CHAPTER-2
REVIEW OF LITERATURE

2.1. INDIAN SYSTEMS OF MEDICINE

Indian systems of medicine have always played a stellar role in providing global healthcare needs. In India, apart from modern medicine, patients are given free choice to choose any Indian systems of medicine *viz.* Ayurveda, Yoga, Unani, Siddha, and Homeopathy, collectively called as AYUSH for managing different ailments. These systems of medicine are highly classified having their own proven validity and logic (Singh *et al.,* 2020). Ayurveda written 5000 years ago mostly has clinical scientific evidence. It mostly uses plant-based formulation comprising of some mineral and animal products for curing ailments. In general, it emphasizes more on "*Swasthyashya Swasthya Rakshanam*" (maintaining healthy life) rather than "*Aturashya Vikara Prashamanancha*" (treating ailment of diseased) (Nandan *et al.,* 2020; Kala *et al.,* 2006). Yoga is a discipline that focusses on adopting specific bodily movements and postures, controlling breathing, meditation, chanting to manage good health (Falkenberg *et al.,* 2018). Unani healthcare system is based on the guidance of Greek scientists Hippocrates and Gallen. This Perso-Arabic disciple uses mostly plants, minerals, and animals origin drugs for treating diseases. It comprises of solid, semi-solids, liquid, and gaseous formulations (Husain *et al.,* 2010). The Siddha system is known as the mother medicine of ancient Tamils/Dravidians of south India. It emphasizes on restoring proper balance between mind and the body. This system uses herbal materials, animal products, and inorganic substance to cure disease. There are numerous Siddha formulations that have successfully achieved clinical trials to cure peptic ulcers, hepatitis, and amoebic dysentery (Singh *et al.,* 2020a; Subbarayappa, 1997). On the other hand, Homeopathy uses starting materials derived from herbals, minerals, animal origins in diluted forms of numerous substances to heal the body. The evidence of Homeopathy system is mostly clinical utilizing the Randomized Clinical Trails (RCT) (Nandan *et al.,* 2020; Ravishankar and Shukla, 2007). The Indian systems of medicine have achieved global recognition especially in the past two decades and Ayurvedic drugs are now used as food supplements in USA, Europe, and Japan. The increasing interest of the population in complementary and alternative systems, particularly in the Indian Systems of Medicine is leading to a surge in the demand for Ayurvedic, Siddha, and Unani (ASU) drugs which are mostly made from medicinal plant parts (Ravishankar and Shukla, 2007). In the aftermath of COVID-19, there are reports highlighting the instant increase in the demand for traditional formulations such as "*Chyawanprash*", AYUSH-64 responsible for possessing anti-viral, and immunity-booster properties (Sharma *et al.,* 2019).

2.2. DEMAND FOR MEDICINAL PLANTS

The increasing interest of the population in complementary and alternative systems is leading to a surge in the global demand for medicinal plant parts (Barata *et al.*, 2016). Many studies report that 80 per cent of the world population depends on medicinal plants and associated formulations for primary healthcare (Singh *et al.,* 2018). The global market of medicinal plants is touching US $ 60 billion per year which is further increasing at the rate of 7 per cent per annum. The global trade of botanicals is US $ 32.702 billion out of which Asia alone accounts for US $ 14.505 billion (Paroda *et al.,* 2014). According to the WHO estimate, the global herbal industry is projected to be worth US$ 5 trillion by the year 2050 globally. The World Bank has highlighted that though the cultivation of medicinal plants is done on a small scale it is projected to show 'dramatic growth' in the coming decade favoring organic and mixed cropping (Nirmal *et al.,* 2013). Asia has a long tradition of using herbal medicine for treating the ailments. Out of 8,000 species having ethno-botanical values, 2,500 MAPs are consumed in different forms of medicines and 250 MAP species are traded in large volumes across the globe (Paroda *et al.,* 2014). India and China has the largest number of registered medicinal plants in Asia (George, 2011). India's plant diversity is one the richest diversity in the world. It is host of two of the 34 biodiversity hotspots in the world and lies in Indo-Malayan ecozone. It has six climate zones i.e. Montane, humid sub-tropical, tropical wet and dry, tropical wet, semi-arid and arid (Stephen *et al*., 2015). This vast natural resource in supplied to various industries for herbal formulations, perfumery, spices, nutraceuticals, cosmetics, etc. (Sen *et al.,* 2011). The present export of herbal raw materials is about US $ 100-114 million per year. In India, 134 species are exclusively obtained from cultivation and about 160 species are partially cultivated and collected from the wild. India exports crude drugs to six major developed countries, *viz*., USA, France, Germany, U.K., Switzerland, and Japan (Paroda *et al.,* 2014). According to the latest report of NMPB, there is an estimated increase of 62% in the volume of annual demand of herbal raw drugs for the year 2014-2015, compared to the report of Ved and Goraya for the year 2005-06. The report further highlights that Punjab has nearly 284 licensed herbal units based on Ayurveda and *Majith mandi* situated in Amritsar, Punjab is one the biggest herbal *mandis*, comprising of approximately 35 traders, 70 major entities being traded bearing annual trade of ≈≈ 20,000 volume MT (Ved and Goraya, 2017). The increasing demand for herbs has raised concerns regarding the need for a sustainable supply of raw herbal drugs thereby focusing the attention of experts on *in-situ* and *ex-situ* conservation of the medicinal plants.

2.3. AGRICULTURE IN PUNJAB

The cultivable area of Punjab is 4.20 million hectares (83.4% of total geographical area). The implementation of Green Revolution in the mid 1960's has helped India to transform from "a begging bowl to a breadbasket". Punjab is popularly called as the 'Bread Basket of India' as it produces twenty per cent of wheat and nine per cent of rice (Krishan *et al.,* 2021; Shirsath *et al.,* 2020; Ahada and Suthar, 2018; Chatterjee and Devesh, 2016). The implementation of the green revolution in Punjab possessed good results at the time but this impression no longer exists. The positive effects of the green revolution started to diminish, and dominance of wheat-rice monoculture led to a decline in soil fertility, underground water exploitation, slow productivity growth, and pesticide resistance. The water table in the paddy growing areas has alarmingly gone down. As per the Indian Agricultural Research Institute, 15,000 litres of water is used to produce one Kg of paddy, while the requirement is just 600 litres (Baweja *et al.,* 2017; Singh and Benbi, 2016). This high reliability of farmers on wheat and rice in *rabi* and *kharif* season respectively, has resulted in negative ecological impact and has attracted the agricultural experts and policymakers that are recommending crop diversification for sustainable agriculture in Punjab (Pujara and Shahid, 2016; Chhatre *et al.,* 2016). Despite favorable climatic and trade opportunities, Punjab has less than 1 % of its cultivable area under MAP cultivation. The drop in the area and production of medicinal plants can be related to the various constraints faced by the farmers in cultivation of medicinal plants (Horticultural Statistics at a Glance, 2017). Though farmers of Punjab have started cultivation of medicinal plants but still there is lack in paradigm shift from the traditional cropping pattern (Tiwana *et al.,* 2007). A total of 503 medicinal plant species are used in the state out of which 334 species occur in Punjab and rest are collected from the other states. Among 334 species of Punjab 127 are herb species, 110 are tree species, 63 are shrubs and 34 are climbers. Most of the medicinal plants consumed by the herbal industries in Punjab are *Aloe barbadensis, Emblica officinalis, Terminalia chebula,* etc. (Gaire and Subedi, 2014; Jerath *et al.,* 2012). The medicinal plants used for the herbal preparations are mostly collected from the wild in Punjab. Therefore, the high demand for this vast natural resource has started being over-exploited by un-scientific collection resulting in sparse availability of some important species. This increasing threat to medicinal plants will not only affect the health of herbals dependent people but also result in livelihood of poor people and communities that depend upon them. Hence it becomes important to conserve the medicinal plants both *in-situ* and *ex-situ*.

2.4. GOOD AGRICULTURAL PRACTICES

There are reports regarding the presence of unwanted or tacit material in the herbal formulations around the globe. The substances such as pesticides residues, heavy metals, microbes, aflatoxins, etc. have been reported to be present in the herbal medicines. Therefore, need for quality assurance of the herbal medicines have taken a center stage worldwide. The factors affecting the quality of raw herbal material is represented in Fig. 2.1. The fundamental guiding principle for obtaining the quality of the herbal medicine is the implementation of GACP for medicinal plants (Singh *et al.,* 2018). The GAP for medicinal plants is set of guidelines that ensure sustainable production of medicinal plants of rich-quality. In the year 2003, a resolution relating to herbal medicine was passed, and 56th session of the World Health Assembly urged the member states to ensure quality, efficacy, and safety of herbal formulation by drafting national standards, developing monographs on raw herbal material (Saha *et al.,* 2018). Furthermore, WHO in the year 2003 drafted GACP for the medicinal plant cultivation and urged the member states to develop region specific GACP guidelines. The advents of GAP are represented in Fig. 2.2.

Keeping the work of David Connor (a visiting scientist) as a reference, discussions were held on the common principles of GAP in the early stages. The principles highlighted GAPs as farming practices that optimally utilizes presently available technology to encourage sustainable agriculture producing safe and healthy food also achieving economic feasibility, social responsibility (even though social perspective are inadequately addressed in grid lines), and environmental sustainability. In general, GAP is using presently available knowledge for sustainable use of natural resources ensuring production of safe and healthy food or non-food in humane manner also considering economic and social viability factors (Saha *et al.*, 2018; FAO, 2003).

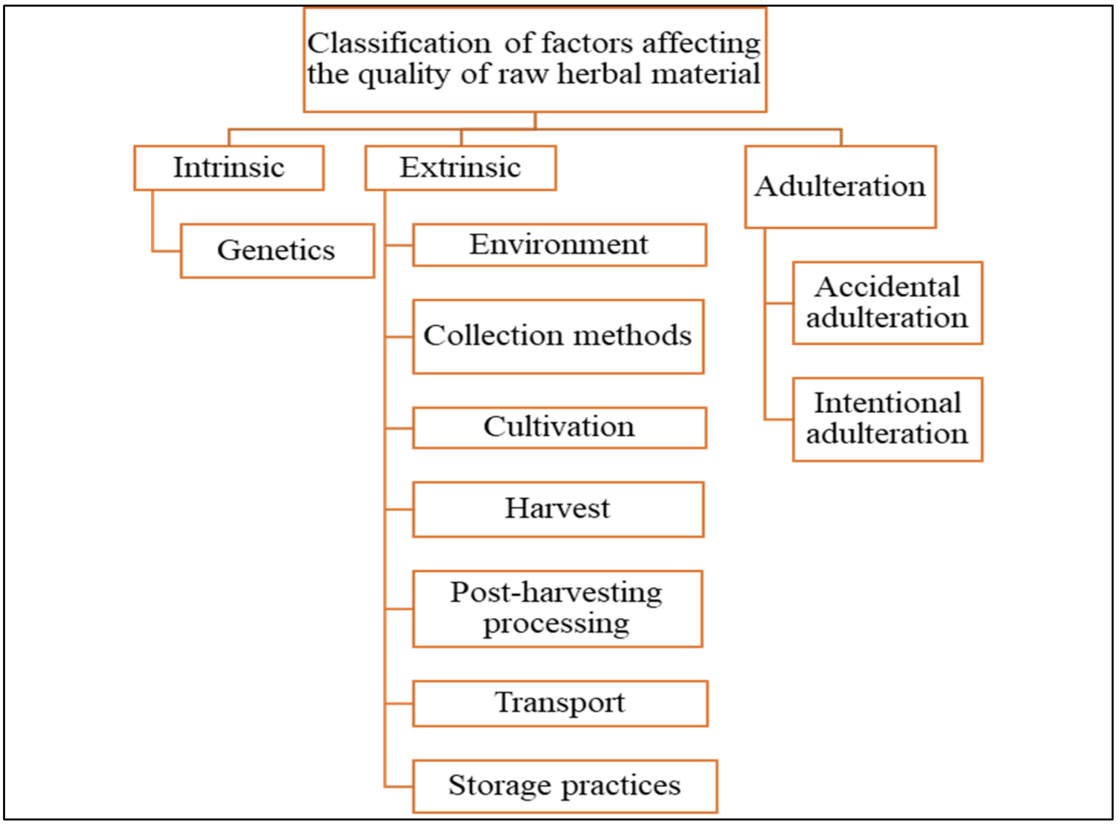

Figure 2.1: Factors affecting the quality of raw herbal materials.

