CHAPTER-5

RESULTS AND DISCUSSION

5.1. SELECTION OF MEDICINAL PLANTS

The medicinal plants for the agro-climatic studies were selected based on the consumption by the herbal industries, estimated annual trade, expert consultation and prior traces of their cultivation in the state (Goraya and Ved, 2017). The selected medicinal plants for the study are mentioned in Table 5.1.

Table 5.1: Medicinal plants selected for the agro-climatic zoning.

Medicinal plants	Estimated consumption by herbal industries (Dry weight MT)*	Estimated annual trade (MT)*
A. vera	15677.08	>10000
P. emblica	14178.23	>10000
W. somnifera	4198.0	2000-5000
G. glabra	2832.10	2000-5000
A. racemosus	2723.00	2000-5000
A. paniculata	1828.35	2000-5000
O. sanctum	1362.81	2000-5000
C. longa	1334.13	1000-2000
C. asiatica	781.02	500-1000
A. calamus	590.10	500-1000
R. serpentina	275.34	200-500
O. basilicum	73.30†	200-500
C. borivilianum	25.80†	100-200

The industrial experts from leading herbal industries *viz.* Dabur Ghaziabad, Unnati Marketing Cum Processing Society Ltd. Talwara, Hoshiarpur, Herbal Trends Gidderbaha etc. were consulted for the selection of medicinal plants for the present study. Similarly, experts from NMPB, RCFC-North, Ministry of AYUSH, FITM, State Forest Department Punjab, PAU Ludhiana also gave positive inputs regarding the medicinal plants. It was observed that among these 13 medicinal plants, 05 medicinal plants were cultivated by the farmers of Punjab, therefore, five medicinal plants *viz. A. vera, P. emblica, O. sanctum, C. longa*, and *R. serpentina* were selected for survey-based study to understand constraints in medicinal plants adoption. In context to agricultural pattern in Punjab, the state required competitive medicinal

* Report on Medicinal Plants in India: An Assessment of their Demand and Supply” by National Medicinal Plant Board and Indian Council of Forestry Research and Education, Dehradun, compiled by G.S. Goraya and D.K. Ved, 2017.

† Estimated total annual consumption (MT) by the rural households.

plants that could compete with conventional crops such as wheat and rice. In this context, out of these five medicinal plants, three medicinal plants i.e. *A. vera, O. sanctum, C. longa* were selected further for the development of GAP monographs based on their short crop cycle in terms of first harvest as *P. emblica* and *R. serpentina* gave first harvest after 3-4 years and 18 months respectively. Furthermore, all the selected medicinal plants were among top 198 medicinal species covering 95% of total herbal raw drugs consumed by the Indian herbal industry (Goraya and Ved, 2017).

5.2. AGRO-CLIMATIC FEASIBILITY ANALYSIS INCLUDING AGRO-CLIMATIC MAPPING AND ZONING TO FIND BEST SUITABLE ZONE OF THE SELECTED MEDICINAL PLANT

5.2.1. Collection of Meteorological Data

The annual temperature data obtained from the various research stations depended upon the availability of the data and time-period of the data in particular station as mentioned in Table 5.2. The maximum average temperature (31.3 °C) was observed in the research station present in the Bathinda district of Punjab represented in zone-IV, similarly the minimum average temperature (15.5 °C) was observed in the research station present in Amritsar district represented in zone-II. The cropping pattern in Punjab is divided into *kharif* and *rabi* season representing the sowing of crops at the beginning and the end of the rainy season respectively (Kaur *et al.,* 2010). Two major crops of Punjab i.e. Rice and Wheat are sown in *Kharif* and Rabi season respectively. As per the climatic data, the mean maximum temperature during the *Rabi* and *Kharif* season was 25 °C and 38 °C respectively. The average annual temperature of the state was 23.9°C. However, the mean maximum and minimum temperature can reach 44°C maximum and 8 °C minimum. Long term historical meteorological analysis of Punjab revealed that the frequency of occurrence frost was limited to only two days in December, five days in January, and one day in February (Kaur *et al.,* 2016).

Table 5.2: Research stations with temperature ranges in Punjab.

Research stations	Location co-ordinates of research stations	Period of collected data	Representing agro-climatic zone	Average minimum and maximum temperature ranges (°C)	Average temperature range of the stations (°C)
Ballowal Saunkri	31.0993 °N, 76.3870 ° E	1984-2015	Zone-I and II	16.2-30.0	23.1
Amritsar	31.6340 °N, 74.8723 ° E	1970-2018	Zone-II and III	15.5-30.3	22.9
Jalandhar	31.3260 °N, 75.5762 ° E	1971-2015	Zone-II and III	16.4-29.3	22.85
Ludhiana	30.9010 °N, 75.8573 ° E	1970-2018	Zone- II and III	16.7-29.8	23.25
Patiala	30.3398 °N, 76.3869 ° E	1970-2018	Zone-II and III	17.6-30.2	23.9
Bathinda	30.2110 °N, 74.9455 ° E	1977-2015	Zone-IV	16.9-31.3	24.1
Faridkot	30.6769 °N, 74.7583 ° E	2000-2015	Zone-IV	20.3-29.9	25.1
Abohar	30.1469 °N, 74.2008 ° E	2004-2015	Zone-V	17.6-30.2	23.9

The Indian climate is mainly characterized by monsoon rainfall as supported by several studies (Krishan *et al.,* 2015). The rainfall data collected from the research stations ranged from 350-above 1000 mm as mentioned in the Table 5.3. The maximum amount of rainfall was received during the southwest monsoon occurring from June to September. There is a high variability of rainfall in space and time in Punjab. The annual rainfall variability in Punjab is 25 to 30 per cent while monthly variability ranged between 35 to 230 per cent (Kaur *et al.,* 2016). The zone-I represented the highest level of rainfall ranging from 1000-1500 mm followed by zone-II, III, IV, and V. The zone-V represented the lowest range of rainfall in Punjab covering south western districts of Punjab such as Fazilka.

Table 5.3: Research stations with rainfall ranges in Punjab.

Station	Location co-ordinates	Period of collected data	Total rainfall (mm)	Representing agro-climatic zone	Total rainfall range (mm)
Ballowal Saunkri	31.0993 °N, 76.3870 ° E	1984-2015	1049	Zone-I & II	1000-1500
Gurdaspur	32.0414 ° N, 75.4031 ° E	2002-2018	1063		
Jalandhar	31.3260 °N, 75.5762 ° E	1971-2018	990	Zone-II & III	550-1000
Amritsar	31.6340 °N, 74.8723 ° E	1970-2018	722		
Patiala	30.3398 °N, 76.3869 ° E	1970-2018	774		
Ludhiana	30.9010 °N, 75.8573 ° E	1970-2018	759		
Nawashahr	31.1256 ° N, 76.1186 ° E	2004-2018	749		
Bathinda	30.2110 °N, 74.9455 ° E	1977-2018	517	Zone-IV	350-550
Faridkot	30.6769 °N, 74.7583 ° E	2000-2018	468		
Mukstar	30.4762 ° N, 74.5122 ° E	2004-2018	368		
Abohar	30.1469 °N, 74.2008 ° E	2004-2015	323	Zone-V	<350

5.2.2. Base Maps

As agro-climatic zones are classified on the basis of common ecological parameters, so the temperature range corresponding to the research station present in the specific zone was considered the temperature of the entire agro-climatic zone. The research stations from where meteorological data was collected were geo-tagged using their latitude and longitude specifications on digital maps using GIS. The annual average maximum and minimum temperature ranged between 29 to 32 °C and 15-20 °C respectively in Punjab. The mean annual rainfall in the state and different locations ranged from 400 to more than 1000 mm. The base maps of temperature and rainfall are represented in the Fig. 5.1 and 5.2. On the other hand, an agro-eco-subregion based benchmark soils network was utilized for the preparation of digital soil maps based on texture and pH. In the agro-eco-subregion model, soils in the same family generally required the same management practices and maximum production result acquired from a soil family can be utilized as production targets of other soils belonging to the same family (Kumar *et al.*, 2008; Chahal, 2005; Saini *et al.*, 1995). The base maps for the soil highlighted that the agro-ecological zone-I comprised of sandy skeleton, loamy sand and sandy loamy soil with pH ranging from 7.5 to 8.2. The zone-II represented sand to loamy sand, to calcareous soils with pH 6.8 to 8.3;

zone-III represented sandy loam to clay loam to calcareous soil with pH 7.5 to 9.3; and zone-IV and V corresponded to sandy loamy soils to loam and calcareous soils with pH 8.1 to 8.5. The base maps corresponding to the soil texture are represented in the Fig. 5.3.

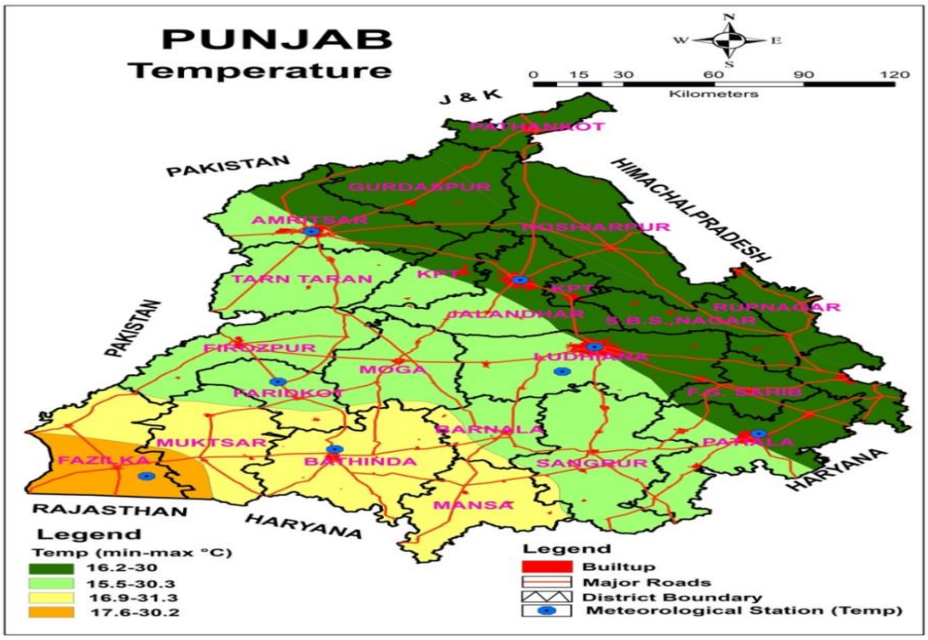


Figure 5.1: Spatial distribution of meteorological research stations representing average maximum and minimum temperature ranges.

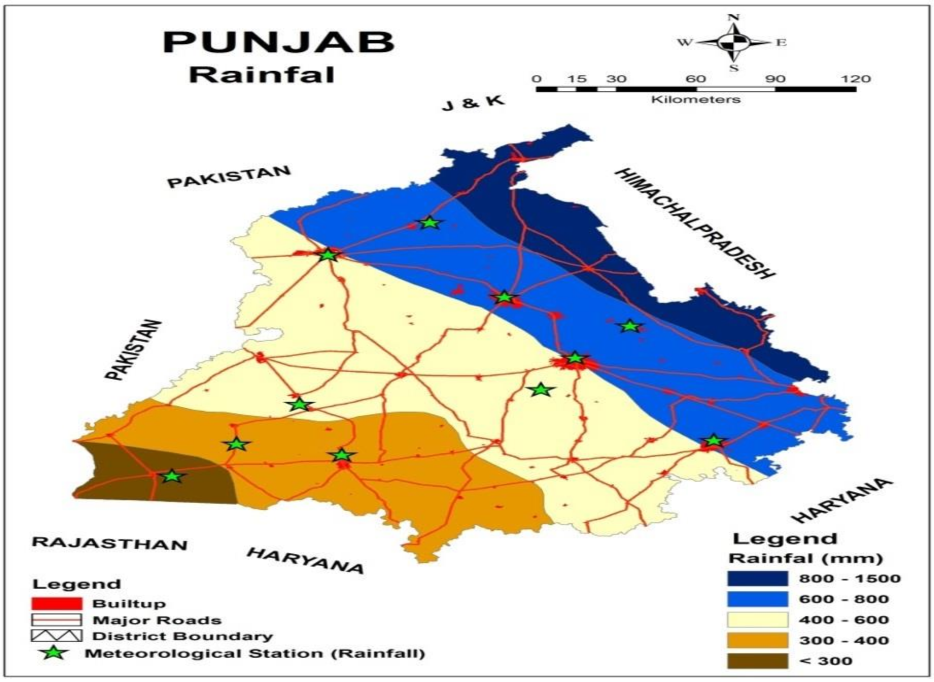


Figure 5.2: Spatial distribution of meteorological research stations representing rainfall ranges.

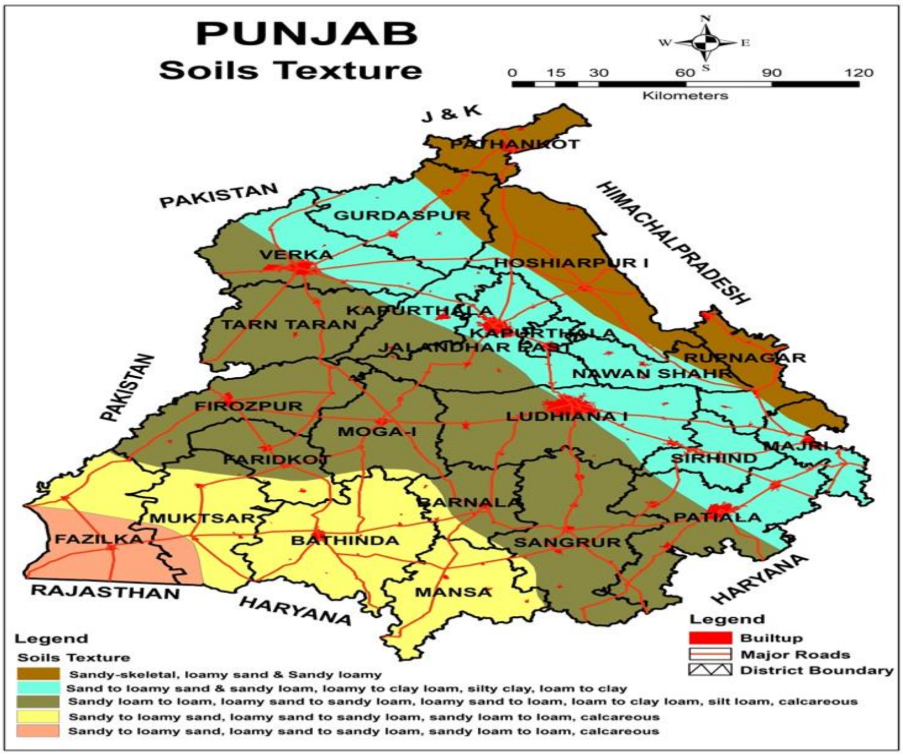


Figure 5.3: Soil texture of benchmark soils present in Punjab.

