drugs, e.g. adding Citral to oil of lime and orange.

f. *Adulteration of powders* [20, 21]: the drugs which are in the form of powders are frequently adulterated as it is almost impossible to detect the adulteration without any technological tool. For example, dextrin is added in ipecacuanha, exhausted ginger in ginger, red sanders wood in capsicum powder and powdered bark adulterated with brick powder, metanil yellow in turmeric powder, chalk powder in wheat flour, red brick powder in red chili powder, chicory powder in coffee powder, etc.

g. *Presence of vegetative matter of same plant* [20, 21]: small pieces of all dried root, stem and leaf of different plant look similar. Some miniature plants growing along with the medicinal plants are added due to their colour, odour, and constituents. Small twigs, stems, leaves are often added to the

crude dried drug which cannot be differentiated by naked eye. For example, Mixture of crude Dashmoola drugs is often adulterated with some random twig, leaf and bark.

4.1.2 Reasons for adulteration and substitution

a. *Non-availability of the authentic drug* [20, 21]: due to over exploitation and unregulated deforestation, there has been shortage of many medicinal floras which has resulted in the endangerment of the species. Some of the plants have been extinct also, e.g. substitution of *Oroxylum indicum* in Dashmoola drugs.

b. *Uncertainty in the identity of the drug* [20, 21]: the local collectors of the medicinal flora are not much educated and get confused with the identity of the drugs that look similar. Also, some of the plant species are debatable among Ayurveda practitioners for the authenticity and thus interchangeably used by different practitioners, e.g. for the herb Lakshmana different species such as *Arlia quinquefolia*, *Ipomea sepiaria*, etc. are considered.

c. *Cost of the drug* [20, 21]: due to lesser prevalence of many medicinal floras, the cost of their respective drug rise. Manufacturers adulterate such drugs to make more money, e.g. saffron, asafoetida, etc.

d. *Geographical distribution of the drug* [20, 21]: many of the drugs that are found in one part of the country are not found in the other. This has resulted in substitution of such drugs with functionally similar drugs. For example, as Rasna, *Plucia lanceolata* is used in Northern India while in southeren parts *Alpinia galanga* is considered as the source.

e. *The adverse reaction of the drug* [20, 21]: different drugs have their varied impact on people depending upon their age, gender, physical condition, disorder, etc. Some of the drugs that show medicinal benefits in one person may show toxic effects in another. For example, Vasa is a well-known Rakta-Pittahara drug, but due to its Abortifacient activity its utility in pregnant women is limited, instead drugs such as Laksha, Ashoka, etc. are substituted.

f. *Confusion in vernacular names* [20, 21]: different species having similar vernacular names and vice a versa an cause confusion that may result in adulteration. In Ayurveda, 'Parpatta' is a plant that refers to *Fumaria parvifloran* originally and in Siddha, 'Parpadagam' is another plant that refers to *Mollugo pentaphylla*. But due to similarity in the names in traditional systems of medicine, these two herbs are often interchanged or adulterated or substituted [19].

g. *Lack of knowledge about original or authentic source* [20, 21]: an example of such type of adulteration can be *Mesua ferrea* commonly known as Nagakesar. Market samples of Nagkesar is adulterated with flowers of *Calophyllum inophyllum* because the suppliers are not aware about the abundance of authentic drug *Mesua ferrea* in the Western Ghats region and the parts of Himalayas. There may be some restriction s in the collection of drug from the protected forests too [19].

h. *Similarity in morphology* [20, 21]: owing to the similarity in morphological characteristics within the same genus, often the species are interchangeably used. *Mucuna pruriens* is adulterated with other similar Papilionaceae seeds

having similarity in morphology. *M. utilis* (sold as white variety) and *M. deeringiana* (sold as bigger variety) are popular adulterants.