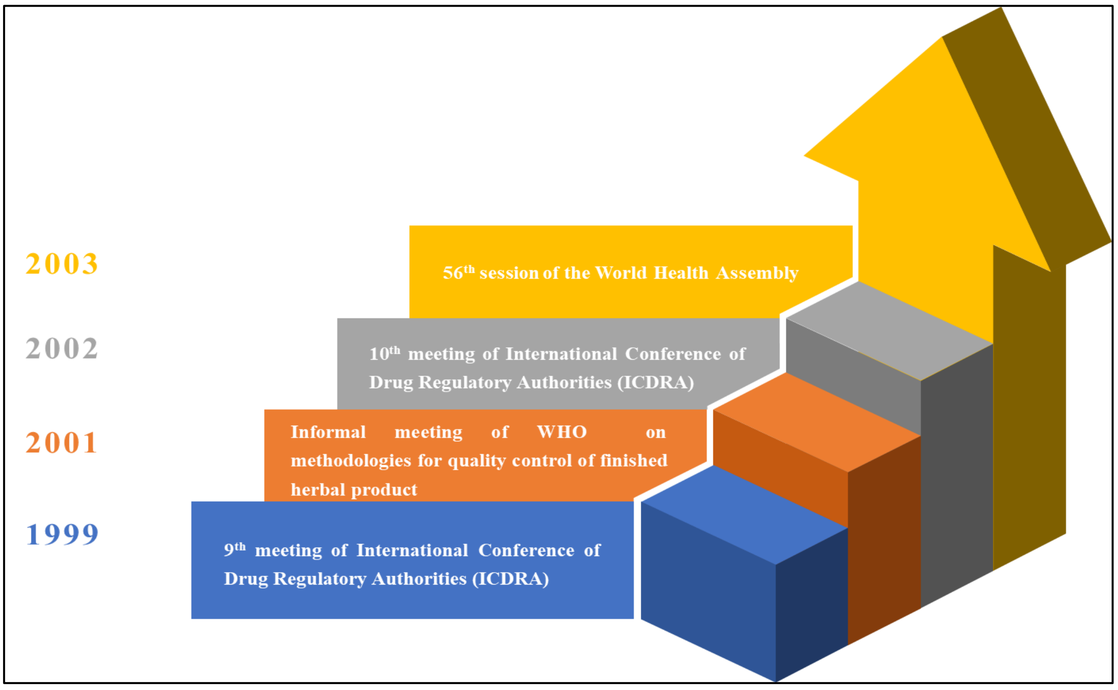

Figure 2.2: Chronological advents of GAP.

GAP suggests agricultural practices towards a sustainable agriculture, obtaining harmless products of higher quality, contributing to food security, generating income through the access to markets and improved working conditions of producers and their families. It has also assured different countries to draft their country specific GACP guidelines for medicinal plants cultivation for better development of medicinal plants utilization (Organización Mundial de la Salud, World Health Organization, 2003).

So, in accordance to WHO suggestions, NMPB India has drafted its own set of GACP guidelines for the cultivation of medicinal plants (Saha *et al.*, 2018). Likewise, many other countries like Japan, China, Europe, America, etc. have developed their own country specific GACP guidelines in coordination with WHO guidelines. European Medicines Agency Evaluation of Medicines for Human Use constituted a committee to draft Guidelines on Good Agricultural and Collection Practices for herbal starting material which was adopted in the year 2006. Proper cultivation, collection, primary processing of medicinal plants directly effects the active constituents of the plant and obviously the potential of the plant. GACP does not fall directly under the Good Manufacturing Practices (GMP) but goes along with it and forms a basis to ensure the quality of finished medicinal product. The guidelines of GACP for Europe covers essential parameters like quality assurance, personnel and education, buildings and facilities, equipment, documentation, seeds and propagation material, cultivation, collection, harvest, primary processing, packaging, storage and distribution for maintaining the quality of the medicinal plants (Committee on Herbal Medicinal Products, 2006).

The American Herbal Products Association (AHPA) in cooperation with American Herbal Pharmacopoeia (AHP) drafted guidelines on Good Agricultural and Collection Practice for Herbal Raw Material in the year 2006. Teas, drugs, cosmetics and dietary supplements are widely available in United States. These products either cultivated or wildly collected come from all around the world for further processing and manufacturing. Thus, it was important to ensure their quality by defining scientific standards and GACP of herbal raw material is one of them. The voice of herbal products industry in United States and National trade association, AHPA represented growers, harvesters, manufacturers and marketers of herbal products. On the other hand AHP is involved in development of standards, purity, analysis and reviews traditional knowledge with scientific inputs for their efficacy and safety. AHPA and AHP collectively identified the need to document the America specific GACP for herbal finished products. Establishing Standard Operating Procedures (SOP) ensure good quality of herbal raw materials. The document focusses on the agricultural issues as well as the wild collection of the medicinal plants. Post-harvesting handling is followed by personnel and record keeping and retention samples (American Herbal Products Association and American Herbal Pharmacopoeia, 2006). The agricultural experts and scientists of China were well aware regarding the need for sustainable production and quality of the medicinal plants and the first meeting was conducted in the year 1998 to put GAP guidelines on agenda. In the year 2002, the first document related to GAP of Chinese medicinal plants was drafted (Leung and Cheng, 2008). More than 90% of the formulations under India system of medicines like Ayurveda, Siddha, and Unani (ASU) contain plant-based raw material. To maintain the quality and efficacy of the herbal formulations, NMPB India has developed GACP for the selected medicinal plants and has mentioned that their guidelines may not meet exact agronomic requirement of a particular crop in another agro-climatic region. As most of the medicinal plants are harvested wildly, stringent collection practices guidelines must be implemented for biodiversity conservation and conservation of rare medicinal plants. The NMPB has prepared India specific GAP on the pattern of GACP guidelines developed by WHO. The essential parameters like site selection, compliance to regulatory requirements, permission of collections, botanical authenticity etc. of the document were divided into critical, major and minor categories. NMPB has also drafted GAP standard for medicinal plants requirements. A model structure for developing monograph on GAP for individual species of medicinal plants was prepared. Critical parameters like seeds and propagation materials, cultivation, spacing in cm (Row×Row and Plant×Plant), fertilizers, chemicals, plant protection, herbicides usage, drying practices were covered in the document (National Medicinal Plant Board, 2009).

The WHO has drafted a monograph on GACP for *Artemisia annua* L. (*A. annua*). The extraction of artemisinin from traditional herbs has proved to be a potent antimalarial drug. China is the place of origin of *A. annua*. raw material on the global market and the first country to extract artemisinin. China actively participated with WHO in drafting the monograph of cultivation practices of *A. annua*. Botanical and pharmacological characteristics, good agricultural practices including harvest and post-harvest processing, seeds, preferred growing conditions, good collection practices, quality control requirements for herbal materials of *A. annua*, other common management and technical requirement for both cultivated and collected *A. annua* were covered in the monograph. The comprehensive document and monograph provided the clear insights into the GACP of the selected plant (World Health Organization, 2006). Comparative evaluation of quality parameters, effect of sowing dates, seed rates and irrigation on different medicinal plants were studied. GAP feasibility studies were carried out on the selected medicinal plants. Standardization of planting methods and spacing were also carried on the selected plants for agricultural practices. Effect of organic manure, post-harvest and storage studies were also carried out to check the best methods for the cultivation of medicinal plants (DMAPR, 2015). The medicinal plants in Brazil have rich potential in providing population with safe and effective herbal medicines. So, it was essential to develop monographs of the medicinal plants for their conservation. In a study, monograph model with standardized information including botany, agronomy, quality control, safety, efficacy and regulatory aspects was developed. The model also highlighted lack of studies that should be carried out to nurture necessary regulatory information for the medicinal plants. Information about the regulatory conditions in different countries and licensing by Anvisa or other regulatory agencies was also highlighted. This information was required to guarantee that the plant was evaluated and its use in other countries was allowed. Information regarding the nonclinical and clinical assays was also essential for the development of monograph of selected medicinal plant (Carvalho *et al.*, 2014).

The authors have developed agronomic practices for the production of *C. borivilianum* in India. Optimal agronomic conditions and cultivation practices like soil, climate, propagation, land preparation, planting, manures and fertilizers, cropping system, irrigation, inter culture, harvesting, yield, and economics were evaluated for the cultivation. The work suggested to cultivate *C. borivilianum* in warm and humid area that receive 50-150 cm of annual precipitation, well drained upland soils that are rich in organic matter with pH below 8.0. Planting of *C. borivilianum* should be carried out on raised beds during June-July, using 600-700 Kg/ha planting materials (Singh *et al.*, 2003). Similarly, Jat and co-workers have complied monographs on GAP for *O. sanctum* and *A. vera.* The parameters of the monographs included name of the plant, plant part, characteristics of the plant, major production area, and characteristics of strain, cultivation methods, summary of varieties and strains, and cultivation calendar. The monographs were prepared in the ICAR-DMAPR, Anand, Gujrat, India (Jat *et al.*,2015a,b,c, 2014).

In the case for *O. Sanctum*, NMPB has suggested to raise the nursery in the month of February followed by transplantation in the April. It suggested requirement of 15 tonne farm yard manure for good growth of the plant. Water logging in *O. Sanctum* can cause root rot so proper drainage must be ensured for its optimum growth. According a study conducted by Makri and Kintzios, the cultivation of *O. Sanctum* is best suited between 7 to 27°C annual temperature with 0.6 to 4.2 m annual rainfall and soil pH ranging from 4.3 to 8.2. The seeds must be sown 0.3 to 0.6 cm deep and spacing between the rows must be maintained 10-15 cm (Makri and Kintzios, 2008). Through the technical support of various agricultural research institutions, NMPB has suggested agro-techniques of more than 45 medicinal plants including *Abroma augusta, Aconitum balfourii, Aconitum heterophyllum, Alpinia galangal, Alstonia scholaris, Asparagus racemosus, Bacopa monnieri, Caesalpinia sappan, Colchicum luteum, Commiphora wightii*, etc. in the year 2008. The document highlights the need for assured marketing, and suitability of optimum agro-ecological conditions for achieving best outcomes from its cultivation. It also highlighted that the reported agro-techniques may vary depending upon the region's agro-ecological conditions (National Medicinal Plants Board, 2008).

2.5. QUALITY PARAMETERS OF MEDICINAL PLANTS

The API is a standard document for assessing the quality of the raw herbal drugs. The API consisted of plant name, synonym, description (macroscopic, microscopic), identity, purity, strength (ash values, extractive values, moisture content), constituents, properties, action, formulations, therapeutic uses, and doses of the medicinal plants. It is one of the most referred books by the herbal scientists for standardizing the herbal formulations. It also encompasses apparatus for tests, testing drugs, methods for determining quantitative data of drugs, limit tests, physical tests and determinations in the form of appendixes (The Ayurvedic Pharmacopoeia of India, 1989). Similarly, the Indian Herbal Pharmacopoeia comprises of 40 monographs of medicinal plants comprising of qualitative and quantitative parameters that are published by Indian Drugs Manufacturer Association (IDMA) in association with Regional Research Laboratory (RRL) Jammu (Kumar, 2015). ICMR has published quality standards on Indian medicinal plants monographs in 15 different volumes. The monographs encompassed botanical identification, morphological, microscopical examination, physico-chemical parameters, qualitative and quantitative ranges and methods of estimation of important chemical constituents present in the medicinal plants. The common authentication techniques mentioned in different regulatory texts are represented in Fig. 2.3.

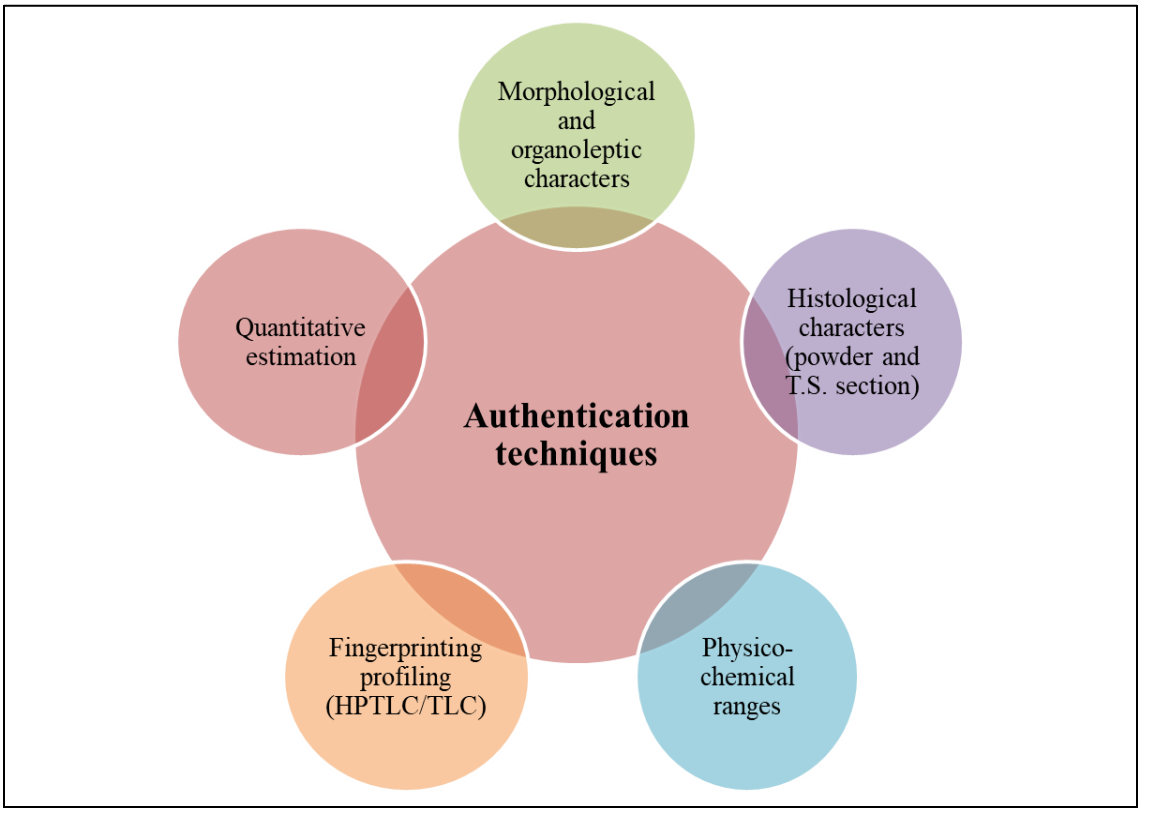

Figure 2.3: Common authentication techniques.