5.2.3. Ecological Requirements of Selected Medicinal Plants

To conduct agro-climatic feasibility studies, the primary step was to highlight optimum climatic requirements of the selected medicinal plants and then correlate the requirements with the climatic conditions offered by the different climatic zones of Punjab. For this, extensive literature was surveyed to highlight standard climatic and edaphic requirements for the medicinal plants *viz*. *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* (Anonymous, 2016; Anonymous, 2014; Jat *et al.*, 2015a; Jat *et. al.*, 2015b; Jat *et al.*, 2015c; Jayashree *et. al.*, 2015; Anonymous 2008; FAO, 2007). As a result, requirements, limits and tolerance of bio-meteorological conditions of selected plants were identified taking into account the climatic characteristics of the native areas for the successful cultivation of selected medicinal plants in Punjab. The optimum ecological requirements for the selected medicinal plants were highlighted to corroborate with the ranges of temperature, rainfall and soil digital base maps. The standard ecological requirements of the selected medicinal plants are mentioned in Table 5.4.

Table 5.4: Standard ecological requirements of medicinal plants.

Name of the plant	Average annual temp (°C)	Average annual rainfall (mm)	Soil texture	Soil pH	References
A. vera	20-40	350-400	Loam to coarse sandy loam	Up to 8.5	Bahmani *et al.*, 2016; Jat *et al.*, 2015b; Cousins and Witkowski, 2012
P. emblica	14-35	700-4200	Loamy soil, calcareous, rocky substratum	Up to 8.5	Liu *et al.*, 2020; Jalal *et al.*, 2018; Anonymous **,** 2008
W. somnifera	20-35	600-750	Sandy loamy	7.5-8	Jat *et al.*, 2015a; Kumar *et al.*, 2012
G. glabra	5-25	300-1200	Sandy loamy	5.5-8.2	Anonymous, 2014; FAO, 2007
A. racemosus	17-40	600-1000	Sandy loam to clayey loam	6-8	Kaur *et al.*, 2018b; Joshi, 2016; Sharma and Sharma, 2013
A. paniculata	14-38	1500-4000	Sandy loam to clayey loam	6.5-8.5	Verma *et al.*, 2019; Anonymous, 2014; Niranjan *et al.*, 2010; Patra *et al.*, 2004
O. sanctum	15-35	700-7600	Sandy loamy	5-8.5	Jat *et al.*, 2014; Makri and Kintzios, 2008; FAO, 2007
C. longa	20-35	800-1500	Sandy or clay loam	4.5-7.5	Jayashree *et al.*, 2015
C. asiatica	28-44	800-1500	Sandy loamy to clayey soil	6- 7.5	Times-is, 2009a
A. calamus	10-38	430-4200	Clayey loam & sandy loam	5.5-7.5	Times-is, 2009b
R. serpentina	10-38	1100-4500	Sandy loam	6-8	Bhattarai, 2013; FAO, 2007
O. basilicum	7-36	600-4300	Rich loam to poor laterite, sandy loam soil	4.3-8.2	Jat *et al.*, 2014; FAO, 2007
C. borivilianum	15-35	500-1500	Loamy to sandy loamy clay	Not more than 8	Tiwari, 2018; Jat *et al.*, 2015c; Vijaya and Chavan, 2009

5.2.4. Agro-climatic Zoning Model

Before introducing a new crop in an area, such as medicinal plant species, crop-land suitability analysis is a prerequisite to achieve an optimum exploitation of the available land resources for a sustainable agricultural production. To evaluate the land suitability it is important to take into account the habitats of the plant species. Moreover, agronomic, logistic and product quality aspects have to be considered.

Sustainable and rational use of land has become the key issue for policymakers, government, and land users for preserving the resources for present and future generations. In view of the above, agro-ecological zoning model to highlight potential growing areas of medicinal plants can be an initial step towards diversification (Kaur *et al.,* 2015; Ghatak and Roy, 2007; Singh and Sidhu, 2004; Chand, 1999; FAO, 1996).

The base maps of temperature, rainfall, soil were superimposed to highlight optimally suitable zone (having all the climatic and edaphic parameters common with the bio-meteorological requirements of selected medicinal plants), suitable zone (having only two parameters common with the bio-meteorological needs of selected medicinal plants), and lesser suitable zone (having only one parameter common with the bio-meteorological need of the plant). The suitability studies for the selected medicinal plants are mentioned below:

A. vera: It is a perennial plant that requires rainfall ranging from 350-400 mm with coarse sandy loam soil. According to the present agro-climatic zoning model, the zone-IV comprising of Mansa, Bathinda, and Muktsar districts was found to be optimally suitable for its cultivation due to suitable rainfall besides temperature, soil and pH ranges as represented in Fig. 5.4. However, it can also be grown on zone-V (comprising of Fazilka district) with more number of irrigation cycles for its optimum growth besides considering suitable soil characteristics.

P. emblica: Based on the present agro-climatic zoning model, it was found optimally suitable for zone-I and II due to optimum rainfall range (700-4200 mm rainfall) besides suitable temperature and benchmark soil characters as represented in Fig. 5.5. Due to its suitable temperature and soil conditions across the Punjab, it can be cultivated in all the remaining three zones with more irrigation cycles.

W. somnifera**:** It is cultivated as a *kharif* crop (starting from June and ending October) in India. The mean maximum and minimum temperature during *kharif* season ranged from 34.4-36.7°C to 22.4-26.7°C which can be correlated to its suitable cultivation during *kharif* season in Punjab. It required rainfall ranging from 600-750 mm, and the *kharif* season rainfall varied from approximately 262-888 mm across Punjab, which further supported the suitability of zone-II and III for the optimum cultivation of *W. somnifera* besides suitable temperature and soil characters. Whereas, zone-V had only temperature regimes suitable for its cultivation so it was considered lesser suitable zone, zone-I and IV were considered suitable due to more rainfall in zone-I and unsuitable soil pH of zone-IV corresponding to the requirements of the plant as mentioned in Fig. 5.6.

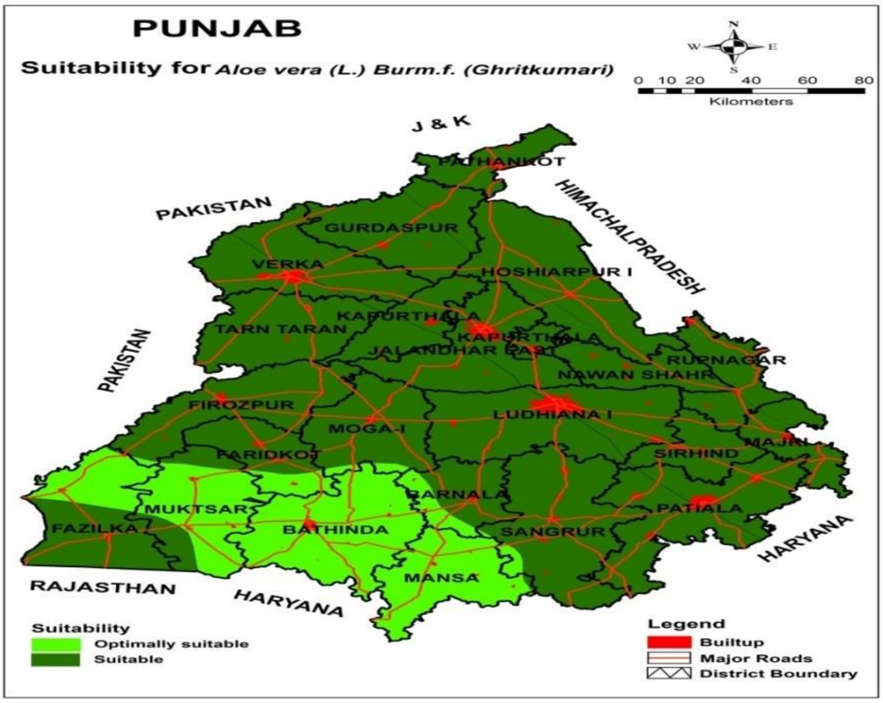


Figure 5.4: Potential growing areas of *A. vera* in Punjab.

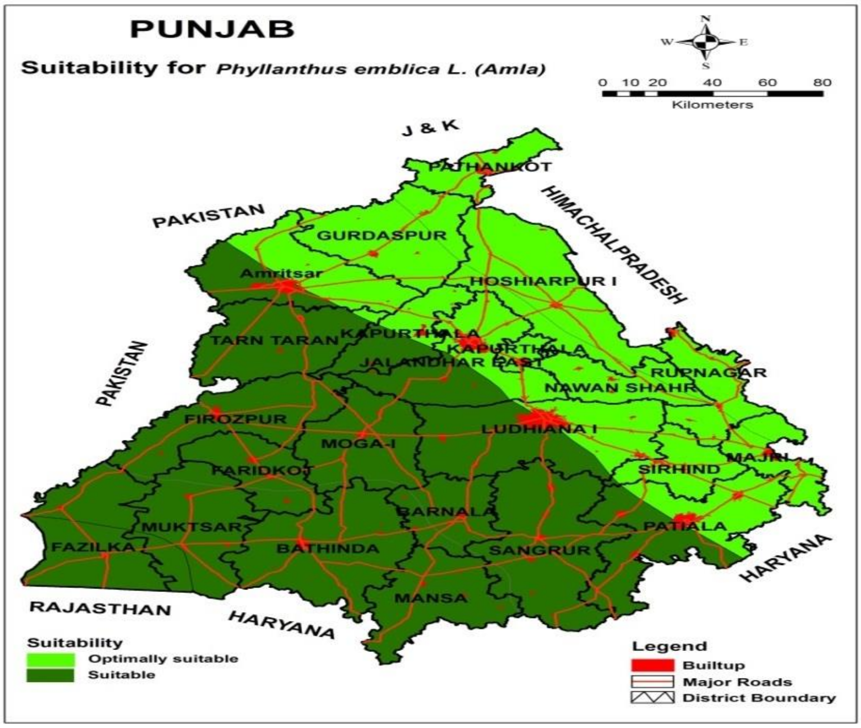


Figure 5.5: Potential growing areas of *P. emblica* in Punjab.

G. glabra: This perennial plant survives at temperature ranging from 5-25°C, it required rainfall between 300-1200 mm annually, and is suitable for sandy to loam soils with pH 5.5-8.2. Considering its agro-ecological requirements and its adaptability in diverse climatic conditions, it can be optimally grown in all parts of Punjab as represented in Fig. 5.7.

A. racemosus: It is a perennial plant, whose roots are consumed for various pharmacological actions. The plant requires annual rainfall from 600-1000 mm that was optimally suitable to zone-II and III of Punjab. Similarly, sandy loam to clay loam soil with pH 6-8 is best suited for the cultivation of the plant. According to the present agro-climatic zoning model, *A. racemosus* was optimally suitable (15.5-30.3 °C; rainfall 550-1000 mm; sandy skeleton, loam to clayey loam to silt clay and calcareous with pH range 6.8-9.3) corresponding to agro-climatic zones II, III; suitable (16.9-30 °C; rainfall 1000-1500 mm; sandy to loamy sand and calcareous with pH 7.5-8.2) corresponding to zone I and less suitable (16.9-30 °C; rainfall 550 to less than 350; sandy to loamy sand and calcareous with pH 8.1-8.5) corresponding to zone IV and V, as represented in Fig. 5.8.

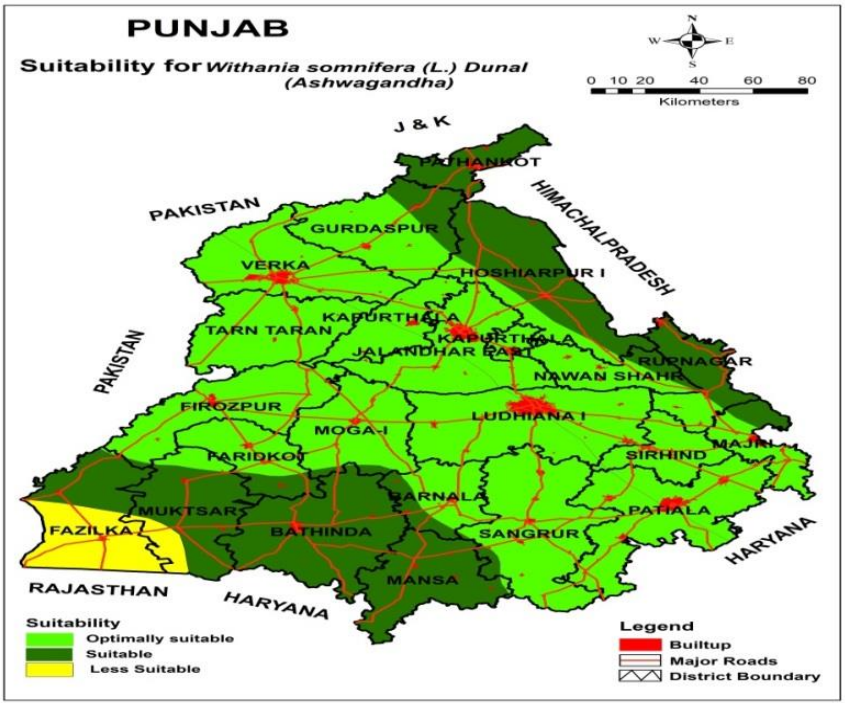


Figure 5.6: Potential growing areas of *W. somnifera* in Punjab.

A. paniculata: In most parts of India, it is cultivated as a *Kharif* crop that requires 1500-4000 mm rainfall. Due to its higher requirement of water, it was found suitable for zone-I corresponding to Roopnagar, Hoshiarpur and Pathankot districts of Punjab. Considering its suitability for temperature and soil, it can be cultivated in all the remaining zones of Punjab by adopting higher frequency of irrigation cycles, as represented in Fig. 5.9.