i. *Similarity in colour or dye* [20, 21]: colour can be a major reason of adulteration. Not all spices and drugs that give a peculiar colour to food or medicine source from original herb but can be adulterated with synthetic dyes. 'Ratanjot', originally derived from *Ventilago madraspatana* and collected from Western Ghats which is known to be the only source of red dye (ratanjot), is now derived from *Arnebia euchroma* var. *euchroma*. Though there is only similarity in the colour of the dye but still, whatever is available in the market, in the name of Ratanjot is originated from *Arnebia euchroma* [19].

j. *Careless collections* [20, 21]: some of the herbal adulterations are due to the carelessness of herbal collectors and suppliers. The collectors are local people who are not much educated and trained in proper collection guidelines. This results in degradation of many of the useful properties of the plant. *Parmelia perlata* is used in Ayurveda, Unani and Siddha. It is also used as grocery. Market samples showed it to be admixed with other species (*P. perforata* and *P. cirrhata*).

5. Laws related to collection, harvest, processing and trade in medicinal Flora

As discussed earlier, with the growing interest in medicinal plants and ayurvedic drugs, there is a need for a long term strategy and planning to conserve and sustainable use of these plants [22–26]. Many medicinal plants like other natural resources are facing extinction and their degradation has accelerated over the years due to many reasons. Medicinal plants also face habitat destruction due to over exploitation. Though **Forest Conservation Act, 1980** and the **Wildlife Protection Act, 1972** provide some protection to medicinal plants. But as there are many medicinal floras that grow away from the domain of protected areas and there is no well-planned strategy for their conservation, many of such unchecked floras face endangerment and become extinct. Even the floras within protected areas face depletion without proper conservation strategy. Beside this, indiscriminate and unregulated exploitation of medicinal plants for their roots, stem, bark, fruit, leaves, or whole plant leads to destructive harvesting which include 70% of the wild flora out of 95%t used [16]. If not carefully monitored, this practice could lead to the depletion of genetic stocks and ultimately to the diversity of medicinal flora.

Though, government is making efforts to manage and regulate the collection of wild flora, but a long term strategy is needed. The efforts are scattered and do not yield satisfactory results. These efforts along with the well-planned strategies and policies are needed with major involvement of local communities and indigenous habitants.

Both in-situ and ex-situ conservation strategies need to be undertaken. **In-situ conservation** involves protecting bioreserves and biodiversity hotspots, e.g. The Himalayas, Sunderbans, Eastern and Western Ghats. Such biodiversity hotspots are rich in medicinal floras, thus protection of the indigenous plant species along with collection of raw drugs need to be regulated for sustainable development of natural resources. **Ex-situ conservation** involves setting up of gene banks, herbal botanical gardens, seed banks, drug repositories, nurseries, etc. so that the endangered species can be raised again. The **Department of Biotechnology, Government of India** is working in this line and has taken various initiatives to establish gene banks.

In this regard, loss of traditional knowledge is always felt. Indigenous communities have a culture of worshipping sacred groves which is rich in plant diversity.

They know the ideal growth conditions and micro niches needed for these species to thrive. Even, tribal communities cultivate many medicinal plants for their personal use. For the large scale cultivation of such plants, there is a lot to learn from these communities. Thus, it becomes extremely important to involve tribal people, indigenous habitants in conservation programmes and to document their ethnobotanical knowledge to keep this living tradition alive.

In India, mainly three Acts cover medicinal plant issues at present. They are the **Indian Forest Act, 1927,** the **Forest Conservation Act, 1980** and the **Wildlife Protection Act, 1972**. These acts do not cover much under their domain with respect to import, export, cultivation and trade related issues. Also, they focus on plant and animal resources as a whole but there is no separate law in our country that focuses on the conservation of medicinal flora in particular. The export and import of medicinal flora in India is governed according to **Convention on International Trade in Endangered Species of Wild Fauna and Flora, 1975** commonly known as **CITES**. Being an international law CITES does not cover a vast flora which is country specific. Beside CITES, **International Union for the Conservation of Nature and Natural Resources (IUCN)** is another international organization that works in the field of nature conservation and sustainable use of natural resources. It is involved in data gathering and analysis, research, field projects, advocacy and education. In India, the **Drugs and Cosmetics Rules, 1940** defines ASU drugs; regulate their trade, misbranding, adulteration or substitution and spurious drugs use in any Herbal or Polyherbal ASU formulation. Often, local vendors and manufacturers escape such laws to promote their brand and make profit.