The morphological characterization refers to general appearance of the medicinal plant part and is the first step towards the process of authentication. It encompasses many factors such as shape, size, texture, fracture, smell, etc. The important morphological characters of the medicinal plants are represented in Fig. 2.4.

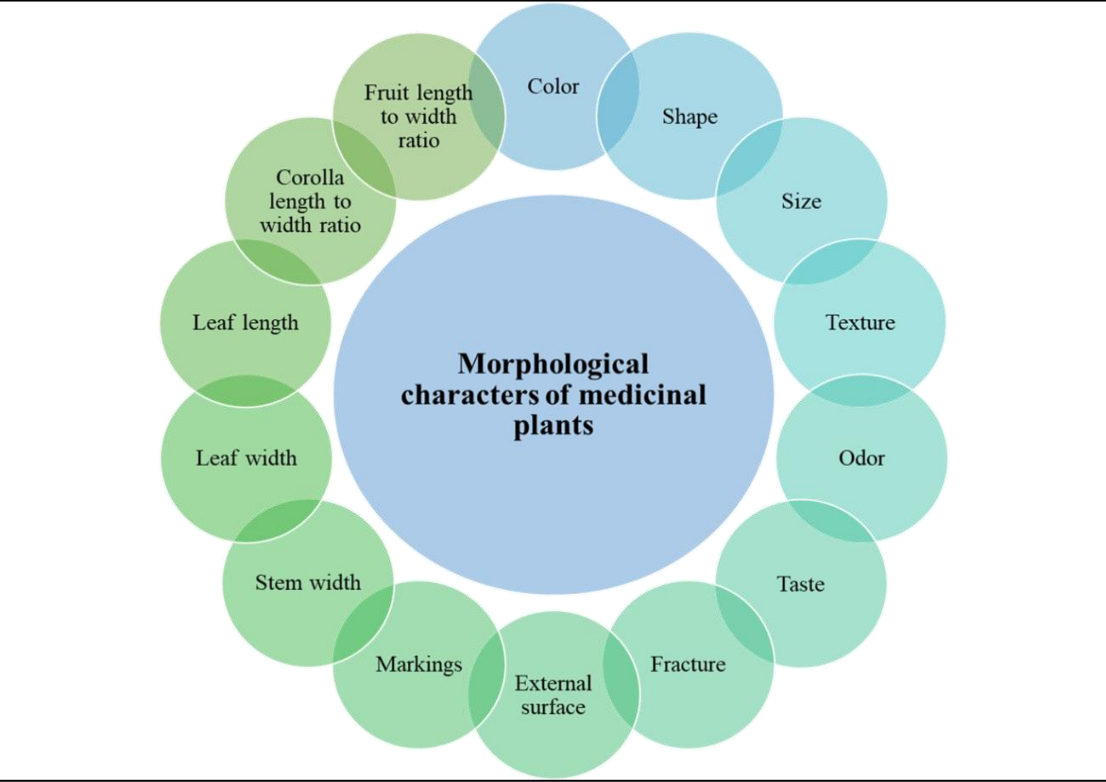

Figure 2.4: Morphological characters of medicinal plants.

The next step after morphological characterization is the microscopical evaluation of the selected medicinal plant for its authentication. It comprises of transverse section (T.S.) Longitudinal Section (L.S.), and powder microscopy. Different stains/dyes such as fast green, methylene blue, etc. are used to identify the specific characters present in the selected medicinal plants. Some common microscopy characters present in the medicinal plants are represented in Fig. 2.5. A set of physico-chemical parameters comprising of acid values, extractive values determines the purity or strength of the medicinal plants. The ash value represents the amount of physiological, non-physiological ash and silica present in the herbal sample. Similarly, the extractive value and qualitative estimation of chemical compounds using Thin Layer Chromatography (TLC), High Pressure Thin Layer Chromatography (HPTLC) or different analytical methods estimates the strength of the selected medicinal plants. The quantitative estimation using High Pressure Liquid Chromatography (HPLC), Gas Chromatography (GC), Mass Spectroscopy (MS), etc. determines the per cent of phyto-constituents present in the selected medicinal plants (Singh *et al.*, 2020b). Some common qualitative and quantitative tests are represented in the Fig. 2.6.

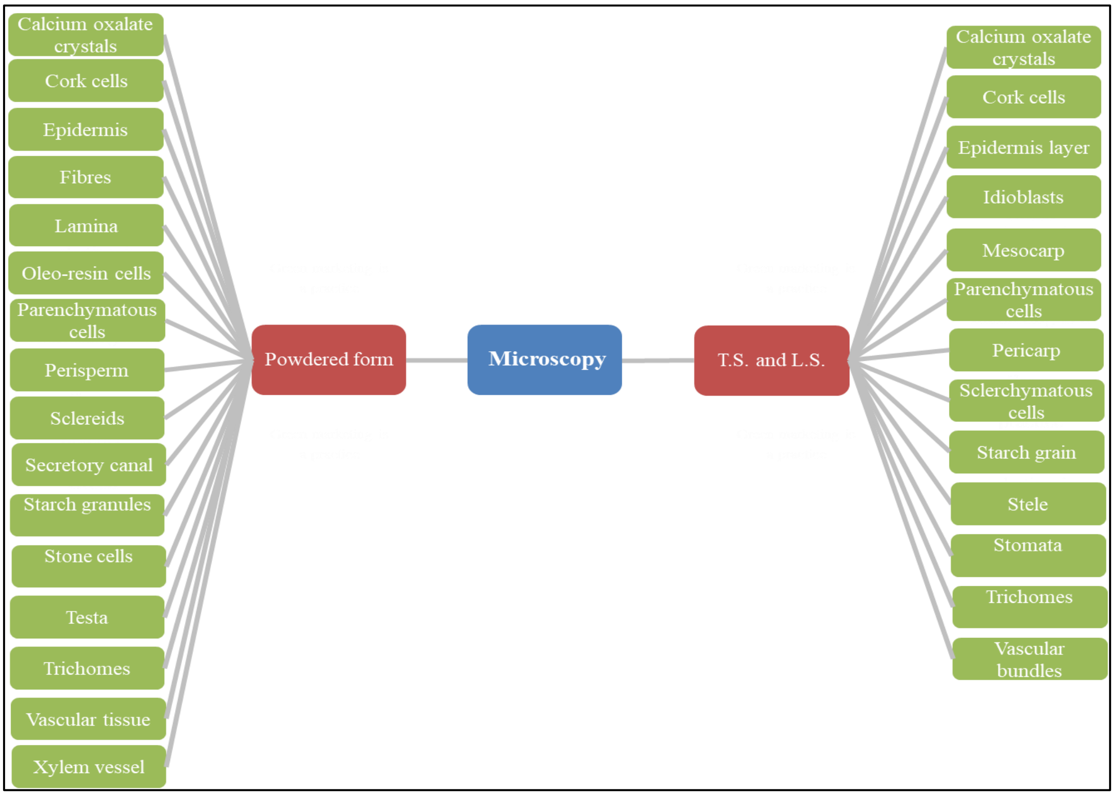

Figure 2.5: Common microscopy characters of medicinal plants.

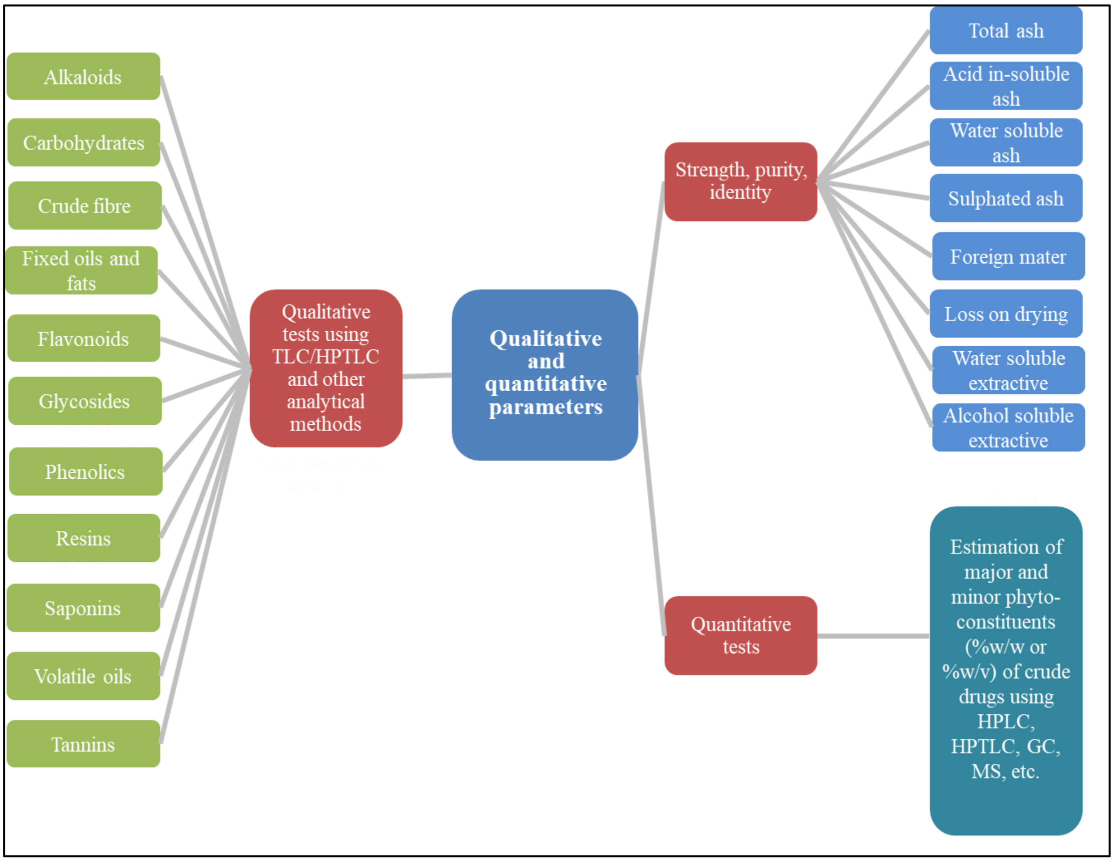

Figure 2.6: Qualitative and quantitative tests of medicinal plants.

Medicinal plants are intended for human and animal use, therefore the toxicity indicators such as heavy metals, pesticides residues, microbial content must be in the desired range. In general, chemical fertilizers, and pesticides are not recommended in medicinal plants cultivation, so these ranges must be in the appropriate ranges for trade and industrial acceptance. The WHO has recommended that pesticides residues such as aldrin and dieldrin must not be more than 0.05 mg/Kg. Similarly, heavy metals *viz*. lead and cadmium, and microbial contamination should not be more than permissible limits (World Health Organization, 2011, 1999, 1998). FSSAI have also prescribed some limits for the food additives in *A. vera*. The presence of phosphates, sulfites, lauric arginate ethyl ester must be in appropriate ranges for surface treated leaves, peeled, cut or shredded leaves whereas the food additives are not permitted in fresh leaves.

2.5.1. Phytoremediation Techniques

Phytoremediation techniques play a major role in agriculture to counter the threat of intentional and un-intentional usage of chemical pesticides, heavy metals. Phytoremediation is a bioremediation process involving specific plants that removes, transfers, destroys contaminants in soil and underground water. In context to Punjab which relies upon high usage of chemical fertilizers and pesticides, it becomes natural to suggest potential phytoremediation techniques that could help in lowering the content of toxicity indicators.