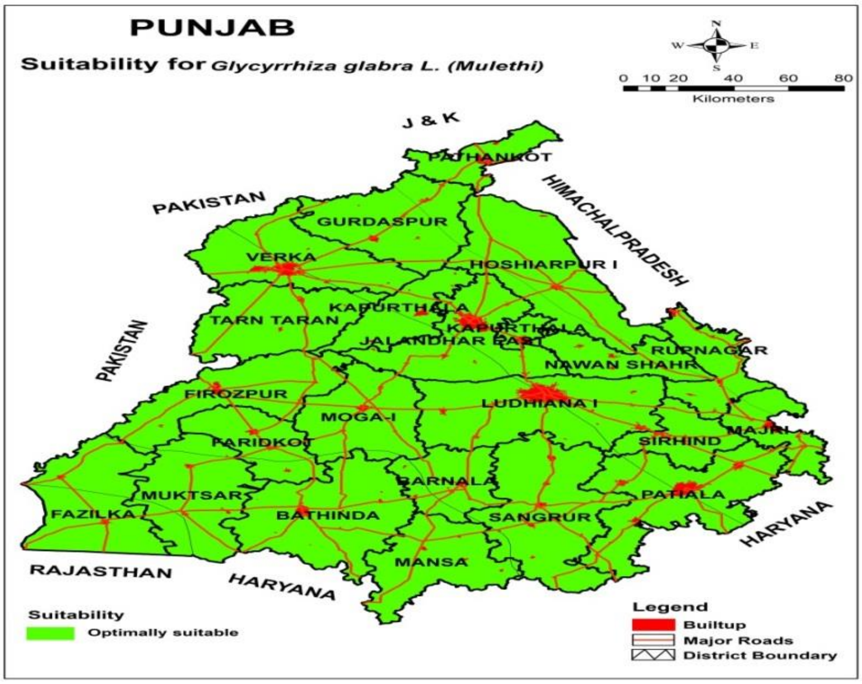


Figure 5.7: Potential growing areas of *G. glabra* in Punjab.

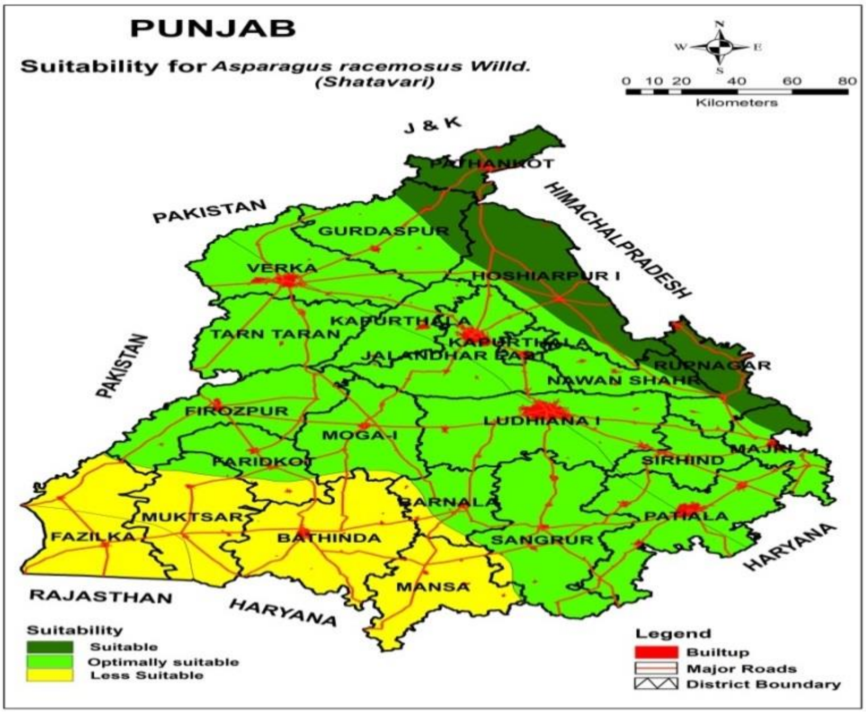


Figure 5.8: Potential growing areas of *A. racemosus* in Punjab.

O. sanctum: It is widely cultivated in India due to its adaptability in diverse climatic conditions. According to the present agro-climatic study, it was found optimally suitable for the zones-I, II and III due to favorable temperature (15-35 °C), rainfall (700-7600 mm), and soil parameters. Whereas, it was found suitable for the zones IV and V due to lesser rainfall ranges, as represented in Fig. 5.10.

C. longa: It is approximately nine month crop, which requires 20-35 °C annual temperature range for its growth. It was found optimally suitable for the zone-I and II due to suitable temperature, rainfall and soil characteristics. The zone-III was considered suitable due to suitable soil, and temperature ranges corresponding to the requirements of the plants. On the other hand, zone IV and V were marked as lesser suitable because of unfavorable soil pH and rainfall as represented in Fig. 5.11. However, the plant can be cultivated in zone-III by increasing the irrigation cycles for the plant. Similarly, certain soil treatments enabling required pH and more irrigation cycles can prompt its cultivation in zone-IV and V as well.

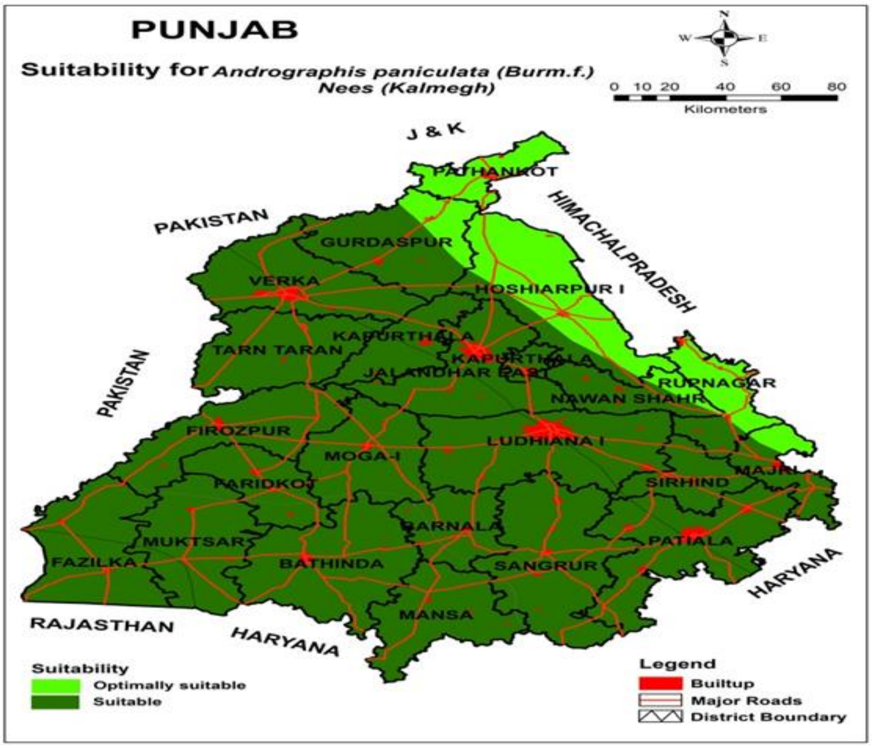


Figure 5.9: Potential growing areas of *A. paniculata* in Punjab.

C. asiatica: The plant is cultivated in the month of June and is harvested after 5-6 months. Therefore, it can be considered as a *kharif* crop that required good amount of rainfall. As discussed, the annual *kharif* season rainfall varied from approximately 262-888 mm across Punjab. Therefore, the rainfall requirements of the plant (800-

1500 mm) can be corroborated with the rainfall ranges of zone-I and II for its optimum cultivation besides suitable temperature and soil ranges. On the other hand, it is lesser suitable for the zone-IV and V due to low rainfall and high soil pH ranges as represented in Fig. 5.12.

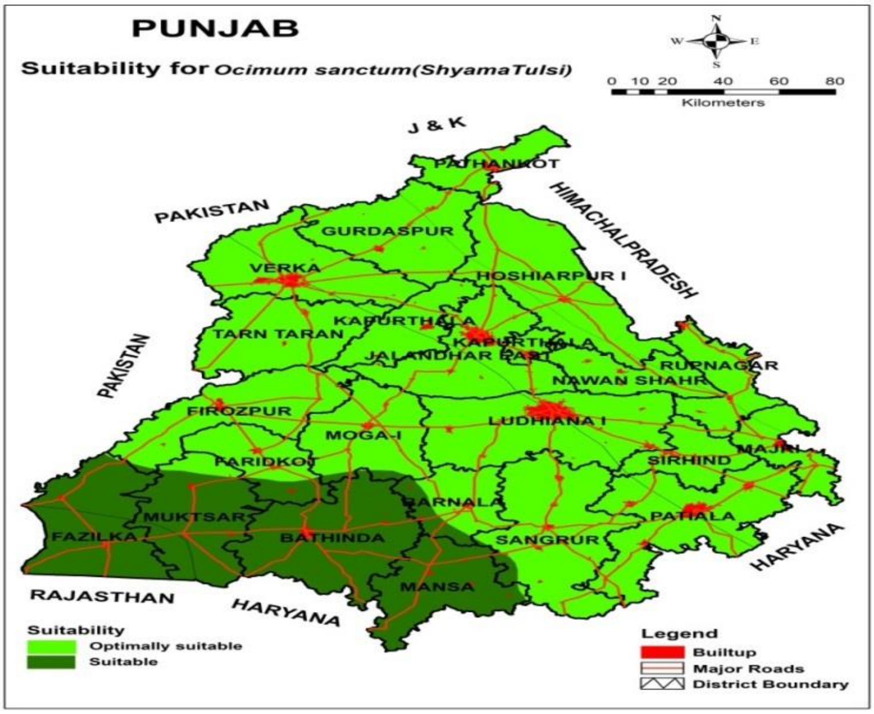


Figure 5.10: Potential growing areas of *O. sanctum* in Punjab.

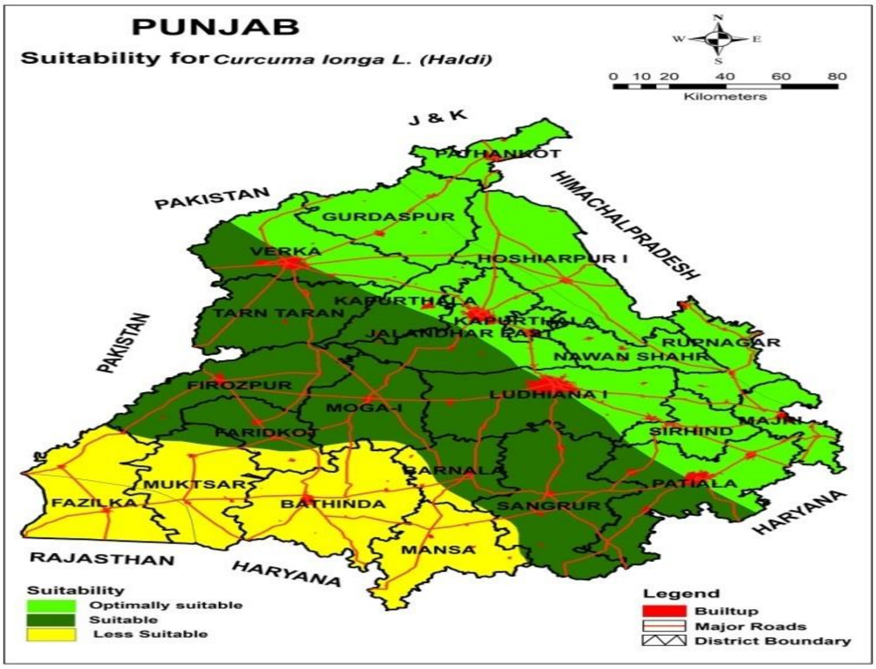


Figure 5.11: Potential growing areas of *C. longa* in Punjab.

***A. calamus*:** This is a perennial, and water-smelly plant. It was found optimally suitable for the zones-I, II, and III due to favorable climatic and edaphic requirements. Due to its semi-aquatic nature, it can be grown in waste-lands, water logged and marshy soils. It was considered less suitable for the zone-V corresponding to Fazilka district due to lesser rainfall, and more soil pH as represented in Fig. 5.13.

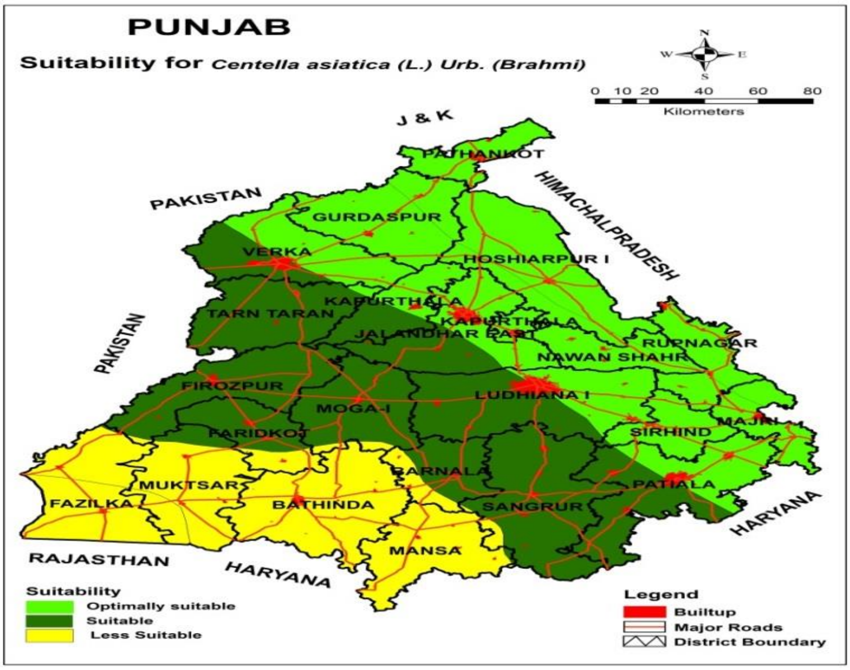


Figure 5.12: Potential growing areas of *C. asiatica* in Punjab.

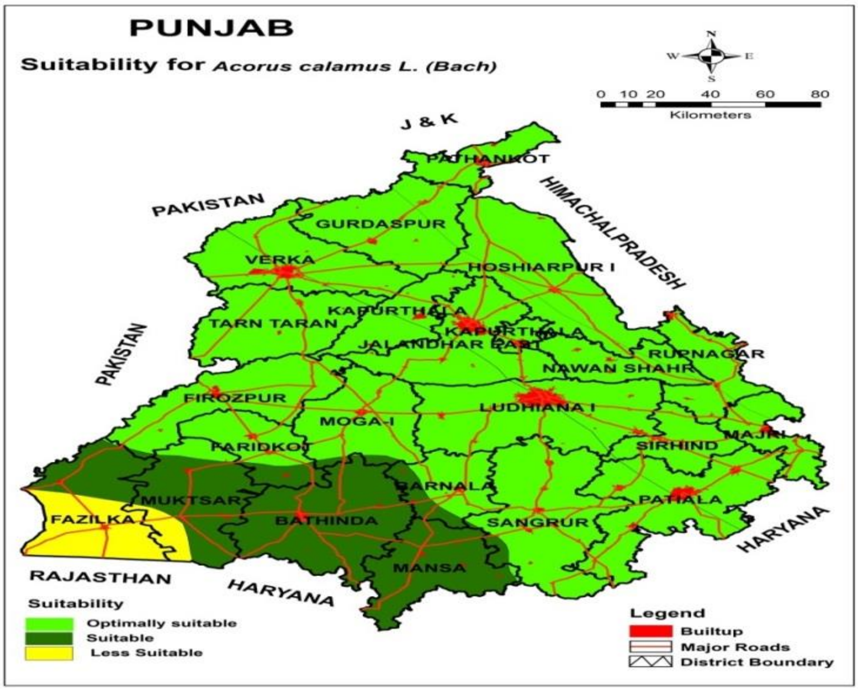


Figure 5.13: Potential growing areas of *A. calamus* in Punjab.