Unregulated harvesting of medicinal plants always takes place outside the protected areas. All over the world, the species of medicinal floras that are banned for export are due to their endangered status in the wild and not because of the medicinal value they hold. There is a need of urgent national level policy for the consolidated effort towards the conservation of medicinal plants. Policies must be formulated keeping in mind the various user groups of medicinal plants. It should advocate in-situ and ex-situ conservation both. The policy should review all existing institutions working in this domain and also build new ones. Most importantly, the policy needs to take into account the legal and regulatory mechanisms related to medicinal plants.

Several efforts are afoot towards the formulation of such policies but we have yet to see something more concrete in this direction.

6. Forensic implications of herbal drugs

A simple understanding about forensics is that anything which is illegal and unregulated by the laws, directly or indirectly tends to harm individuals automatically comes under the purview of Forensic Science.

With the growing trend in medical tourism, most of the western countries have travelers that travel in Asian and East Asian countries for the purpose of taking natural treatment and remedies. Such wellness centres offers a variety of herbal medications for the sale. Patients visiting such centres wrongly believe that they are being treated by natural therapy without getting any harmful chemicals and drugs administered in their body. But how much regulated such centres and their medications are, pose a serious concern. There have been a number of studies that show the adulteration and the substitution in herbal drugs as it is not much regulated by the Pharmacopeia as compared to the allopathic medicines that have strict chemical compositions and are registered under the **Drug and Cosmetic Acts** of different countries [27, 28].

The second most alarming concern about the consumption of adulterated herbal medicines is the **Herb-Drug interaction**. The contaminated herbal

preparations can have anything ranging from heavy metals to pesticides in them that may show antagonistic effects upon interacting with chemical drugs consumed by the patient. Usually patients do not share their history of consumption of herbal drugs as they think it to be natural and posing no side-effects and also there is no such prescription associated with such herbal supplements. The online websites are flooded with such nutraceuticals, dietary supplements and other herbal powder that claim relief and other health associated benefits but neither such companies nor such herbal supplements are often registered under any government regulating agency [29].

Third serious issue is the addition of prescription drugs in the herbal supplements to enhance their efficacy, as this may cause serious issues in the person having allergies to certain compounds. The most common example of such adulterations is the addition of steroidal drugs. Such medications can be contraindicated in a person consuming non-steroidal, anti-inflammatory agents [30].

Fourthly, there is sometimes very high and potentially lethal concentrations of metals are present in these unregulated herbal drugs. When there is an unexpected death occurs, the investigating officers rigorously document all the medications, prescriptions taken by the deceased and found at the crime scene as the medico-legal experts believe the cause of death to the overdose of such prescriptions but unfortunately this is not the case with the natural herbal medicines. Also, there is near to impossible chances of detection of such medicines during autopsy as these medicines are generally consumed by the patient over the long period of time [30].

There have been reports of Lead encephalopathy and acute lead and mercury poisoning in patients consuming herbal drugs. Roger W. Byard in his publication on 'Potential Forensic Significance of Traditional Herbal Medicines' gave examples of such toxicity in which 'a 5- year old boy who had been treated with 'Tibetan Herbal vitamins' and had ingested a total of approximately 63 g of lead over 4 years. He has given another example of a case of a 5-year-old boy with bilateral retinoblastoma whose parents relied on to a traditional remedy that caused him arsenic poisoning.' The issues quoted in the above two cases can be summarized as 'non-medically qualified healers, lack of product standards, undeclared ingredients, nondisclosure of usage and long-term medication' [29].