A study was conducted to assess pytoremediation of carbofuran residues in soil. Plant species like *Helianthus annuus* L., *Arachis hypogaea* L., *Glycine max* etc. were selected for the study. In this study, the ability of plants to clean up carbofuran residues in rice field soil was examined. Plants were grown in 8 inches diameter plastic pots filled with soils containing 5 mg/Kg carbofuran. The phytoremediated samples were analyzed for carbofuran concentration. The results showed that carbofuran was rapidly degraded under planted soil and non-planted soil with half-lives ranging from 2-7 days. These facts suggest that phytoremediation could accelerate the degradation of carbofuran residues in soil and carbofuran was not persistent in the soil environment (Teerakun and Reungsang, 2005). In a systematic review, the authors have highlighted the major research outcomes by Indian researchers working in the area of technologies like phytoextraction, phytoaccumulation, rhizofiltration and phytostabilization. They have concluded that finding the suitable hyperaccumulator plant species is of first and foremost step for successful application of this economic and useful technology. The review attempted to address the major works done in India in relation to phytoremediation with its possible benefits on agriculture. Phytoremediation of contaminated environment offers an environmentally friendly, cost effective, and carbon neutral approach for the cleanup of toxic pollutants in the environment. Toxic heavy metal like Cu, Ni, Pb, Arsenic etc. can be bio-monitored for identifying metal contamination by using species like mustard, sunflower, spinach, poplar etc. (Mandal *et al.*, 2014). The study was conducted to screen five species of Brassica, (1) *B. juncea* (Indian mustard) cv. Pusa Bold, (2) *B. campestris* (Yellow mustard) cv. Pusa Gold, (3) *B. carinata* (Ethiopian mustard) cv. DLSC-1, (4) *B. napus* cv. Early napus, (5) *B. nigra* cv. IC-247 for identifying a suitable species for hyperaccumulation of heavy metals, viz. Zn, Cu, Pb, Ni and Cd. It was concluded that *B. carinata* cv. DLSC1 could reduce the metal load by 15% for Zn, 12% Pb and 11% for Ni from a naturally contaminated soil from peri-urban Delhi, while *B. juncea* cv. Pusa Bold emerged promising that reduced soil Cu content by 21% in a single cropping. Castor (*Ricinus communis* L.) was reported to accumulate large amount of Ni and therefore, it could be used as a potential plant for phytoremediation of Ni-contaminated soils (Purakayastha *et al.*, 2009).

The study reported that there is high potential of fenugreek (*Trigonella foenum graecum* L.), spinach (*Spinacia oleracea* L.), and rye (*B. campestris* L.) for the cleanup of Cr contaminated silty loam and sandy soils. The findings indicated that family Cruciferae (raya) was the most tolerant to Cr toxicity, followed by Chenopodiacea (spinach) and Leguminosae (fenugreek) (Dheri *et al.*, 2007). In a doctoral dissertation, the researcher introduced integrated phytoremediation design, in which field experiments (3m x 3m plots) were conducted incorporating vermicompost and canna plant along with the Knol khol vegetable crop to accommodate soil sampling at different intervals with minimum disturbance. Except TO (soil spiked with 10 ppm chlorpyrifos, control), all the treatments contained 1% vermicompost and designated plants i.e. knol khol, canna, and mixture of canna and knol khol. Treatments with canna, and mixture of canna and knol khol showed comparatively higher (99.3%) chlorpyrifos degradation on 65th day with almost same residual pesticide (0.07 ppm) whereas TO and knol khol showed 2.5 and 1.8 times more residual CPF in soil, respectively (Kadian, 2010).

2.6. SELECTED MEDICINAL PLANTS

Based on industrial demand, cultivation feasibility, and expert consultations, total thirteen plants (*A. vera*, *P. emblica*, *W. somnifera*, *G. glabra*, *A. racemosus*, *A. paniculata*, *O. sanctum*, *C. longa*, *C. asiatica*, *A. calamus*, *R. serpentina*, *O. basilicum*, *C. borivilianum*) were selected for the agro-climatic zoning studies, among them five plants i.e. *A. vera, P. emblica, O. sanctum, C. longa* and *R. serpentina* were cultivated by the farmers of Punjab, therefore included in the survey study, subsequently, from these five plants three plants (*A. vera, O. sanctum and C. longa*) were selected for drafting GAP based on farmer's inputs and literature search. The selected medicinal plants possessed huge demand and traditional uses against many diseases.

2.6.1. *A. vera*

Name: *Aloe*

Biological source: Leaves of *A. vera.*

Taxonomic classification: The taxonomic classification of the plant is mentioned in Table 2.1.

Table 2.1: Taxonomic hierarchy of *A. vera.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Lilianae
Order	Asparagales
Family	Xanthorrhoeaceae
Genus	Aloe L.
Species	*Aloe vera* (L.) Burm. f.

Botanical descriptors: The fresh leaves of *A. vera* are 20-30 cm in length, 5 to 10 cm in width. The dried juice of the plant is opaque having different sizes (Bahmani *et al.*, 2016; Jat *et al.*, 2015b).

Chemical constituents: A procedure has been developed for determination of aloesin, 2′-*O*-feruloylaloesin, aloeresin A, barbaloin, isobarbaloin, aloenin, aloe-emodin, 8-*C*-glucosyl-7-*O*-methyl-(*S*)-aloesol, isoaloeresin D and aloeresin E which are phenolic constituents of aloe. Aloe or commercial aloin was extracted with methanol multiple times, centrifuged and then filtered. Filtrates were analyzed by a reversed-phase high-performance liquid chromatography employing Ultra Violet (UV) detection (290 nm). The samples were separated with a Wakosil-II 5C18 Hg column by linear gradient elution using water-acetonitrile (88:12 to 54:46) as the mobile phase at a flow-rate of 1.0 mL/min. The detection limits of these compounds were 0.04–0.35 mg per injection (5 μL) and linearity of response existed. Very satisfactory and reproducible results were obtained within 38 min for simultaneous determination of these compounds (Eshun and He, 2010; Okamura *et al.,* 1996; Saks and Gordon, 1995).

Pharmacological uses: Both fresh and dried juice is used in medicinal as well as cosmetics industries. The fresh leaves of the plant are used for preparing gel and juice. Its gel is used in the treatment of skin diseases, burns, jaundice, gonorrhea, piles, menstrual suppressions (Sánchez *et al.,* 2020; Eshun and He, 2010). The recent studies conducted highlights that the plant possesses anti-diabetic, anti-cancer, and anti-microbial properties. It is also used as a protective agent against diseases related to digestion, and cardiac problems. Apart from this, it is good laxatic, stomachic, astringent, antidotal, cathartic, anthelmintic and hepatic stimulant. In a study, Emodin was reported to inhibit cell growth of four gall bladder cancer cell lines by regulating epigenetic modifications in time-dependent and dose-dependent manner. In a study, emodin was highlighted as useful agent in reversion of multidrug resistance, Emodin in combination with cisplatin inhibited growth of human ovarian and gallbladder cancer cells by successfully sensitizing tumor cells to chemotherapeutic agents through inhibiting pathways. Emodin also acted as anti-inflammatory agent by inhibiting nuclear factor-κB which is responsible for transcription of various pro-inflammatory genes (Dong *et al.,* 2016). Effect of different climatic conditions on the phytochemical diversity and anti-oxidant activity of *A. vera* was studied. The study utilized collection of samples from highland, semi-arid and tropical zones and Fourier Transform Infrared (FTIR) spectroscopy was utilized for determining phytochemical analysis. Similarly, DPPH free radical scavenging assay, hydrogen peroxide scavenging assay, metal chelating assay, reducing power assay was utilized for assessing anti-oxidant activity. It was confirmed that all the collected samples showed presence of different phyto-constituents whereas highland and semi-arid zone samples possessed more anti-oxidant activity than the samples collected from tropical zones (Kumar *et al.*, 2017).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.2.

Table 2.2: Classical uses and formulations of *A. vera.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Jvara, Udararoga, Kastārtava, Yakrdvikāra, laxative, In treatment of psoriasis, Acne, Anti-diabetic, Wound healing, etc.	Rajahpravartini Vati, Cukkumtippalyādi Gutika, Juices, Tablets, Tonic, etc.

2.6.2. *P. emblica*

Name: Indian gooseberry

Biological source: Fruits of *P. emblica.*

Taxonomic classification: The taxonomic classification of the plant is mentioned in the Table 2.3.

Table 2.3: Taxonomic hierarchy of *P. emblica.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Rosanae
Order	Malpighiales
Family	Phyllanthaceae
Genus	Phyllanthus L.
Species	*Phyllanthus emblica* L.

Botanical descriptors: The fresh fruits are fleshy, smooth with six prominent lines with few dark specks. The colour of the fruits is greenish turning to light yellowish and pinkish when matured.The fresh fruits are 2.5-3.5 cm in diameter. The dried fruits have shriveled and wrinkled external convex surface to concave with rough texture. The color of the dried fruit is bulk grey color to black and surface shows few whitish specks.

Chemical constituents: The major chemical constituents investigated in the plant are ascorbic acid and tannins (Tandon and Sharma, 2010, 2008).

Pharmacological uses: It is used in jaundice, diarrhoea, inflammation, anti-diabetic, antibacterial, hypo-lipidemic, anti-ulcerogenic, antioxidant, gastro protective, hepato-protective, and possess chemo-preventive properties (Dasaroju and Gottumukkala, 2014; Tandon and Sharma 2008; Scartezzini *et al*., 2006). The compound ascorbic acid is responsible for the treatment and prevention of scurvy. It is also a potent anti-oxidant agent that fights against bacterial infections. It helps in the formation of bones, teeth, skin, connective tissue and fibrous tissue. Ascorbic acid is not formed or stored in the body so it must be taken from the diet. It is found mostly in citrus fruits and vegetables. Gallic acid possesses anti-microbial, anti-cancer, and it is protective against gastrointestinal disorders, cardiovascular diseases, neuropsychological disorders, and metabolic disorders (Kahkeshani *et al.,* 2019; Tandon and Sharma 2010; Raghu *et al.,* 2007).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.4.

Table 2.4: Classical uses and formulations of *P. emblica.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Raktapitta, Amlapitta, Prameha, Dāha, Vitality and vigor booster, In treatment of diarrhea, Jaundice, Inflammation, and Dietary source of vitamin C, etc.	Cyavanaprasa, Triphala, Juices, Candies, etc.

2.6.3. *W. somnifera*

Name: Indian ginseng

Biological source: Roots, leaves, and seeds of *W. somnifera.*

Taxonomic classification: The taxonomic classification of the plant is mentioned in Table 2.5.

Table 2.5: Taxonomic hierarchy of *W. somnifera.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Asteranae
Order	Solanales
Family	Solanaceae
Genus	Withania
Species	*Withania somnifera* (L.) Dunal

Botanical descriptors: The roots of the plants are un-branched, straight, and thick which bears secondary fibre-type roots. The color of the roots varies from buff to grey-yellow having longitudinal wrinkles (Jat *et al.,* 2015a). The crown bears 2-6 remains of bases of stem with variously thickened stems. The roots have characteristic odor having bitter taste.

Chemical constituents: The major chemical constituents are alkaloids, steroidal lactones (withanolides), and saponins. A simple, sensitive and accurate High Performance Thin Layer Chromatographic (HPTLC) method has been developed for the estimation of withaferin-A and withanolide-A in different plant parts such as, leaf, root, stem and fruit of two morphotypes of *W. somnifera*. The HPTLC of *W. somnifera* methanolic extract was performed on Si 60 F254 (20 cm × 20 cm) plates with toluene:ethyl acetate:formic acid (5:5:1), as mobile phase. Quantitative evaluation of the plate was performed in the absorption-reflection mode at 530 nm. The method was validated for precision, repeatability, and accuracy. The average recovery of withaferin-A and withanolide-A in two levels were 96.0 and 96.7%, showing the excellent reproducibility of the method. The calibration curves were linear for both in the range of 200–3,200 mg. The technique has been applied, for the first time, for the estimation of withaferin-A and withanolide-A in different parts of the two morphotypes of *W. somnifera*. The method was simple, precise, specific, sensitive and accurate and can be used for routine analysis as well as for quality control of raw materials and herbal formulations (Sharma *et al.,* 2007).

Pharmacological uses: The plant possesses rejuvenating properties, besides this, it is used as tonic, diuretic and aphrodisiac. It is also recommended in fever and swellings.

Recently, Ministry of AYUSH has recommended the traditional formulations of *W. somnifera* for prevention and prophylaxis of COVID-19 (Singh *et al.*, 2020a).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.6.

Table 2.6: Classical uses and formulations of *W. somnifera.*

Medicinal applications (AYUSH & Allopathy)	Representative formulations (AYUSH & Allopathy)
Śotha, Klaibya, Ksaya, Vātaroga, Daurbalya, Anti-viral, Anti-bacterial, Anti-oxidant, etc.	Aśvagandhādyarista, Leha, Aśvagandhadi, , Balāśvagandha Lāksadi Taila, Capsules, Tablets, Syrups, etc.

2.6.4. *G. glabra*

Name: Licorice

Biological source: Dried stolon and roots of *G. glabra*.

Taxonomic classification: The taxonomic classification of the plant is mentioned in Table 2.7.

Table 2.7: Taxonomic hierarchy of *G. glabra*.

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Rosanae
Order	Fabales
Family	Fabaceae
Genus	Glycyrrhiza
Species	*Glycyrrhiza glabra* L.