R. serpentina**:** The bio-meteorological requirements and climatic conditions for the plant suggested that it was: optimally suitable (16.2-30 °C; rainfall 1000-1500 mm; sandy skeleton loamy sand to sandy loam pH range 7.5-8.2) corresponding to agro-climatic zone I; suitable (15.5-30.3 °C; rainfall 550-1000 mm; sandy to loamy sand, silt clay-loam and calcareous with pH 6.8-9.3) corresponding to zone II & III; less suitable (16.9-31.3 °C; rainfall <350-550 mm; sandy to loamy sand and calcareous with pH 8.1-8.5) corresponding to zone IV-V as represented in Fig. 5.14.

O. basilicum**:** Similar to *O. sanctum,* it was also found optimally suitable for the zones-I, II and III. Subsequently, it was found suitable for the zone-IV and V as represented in Fig. 5.15.

C. borivilianum**:** The crop is cultivated in the month of June considering the onset of the monsoon and is harvested after 04 months of planting. The mean maximum and minimum temperature during *kharif* season ranged from 34.4-36.7 °C to 22.4-26.7 °C in Punjab. Therefore, this plant can be optimally grown during the *Kharif* season with rainfall ranging from 500-1500 mm. Based on the agro-climatic zoning model, the plant was optimally suitable for the zones-I, II and III corresponding to Pathankot, Hoshiarpur, Roopnagar, Gurdaspur, Amritsar, Tarn taran, Ludhiana, Jalandhar, Patiala, Moga, Sangrur, Moga districts of Punjab. It was found suitable for the zone-IV due to higher pH ranges of benchmark soil. The zone-V was highlighted as lesser suitable zone due to higher pH of benchmark soil, and lesser rainfall ranges as represented in Fig. 5.16. However, appropriate treatments of the soils, and more irrigation cycles can convert the optimally suitable and lesser suitable zone into optimally suitable zones.

On developing agro-ecological zoning model for 13 medicinal plants, it was found that the agro-climatic zone-I was optimally suitable for *P. emblica*, *C. longa, O. sanctum*, *O. basilicum*, *R. serpentina*, *A. calamus*, *C. asiatica*, *G. glabra, A. racemosus, A. paniculata, and C. borivilianum*. Similarly, zone-II was optimally suitable for the all medicinal plants corresponding to zone-I except *A. paniculata*. Additionally, *W. somnifera* was optimally suitable for agro-climatic zone-II & III. Agro-climatic zone-III was optimally suitable for both the species of *Ocimum, A. calamus*, and *C. borivilianum*. Likewise, agro-climatic zone-IV was optimally suitable for *A. vera*.

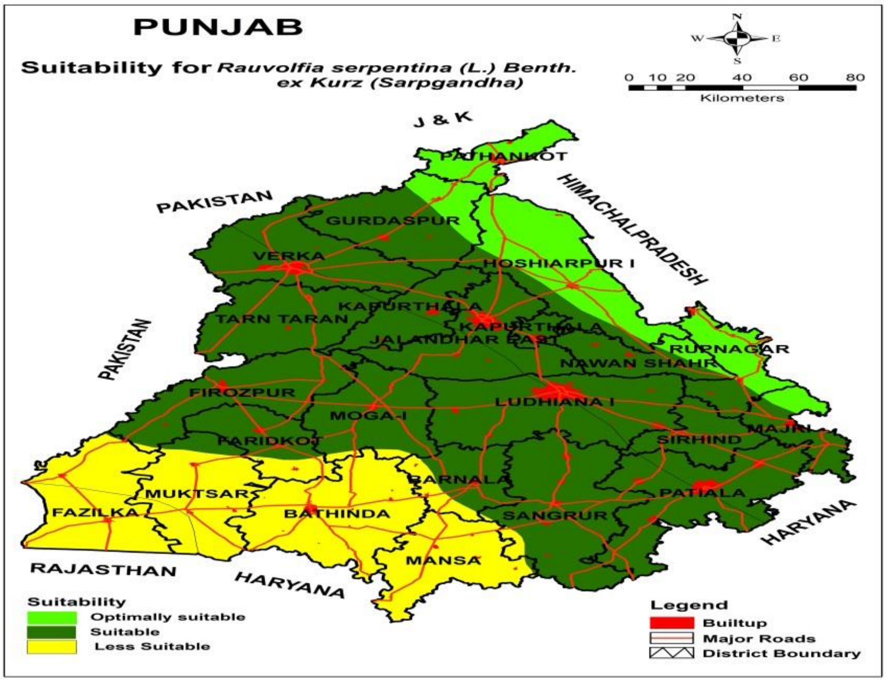


Figure 5.14: Potential growing areas of *R. serpentina* in Punjab.

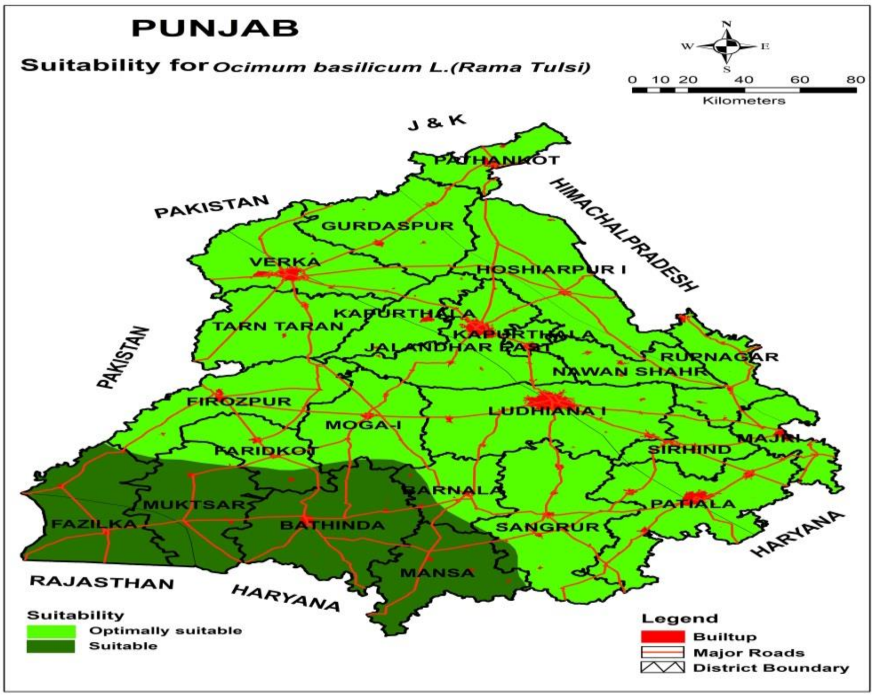


Figure 5.15: Potential growing areas of *O. basilicum* in Punjab.

A study was conducted that highlighted optimal cultivation of *A. vera* at 20-40 °C considering sandy soil having pH ranging upto 8.5 which can be co-related with the present agro-climatic zoning finding of the plant (Bahmani *et al*., 2016; Jat *et al*., 2015b).

Figure 5.16: Potential growing areas of *C. borivilianum* in Punjab.

Similarly, a study conducted by Singh and co-workers highlighted potential growing areas for medicinal plants such as *O. sanctum*, *R. serpentina*, *W. somnifera*, and *A. racemosus* using an agro-ecological zoning model in Punjab. The results highlighted that the agro-climatic zone-I was optimally suitable for cultivating *R. serpentina* and agro-climatic zones-I, II, II were found optimally suitable for cultivating *O. sanctum* which can be correlated with the present study in terms of plant's natural bio-physical requirements and obtaining good yields (Singh *et al.*, 2021a,b).

A report published by the NMPB has highlighted *P. emblica* can be best grown on loamy and calcareous soil with pH ranging upto 8.5. It also mentioned that 700-4000 mm annual rainfall was required for the plant's optimum growth (Anonymous, 2008). The plant is also reported to grow optimally at 14-35 °C annual temperature range, which can be corroborated with the present study that highlighted zone-I and II to be optimally suitable for the plant. In the present agro-climatic zoning study, *G. glabra* was found to be optimally suitable for all the zones of Punjab as it has diverse climatic adaptability (Anonymous, 2014; FAO, 2007). Likewise, some studies highlighted *A. paniculata* required 1500-4000 mm annual rainfall with 14-38 °C annual temperature for its optimal growth, therefore the present agro-climatic zoning study suggested zone-I to be optimally suitable for the plant as the upper region of the

Kandi belt is reported to offer suitable climatic conditions as per the plant's requirements (Verma *et al*., 2019; Patra *et al*., 2004). A study was conducted that described *C. longa* was best suited to grow at 15-35 °C annual temperature having sandy to clay loam soil (4.5-7.5 pH) with 800-1500 mm annual rainfall requirement which can be correlated to the present findings that highlighted zones I and II to be optimally suitable for the plant (Jayashree *et al.*, 2015).

A study conducted by the Technology Innovation Management & Entrepreneurship Information Service, Department of Science and Technology, Government of India, to find best growing climatic conditions for *C. asiatica* and *A. calamus.* The study highlighted that *C. asiatica* required sandy loamy to clayey soil possessing 6 to 7.5 pH, 800-1500 mm annual rainfall and 28-44 °C annual temperature ranges for its optimal growth. The findings of the study can be related to the results of the present agro-climatic zoning model that highlighted zones I and II offering the best climatic conditions and zones IV and V were highlighted to be lesser suitable as per the agro-climatic requirements for *C. asiatica*. Similarly, the study highlighted, 10-38 °C annual temperature, 430-4200 mm annual rainfall ranges with clayey loam to sandy loam (5.5-7.5 pH) soils which supported the findings of the present study that highlighted zones I, II and III were optimally suitable for the plant (Times-is, 2009a,b).

Likewise, Jat and co-workers highlighted, 15-35 °C annual temperature, 500-1500 mm annual rainfall, and loamy to sandy loamy soil having not more than 8 pH for the optimal growth of *C. borivilianum* which corroborated the findings of the present agro-climatic zoning model that suggested zones I, II, and III for its optimal growth (Jat *et al.,* 2015c; Vijaya and Chavan, 2009). Today, the use of natural products and treatments has become increasingly prevalent in place of chemical products. To this end, the identification of natural lands with vegetative potential of medicinal herbs can help in addition to the development of the medicinal plants in that area as a job and source of income to identify and protect these valuable sources of genetic resources (Hooshiar Khah and Mehdi Nejad, 2011). The place of medicinal plants has been privileged in India due to different weather, soil and climatic conditions. Given the fact that the use of medicinal plants has historically been one of the most effective methods of treatment, it seems necessary to recognize more the medicinal plants of each area (Nori and Rezaie, 2013). Climatic variation and different ecological conditions has led to the species diversity and richness of medicinal plants throughout the country.

Many studies related to the development of the agro-ecological zoning model have been conducted in past. In the year 2012, Falasca and co-workers have established a suitable agro-ecological zoning model to determine production areas of castor bean in Argentina. The study utilized meteorological data such as average temperature, annual rainfall, frost-free days for highlighting suitable production zones of the crop (Falasca et al., 2012). Similarly, potential growing areas for *Cyamopsis tetragonoloba, Acrocomia aculeate, Lesquerella fendleri, Jatropha curcas, Salicornia bigelovii, Camelina sativa, Panicum virgatum,* and *Argania spinosa* were highlighted in different zones of Argentina (Falasca *et al.,* 2018a,b, 2017a,b, 2016, 2015, 2013, 2012; Van Wart *et al.,* 2013; Fischer *et al.,* 2000).

Most of the studies on the agro-climatic zoning model were limited to analyzing the meteorological data such as temperature, rainfall, frost-free days, etc. for highlighting potential zones, however, the inclusion of significant land pattern data like soil texture and pH could have added more strength to the present work. Since benchmark soil network based on soil texture and pH had played a pivotal role in determining the land potential for selected medicinal plants, consideration of both meteorological as well as land pattern data was the major advantage of the current study. The present study was limited to the climatic data available at research stations, however, the findings could have been more specific if more meteorological stations were set up in the state. The study was limited to the findings based on temperature, rainfall, soil pH, and texture, however other climatic and edaphic variables can be considered in future studies taking this model as a case study. Besides following this agro-ecological model, the authors strongly recommend adopting GAP of the selected medicinal, resorting to prior assurance of the marketing to achieve quality-rich herbal produce with economic benefits.

Indian Institute of Tropical Meteorology (IITM), Pune prepared Providing Regional Climates for Impact Studies (PRECIS) model having simulated baseline (1961-1990) and mid to end century (2021-2100) climatic data for different agro-climatic zones were downscaled to check the projected climatic variability in Punjab. The model analyzed the changes in temperature and rainfall by mid (2021-2050) and (2071-

2100) under different scenarios classified as A1B (describing the future world of rapid economic growth), A2 (describing heterogeneous world), B2 (describing world emphasizing on local solutions to social, economic and environmental sustainability). The temperature and rainfall trend analysis revealed that by the end of the 21st century, there would be no significant change in temperature and rainfall under different scenarios of research stations (Kaur *et al.,* 2016). The study conducted by Krishnan and co-workers highlighted that there is no major climatic change observed from the year 1901 to 2018 in India and considering the projected climatic variability in Punjab, it is worthy to mention that there would be no significant effect on the climatic conditions of Punjab (Krishnan *et al.,* 2020; Kaur *et al.,* 2016). Considering this, it can be assumed that the present agro-ecological zoning model would be suitable up to at least 50 years for the domestication of selected medicinal plants.

At present, no policy regulates to suggest which medicinal plants are best suited in the right location. In this direction, this study would be helpful to the policymakers in suggesting optimal regions to cultivated selected medicinal plants. Based on available international and national bibliographic data, the climatic requirements for selected medicinal plants were identified. As a result, requirements, limits and tolerance of bio-meteorological conditions of the plants were identified taking into account the climatic characteristics of the native areas for the successful cultivation of selected medicinal plants. After obtaining bio-meteorological conditions, the base maps of temperature, rainfall, soil texture and pH were superimposed to find optimally suitable, suitable and less-suitable agro-climatic zones of selected medicinal plants in Punjab.

5.3. IDENTIFICATION OF MEDICINAL PLANTS CULTIVATORS

5.3.1. Collection of Medicinal Plant Cultivators Data from Various Channels

The data collected from all the explored channels, resulted into identification of 68 medicinal plant cultivators involved in commercial cultivation of medicinal plants like *C. longa A. vera*, *P. emblica, O. sanctum*, and *R. serpentina*. The farmers cultivating specific medicinal plants and area under cultivation are mentioned in Table 5.5.