7. What can be done: a way forward

In the light of the above stated issues, there are a number of measures that can be taken at the country as well as local level for improving the Herbal drug sector and enhancing the development of a more effective trade in medicinal plants and their products in developing countries [16].

a. **Improvement of land resources:** in order to guarantee an uninterrupted supply of raw drug, there must be provisions for organized and protected cultivable land that ensures regular supply.

b. **Reduction in intermediaries:** there are a number of middlemen and intermediaries involved in the market chain of herbal medicines that are needed to be reduced to avoid malfunctions and enhance the profit of primary beneficiaries like farmers and cultivators.

c. **Research and development:** trade and development in any country can grow with more and more investment of GDP in research and development. Research

and development on selected species, their active constituents, processing and preservation is highly needed in developing countries like India. Not only this, but R&D has a major role to play in identification and detection of adulteration in traded herbal products. Thus this area needs a lot of development.

d. **Legal provisions:** for a healthy competition in market, high quality supply of planting materials, quality control systems, improved cultivation and encouragement of investments in new technologies, there should be strict laws and regulatory provisions that guides in these areas.

e. **Value addition:** through processing, and improved marketing of the medicinal plants, value should be added to this industry so that the benefits of the expanded interest in medicinal plants be more equitably shared.

f. **Development of market chain:** a holistic approach needs to be adopted for the promotion of trade. Specific interventions which only target the collectors are insufficient. The organic nature of the produce should be explored and capitalized on for export marketing.

g. **Post-collection handling:** improvements are needed in the areas of post-collection handling, value addition and product presentation.

h. **Sustainable development:** developing countries like India should aim to cultivate their resources in a sustainable manner so that judicious use of resources is ensured.

i. **In-depth approach:** a more in-depth approach should be undertaken to clarify market issues, and consider more effective solutions. Case studies of successful marketing approaches being used may assist other organizations or countries. Products which would be most amenable to sustainable commercial development and industrial processing in the supplying countries must be identified.

j. **Awareness and knowledge:** there should be awareness programmes conducted at intervals for the consumers to educate them about what they consume, how they can decide which product is good for their health, how they can detect in a simple way about the authenticity of herbal drugs while purchasing.

k. **Standardization and quality assurance:** regulating agencies must codify certain standards and parameters that must be fulfilled by the product in order to be sold in the market and the ones that do not qualify those standards should be eliminated at once.

l. **Forensic aid:** whenever any illegal trade, import or export of herbal drugs comes in knowledge of the officials, there is no separate wing of government that tackle such issues. Every country must recognize the need of Forensic intervention in cases of Herbal drugs. There should be well-defined laboratories under forensic department that can analyze the trafficked herbal drug, authenticate it, trace its source and find adulterants and substitutes present in it. Not only trafficked drugs but the drugs from the local market should also be taken into account. Fraud is always a crime whether it is related to accounts/documents/funds which causes monetary loss or related to products sold in the market that causes physical harm.

8. Scientific practices

Unlike conventional Allopathic and Homeopathic drugs that are usually prepared from synthetic, chemically pure materials by means of reproducible manufacturing techniques and procedures, ASU drugs may vary in composition and properties a lot [31]. Thus, in case of ASU drugs also, it is a prerequisite to ensure the reproducibility of batches of medicines by its correct identification and quality assurance so that its safety and efficacy can be maintained [32, 33]. Adulteration, substitution, counterfeiting and usage of inferior quality of drugs often result in degradation of clinical effects of ASU drugs. This makes authentication a crucial step in successful and reliable applications. In cases where there is availability of similar looking drugs or drugs of same chemical nature, authentication becomes more crucial to avoid even any chance adulteration with other varieties of drug. Using a wrong drug may result in worsening the condition or may act as antagonist [34]. Evaluation has become even more difficult when several different individual species were powdered and mixed together in a proprietary medicine [35]. It is also important to take care of each step of harvest, storage, processing and formulation because it has a huge impact on the final quality of the product. Thus, to ensure the optimal safety and efficacy of these products, quality assurance in manufacturing and storage is a must. Also, these control measures are critical for the pharmacological and toxicological evaluation of the ASU drugs. Authentication of ASU drugs involve following techniques:

8.1 Taxonomic identification

In this method, the plant at its source is determined based on its scientific binomial nomenclature, i.e. genus and species determination. This gives the information about the botanical origin of the plant. Before designating the plant to its taxonomic class, its binomial name, vernacular names, site of collection of plant material, details of collector, habitat, season of collection, flowering, altitude and part collected, etc. are required [36].