Botanical descriptors: It is a perennial, tall herb reaching up to 120 cm in height. The flowers are blue colored which occurs after 2-3 years of plantation. The outer layer of the stolon is yellowish brown to dark brown in color, wrinkled longitudinally having small buds covering scale leaves. Its taste is sweet and odour is characteristic (Anonymous, 2014).

Chemical constituents: The major chemical constituents are glycyrrhizic acid, glycyrrhizin, asparagine, glycyrrhetinic acid, resins, etc.

Pharmacological uses: It is used as expectorant, demulcent, and anti-inflammatory agent. The root extract of the plant is used for treating peptic ulcers. The constituent glycyrrhizic acid is used as anti-inflammatory and anti-viral agent. The extract is widely as laxative, sweetener in tonics, and used for treating cough remedies (Pastorino *et al.*, 2018).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.8.

Table 2.8: Classical uses and formulations of *G. glabra.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Kāsa, Svarabheda, Vrana, Vātarakta, Ksaya, Anti-tissusive, Skin diseases, Rheumatism, etc.	Yastimadhuka Taila, Elādi Guikā, Madhuyastyādi Taila, Syrups, Tonics, etc.

2.6.5. *A. racemosus*

Name: Shatavari

Biological source: Roots of *A. racemosus.*

Taxonomic classification: The taxonomic classification of the plant is mentioned in Table 2.9.

Table 2.9: Taxonomic hierarchy of *A. racemosus.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Lilianae
Order	Asparagales
Family	Asparagaceae
Genus	Asparagus
Species	*Glycyrrhiza racemosus*

Botanical descriptors: The spinous under-shrub is much-branched and scandent having tuberous roots of 10-30 cm in length. The roots are spindle-shaped, fascicled having ash-colour externally and white internally. On the drying the roots become longitudinally wrinkled which are smooth when fresh. The branches change into cladodes having decurved spines (Selvaraj *et al.*,2019).

Chemical constituents: Glycosides, isoflavones, steroidal saponins (shatavarins I-IV), sitosterol, saponin, sugar, etc.

Pharmacological uses: The plant is well known used as tonic and geriatric. The roots possess diuretic, aphrodisiac, anti-diarrhoetic, nutritive properties. It is also reported to increase the lactation. It is widely used to treat gleet, rheumatism, and gonorrhea (Alok *et al.*, 2013).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.10.

Table 2.10: Classical uses and formulations of *A. racemosus.*

Medicinal applications (AYUSH & Allopathy)	Representative formulations (AYUSH & Allopathy)
Amlapitts, Atisāra, Ksaya, Raktapitta, Sula, Vatajvara, Sutika Roga, Vatarakta, Arsa, Gulma, Raktātisara, Raktavikāra, Stanya Ksaya, Galactagogue, Stomachic, etc.	Brahma Rasāyana, Satāvari Guda, Asvagandharista, Satāvari Ghrta, Atisara, Mahanārayana Taila, Powder, Capsules, Tablets, Tonics, Syrups, etc.

2.6.6. *A. paniculata*

Name: Green chiretta

Biological source: Mostly roots and leaves of *A. paniculata.*

Taxonomic classification: The taxonomic classification of the plant is mentioned in Table 2.11.

Table 2.11: Taxonomic hierarchy of *A. paniculata.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Asteranae
Order	Lamiales
Family	Acanthaceae
Genus	Andrographis
Species	*Andrographis paniculata*

Botanical descriptors: It is an annual erect herb of 30-90 cm height, the upper segment of the stem is quadrangular and lower segment rounded stem. The leaves are subsessile or opposite sessile, lanceolate or linear lanceolate. The flowers of the plant are white-purple, biliped, pedicelled. The pedicel of the flower is slender and 2.5-10 mm in size.

Chemical constituents: Diterpenoids, andrographolide, β-sitosterol, skullcapflavone I, etc. (Tan *et al.,* 2016).

Pharmacological uses: The plant is acrid, laxative, anti-inflammatory, expectorant, anthelmintic, stomachic, and also used in hemorrhoids (Rao *et al.,* 2004).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.12.

Table 2.12: Classical uses and formulations of *A. paniculata.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Rakta shodhak, Deepan pachan, Antipyretic, Anti-fertility, Anti-bacterial, Anti-viral, Dyspepsia, Amoebic dysentery, Indigestion, biliousness.	Syrups, Tablets, Tonics.

2.6.7. *O. sanctum*

Name: Holy basil

Biological source: Whole plant of *O. sanctum.*

Taxonomic classification: The taxonomical classification of the plant is mentioned in Table 2.13.

Table 2.13: Taxonomic hierarchy of *O. sanctum.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Asteranae
Order	Lamiales
Family	Lamiaceae
Genus	Ocimum
Species	*Ocimum sanctum*

Botanical descriptors: The plant is 30-60 cm high and leaves of the plant have petiolate and thin petiole of 1.5-3 cm long. It is a biennial or triennial plant mostly cultivated in the *kharif* season (Jat *et al.,* 2014).

Chemical constituents: Eugenol, and carvacrol are the major chemical constituents present in the plant. Eugenol have clove like odour and is soluble in glacial acetic acid. A simple, sensitive, and accurate Liquid Chromatography-Mass Spectrometry (LC-MS) using an Atmospheric Pressure Chemical Ionization (APCI) method for the determination of Rosmarinic Acid (RA) and Ursolic Acid (UA) in the leaves of ethanol extract of *O. sanctum* (holy Basil, an Indian traditional herb) has been developed for the first time and validated. The mobile phase consisting of 0.5% formic acid–acetonitrile (75:25%) and ammonium acetate–acetonitrile (70:30%) were used for RA and UA, respectively, and delivered at a flow rate of 0.5 mL/min. Using the optimized conditions, the quantity of RA and UA in extract was found to be 0.27 and 0.40% w/w, respectively. The method is simple, sensitive, reproducible, and ideally suited for rapid routine analysis (Sundaram *et al.*, 2012). In a study, various factors effecting the yield and essential oil of *O. sanctum* was studied. It was observed that all the cultivars of basil grown in Nova Scotia had acceptable yield and oil concentration. On the contrary higher yields were obtained from Italian broadleaf and Mesten because of early transplantation. Local had lower oil content than the other cultivars and linalool and methyl chavicol were major constituents observed in Mesten and Italian broadleaf respectively. It was also observed that both freeze drying and air drying effected the composition of the essential oil obtained from the *O. sanctum* and *O. basilicum* (Bowes and Zheljazkov, 2004).

Pharmacological uses: In Ayurveda, *O. sanctum* is mentioned as “Mother medicine of nature” as it prevent diseases, stress, promote general health and longevity. The plant is known to possess anti-bacterial, anti-fungal, anti-viral, anti-malarial, anti-protozoal, anthelmintic properties. It also has hepato-protective, anti-diarrheal, mosquito repellent, anti-inflammatory, cardio-protective, anti-asthmatic, anti-stress properties. Its oil comprising of eugenol is used in perfumery, cosmetics, herbal, and nutraceutical industries (Jat *et al.*, 2014). Luteolin present in the plant is reported to possess anti-cancer activity against MCF-7 cell line. Eugenol has reported to possess 97 per cent COX-1 inhibition compared to naproxen, ibuprofen, and aspirin. The essential oil obtained from the plant possessed anti-leishmanicidal activity against *Leishmania donovani*. Caryophyllene oxide and eugenol possessed IC_{50} value >25µg/mL against *Leishmania major* (Singh and Chaudhuri, 2018).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.14.

Table 2.14: Classical uses and formulations of *O. sanctum.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Svasa, Kustha, Kāsa, Krmiroga, Asmari, Pārsva Sula, Hikkā, Chardi, Netraroga, In treatment of bronchitis, Bronchial asthma, Malaria, Diarrhea, Dysentery, Skin diseases, Arthritis, etc.	Tribhuvanakirti Rasa, Manāsamitra Rasa, Muktāpancāmrta Rasa, Muktādi Mahājana, Churnas, Tablets, Pills, Juices, Eye drops, Expectorants, Oils, etc.

2.6.8. *C. longa*

Name: Turmeric

Biological source: Rhizomes of *C. longa.*

Taxonomic classification: The taxonomical classification of the plant is mentioned in Table 2.15.

Table 2.15: Taxonomic hierarchy of *C. longa.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Lilianae
Order	Zingiberales
Family	Zingiberaceae
Genus	Curcuma
Species	*Curuma longa* L.

Botanical descriptors: As many as 133 species of *Curcuma* have been identified worldwide (ITIS, 2021). The rhizomes of the plant are longitudinally wrinkled and condensed swollen with marked circular rows. The rhizomes are hard, heavy with short fracture having 3 to 5 large depressions scars. The rhizomes are 2-5 cm long and 1-1.8 cm thick having yellowish to brown colour (Jayashree *et al.,* 2015).

Chemical constituents: The important pharmacological chemical constituents present in the plants are curcumin, bisdemethoxycurcumin, demethoxycurcumin, turmerone, zingiberene, etc. (Ishimine *et al.,* 2004). The purity of the curcuminoids was analyzed by an improved HPLC method. HPLC separation was performed on a C_{18} column using three solvents, methanol, 2% Acetic acid, and acetonitrile, with detection at 425 nm. Four different commercially available varieties of turmeric, namely, Salem, Erode, Balasore, and local market samples, were analyzed to detect the percentage of these three curcuminoids. The percentages of curcumin, demethoxycurcumin, and bisdemethoxycurcumin as estimated using their calibration curves were found to be 1.06 ± 0.061 to 5.65 ± 0.040, 0.83 ± 0.047 to 3.36 ± 0.040, and 0.42 ± 0.036 to 2.16 ± 0.06, respectively, in four different samples. The total percentages of curcuminoids are 2.34 ± 0.171 to 9.18 ± 0.232% (Jayaprakasha *et al.,* 2002).

Pharmacological uses: The name turmeric is derived from the Latin word *terra merita* known as meritorious earth due to the colour of ground turmeric. The use of this plant to treat ailments can be traced back to 4,000 years (Prasad and Aggarwal, 2011). Curcumin which is one of the potential constituent present in the plant is known to repress the edema formation, and lower the cell proliferation of prostate cancer cells in mouse. It blocks COX enzymes to possess anti-inflammatory effects (Beevers and Huang, 2011). The plant is used to build up the body energy, regulates menstruation, expells gall stones, relieves gas and used in the treatment of arthritis (Sandeep *et al.,* 2016; Labban, 2014; Sharma and Sharma, 2012; Prasad and Aggarwal, 2011).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.16.

Table 2.16: Classical uses and formulations of *C. longa.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Pāndu, Prameha, Vrana, Sitapitta, Tvagroga, Pinasa, Kustha, Visāvikara, Antioxidant, Anti-cancer, Anti-inflammatory, Nematocidal, Anti-microbial etc.	Tribhuvanakirti Rasa, Manāsamitra Rasa, Muktāpancāmrta Rasa, Muktādi Mahājana, Churnas, Tablets, Pills, Juices, Expectorants, Oils, etc.

2.6.9. *C. asiatica*

Name: Indian pennywort

Biological source: Dried whole plant of *C. asiatica.*

Taxonomic classification: The taxonomic classification of the plant is mentioned in Table 2.17.

Table 2.17: Taxonomic hierarchy of *C. asiatica.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Asteranae
Order	Apiales
Family	Apiaceae
Genus	Centella
Species	*Centella asiatica*

Botanical descriptors: It is a prostate, stoloniferous, faintly aromatic perennial herb which is found as weed in crop fields and waste places. It is a creeping herb having slender stem, permitting rooting at nodes to give rise to thin grey-brownish roots varying 2.5 to 6.0 cm in length. The leaves of the herb are 1-3 cm from each node, crenate, orbicular-reniform, base cordates, umbela possessing 3 to 4 flowers. The fruits possess multiple ridges in the outline, the epicarp possesses single layered epidermis surrounded with thick cuticle (Times-is, 2009a).

Chemical constituents: It consists of triterpenes such as asiatic acid, asiaticoside, madecassoside, madecassic acid, centellin, etc. (Gohil *et al.*, 2010).

Pharmacological uses: It is reported for the treatment of leprosy, varicose ulcers, lupus, eczema, diarrhea, psoriasis, amenorrhea, fever, etc.

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.18.

Table 2.18: Classical uses and formulations of *C. asiatica.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Śotha, Kāsa, Kustha, Aruci, Kandu, Jvara, Pra Raktapitta, Svaśa, Meha, Raktadosa, Blood purifier, Memory enhancer, etc.	Brahma Rasāyana, Syrups, Tablets, etc.

2.6.10. *A. calamus*

Name: Sweet flag

Biological source: Dried rhizomes of *A. calamus*

Taxonomic classification: The taxonomic classification of the plant is mentioned in Table 2.19.

Table 2.19: Taxonomic hierarchy of *A. calamus.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Lilianae
Order	Acorales
Family	Acoraceae
Genus	Acorus
Species	*Acorus calamus*

Botanical descriptors: It is a tall wetland herbaceous plant and the drug arises in rarely or simple with thumb-like branches at nodding, slightly flattened to sub-cylindrical, rarely straight or tortuous, pieces having 0.5-1.5 cm thickness and 1-5 cm long, the leaf scars surrounds the rhizome. The leaves are erect, sword-shaped, yellowish-brown in colour. The rhizomes are buff internally, reddish to pinkish externally, odour is aromatic, and taste is bitter (Times-is, 2009b).