Table 5.5: Number of medicinal plant cultivators and area under cultivation.

S.No.	Selected medicinal plants	No. of farmers	Total area of cultivation (Acres)/ No. of plants
1	*C. longa*	24	86.5 acres
2	*A. vera*	20	128.5 acres
3	*P. emblica*	16	13,370 plants
4	*O. sanctum*	05	04 acres
5	*R. serpentina*	03	03 acres

The medicinal plants cultivator data was obtained from the Regional-cum-Facilitation Centre (RCFC)-North as it provides facilitation and promoting the medicinal plants adoption and conservation. The NMPB through its facilitation centres provides a service window for growers of medicinal plants for supporting cultivation; provide handholding support to stakeholders in terms of technology dissemination, trainings, data compilation and maintenance etc. The facilitation centres works in close co-ordination with the concerned departments of Indian states and also provide training in the formulation of projects of medicinal plants cultivation, development. Likewise, state forest department, Punjab was consulted as it has direct linkage with the farmers of the state cultivating medicinal plants. The subsidies provided to farmers for cultivating selected medicinal plants are disbursed to the farmers through state forest department by the NMPB. The state horticulture department, Punjab deals with the horticulture and aromatic crops like *Curcuma longa* and other spices. The department provides facilities to the growers on priority basis to upscale the adoption of horticultural crops and therefore was consulted. Punjab Agricultural University Ludhiana, is engaged in providing agricultural extension services through a network of Krishi Vigian Kendras (KVKs) and Farm Advisory Services Centers (FASCs) located in different districts of the state. It has direct link with the farmers and potentiates quick transfer of technology among the farmers of the state and getting first hand feedback of their field problems, therefore PAU was consulted for obtaining farmer's data.

Following snowball method, various private channels were also explored in identification of medicinal plants cultivators. Personal appointments with the concerned officials of different herbal industries, herbal consortium, farmer-producer companies, traders of herbal *mandis*, and other progressive farmers throughout Punjab helped in determining medicinal plant cultivators. *Majith mandi* situated in Amritsar is the largest herbal *mandi* after *Khari Baoli* herbal *mandi* of Delhi, India. It has approximately 35 traders and more than 70 major entities are traded from the mandi with annual trade volume of approximately 20,000 MT (Ved and Goaraya, 2017, Singh *et al.*, 2021). Similarly, attending seminars and MAP stakeholders meeting conducted by the NMPB helped in getting substantial data regarding farmers cultivating medicinal plants in Punjab. The medicinal plants adopted by the farmers of Punjab have huge industrial demand (as these species are among 198 species classified by the NMPB covering 95% of herbs consumed by herbal industry) and possess large spectrum of pharmacological values (Goraya and Ved, 2017).

5.4. GEO-TAGGING OF MEDICINAL PLANTS CULTIVATORS USING GIS

5.4.1. Spatial Distribution of Farmers on Agro-ecological Zones of Punjab

Geo-tagging is a function of the location services associated with your devices. It's powered by the Global Positioning System (GPS) or satellite positioning used by your system and based on the position and co-ordinates of the metadata, geo-tagging may be used to find location-specific destinations. In the present study, it was found that 24 *C. longa* farmers were found in almost every district of Punjab, 20 farmers were cultivating *A. vera* in Bathinda, Shri Mukstar Sahab, Mansa, Roopnagar districts. Similarly, 16 farmers were cultivating *P. emblica* in Hoshiarpur district, 05 *O. sanctum*, and 03 *R. serpentina* farmers were cultivating in Roopnagar district. The geo-tagging of farmers on the agro-ecological specific map has been carried out using GIS. The geo-tagging helped in mapping the medicinal plant cultivators, which potentiated to determine the number of farmers cultivating the specific medicinal plant in the specific agro-ecological zone of Punjab highlighting the natural biophysical potential of the specific area as represented in Fig. 5.17.

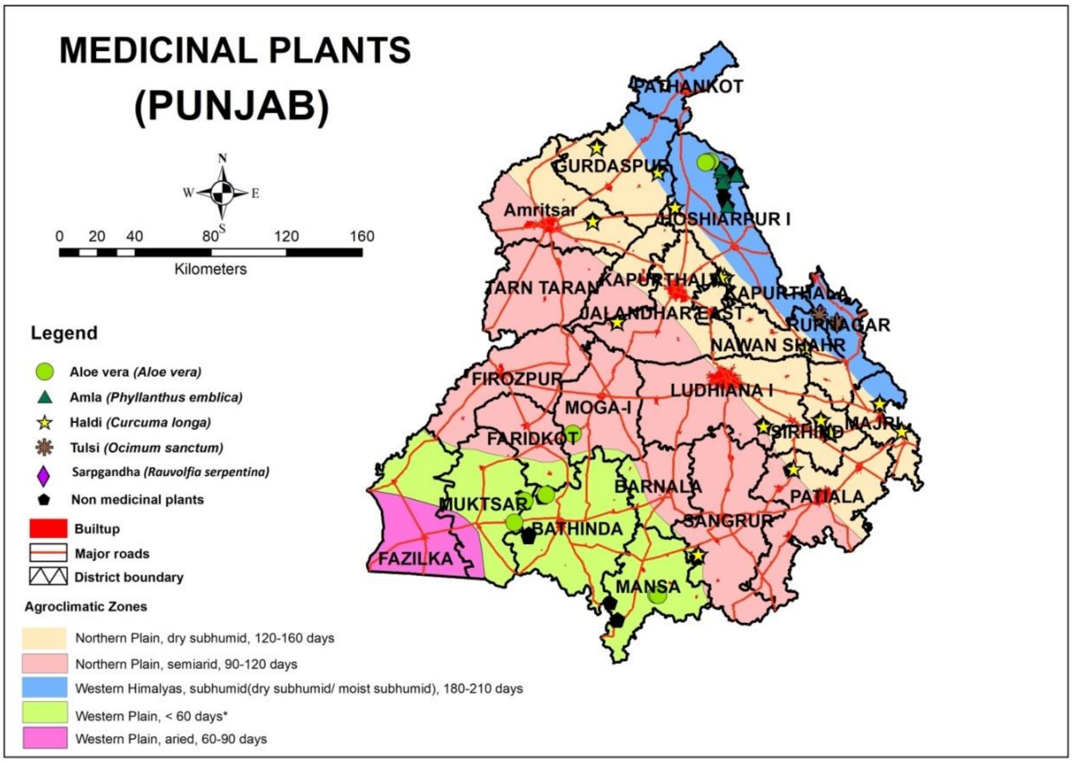


Figure 5.17: Geospatial distribution of medicinal plant cultivators on agro-climatic zones of Punjab.

P. emblica is found in tropical and sub-tropical regions. It is native to southeast Asia's moist and deciduous forests and is found along the hill slopes ranging 800-1500 m and above altitude. In the present study, it was observed that *P. emblica* was mostly cultivated in the western Himalayas, subhumid agroclimatic zone of Punjab which can be corroborated to its suitable agro-ecological requirements as per the literature (Anonymous, 2009). *R. serpentina* is native to tropical and sub-tropical regions and is found up to an elevation of 1300-1400 m requiring 1100-4500 mm annual rainfall. In the present study, *R. serpentina* was found to be cultivated in agro-climatic zone-I (western Himalayas, sub-humid belt) by the farmers, which can be attributed to the plant's suitable agro-ecological requirements (Bhattarai, 2013). *O. sanctum* which is found in the entire Indian subcontinent ranging from the Himalayas (1800 m) to Andaman and Nicobar islands, was cultivated in the agro-climatic zone-I (western himalayas, sub-humid belt) corresponding to its suitable agro-ecological conditions (Jat *et al.,* 2014). *A. vera* originated in Africa due to dry climate, hence it is highly suited for aried and semi aried zones corroborating with the findings of the present study, in which it was predominantly found in the western plain aried zone of Punjab (Eshun and He, 2010). *C. longa* is found in diverse tropical regions from sea level to 1500 m above sea level. It was observed that the plant was cultivated in different agro-climatic zones of Punjab especially in the northern plain, dry subhumid zone, and western himalayas, subhumid agro-climatic zones, which represented its natural agro-ecological requirements.

5.4.2. Embedding of Farmer's Demographic in Maps

In developing countries like India, information on medicinal plant cultivators, private health providers, etc. is scanty and also scattered. This is a major hurdle for effective health care planning, linkage with industries, trade and policy development (Deshpande *et al.*, 2004). In this context, the farmer's demographic information was digitalized and embedded on respective maps. Relevant data was inserted in such a way that the detailed information like name of the farmer, photograph of the farmer, father's name, village, district, a medicinal plant cultivated, its area and contact number displayed on each marking on the map, when clicked, as represented in Fig. 5.18.

In the present study, a systematic survey of medicinal plant cultivators has been carried out by digitally mapping the cultivators with their socio-demographic characteristics using GIS. Punjab alone has 284 licensed herbal units based on Ayurveda out of 1,95,000 herbal units across India (Goraya and Ved, 2017). Therefore, digital mapping, representing collected data compiled in a virtual image could be used to link clients, farmers, industries, and concerned officials to plan strategies for improved access, trade, and outreach in the future studies. Mapping also potentiated to determine the number of farmers cultivating particular medicinal plant in a specific agro-climatic zone of Punjab highlighting the natural biophysical potential of the specific area.

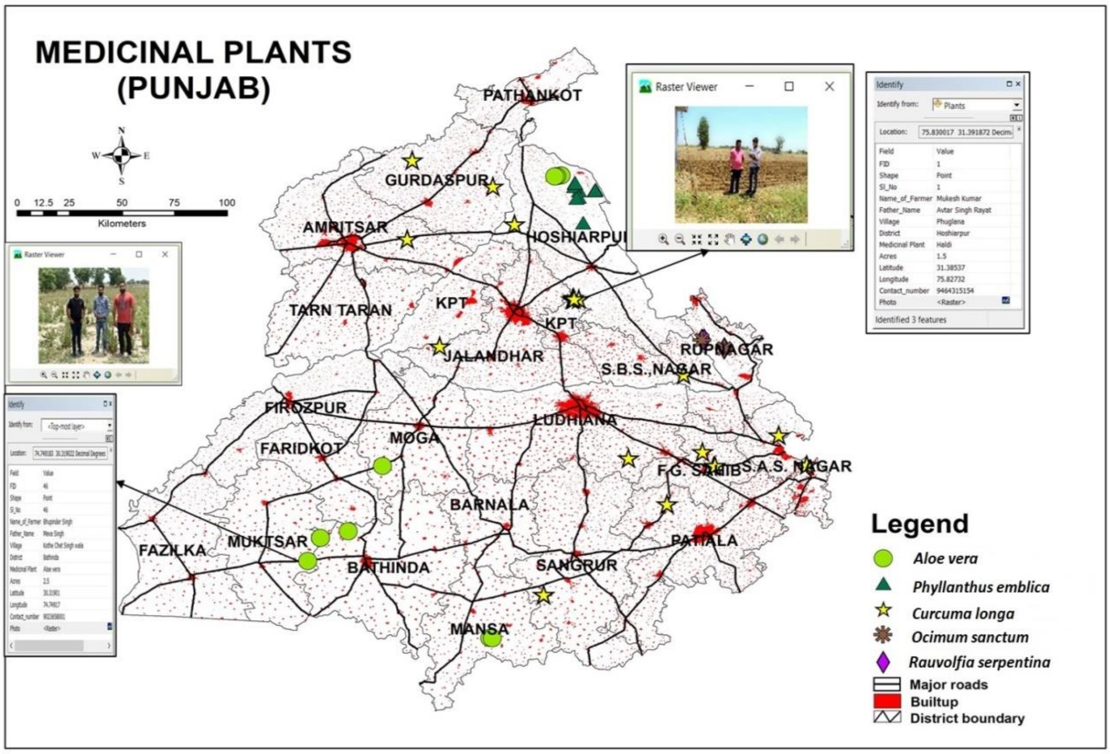


Figure 5.18: Embedded demographic information of medicinal plant cultivators.

5.5. SURVEY FOR IDENTIFICATION OF CONSTRAINTS IN MEDICINAL PLANT CULTIVATION BY FARMERS OF PUNJAB

5.5.1. Descriptive Analysis of Data

The descriptive analysis of the data revealed that maximum (30.9 %) of the medicinal plant cultivators were aged between 36-45 years category followed by 25-35, 56-65, 46-55 years categories having 25%, 20%, and 16.2 % respectively. This finding can be correlated with a study conducted by Kanwat and co-workers that highlighted medium age group level involved in the cultivation of medicinal plants (Kanwat *et al.,* 2012). It was notable among the respondents that 36.8% of the farmers were graduates, 17.6% were post-graduate and only 2.9% of the respondents were illiterate. This finding can be corroborated with a study that highlighted significance of literate farmers in promoting medicinal plants cultivation (Phondani *et al.*, 2016). Caste in India is a determinant factor of economy, power, poverty, inequality, etc. among its population in contemporary India. General caste category or forward caste is among the top in wealth, followed by the Other Backward Class (OBC), Backward Class (BC) and most disadvantaged Scheduled Class (SC) and Scheduled Tribe (ST) caste

(Zacharias and Vakulabharanam, 2011). It was observed that 42.6% of farmers belonging to the general caste category were involved in the cultivation of medicinal plants followed by backward class, other backward class, and scheduled caste categories. Among the selected population, it was found that 41.2% of the farmers were small farmers (owning up to five acres of land), and 58.8% were large farmers (owing more than 5 acres of land) that were involved in the cultivation of selected medicinal plants as represented in Fig. 5.19.