8.2 Herbarium voucher sample

The sample of collected material should be authenticated by an expert in the field and kept as a voucher sample in a herbarium or a research institute for future references [36].

8.3 Macroscopic method

Macroscopic examination of botanical materials involve examination of certain macroscopic properties also known as organoleptic properties like shape, size, colour, texture, surface characteristics, fracture characteristics, odour, taste, etc. [37].

8.4 Microscopic method

Microscopy is a technique that is used to determine the structural, cellular and internal tissue features of plant material. It helps in identification and differentiation between two herbals that are similar in morphology [38, 39]. This is the commonly used technique, convenient, quick and non-destructive [40]. Microscopy involves varied techniques like compound, bright field, dark field, fluorescence and electron microscopy (Scanning Electron Microscopy known as SEM and Transmission Electron Microscopy known as TEM) that offer different features based upon the requirement.

8.5 Physicochemical methods

Physicochemical parameters include moisture content, total ash content, water soluble ash, acid insoluble ash and sulphated ash. These values of the individual drugs can be compared with the standard values of Indian pharmacopeia and thus their identity can be ascertained [41].

8.6 Spectral methods

Spectral methods like infrared (IR) spectroscopy and ultraviolet- visible (UV–Vis) spectroscopic methods are extremely helpful structural elucidation of active constituents derived from botanical material. Not only structural elucidation but also its fingerprinting can be done by these techniques. They offer comparison between the natural and the synthetic compounds. Also, both qualitative and quantitative analysis can be done. Such techniques when integrated with chemometric tools like Principal Component Analysis (PCA) that help in handling multivariate data without prior knowledge about the study samples, becomes a boon [42, 43]. As chemometric analysis of spectral data does not require any chemical treatment, the method offers a rapid and simple analysis [44].

8.7 Chromatographic methods

High Performance Liquid Chromatography (HPLC), Capillary Electrophoresis (CE) and Thin Layer Chromatography (TLC) are the most commonly used analytical techniques for the profiling of herbal products [45]. Beside these, gas chromatography (GC) can be used for the analysis of volatile components in herbal medicines [46].

8.7.1 Thin layer chromatography (TLC)

TLC is the earliest of chromatographic methods employed for the separation of plant constituents. As the herbal extract is a combination of hundreds of components that are responsible for its activity, it is very important to separate those components and study each of them individually. TLC provides first characteristic fingerprints of herbs. The main advantages of using TLC to develop the fingerprint or chemical profile of herbal medicines are its simplicity, versatility, high velocity, specific sensitivity, simple sample preparation and its economy. Thus TLC is a convenient method to determine the quality and possible adulteration of herbal products [47].

8.7.2 High performance liquid chromatography (HPLC)

After TLC, HPLC has become the most popular method for the analysis of herbal medicines. Though it is more complex than TLC, but still easier to learn and use and is not limited by the volatility or stability of the sample compound as is the case with GC. In general HPLC can be used to analyze almost all the compounds in herbal medicines [48]. HPLC can be linked to various detectors like UV detector, Refractive index detector and Mass Spectrometric (MS) detector that can help in knowing the exact chemical makeup of the components.

8.7.3 Gas chromatography (GC)

Volatile oils and other thermally unstable components that cannot be detected by HPLC technique can be detected by GC. The extraction of the volatile compounds or oils is relatively simple and can be standardized and the components can

be readily identified using GC–MS analysis. The advantages of GC lie in its high sensitivity of detection for almost all the volatile chemical compounds [46].