Chemical constituents: The rhizomes consist of volatile oils such as asamyl alcohol, asarone, eugenol, and bitter constituent acorin, sesquiterpenes, etc. (Rajput *et al.,* 2014).

Pharmacological uses: The plant is used for nervous disorders, bronchitis, cramps, digestive disorders, hemorrhoids, skin diseases, sedative, cough, chest pain, vascular disorders, etc.

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.20.

Table 2.20: Classical uses and formulations of *A. calamus.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Sula, Svasa, Vibandha, Adhmana, Smriti daurbalya, Apasmara, Kasa, Karna srava, CNS depressant, Antispasmodic, Anti-inflammatory, Anti-microbial, Anti-cancer, etc.	Vacādi Taila, Sārasvata, Sārasvata rista, Vacā lasunadi, Curna, Hinguvacādi Curna, Candra Prabhā vati, Tablets, Powder, etc.

2.6.11. *R. serpentina*

Name: Indian snake root

Biological source: Dried roots of *R. serpentina.*

Taxonomic classification: The taxonomic classification of the plant is mentioned in the Table 2.21.

Table 2.21: Taxonomic hierarchy of *R. serpentina.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Asteranae
Order	Gentianales
Family	Apocynaceae
Genus	Rauvolfia
Species	*Rauvolfia serpentina*

Botanical descriptors: The surface of the root is rough, short, possessing brittle wiry rootlets or the scars left by them. The roots are prominent, tuberous, and rarely branched with irregular longitudinal fissures. The roots are 8-15 cm long, 0.5 to 2 cm thick and rootlets are 0.1 mm in diameter bearing greyish-yellowish to brown colour. The odour of the roots is slight and taste is bitter (Tandon and Sharma, 2010).

Chemical constituents: The major chemical constituents investigated in the plant are reserpine, reserpinine, serpentinine, and ajmalicine (Khan *et al*., 2018; Usmani *et al*., 2014; Kumari *et al*., 2013; Panwar and Guru, 2011; Tandon and Sharma, 2010).

Pharmacological uses: It is used in India as a folk medicine for centuries to treat snake bite, insect bites, malaria, febrile conditions, febrifuge, dysentery, uterine stimulant, abdominal pain and cure for insanity. It is also useful in curing high pressure, anxiety, traumas, excitement epilepsy, mental agitation and eight schizophrenic disorders (Abhijit and De, 2010). The root of the plant is used to lower the blood pressure. It is also used to treat mental disorders including bipolar disorders, schizophrenia, and insomnia. It is reported to possess anti-autism properties in children aged 3.5 to 9 years. It is used in the treatment of breast cancer, migraine and improve psychogenic and pruritic dermatitis (Douglas, 2015). In the year 1952, (Novartis) published detailed report on the chemistry and pharmacology of reserpine. Also in the same year, reserpine was introduced as Serpasil drug to treat tachycardia, hypertension, thyrotoxicosis. The oral bioavailability of reserpine ranges from 50-70%. It is used to prevent strokes and problems related to kidney (Lobay, 2015).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.22.

Table 2.22: Classical uses and formulations of *R. serpentina.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Jvara, Sula, Apasmāra, Bhrama, Anidrā, Bhutabādhā, Madaroga, Mānasaroga, Krmiroga, Unmāda, Raktavita, Visucika, Treating snakebite, Hypertension, etc.	Sarpagandhādi Cūrna, Sarpgandhā Vati, Sarpagandhāyoga, Sarpagandhā Ghana Vati, Powder, Capsules, Extracts, etc.

2.6.12. *O. basilicum*

Name: Sweet basil

Biological source: Whole plant of *O. basilicum.*

Taxonomic classification: The taxonomic classification of the plant is mentioned in Table 2.23.

Table 2.23: Taxonomic hierarchy of *O. basilicum.*

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Asteranae
Order	Lamiales
Family	Lamiaceae
Genus	Ocimum
Species	*Ocimum basilicum*

Botanical descriptors: The herb is large, erect, herbaceous, annual, and strongly aromatic having height of 30 to 90 cm. The stems of this aromatic herb are cross-sectional square and profusely branched. Decussate arrangement is found for stalked leaves where opposite pair of leaves intersects the next to generate a cross and so on. There are generally 6-10 small flowers displayed in whorls at the nodes of inflorescence. The corolla and calyx are bell-shaped and calyx having two lips with upper lip generally broad (Nassar *et al.*, 2013).

Chemical constituents: The oil contains linalool, eugenol, methyl chavicol, methyl cinnamate, and 1,8-cineole (Smitha *et al.*, 2014).

Pharmacological uses: It has been reported to possess anti-viral, anti-bacterial, anti-cancer, anti-oxidant properties and treating menstrual irregularities, anorexia, etc.

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.24.

Table 2.24: Classical uses and formulations of *O. basilicum*.

Medicinal applications (AYUSH & Allopathy)	Representative formulations (AYUSH & Allopathy)
Svāsa, Hikkā, Krmiroga, Anti-ageing, Perfumery, Treating cold, etc.	Tribhuvanakirti Rasa, Muktādi Mahānjana, Eye drops, Syrups, Tonics, Oil, etc.

2.6.13. *C. borivilianum*

Name: Safed musali

Biological source: Roots of *C. borivilianum.*

Taxonomic classification: The taxonomic classification of the plant is mentioned in Table 2.25.

Table 2.25: Taxonomic hierarchy of *C. borivilianum*.

Kingdom	Plantae
Subkingdom	Viridiplantae
Infrakingdom	Streptophyta
Superdivision	Embryophyta
Division	Tracheophyta
Subdivision	Spermatophytina
Class	Magnoliopsida
Superorder	Lilianae
Order	Asparagales
Family	Asparagaceae
Genus	Chlorophytum
Species	*Chlorophytum borivilianum*

Botanical descriptors: It is a perennial herb having small hard root stocks that are fleshy, thick and cylindrical. The leaves are sub-erect, and the herb possesses tuberous root system. The flowers are arranged in raceme inflorescence and white in colour, having six petals that are generated on sparse panicles. The seeds of the plants are very light in weight (Jat *et al.*, 2015c; Vijaya and Chavan, 2009).

Chemical constituents: Fructans, steroidal saponins, acetylated mannans, fructoligosaccharides.

Pharmacological uses: It is used as general tonic, the tubers have high aphrodisiac property, and is useful in diseases such as leucorrhoea, diabetes, and renal calculus (*Jat et al.*, 2015c).

Classical uses and formulations: The traditional uses and formulations are mentioned in Table 2.26.

Table 2.26: Classical uses and formulations of *C. borivilianum.*

Medicinal applications (AYUSH & Allopathy)	**Representative formulations (AYUSH & Allopathy)**
Vajikarana, Rasayana, Madhura, Anti-stress, Aphrodisiac, Erectile dysfunction, Improves lactation, Arthritis, Anti-cancer, Anti-diabetic, etc.	Churna, Powder, Tablets, Capsules, etc.

2.7. AGRO-CLIMATIC ZONING

Today's agricultural system has succeeded in supplying huge quantity of food and related stuff to the global market. The utilization of extreme resource-intensive agricultural system and high external inputs has caused massive deforestation, biodiversity loss, and water scarcity. In this context, agro-ecological zoning methodology was developed using complex software packages to circumvent problems related to land resources leading to sustainable agriculture. In developing countries, socio-economic needs of quickly expanding populations are the major reason for designating land resources for different uses. Sustainable and rational use of land has become the key issue for policy makers, government and land users for preserving the resources for present and future generations. The major challenge for the policy makers is to flip the trends of land degradation in already cultivated areas by improvising the conditions and re-establishing the land fertility (FAO, 1996). In short, agro-ecological zoning is a science that endorses sustainable use of land resources considering climatic, soil and landform conditions. The agro-ecological methodology characterized the tract of land by quantifying the knowledge of climate, soil, and other physical factors to ascertain or pre-determine the productivity of various crops based on their specific bio-climatic requirements. The agro-ecological zoning studies with the help of GIS involve the combination of layers of spatial information to highlight zones for crop planning (Deshpande *et al.,* 2004).

The medicinal plants or any other plant species require specific climate and soil conditions for expressing their quality and at present there is no policy to regulate the right medicinal plant species in right location. India is located to equator's north extending between 8°4' to 37°6' north latitude and 68°7' to 97°25' east longitude. India has 329 million hectares geographical area covering larger part of the Southern Asia and making it seventh largest country in the world (Garg, 2012). The country possesses tropical monsoon climate with summers (March-May), winters (January-February), south-western monsoon (June-September) and north-eastern monsoon in southern peninsula (October-December) season (Attri and Tyagi, 2010). India has the most alluring ecological conditions in the world possessing nearly rainless Thar desert to Cherrapunjee, the rainiest place on earth and extending to hot-salty Ran of Kutch to everlasting snow bonded Himalayan peaks (Kelkar, 2002). Punjab falls in the agro-climatic zone-VI, and is further divided into five sub-zones (Hamadani and Khan, 2015). Most of Punjab lies in the fertile plain; toward the southeast one finds semi-arid and desert landscape; a belt of undulating hills extends along the northeast at the foot of the Himalayas (Singh and Rath, 2013; Sidhu, 2011)**.** Punjab has diverse climatic zones having specific temperature, rainfall and soil conditions as represented in Fig. 2.7. Considering diverse climatic aptitudes of Punjab and no policy to guide farmers regarding adoption of right medicinal plants in right location, it becomes imperative to highlight potential growing areas for selected medicinal plants in Punjab based on climatic and land pattern data as represented in Fig. 2.8. In a study, the aim was defined to analyze the agro-climatological aptitude for Argentinean semiarid and arid zones to produce industrial oil from castor. This model worked on potential cultivation areas considering the species bioclimatic needs. To define the agro-climatic zoning of the selected crop, climatic data from the meteorological station from the period of 1981-2010 was analyzed. Using available databases and geographical limits for the different variables, aptitude types were mapped. The optimal conditions of the crops were defined considering temperature, frost free days etc. The areas where the crop was optimally cultivable were highlighted as suitable. The agro-climatic zoning model to determine the potential production of the crop can be implemented at global level with the same optimal agro-climatic conditions (Falasca *et al.*, 2014a; 2012).

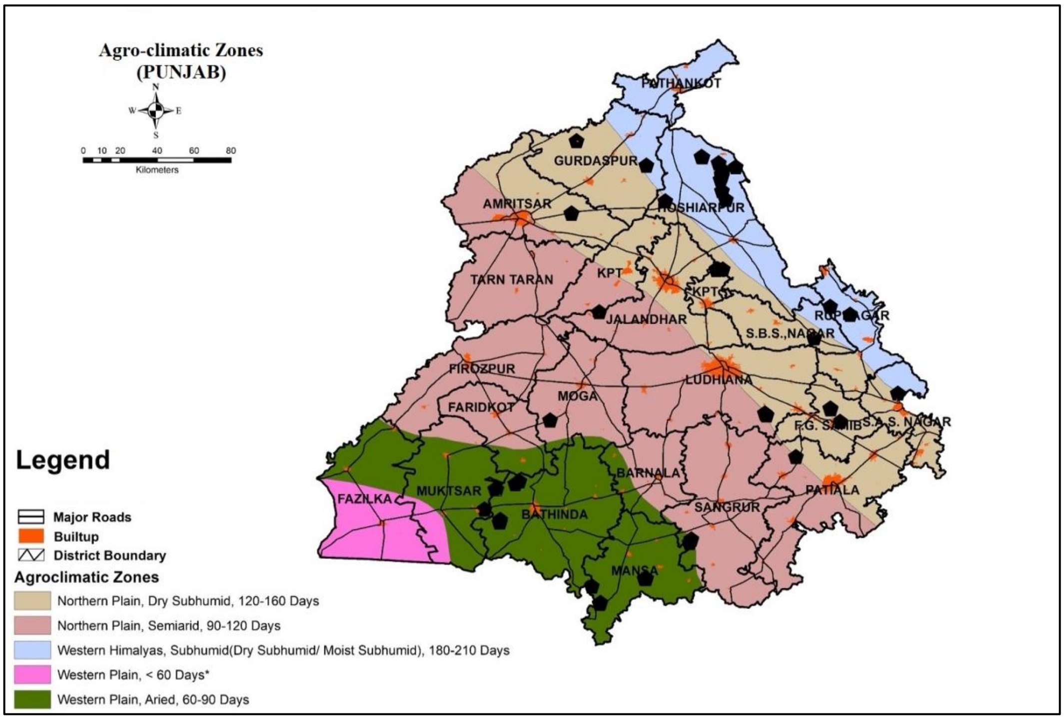

Figure 2.7: Agro-climatic zones of Punjab.