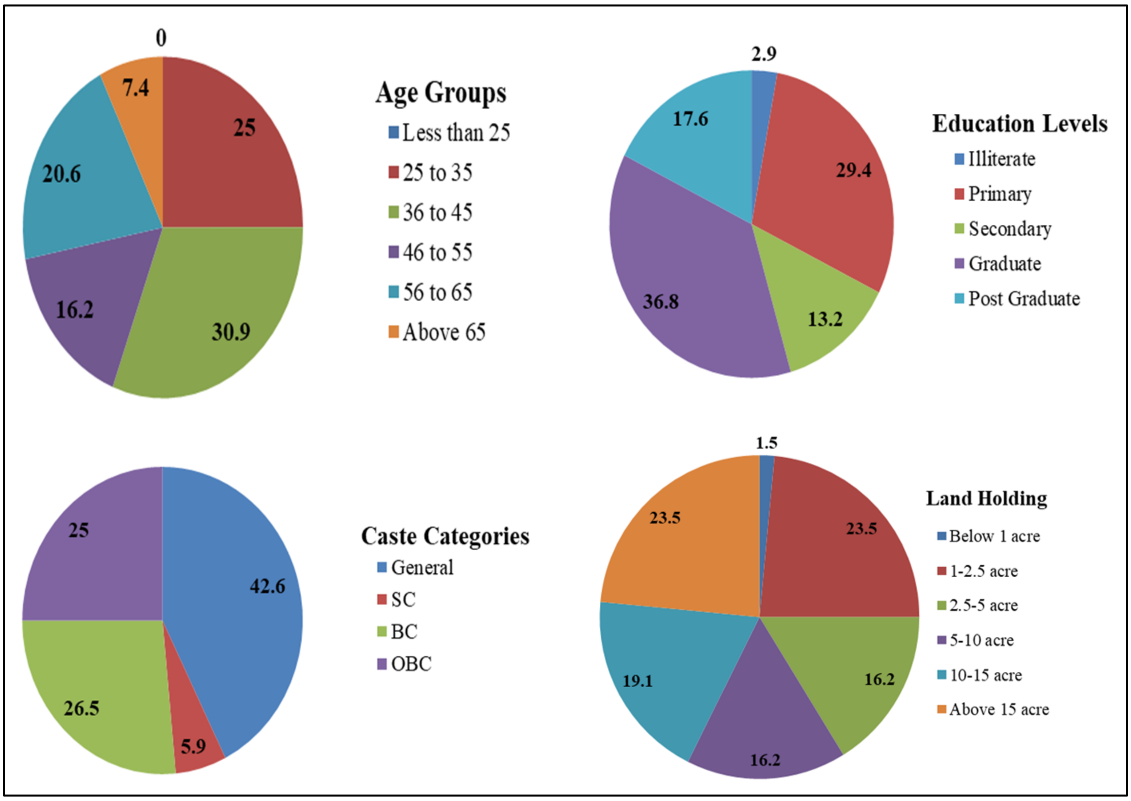


Figure 5.19: Descriptive analysis of respondent's data.

The descriptive analysis of data highlighted that most of the medicinal plant cultivars were young, graduates, large farmers belonging to general caste category. Therefore, awareness regarding the demand and uses of medicinal plants should be translated more to lesser educated farmers through NMPB stakeholders meetings for its wider its adoption.

5.5.2. Technical Constraints

The technical constraints represented the statements concerning the technical issues faced by the medicinal plant cultivators. The technical constraints faced by the small and large farmers are mentioned in Table 5.6.

Table 5.6: Technical constraints faced by the respondents.

Statements relating to technical issues	Small farmer (n1=28)	Large farmer (n2=40)	Total (n1+n2=68)
	MPS	MPS	MPS
No labelling material for the medicinal plant produce	92.86	77.5	85.18
No processing/distillation units installed	89.29	67.5	78.4*
No knowledge of suitable agro-climatic zone before cultivating selected MAP	64.29	52.5	58.4
Do not get sufficient seeds for cultivation	42.86	20	31.43*
Have no proper washing facility	17.86	10	13.93
Do not have sufficient storage area	10.71	2.5	6.605
No knowledge regarding characteristics of soil and water for selected medicinal plants	7.14	2.5	4.82
No refinement required in agro-technology	3.57	5	4.285
Do not procure right seeds or planting material from reliable sources	0	7.5	3.75

*p-value < 0.05; MPS: Mean Percentage Score

Different technical constraints faced by the farmers cultivating medicinal plants were accessed based on their MPS and ranking. It was observed that 78.4% of the respondents (both small and large farmers) had no processing or distillation units installed at their place. Lesser availability of processing units resulted in higher processing costs of the medicinal plants. There are few public processing units maintained by the societies, which are comparatively cheaper than other commercial processing units. To circumvent the high processing cost of medicinal plants, the government must install more processing and distillation units in different parts of Punjab. Village co-operatives societies can play a significant role in this mechanism with the help of government (Singh, 2006). The findings can be correlated with studies highlighting technical constraints as one of the most prominent perceived constraints by the medicinal plants cultivators in the Rajasthan, India (Kanwat, 2011; Kanwat *et al.*, 2017). Similarly, packing and labeling equipment or material must be provided by the NMPB through state forest officials to promote farmers for value additions.

On the other side, it was observed that 58.4% of the respondents didn’t have prior knowledge of suitable ago-climatic zones before cultivating selecting medicinal plants. As Punjab has diverse ecological conditions, agro-climatic suitability studies of the selected medicinal plant should be translated to the farmers. A complete blueprint regarding potential agro-zones of medicinal plants with reference to Punjab bio-physical attributes should be provided to the farmer. Similarly, 31.43% of the population didn't get sufficient seeds for the cultivation of medicinal plants, 13.93% of the population didn't have proper washing facility for removing earthy materials from the plants, moreover, 3.75% of the respondents said that they didn't procure seeds from reliable sources. The medicinal plant cultivators have to go far places or other states to get reliable seeds and QPM (Quality Planting Material) that eventually increases the input costs of the farmer (Kala *et al.,* 2006). To circumvent this, various agricultural and all the related organizations of Punjab should be provided with adequate funds and equipped with facilities to provide seeds and QPM to the interested farmers. It was also observed that only 4.285% of the respondents were satisfied by their agro-technology and above 95% of the population thought that their agro-technology needs more refinement according to their suitable agro-climatic zones.

5.5.3. Trade Related Constraints

Based on MPS, it was noticed that 95.72% of the farmers were not signing contract farming agreement for cultivation of the selected medicinal plants. There is no regulated existence of a market mechanism to control the supply chain of medicinal plants (Sharma *et al.,* 2008). Therefore, Self Help Groups (SHGs) or marketing cooperatives need to be built at the producer's level. Another method is by establishing a strong official link between the farmers and the herbal industries (Paroda *et al.,* 2014). The existence of a 100% buyback contract agreement between the farmers and industry can assure farmers to adopt medicinal plants in Punjab. The proper functioning of the contract can be supervised by the forest officials of Punjab which is the concerned body for promoting medicinal plants with the coordination of NMPB. It was observed that 91.43% of the population did not participate in *Kisan mela's* or other exhibitions for selling their produce. *Kisan mela's* provides a direct link between farmer and consumer and also provide great exposure to farmer in updating his knowledge. It was also observed that 56.25% of the farmers directly sold their produce to the consumers than relying upon any middlemen or traders. Similarly, 71.61% of the farmers cultivating selected medicinal plants said that they didn't manufacture their herbal products; they sell their produce to the buyers without any value additions. 33.04% of the farmers strongly disagreed that industry gave them fair prices of their produce. Only 29.65% of the population had basic packing equipment for selling their produce to the consumers, rest most of the population was devoid of the basic packing materials. Out of the surveyed population, 26.62% disagreed that transportation is the major issue in the economics of the medicinal plants. Rest most of the population agreed that transportation is the major issue in the economics of medicinal plants. The trade related constraints are represented in the Table 5.7.

Table 5.7: Trade related constraints faced by the respondents.

Statements relating to trade issues	**Small farmer (n1=28)**	**Large farmer (n2=40)**	**Total (n1+n2=68)**
	MPS	**MPS**	**MPS**
No signing of contract farming agreement	96.43	95	95.72
Don’t sell herbal products at Kisan Mela’s/ exhibitions/ seminars/ any other	92.86	90	91.43
No manufacturing of herbal products/formulations	85.71	57.5	71.61*
Sell medicinal produce directly to the consumer	75	37.5	56.25*
Thinks industry won’t give fair price	53.57	12.5	33.04
Have basic packaging equipments	14.29	45	29.65*
High transportation cost	35.71	17.5	26.61
Do not want FSSAI approval	17.86	20	18.93*

*p-value < 0.05; MPS: Mean Percentage Score

The medicinal plants cultivated by the farmers in Punjab have a huge demand and economical potential. These medicinal plants are utilized for the preparation of different ayurvedic, nutraceutical, and also allopathic formulations. On the other hand, *R. serpentina* being an endangered species in India fetches a handsome price of Rs. 800-850/kg with 200-500 MT annual trade (Goraya and Ved, 2017). These plants are used for making tablets, juices, tonics, candies, lozenges, eye drops, etc. for the treatment and prevention of a large spectrum of diseases. Popular ayurvedic formulations like *Haridra Khanda*, *Rajahpravartini Vati*, *Cukkumtippalyadi Gutika*, *Chyavanaprasa*, *Tribhuvanakirti Rasa*, *Muktapancamrta*, *Muktadimahajana*, *Laksadi Taila*, etc. are prepared from these medicinal plants (The Ayurvedic Pharmacopoeia of India, 1989). Therefore, cultivating these medicinal plants could provide huge benefits to the farmers of Punjab, if constraints especially related to marketing are addressed by the concerned organizations. Similarly, farmers should be made aware of the significance of value additions and FSSAI approval for their medicinal products for agri-business ventures. The FSSAI in India is a government body ensuring food quality and safety of spices, juices, herbal products thereby providing satisfaction to every customer (Shukla *et al.*, 2014). Hence, farmers should be motivated to apply for FSSAI approval for their respective herbal products.

5.5.4. Social Participation and Awareness Related Constraints

Social participation plays a vital role in updating the knowledge of the farmers. Therefore, it was necessary to understand the role of social participation in adoption of medicinal plants cultivation in Punjab. In the present study, it was observed that 89.65% and 64.82% of the farmers were not member of any self-help group or farmer-producer company respectively. There are many Self-Help groups especially working in the *Kandi* belt of Punjab that are involved in the collection and processing of different medicinal plants such as *Terminalia chebula*, *Terminalia bellirica*, *Emblica officinalis*, *Tinospora cordifolia*, etc. to manufacture *Chyawanprash*, *Triphala* etc. (Rawat *et al*., 2013). Therefore, awareness regarding successful self-help group and farmer-producer companies should be provided to the farmers through RCFC-North, NMPB, and other concerned organizations. In the present study, 'Suhavi' a farmer-producer company was involved in cultivation of *R. serpentina, O. sanctum* to open a new line of agriculture in Punjab. It was also observed that 72.86% of the population had internet access and only 68.57% of the farmers used internet to update themselves regarding agriculture as mentioned in table 3.3**.** Similarly, awareness among farmer plays an important role in adopting new crops. In this study, constraints related to awareness of the farmers were studied and it was observed that 80% of the population was not aware regarding *e.charak* mobile application which is the official mobile app. developed by NMPB, Ministry of AYUSH for all the concerned stakeholders of medicinal plant for trading, agro-techniques and pricing related updates. Majority of the farmers i.e. 74.47 % were not aware regarding GAP. On the other hand only 28.4% of the population was not aware regarding subsidy given on medicinal plant cultivation by NMPB through state forest department officials. It was observed that 45.72% of the population was not aware of the quality of medicinal plants demanded by the industry as mentioned in Table 5.8.

Table 5.8: Social participation and awareness related constraints faced by the respondents.

Statements relating to social participation and awareness	Small farmer (n1=28)	Large farmer (n2=40)	Total (n1+n2=68)
	MPS	MPS	MPS
Not a member of any self-help group	89.29	90	89.65
Have internet connection	60.71	85	72.86*
Access internet for updates regarding agriculture	57.14	80	68.57
Not a member of any farmer-producer company	57.14	72.5	64.82
Statements related to awareness constraints			
No awareness regarding NMPB's official *e.CHARAK* mobile app. for latest market prices, agro-techniques of medicinal plants	75	85	80
No awareness regarding Good Agricultural Practices	71.43	77.5	74.47
No awareness regarding industrial requirement in context to the quality of medicinal plants	46.43	45	45.72
No awareness regarding the subsidy on medicinal plants	14.29	42.5	28.4*

*p-value < 0.05; MPS: Mean Percentage Score

5.5.5. Attitude and Policy Related Constraints Faced by the Farmers

As mentioned in the Table 5.9, 98.22% of the population admitted that more demonstration plots should be installed by the govt. for wider dissemination of the knowledge regarding medicinal plant cultivation. Also, 95.18% of farmers agreed on the establishment of a government mechanism to buy their produce will encourage the cultivation of medicinal plants at a wider level. Among the selected population 94.47% of the respondents agreed to the organic certification of their fields. Most of the *Kandi* region of Punjab has natural organic land and the belt has great potential for medicinal plants cultivation because of the absence of pesticide residue which is one of the determining factors of herbal formulation in terms of quality (Bala, 2014; Kaur and Kaur, 2019). So, the farmers should be made aware regarding organic certifications through RCFC-North, India for fetching higher prices for their produce. Farmers were not equipped with a proper agro-technique manual, so the majority of the respondents i.e. 92.68% agreed that providing them with an agro-technique manual will help them cultivate medicinal plants. Good Agricultural Practices of medicinal plants provide medicinal products of desired quality as well as quantity (Singh and Baldi, 2018). Therefore, farmers must be provided with agro-technique manuals regarding good agricultural practices for selected medicinal plants. Extension services must be made robust by establishing state-of-art medicinal plant department in the Punjab Agricultural University (PAU), Ludhiana, India and frequent training programs must be conducted by the PAU in cooperation with the NMPB. Among the selected respondents 84.82% of the farmers said that they were not satisfied with the amount of subsidy given by the government and 44.47% of the farmers only participated in NMPB/other related institute training programs. The NMPB provides subsidies on selected medicinal plants per acre through forest officials. The farmers were not satisfied with the subsidies, so it becomes imperative that the amount of subsidy allocated on different medicinal plants by the NMPB be revised for the wider adoption of medicinal plants in Punjab.

Table 5.9: Respondents attitude and policy related constraints.