8.8 Chemical fingerprinting

A chemical fingerprinting is a unique pattern just like human fingerprints which is unique for every individual, which indicates the multiple chemical markers within a sample [49]. The European Medicines Agency (EMEA) defines chemical markers as chemically defined constituents, or group of constituents of herbal medicinal product which are of interest, regardless whether they possess any therapeutic activity [50]. Such chemical markers are critical in identification and authentication of the plants from which they are derived. The quantity of a chemical marker is proportional to the quality of herbal medicine. The study of chemical markers is applicable to many research areas, including authentication of genuine species, search for new resources or substitutes of raw materials, optimization of extraction and purification methods, structure elucidation and purity determination.

8.9 Molecular markers

Molecular markers are the constituents that include primary and secondary metabolites and other macromolecules like nucleic acids. DNA as a marker can be a reliable instrument as it is in cases of disputed identity of human beings, in establishing the genetic makeup and polymorphisms of each species [51]. The main advantage associated with DNA is that, it can be extracted from both fresh and dried organic tissue of the botanical material and thus is not restricted by the physiological nature of the sample to be assessed [52, 53]. Various types of DNA based molecular techniques such as hybridization based methods, polymerase chain reaction (PCR) based methods and sequencing based methods are utilized to evaluate DNA polymorphisms [54–56].

9. Conclusion

This chapter has provided an overview of trends and conditions relating to medicinal plants, their production, markets and malpractices. It is never possible to include each and every detail, data and analysis related to medicinal plants in a single chapter. Thus, the chapter is initial effort to increase awareness of both the potentials and problems associated with medicinal plants and its industry. Substitution of herbs can never be eliminated as with more and more dependence on ASU drugs, more than 300 medicinal plants have become red listed. So, in order to achieve constant supply of botanical drugs, experts must find suitable substitute in a regulated manner. Substitution in a well-defined manner may provide a greater scope for the physicians to utilize herbs that are easily available, cost effective and most appropriate for the clinical condition. The need of substitution should always be separated with the intention to substitute and adulterate in order to make more profits. Not all adulterations are intentional. Sometimes it is the lack of awareness of the suppliers about the spurious materials, their toxic effects, confusion in name, non-availability and lack of knowledge about authentic plant may also result in adulteration and substitution. WHO, in its publication on quality standards for medicinal plant materials, recommends rejecting any batch of raw material, which has more than 5% of any other plant part of the same plant (e.g. stem in leaf drugs), never the less if they are derived from the authentic plant. Based on these standards, adulteration whether, intentional or unintentional, should be rejected. In order to

detect such adulterations, technologies have a crucial role to play. The detection of chemical markers is always a good choice in such cases. According to EMEA these chemical markers have nothing to do with the therapeutic activity of the drug; they help in chemical fingerprinting of the botanicals to authenticate its source. Nowadays, Ayurvedic drug industries follow high quality standards using modern techniques and instruments to maintain their quality. Thus, suppliers and traders should also be educated about these parameters to avoid any chance adulteration. Beside all these, there should be strict regulatory laws to govern the quality standards and trade in medicinal flora. Whenever there is any fraud or illegal practice, Forensic Science has always a role to play. Herbal drugs forensic is that only branch of Forensic Science that deals with all such issues.

> *'We can't talk about our own health without understanding our place in our environment, because in order to fulfil our potential we have to live in the context of our surroundings. We have to know our place in the ecosystem of which we are a part, and this means living 'consciously': being aware of nature and how it affects us and how we, in turn, affect nature'.*

A quote from Sebastian Pole's 'Discovering the True You with Ayurveda: How to Nourish, Rejuvenate, and Transform Your Life', very well explains the importance of awareness, be it our surrounding, our body, our food or our medicine. Therefore, Herbal drug forensics is one of the most significant emerging fields of forensic science.

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Conflict of interests

The authors declare no conflict of interests.

Author details

Shalvi Agrawal[1] and Astha Pandey[2*]

1 School of Forensic Science (School of Doctoral Studies and Research), National Forensic Sciences University, Gandhinagar, Gujarat, India

2 School of Forensic Science, National Forensic Sciences University, Gandhinagar, Gujarat, India

*Address all correspondence to: astha.pandey@gfsu.edu.in

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