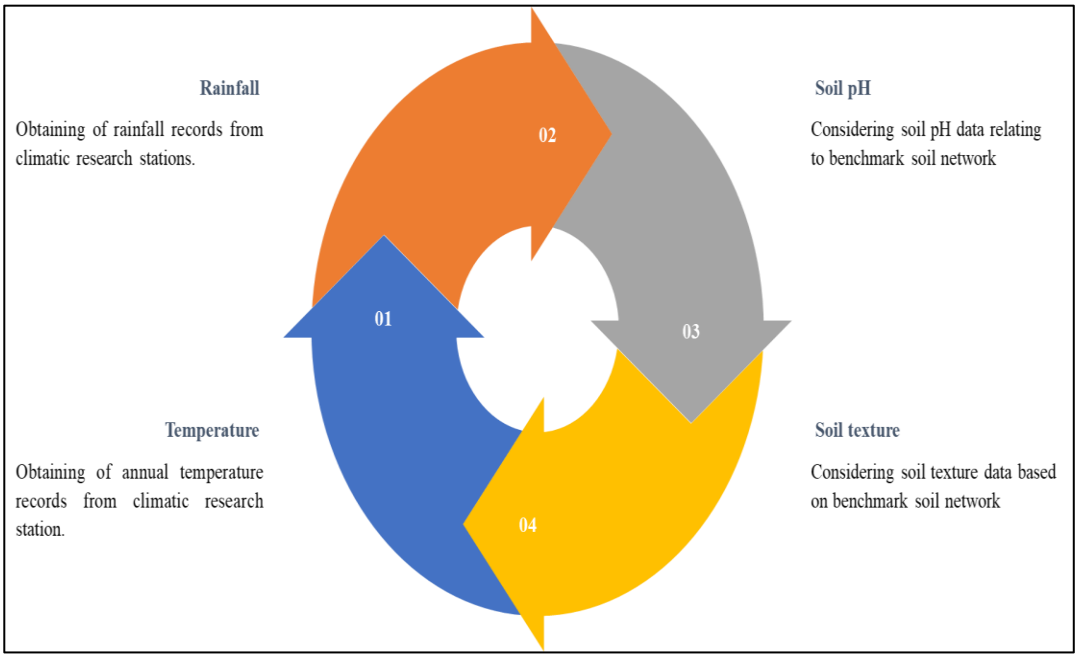

Figure 2.8: Parameters for agro-climatic zoning.

Some of the studies based on agro-ecological zoning model are mentioned in Table 2.27.

Table 2.27: Agro-climatic zoning studies of crops.

S.No.	Crops	Geographical regions	Reference(s)
1	*Acrocomia aculeata*	Brazil	Resende *et al.*, 2020
2	*Glycine max*	Ukraine	Zymaroieva *et al.*, 2019
3	*Zea mays*	Indonesia	Kandari *et al.*, 2013
4	*Lesquerella fendleri*	Argentina	Falasca *et al.*, 2018
5	*Panicum virgatum*	Dry-subhumid regions of Argentina	Falasca *et al.*, 2017
6	*Ricinus communis*	Argentina	Falasca *et al.*, 2012
7	*Solanum tuberosum*	Argentina	Caldiz *et al.*, 2001
8	*Amaranthus caudatus*	Argentina	Falasca *et al.*, 2014b
9	Halophytes: (*Arundo donax*, *Chloris gayana*, *Euphorbia tirucalli*, *Moringa oleifera*, *Phalaris arundinacea*, *Pongamia pinnata*, *Salsola kali*, *Salvadora persica*)	Argentina	Falasca *et al.*, 2014a
10	*Cyamopsis tetragonoloba*	Argentina	Falasca *et al.*, 2015
11	*Jatropha curcas*, *Acrocomia aculeate*, *Salicornia bigelovii*	Argentina	Falasca *et al.*, 2013
12	*Salsola kali*	Drylands of Argentina	Falasca *et al.*, 2016
13	*Argania spinosa*	Dryland of Argentina	Falasca *et al.*, 2018
14	*Acrocomia aculeata*	Argentina	Falasca *et al.*, 2015
15	*Triticum aestivum*	India	Aggarwal, 1993
16	*Medicago sativa*	Iran	Taati *et al.*, 2015
17	*Ziziphus jujuba*	Iran	Ashrafi *et al.*, 2013
18	*Triticum aestivum*, *Beta vulgaris*, *Zea mays*	Iran	Neamatollahi *et al.*, 2012
19	Wheat, maize, rice and soybean	Central North America, Central and Eastern Asia	Teixeira *et al.*, 2011
20	Cereals (wheat, Rice, maize)	Japan	Tatsumi *et al.*, 2011

There are many studies conducted to highlight the potential growing areas for various crops worldwide. In a study, yield gap analysis which means to evaluate magnitude and variability of difference between the crop yield potential (Yp) and actual farm yields was evaluated. It provides a measure of untapped food production capacity. Location specific estimates of yield gaps derived from research plots and simulation models are available for limited number of locations and crops due to cost and time required for the analysis. The scientists have compared global agro-climatic zonation schemes to up-scale location specific estimates of yield potential and water limited yield potential. Six global climate zonation schemes were evaluated for climatic homogeneity with in delineated climate zones and coverage of crop area. It was found that some climate zones schemes are crop specific, which limits utility for up scaling location specific evaluation of yield gaps in regions with crop rotation rather than single crop species (Van Wart *et al.,* 2013).

Similarly, in a study agro-climatic zoning model was employed to upscale the production of biokerosene oils for aviation in dry and arid areas in Argentina. Perennial species such as *Jatropha curcas, Ricinus communis* were selected for the for their agro-climatic suitability studies in Argentina. The thornthwaite's moisture index was delimitated to highlight arid, semi-arid, humid, and sub-humid areas. The base maps of rainfall, temperature were superimposed on each other to obtain the potential growing areas. Excluding the Argentinean traditional cropping areas, the other areas were marked for the cultivation of selected selection to upscale the production of biokerosene (Falasca *et al.,* 2013; FAO, 1996).

2.8. CRITICAL AGRICULTURAL ATTRIBUTES OF MEDICINAL PLANTS

The study is based on a scientific approach that begins with pre-defined quality parameters, processes and materials based on sound science and literature to pre-determine the risks involved in pharmaceutical product development (Sangshetti *et al.,* 2017). The same approach has been designed in the present study to understand pre-defined effects of various materials and agricultural processes on the quality of medicinal plants in terms of productivity, active constituents, physico-chemical parameters, toxicity indicators (heavy metals, pesticides residues), and microbial content (aflatoxins, damaged crop) in order to counter risk management (Lawrence *et al.,* 2014). The study has pre-defined three set of variables such as CQA, CPP and CMA that are linked to each other defining the quality of the herbs in a scientific manner (Rathore and Winkle, 2009). Critical material is any agricultural material form that affects the quality of the raw herbs such as soil, water, seeds, site, fertilizers, etc. Similarly, the processes involved in agricultural practices such as soil preparation, sowing, manure addition, irrigation, protection from weeds/pests, harvesting, storage, etc. can be termed as critical process parameters based on the inputs of farmers and sound literature survey.

Prior understanding of risk in agricultural system is essential to coordinate, facilitate and improve science-based decision making with respect to the risk to the quality of herbs (Kelley *et al.,* 2016). The evaluation of the risk on the quality of the herbal raw drug must be based on the scientific knowledge and shall be linked to the quality of herbal formulation which is intended to be administered to the patients. Therefore, the risk management study based critical alignment study of agricultural attributes would enable the farmers to understand the critical agricultural materials and processes that have huge impact on the quality of the medicinal plants. Furthermore, risk management studies would enable the farmers to adopt risk reduction measures to lessen the probability of occurrence of harm and the severity of that harm on the medicinal produce (Alt *et al.,* 2016; Maguire and Peng, 2015).

2.8.1. Pre-cultivation Phase

Seed used in the sowing process is essential for achieving good quality of herbal raw material and its proper authentication and quality has direct link with the productivity, active constituents, physicochemical parameters, and vulnerability of diseases**.** In general, most of the medicinal plants cultivators rely upon oral assurance by the seed provider for authentication. Only oral authentication by the seed provider may result in poor quality of herbal raw produce which can be limiting factor in context to industrial demand. The GAP suggested proper authentication of medicinal plants considering proper taxonomical identity, phenotype/genotype/ breeding history of the medicinal plants (Wangchuk *et al.,* 2011). Understanding the criticality of the quality of seeds on the quality attributes of the medicinal plants, it is suggested to collect authenticated seeds or propagation material (Manivel and Smitha, 2015). The information regarding the approved seeds collection centers is mentioned in NMPB's *e-charak* mobile app. which is easy to operate and freely accessible online (https://www.nmpb.nic.in/content/e-charak-online-market-place-medicinal-plants). As per the GAP guidelines, the site selection should be based on the scientific approach considering meteorological and toxicity indicators (Organización Mundial de la Salud, & World Health Organization, 2003). Analyzing meteorological data such as rainfall, temperature for the past 03 years can suggest the crop suitability in the site. Un-balanced climatic requirements can result in un-necessary stress to the plants leading to decreased productivity, active constituents, diseases, pests and vulnerability to toxicity indicators (Kosalec *et al.,* 2009). Therefore, phyto-remediation techniques could be followed to control the menace of the toxicity indicators in the crops (Jadia and Fulekar, 2009). Furthermore, optimal use of water, quality of water and soil is the essential characteristics for the crop development. Similarly, soil pH and texture which directly affects the positive micro-organisms in the soil leads to lesser productivity. Higher use of nitrogen fertilizers can lead to soil acidity and free calcium carbonate leads to alkaline soils (Ishaq *et al.,* 2015). Similarly, important soil flora such as Azotobacter is sensitive high salt concentration. Furthermore poor quality of water can result in lesser uptake of potassium and calcium leading to nutritional deficiencies (Baligar *et al.,* 2001). Irrigation with both saline and acidic water affects the crop growth and quality which can lead to problems such as poor extraction of water from the soil, suppression of root growth, lesser soil permeability due to de-flocculation effect of sodium, crusting of seedbeds, waterlogging, more uptake of boron, chloride, sulphate, sodium, and bicarbonate leading to plant toxicity, high salt level deposition resulting to burning of leaves, thick cuticle, etc. (Hamdy, 1993). Salinity of water also causes physiological and anatomical adverse effects in the plants leading to reduction of cell division, cell enlargement, protein synthesis, underdevelopment of xylem leading to slower plant growth, lesser secondary metabolites and poor aesthetic quality of crops (Tedeschi and Dell’Aquila, 2005).

2.8.2. Cultivation Phase

Sowing is critical agricultural process, which encompasses plant and row spacing, seeds per acre, seed depth, time of sowing, and method of sowing**.** During sowing, optimal seed to seed and row to row distance should be maintained according to the plant requirements. Lesser or higher distances affects crop growth, root density, plant height, number of leaves, plant biomass, active constituents which eventually affects the quality of the crop (Ngullie and Biswas, 2017). Hence, it is advisable to adopt and validate proper agro-technique for selected medicinal plants for commercial cultivation. Crop nutrition and fertilization should comply with less pesticide residue with negligible toxicity levels as per national or internal standards. Pesticides or fertilizers should be organic and must be applied by a qualified staff (Abhilash and Singh, 2009).

2.8.3. Harvest and Post-harvest Phase

It is a known fact that optimal time of harvest means the time when the plant has highest amount of active constituents in the selected part (Badi *et al.,* 2004). Based on experience, farmers harvest crop analyzing the physical changes of the crop. The harvest must be avoided during rainfall and high humidity to prevent moisture in the finished crop. Also, more attention must be paid the cleanliness of the harvesters which can result in microbial contamination of the produce. During harvest, cloth should be kept between the soil and the harvested material to avoid higher physiochemical limits in the finished crops (Organización Mundial de la Salud, & World Health Organization, 2003). Similarly, post-harvest handling is one of the essential processes to maintain the quality of the medicinal plants. Some medicinal plants need extra post-harvesting care, as in the case of Ghritkumari, the fresh harvested produce needs immediate semi-processing or processing to obtain high therapeutic potential of the plant (Ahlawat & Khatkar, 2011). The gunny bags used to collect the medicinal produce must be clean and special care must be given to the bags having history of fertilizer or pesticide contaminated (Vasisht *et al.,* 2016).

Drying is the most critical, high investment and energy costs oriented process. In case of medicinal plants, drying temperatures between 30 to 50°C are recommended to protect sensitive active constituents of the medicinal plants (Heindl and Müller, 2007). Generally, open sun-light drying is not recommended in medicinal and aromatic plants cultivation to avoid disappearance of volatile oils present in the medicinal or aromatic plants (Asekun *et al.,* 2007). Volatile oils are terpenes made up of isoprene units possessing pharmacological properties. In the present study, plants such as *C. longa, O. sanctum* possessed several volatile oils content such as curcumin, eugenol, camphene, linalool, etc. which are vulnerable to loss of volatile constituents on sunlight drying (Prakash and Gupta, 2005). Therefore, it is recommended to use optimum drying method, drying time, temperature for maintaining the active constituents in medicinal plants (Akram *et al.,* 2010). Methods such as solar drying, freeze drying can be used by the farmers. Similarly, without proper storage, the raw material loses its potency and efficacy (Katayon *et al.,* 2006). Optimum storage time should be considered for medicinal plants for maintaining the active constituents of the medicinal plants (Fennell *et al.,* 2004). Generally, it is recommended to process or semi-process medicinal plants in due course of time, however storage time should not exceed one year for any dried medicinal plants (Lisboa *et al.,* 2018). Proper storage room should have different areas for extruder, milling and cleanliness should be maintained in the storage room which must be free from the attack of rodents. There should be controlled environmental conditions in storage room and it should be protected from the external environment to avoid moisture, microbial, aflatoxin contamination (Khan *et al.,* 2006).