Policy and farmer's attitude related issues	**Small farmer (n1=28)**	**Large farmer (n2=40)**	**Total (n1+n2=68)**
	MPS	**MPS**	**MPS**
There should be more demonstration plots to disseminate knowledge	96.43	100	98.22
Establishment of Government mechanism to buy medicinal produce, will encourage cultivation of MAP	92.86	97.5	95.18
Interested in organic certification	96.43	92.5	94.47
A proper agro technique manual will help in MAP cultivation	92.86	92.5	92.68
Farmer's willingness to conduct trial for medicinal plant cultivation in field	85.71	95	90.36
Success stories will motivate increase the land under MAP cultivation	85.71	90	87.86
Mobile app. based on quality and certification, will help farmers in determining the quality of the produce	85.71	85	85.36
Not satisfied with the amount of subsidy provided by NMPB on selected medicinal plants	82.14	87.5	84.82
You are getting desired amount of subsidy from the NMPB for cultivating selected MAP	82.14	60	71.07
You are participating in training programmes being conducted by the NMPB/other related institutes on MAP cultivation/processing	46.43	42.5	44.47

MPS: Mean Percentage Score

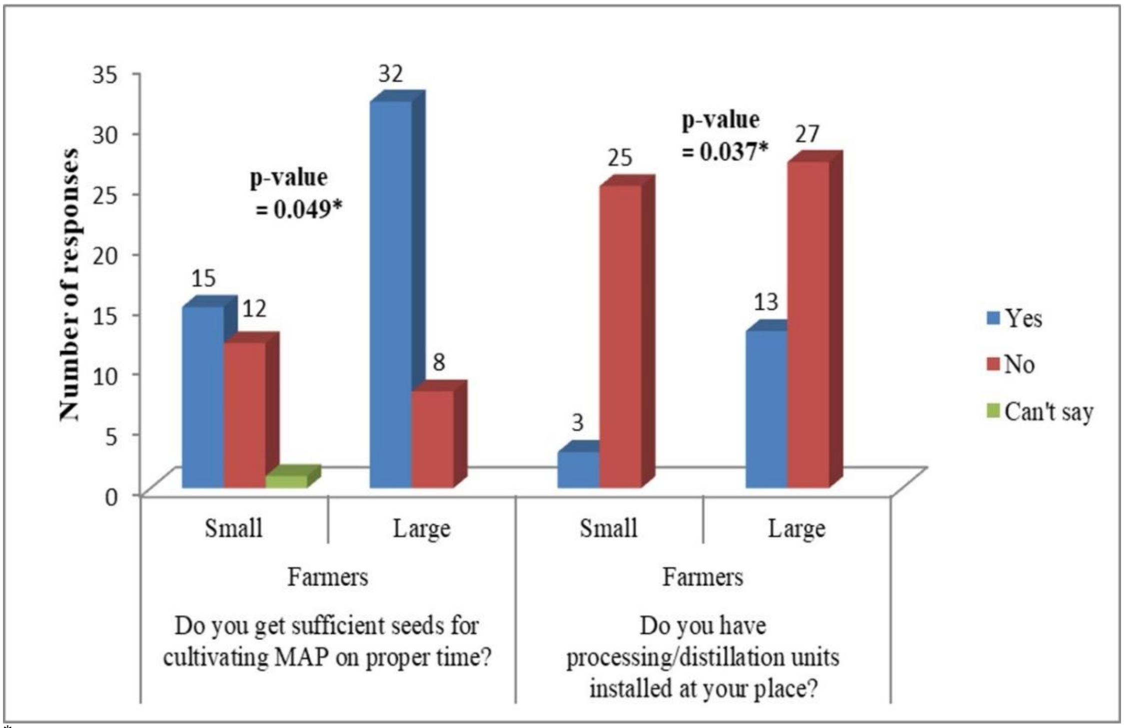
Similarly, 90.36% of the population agreed that they would actively participate in the conduction of trail plots in their respective fields if selected by the government. Likewise, 85.36% of the respondents agreed that mobile app. enabling evaluation of the quality of the medicinal would help them in maintaining the quality of the produce and 87.86% of the population said that success stories of farmers involved in medicinal plants cultivation would motivate them to cultivate the crops at a larger level.

5.5.6. Inferential Analysis of Data

In order to validate null hypothesis that considered no significant relationship existed between the small and large farmers in context to the various constraints, Chi-square test was applied. In this section, only the significant relationships found between farmer's landholdings and constraints were highlighted.

5.5.6.1. Relationship Between Farmer's Landholdings and Technical Constraints Statement

The null hypothesis assumed that small and large farmers did not differ significantly in getting sufficient seeds and owing processing units. In the present study, some statements rejected the null hypothesis and significant relationship existed between the landholdings of the farmers with getting sufficient seeds for cultivation and owing processing units for medicinal plants due to high income of large farmers than the small farmers as represented in Fig. 5.20. In tradition, farmers resort to selling their medicinal produce in raw form to the customers, which eventually fetches low return. Considering this, processing units are essential for generating value additions products and enable the farmers for small and large agro-business. Similarly, farmers have to collect seeds and quality planting material from far places. This process increases the input costs building lesser confidence among the farmers. In contrast, the large farmers are expected to have high annual income than the small farmers and it can be assumed that because of high annual income, the large farmers can bear the transportation cost to buy seeds and also own processing units for their crop (Mittal and Mehar, 2016; Dev, 2012).

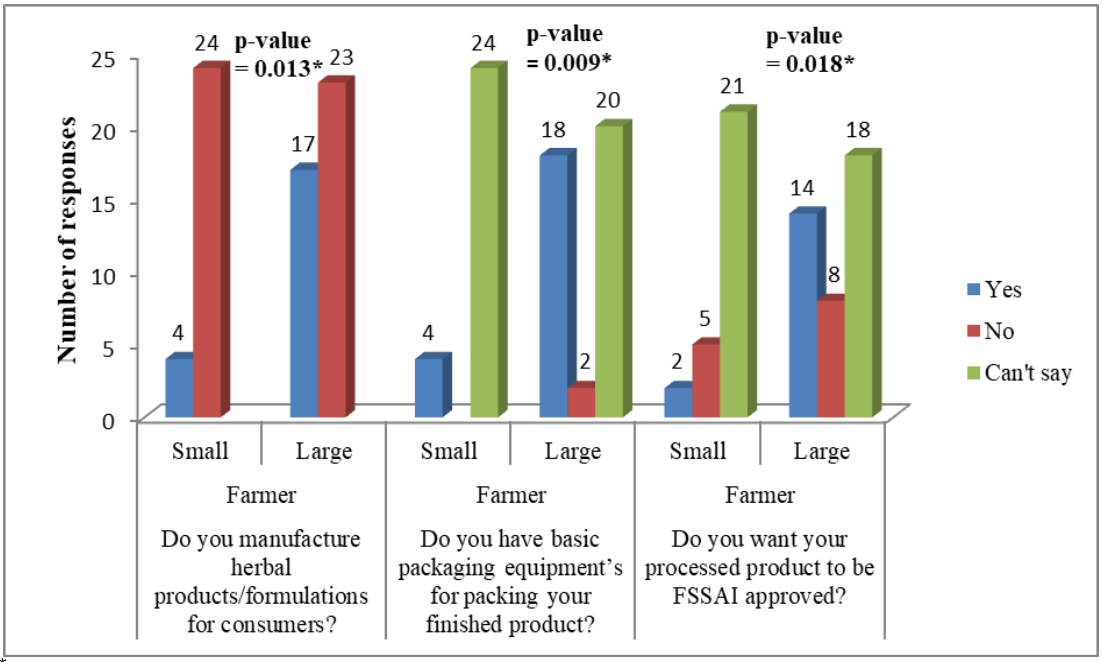


*Statistically significant ($p<0.05$)

Figure 5.20: Relationship between landholding and getting seeds and owning processing units for medicinal plants for cultivation.

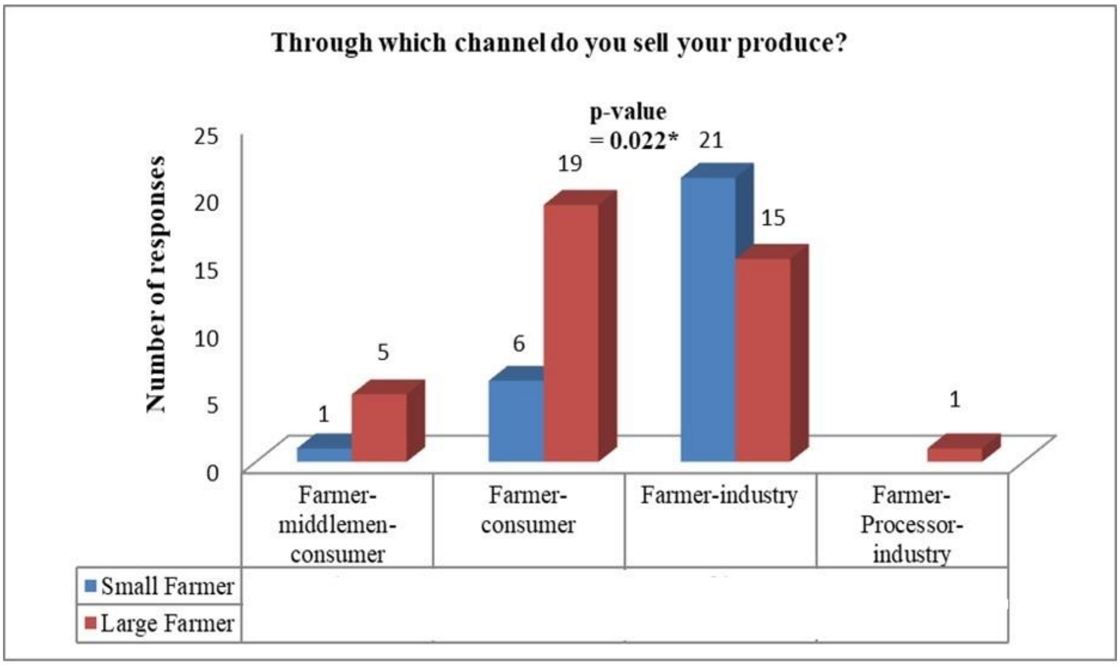
5.5.6.2. Relationship Between Farmer's Landholdings and Important Trade-related Constraints Statement

The farmer landholdings had a significant relationship between the manufacturing of herbal products, availability of packing equipment, and willingness for FSSAI approval as represented in Fig. 5.21. It was observed that the large farmers were mostly involved in manufacturing of herbal formulations as compared to the small farmers. This can be corroborated with the fact that the large farmers due to their high annual income owned processing units and basic packaging equipment for the value additions. Most of the small farmers answered 'can't say' for the availability of packing equipment and FSSAI approval of their product. This can be corroborated with a study conducted by Shetty and co-workers that highlighted that more awareness regarding the quality of food, value additions, need for packaging equipment, and role of FSSAI must be disseminated to the farmers for fetching higher costs (Shetty *et al.*, 2010). The results can also be correlated with a study conducted by Jairath and Purohit, highlighted that food safety law is poorly implemented for fruits and vegetables. The study also emphasized the need for small farmers and traders to integrate into food quality and safety network by establishing more number of supermarkets (Jairath and Purohit, 2013). Similarly, a significant relationship was found between the farmer landholding and the type of market channel used by the farmers to sell their medicinal produce (Mitra *et al*., 2018; Ranjan, 2017). Majority of the farmers included in the study sold their produce directly to the industry and consumer as mentioned in Fig. 5.22.



*Statistically significant (p<0.05)

Figure 5.21: Relationship between landholdings with manufacturing of herbal products, owing packing equipment and willingness for FSSAI approval.

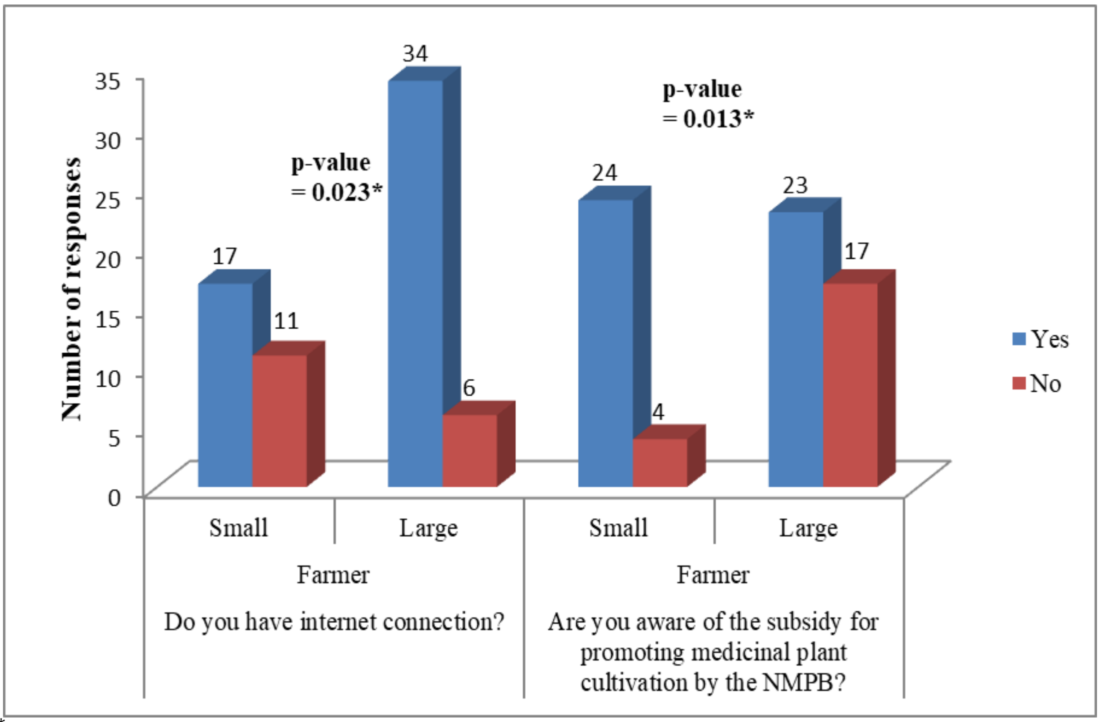


*Statistically significant (p<0.05)

Figure 5.22: Association of farmer's landholdings with type of marketing channel used.

5.5.6.3. Relationship Between Farmer's Landholdings and Important Social Participation and Awareness Related Constraints Statement

All the statements related to the social constraints passed the null hypothesis except farmer's landholdings with the availability of internet connection. Considering easy availability of internet connection now days, it was assumed (null hypothesis) that farmer landholding's had no significant relation on the availability of internet facility. But in the present study, it was observed that large farmers had better internet facility than the small farmers. The findings can be correlated with a study, which highlighted less accessibility of the internet among the small farmers but also emphasized positive role of internet connection in updating the knowledge and positive growth of the small farmers (Mittal and Mehar, 2012). Similarly, in the year 2003, a study highlighted the role of information and communication technology to reduce poverty especially among poor people by improving their access to health, education, and government services (Cecchini and Scott, 2003). The awareness of a farmer is a crucial factor in the adoption of new crops; therefore farmer's landholding had a significant relationship with the awareness regarding subsidy given on selected medicinal plants by the NMPB as represented in Fig. 5.23.



*Statistically significant ($p<0.05$)

Figure 5.23: Association of farmer's landholdings with the availability of internet and awareness regarding subsidy.

5.5.6.4. Relationship Between Farmer's Landholdings and Attitude and Policy Related Constraints

It the present study, no significant relationship was found between the farmer's landholdings and attitude and policy related constraints, therefore no inferential data was generated for this section.

In contrast, the market of medicinal plant is not mature in the state, hence providing farmers with processing units, packaging equipment to promote value additions can be good initiative to increase the clusters of the farmers. Furthermore, contract agreement with 100% buyback guarantee must be assured between the farmer and industry with the help of government officials to avoid marketing related risks. Highlighting suitable agro-ecological zones for selected medicinal plants, and providing agro-technique manuals ensuring GAP can be promote the quality of produce as per industrial standards. The significant relationship was found between farmer landholdings in getting sufficient seeds, having distillation units, manufacturing herbal formulation, having packaging equipments, willingness for FSSAI approval, selling channels, availability of internet and awareness regarding subsidy of medicinal plants, and therefore small farmers needed more attention of the policymakers than the large farmers in context of addressing constraints to promote medicinal plants adoption in the state.