2.9. FAILURE MODE EFFECT ANALYSIS

FMEA is a tool and a process to identify potential failures, its effects, and risks in the processes and then eliminate or reduce them. FMEA is a potential tool that is used in the management studies. Its output is the FMEA chart which highlights potential risks based on severity, occurrence and detection. The same approach can be applied in different subject disciples to avoid risks in the processes to validate. FMEA can also be applied in the early phases of the agricultural process to avoid risks at the later stages of plant production and prevent consequences of delayed phase of improvements associated with widespread testing and probabilistic reliability modeling (Lipol and Haq, 2011). FMEA is a quality risk management strategy to evaluate reliability issues in the early hours of medicinal plants cultivation where it is simple to acquire actions to overcome the intensity of risks thereby suggesting quality-quantity improvements methodologies. FMEA is applied to determine RPN which is calculated by multiplying the Severity (SEV)×Occurrence (OCC)×Detection (DET) of a particular process. Severity means the intensity of the severity of the failure effect on the customer, it numerically rates the chances of the occurrence of the failure cause, and detection numerically rates the potential of process controls in detecting the cause of the failure. The basic idea behind calculating the RPN was to determine the intensity of the risk involved in particular agriculture process and take suitable process control measures and actions (Namdhari *et al.*, 2011). Higher the RPN number more was the intensity of the risk factor involved in the agricultural process and quick and concrete actions needed to be taken (Lipol and Haq, 2011; Cassanelli, *et al.,* 2006). FMEA approach is helpful to the farmers interested in medicinal plant cultivation as it successfully provided risks and various methods to avoid risks in each agricultural step of plant production as described in the present study.

2.10. CASE STUDIES OF MEDICINAL PLANTS CULTIVATION

There are many case studies that highlight the adoption of medicinal plants adoption as potential alternative farming option. Natural resources India foundation, not-for-profit Non-Government Organization (NGO) submitted a final report on pilot study on mechanism for sustainable development and promotion of Herbal and Medicinal Plants (H&MP) in the state of Uttaranchal Pradesh, India. A comprehensive study was carried out pointing at the initiatives for sustainable development and management of H&MP by providing year wise seedling availability. Data collection methods by contacting multiple stakeholders of Uttaranchal Pradesh and investigation work matrix (to whom questionnaires were sent) were carried out. Species were mapped according to the climatic zones of India. Conservation strategies and promotion efforts were also carried out in the study. Harvest and post-harvest studies, marketing techniques were included in the comprehensive study of the selected medicinal plants. The report was forwarded to the concerned division, planning commission, Government of India. The results highlighted promotion of sustainable agriculture and economic viabilities through adoption of medicinal plants in the community (Mattoo *et al.,* 2004). Another case study discussed exploration of medicinal and aromatic plants for enhancing farm income. The case of Bihar represented assessment of local conditions and requirements for MAP cultivation. Training of farmers and preparation of manuals in vernacular languages were prepared for promoting the cultivation of medicinal plants. Un-organized farmers were linked with the organized sector and were involved in the pricing mechanism with buy back arrangements with partner industry under public-private partnership. Agro-techniques including propagation methods for MAP cultivation were taken into consideration (Singh *et al.,* 2013). The study indicated increase in the farm income in the sample population.

A different study provided a comprehensive overview to understand the economics, extent of area under cultivation of medicinal plants, estimation of domestic and international demand and to identify bottlenecks in marketing for the selected MAP. Agro-climatic zoning was established and soil, seasons and land use pattern were studied for the work. Many MAP do not require intensive agro-inputs and grow under natural stress conditions. MAP like lemongrass has proved to be potential crop for farmers of Madhya Pradesh as the crop do not require intensive farm inputs. The crop is suitable for salt affected soils providing benefits ranging from INR.15-

20000/hectares/year to the poor family. These crops have great possibilities as large chunk of land is available to grow this plant where vegetables and food crops cannot grow. Factors like good pricing, lesser problems of pests were the motivating factors explored for the cultivation of Isabgol and shift farmers from the cultivation of wheat to Isabgol (Khan and Sharma, 2004).

The study was conducted to find agribusiness opportunities in MAP adoption, based on field level information from the state of Uttarakhand. The financial feasibility and identification of constraints that affect the spread of cultivation of medicinal plants were identified. The major hurdle between was the MAP farming was comparatively a new occupation for the farmers and the risks of failure were particularly high. The farmers faced serious market-related risks and difficulties in getting right price and industry has an upper hand in deciding the rate of the medicinal plant. Other constraints like high initial cost of production, poor quality of inputs, price fluctuations, lack of training programs on cultivation, prevalence of pests, high processing cost, improper handling of herbage, lack of awareness about export market and almost no implementation of GAP were some of the concerning factors. From the study it was concluded that essential parameters like inadequate processing capacities, price risks and non-availability of planting material were some of the constraints related to cultivation of medicinal plants and methods should be explored to overcome the constraints (Mittal and Singh, 2007). Another study was conducted to represent the adoption of Sustainable Agricultural Practices (SAP) to counter the threat of soil depletion for increasing per capita food production for small farmers. The study illustrated some of the adoption decision for sustainable agricultural practices using recent primary data of multiple plot level observations collected in 4 districts and 60 villages of rural Tanzania. The study adopted multivariate probit technique to model the adoption parameters. The analysis revealed that the parameters including rainfall, insect infestation, government effectiveness, plot location and size and household influenced the farmer's investment in SAP (Kassie *et al.*, 2013). Hence, policies must be drafted in order to promote the farmer's willingness to adopt medicinal plants in the state for sustainable agriculture and crop diversification.

In the study, the authors have assessed adoption of GAP in chilies cultivation by the farmers in southern districts of Tamil Naidu. It was concluded that the contract farmers (43.75 %) had high level of adoption followed by medium level (38.75 %).

Less adoption has been observed in the seed treatment process among contract (38.13 %) and noncontract (12.50 %) farmers. The major reason for non-adoption was the lack of knowledge. In order to increase the quality of chilies, the study suggested the need to intensify transfer of technology efforts to popularize the GAP practices by the concerned extension agencies on top priority (Divya and Sivakumar, 2014). In a study, Kanwat and co-workers highlighted that there was no mass adoption of medicinal plant cultivation in India, in this context they devised a survey-based study to determine various socio-economic factors of farmers involved in the decision-making process for the adoption of medicinal plants in the Udaipur and Chittorgarh regions of Rajasthan. A survey was conducted utilizing a random sampling technique in the rural areas using a pre-tested questionnaire. Reliability and validity of the questionnaire was checked to strengthen the dependability of the results. The selected samples were divided into adopters (medicinal plant cultivators) and non-adopters (non-medicinal plant cultivators) to understand the various socio-economic factors involved (Swiontkowski *et al*., 1999). For inferential data analysis, Mann-Whitney test was applied. The results indicated that age, utilization system, yearly income from farming, number of farm patches of the farmers were some of the important factors in medicinal plant adoption (Kanwat *et al.*, 2012). Similarly, another study was conducted to highlight various constraints faced by the farmers in cultivation of Ajwain in Chittorgarh district of Rajasthan. Primary data was collected through personal interviews of the farmers selected for the study using a questionnaire. Sample population was selected using stratified random sampling technique. Total 80 farmers were selected for the study from eight villages of two *Panchyat samities* of the district. It was observed that technical constraints such as complex cultivation practices, lack of agro-technology, untimely advice to the farmers, insufficient literature, etc. were major constraints perceived by the farmers. Followed by technical constraints was the marketing constraints *viz.* lack of regular market, high transportation charges, and unreliable market channels, etc. (Kanwat *et al.*, 2017).

2.11. AGRO-ECONOMICS

Agricultural economics or agro-economics is an applied field of economics based on applying economic theory in evaluating the production and distribution of food. It estimates the relation between the total input costs incurred by the farmers in agricultural processes with the gross returns to highlight returns of the variable costs (profit earned by the farmers). It calculated the per acre cost and returns involved in the cultivation. The cost A1 concept in economics study is one of the best methods to consider actual expenses in cash incurred in agricultural process by owner. It included labour (both human and machine) the costs of seeds, plant protection (insecticides, pesticides), fertilization, irrigation, transportation, miscellaneous expenses. The cost-return analysis are processed using statistics based on the average values of the crops to calculate total variable costs, yield, gross returns, returns over variable costs. The cost A1 analysis is one the most reliable method's for comparative analysis of the inputs given by the farmers (Kaur *et al.*, 2018a). The economics involved in the plant production varies from region to region. It is considered as one of the prerequisite study among the agricultural scientists before suggesting the commercial cultivation of the crop to the farmers. It also determines the potential input cost share of every agricultural process in total variable cost. In case of medicinal plants, there is less mechanization which leads to the high share of labour costs in production process. As described in section 2.3 of this chapter, Punjab relies on extensive cropping patterns and agro-economic studies are suggesting 'zero risks' in the production of rice and wheat as the major driving force for their success in the state.

At present, wheat contributes to approximately 80% of the sown agricultural area, and 60% under rice. Nearly, 85% of the value of crop output of state is given by these crops (Shergill, 2007). A study was published by the PAU Ludhiana, Punjab highlighting district wise cost of cultivation of important crops in Punjab. In this study, agro-economics study was carried out considering costs of wheat, paddy, basmati, potato, and peas in different districts of Punjab in the year 2018. The criteria i.e. crops having more than 5000 hectare of area in the state were finalized for the study. Expenses such as human labour, machine labour, hired machinery charge, cost of seeds, insecticides, pesticides, manure, irrigation, miscellaneous expenses were included in the study. The district wise average gross return of wheat was INR.77919 per hectare and the average returns over variable cost was INR. 54170/-. Similarly, for paddy, the district wise average gross return was calculated to be INR. 94034/- and returns over variable cost was Rs. 61530/- per hectare (Kaur *et al.*, 2018a).

A study was conducted to access the economic viability of organic wheat cultivation in 30 villages of Patiala and Faridkot districts, Punjab. The study was conducted in the year 2008-09 and 80 organic wheat cultivators and 75 inorganic wheat cultivators were selected for the study. The results indicated that the organic wheat incurred less total variable costs as compared to inorganic wheat. The net returns for the organic wheat was higher (INR. 21895/acre) than the inorganic wheat (INR. 16700/acre). However, less productivity (6.7 quintal per acre) was observed in the case of organic wheat as compared to inorganic wheat but the yield was compensated by the higher price it fetched in the market (Singh and Grover, 2011). This study provided a clear understanding that organic cultivation is much more beneficial than the inorganic cultivation in terms of economics. In case of medicinal plants also, it is recommended not to use chemical fertilizers or pesticides during its production providing safety to the end user. Different agro-economics studies are available for various medicinal plants in different regions of India. It is a matter of fact that market of medicinal plants is volatile and varies on region and the demand for specific medicinal plants. Hence, it becomes important to conduct and update agro-economic studies with time considering the inflation of various agricultural input costs that solely depend upon government policies.

A study was conducted by Suresh and co-workers to determine the cost-return analysis and marketing of aromatic plants in Uttar Pradesh. The production cost of medicinal plants such as *O. sanctum, Mentha spicata, Chrysopogon zizanioides* was analyzed using farm-level data from Sitapur, Barabanki, and Raebareli districts. The study highlighted the cultivation of these plants as highly profitable. The returns over cost were higher in *Chrysopogon zizanioides* (INR. 1,53,933/ha) followed by *Mentha spicata* (INR. 53,250/ha) and *O. sanctum* (INR. 40,094/ha). Besides this, the cultivation of these species increased the employment generation in the rural areas. The major factor behind adoption of these species was education of the farmer. The study also underlined the need for providing improved cultivation practices, quality planting material, extension services, and demonstrations plots (Suresh *et al.*, 2012). Similarly, DMAPR reported 15-20 tonne/ha. yield from second year of cultivation and highlighted INR. 10,000-20,000 as net profit of crop grown on marginal to sub-marginal lands (Jat *et al.*, 2015b). In the case of Tulsi, NMPB has highlighted INR.1,000/ as expenditure cost per/ha., INR. 5,000-6,000/- return per/ha., and INR. 4,000 to 5,000/- net income of the farmers (NMPB, 2009). It contrast agro-economics study contributes knowledge in the field of research, rural employment, trainings, project planning, analysis of micro and macro planning.