5.6. DRAFTING OF COMPREHENSIVE GACP GUIDELINES AFTER CRITICALLY ASSESSING AND COMPARING GAP OF WHO AND OTHER COUNTRIES LIKE AMERICA, JAPAN, CHINA, EUROPEAN UNION, INDIA FOR SELECTED PLANTS

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 fundamental guiding principle for obtaining the quality of the herbal medicine is the implementation of GAP for medicinal plants (Saha *et al.,* 2018). WHO emphasized that more countries should develop their own GACP guidelines for the quality control of medicinal plants based on the guidelines developed by the WHO in the year 2003 (Organización Mundial de la Salud and World Health Organization, 2003).

In this regard, countries like America, Japan, China, European Union, and India developed country specific guidelines keeping the guidelines of WHO as fundamental framework. The GACP guidelines developed by different countries were unique in their own manner and aimed to enhance the quality of herbal raw material. In this context, there is need to compare the GAP guidelines drafted by the WHO, America, Europe, China, Japan, and India to draft robust and comprehensive GAP guidelines for the medicinal plants. The comprehensive GAP guidelines encourage developing monograph on GAP for medicinal plants for the countries considering the ecological conditions. The monographs shall be made in view to facilitate cultivation of the selected medicinal plants of reliable quality and also ensuring sustainable supply to meet the demands of market (Jayashree *et al.*, 2015a; Jat *et al.*, 2015, 2014; Bhattarai, 2013; Anonymous, 2009). The objectives of comprehensive GACP are:

- To encourage sustainable cultivation of medicinal plants in the country and worldwide and also protect wild resources.
- To encourage developing monographs of GAP for medicinal plants considering farmers practices, reported literature considering agro-ecological conditions.
- To provide specific practical technical guidelines for the cultivation of selected medicinal plants of good quality.
- To contribute in alleviating the scarcity of selected plant based medicines.
- To ensure quality-rich raw herbal material for achieving efficacious herbal, nutraceutical and cosmetic products.

A comparative study was carried out after exploring the GACP guidelines developed by the WHO, America, Europe, China, Japan, and India to draft robust and comprehensive GACP guidelines for the medicinal plants. The parameters ranging from seeds and propagation materials, site selection, agro-ecological conditions comprising of soil, water and meteorological specifications, cultivation, land pattern, crop management and nutrition including fertilizers, pesticides, harvest and post-harvest, personnel, and documentation are encompassed in the comprehensive GAP guidelines for medicinal plants as mentioned below:

5.6.1. Seeds and Propagation Material

5.6.1.1. Identity: Supplier of the seed, seedling, cuttings etc. should provide proper taxonomical identity, trade name, cultivar selection/phenotype/chemotype/genotype and breeding history of the plant either cultivated or wildly collected. The source of the seeds/cuttings should be duly authenticated.

5.6.1.2. Purity: Seed, seedlings, cuttings (both aerial and underground) propagation material should be free from pests, diseases, extraneous species, sub-standard adulterated material, botanical varieties and strain during production.

5.6.1.3. Quality: Quality of the propagation material (genetically modified germ plasm), seed should comply with national regulation of the country and with the country in which material may be sold. There should be physico-chemical analysis/marker based analysis for end product used in industry. Material should be resistant to diseases, biotic, abiotic factors and should be certified organic.

5.6.1.4. Treatment of Seeds, Seedlings, Propagation Material: Seeds either collected from wild or cultivated should be mature, fresh and originated from recent harvest. Seed treatment if any should be followed as prescribed. Similarly seedling production should be followed as recommended by the agronomic practices and proper time of transplantation should be kept in mind. In case of cuttings, it should be healthy and of uniform dimensions in terms of length and diameter.

5.6.1.5. Transportation of Seeds: Proper inspection should be made to check disease control on seeds/propagation material during production, transportation and storage. Care should be taken to protect animals from physical and sensory injury during transportation and trapping.

5.6.2. Site Selection

5.6.2.1. Meteorological data including average rainfall, temperature, length of the day, field temperature, duration of sunlight, day and night time difference for the past three years should be consulted for suitability.

5.6.2.2. Avoid site having hazardous condition (heavy metals, agricultural agent, and industrial waste, contaminated soil with sludge). Pesticides residual and heavy metal analysis can be done when field history is not known. Proper information regarding recent use of pesticides, herbicide, fungicide and rate of its breakdown should be noted.

5.6.2.3. Corrective measures should be taken to prepare site where environmental contamination is known.

5.6.2.4. Record information that have relevance to either improving or damaging the crop or site.

5.6.2.5. Avoid areas near by mine tailings, parking lots, golf courses, waterways, underground storage tanks, graveyard, crematoria or having traceable history of such usage.

5.6.2.6. As a good indicator for cultivation conditions, plants should be planted where weeds can grow.

5.6.2.7. Identify crops that will be grown in adjoining sites and their treatment followed.

5.6.2.8. Cows and domestic animals should be prohibited from entering the site and history of site as feedlot is also to be accessed.

5.6.2.9. There should be provision of artificial shading for light shade plant.

5.6.2.10. Site should have optimal level of water holding capacity and water logging prevention.

5.6.2.11. Ecological, environmental and social impact should also be taken into consideration for benefits of local communities for selected medicinal plant for cultivation.

5.6.2.12. Potential growing area of a particular medicinal plant should be highlighted utilizing agro-climatic zoning model comprising of at least climatic (temperature, rainfall etc.) and land (soil texture, soil pH etc.) specific indicators to define best agro-climatic zone of the plant.

5.6.3. Soil

5.6.3.1. There should be no use of nigh soil.

5.6.3.2. There should be appropriate amount of nutrients present in soil.

5.6.3.3. Avoid high soil moisture level for mold and fungal problems.

5.6.3.4. Soil sampling and physico-chemical analysis of soil should be done to quantify essential soil nutrients prior to planting should and decide further amendments.

5.6.3.5. Soil type, drainage, moisture, retention, fertility and pH should be considered.

5.6.4. Water

5.6.4.1. There should be proper identification of water sources (on-farm well, open irrigation canal, reservoir, municipal supply or other sources).

5.6.4.2. There should be optimal use of water for cultivation.

5.6.4.3. It should comply with local, regional and national quality standards.

5.6.4.4. It should have reliable source of water (avoiding salinity, acidity and toxicity).

5.6.4.5. There should be planned irrigation cycle for optimal growth.

5.6.4.6. Water harvesting and conservation methods should be applied where ever possible.

5.6.4.7. Water should be analyzed for heavy metal and residual matter including domestic animals or human materials.

5.6.4.8. Lead pipe fitting for water must be avoided.

5.6.4.9. Total salt concentration, sodium absorption ratio, bicarbonate and boron concentration should be accessed in accordance to quality of water and target crop.

5.6.4.10. There should be proper drainage of water and impounding rain water should not be allowed.

5.6.5. Cultivation

5.6.5.1. Parameters such as rate of seedlings per acre should be taken into consideration.

5.6.5.2. Plant to plant distance should be optimally decided.

5.6.5.3. Row to row distance should also be known.

5.6.5.4. Placement of seeds at appropriate depth in moist zone of soil should be considered.

5.6.5.5. Optimum irrigation cycles should be followed and recorded.

5.6.5.6. Standard agro-technique for particular plant should be followed drafted by the authorized agencies of the country keeping in mind the agro-ecological conditions of the area where plant is to be cultivated.

5.6.6. Crop Management

5.6.6.1. Replenishment of plant population to compensate mortality losses in reasonable time frame and gestation period of plant should be considered.

5.6.6.2. Topping, hoeing, bud nipping, pruning, shading, earthing up should be followed depending on the plant selected for the cultivation.

5.6.7. Crop Nutrition

5.6.7.1. Fertilizers for nitrogen fixation and phosphate solubilizing are desired. Organic manure, vermin compost, poultry manure, green leafy manure must be preferred.

5.6.7.2. Do not use manure or compost based fertilizers with sewage sludge of human feces. Human excreta must be avoided.

5.6.7.3. Manure should be fully composited.

5.6.7.4. Fertilizers treated through aerobic process should be preferred.

5.6.7.5. Monitor undesirable microbial pathogens through periodic testing.

5.6.7.6. Documentation of fully composted animal manure should be carried out.

5.6.7.7. Chemical fertilizers approved by the countries should be used with minimize leaching.

5.6.7.8. Fertilizers should provide buffer zones and planting cover crops to minimize soil erosion.

5.6.7.9. There must be qualified staff for application of pesticides.

5.6.7.10. Fertilizers must be applied at early phase for its complete breakdown during harvesting.

5.6.7.11. Ensure quality of water used for fertilizer application.

5.6.7.12. Growers should comply with maximum pesticide and herbicide residues limits.

5.6.7.13. There should be use of bio-pesticides than chemical pesticides. However, pesticides in smallest effective dosage with low toxicity and residue pesticide content should be used.

5.6.7.14. Documentation of pesticide application must be carried out.

5.6.7.15. Follow federal, state, local regulations for chemical fertilizers and use fertilizers as labels directions.

5.6.8. Harvesting/Collection

5.6.8.1. Select optimal time for harvesting as harvesting depends upon the part of the plant to be harvested.

5.6.8.2. Chemical constituents in the plants are responsible for pharmacological/nutraceutical/cosmetology actions, so consultations of pharmacopoeias and other standards of harvest must be studied to assure proper quality and quantity of the active bio-active constituent present in the plant.

5.6.8.3. Avoid presence of foreign matter, weeds, toxic plants during harvest.

5.6.8.4. The cloth used as an interface between soil and harvested material should be clean and made of muslin cloth.

5.6.8.5. Underground parts such as roots, rhizomes should be cleaned from soil as soon as harvested.

5.6.8.6. During harvest, avoid dew, rain and exceptionally high humidity.

5.6.8.7. In certain cases if harvesting is done in wet conditions it should be transported to indoor dry facility.

5.6.8.8. Transport harvested medicinal plant promptly in clean and dry conditions.

5.6.8.9. Place the harvested materials in clean baskets, dry sacks, trailers, hoppers or other well aerated containers for transport subsequently avoid high moisture retention plastic containers.

5.6.8.10. Overfilling of sacks should be avoided.

5.6.8.11. Decomposed medicinal material should be identified and discarded during harvest, post-harvest inspections and grading.

5.6.8.12. During collection of wild fruits, it should be made clear that forests in India are regulated by both central and state governments. So, forests being a concurrently regulated, one should adhere to all the laws regulated by central and state governments.

5.6.8.13. Moreover, India is signatory to many international treaties and forests conservation and biodiversity conventions, so international laws where ever applicable must be respected time to time. International regulations such as CITES may be adhered to while collection from wild. For importing local secretariats of CITES, TRAFFIC and IUCN may be consulted.

5.6.8.14. The collectors of medicinal produce should also be aware of national regulations amendments from time to time. Indian Forest Act 1927, The wildlife (Protection) Act 1972, The forest (Conservation) Act 1980, The Biological Diversity Act 2002, The Scheduled Tribes and Other Tradtional Forest-Dwellers Act 2006 must be consulted as they contain provisions for collection of medicinal plant produce from forests.

5.6.8.15. Collectors should seek written permission from all the local authorized agency for collection, transit and sell of produce. The documentary proof should be kept in safe custody.

5.6.8.16. Good collection practices should be followed during harvest. Fruits should be properly graded according to their quality.

5.6.8.17. The increasing demand of medicinal plant has resulted in exploitation of forests. So regulators (forets and wild life field officials) and collectors must be aware of the current conservation status of the plant species.

5.6.8.18. RET status of the plant species in respective areas should be known. Collection of senstive endemic plant should adhere to legal and ecological prescriptions to ensure prevention of threat to species.

5.6.8.19. Collection of medicinal plants from wild should be done from areas where itrs frequency af occurrence is sustainable.Harvesting should be done in limits,and certain percentage of its population should be left so to allow regeneration.

5.6.9. Post-Harvest

5.6.9.1. There should be proper visual inspection, organoleptic evaluation (appearance, damage, size, color, odor, taste) and sorting before primary processing of the collected medicinal plant to avoid cross contamination by untargeted plants and foreign matter.

5.6.9.2. Primary processing should be accrued out in national, regional quality standards and regulations and norms for producer and purchaser countries.

5.6.9.3. Standard operating procedures should be followed for evaluation and harvesting material should be unpacked immediately after reaching processing facility and should be protected from rain and moisture.

5.6.9.4. The plants that require to be processed immediately should be transported immediately to avoid thermal degradation and microbial contamination.

5.6.9.5. Use of refrigerators, sand boxes and enzymatic measures can be applied.

5.6.9.6. When materials are required in dry form, moisture levels should be checked according to pharmacopoeia.

5.6.9.7. Optimum temperature and humidity should be maintained to achieve desired active constituents and parameters such as duration of drying, drying temperature, humidity with context to part of the plant i.e. root, leaf, stem, bark, flower should be recorded.

5.6.9.8. Drying in sunlight can only be done when specified.

5.6.9.9. Different drying mechanism i.e. open air drying, drying frames, wire screened rooms, direct sunlight, drying ovens, solar dryers, indirect fire, baking, lyophilization, microwave, infrared devices can be used for drying.

5.6.9.10. In open air drying, plants should be properly spread for air circulation and drying frames placed in good height for proper circulation.

5.6.9.11. For direct drying (fire) should be limited to butane, propane or natural gas and temperatures should be kept below 60°C.

5.6.9.12. Smoke and medicinal plant contact should be avoided.

5.6.9.13. Use tarpaulin and other appropriate cloth or sheeting during drying in cemented floor.

5.6.9.14. Rodents, insects should be checked during drying.

5.6.9.15. Preservatives should be avoided, if used should comply with national norms and well documented.

5.6.9.16. A label constituting farmer name, farmer agency, plant name, plant part, its quantity, quality (if quality testing is carried out), and harvesting month must be inscribed on every package.

5.6.9.17. The storage of medicinal plants must be carried out at optimal conditions i.e. under dry conditions, maintaining proper ventilation, preventing condensation, protected from insects, rodents, and other detrimental factors affecting the quality of medicinal plants. There must be separate places for organic and non-organic medicinal plants.

5.6.9.18. When there is storage of multiple medicinal plants, care must be taken to prevent their mixing and cross contamination. Therefore distance must be maintained between different medicinal plants.

5.6.9.19. Appropriate security measures shall be applied for the products that are toxic or poisonous during storage and transportation.

5.6.9.20. The storage area must be restricted for common people and only authorized personnel should be allowed to enter the storage area. In case of visitors, one should adhere to proper protective clothing and maintain personal hygiene.

5.6.9.21. Some plants require specific processing for purity and detoxify such as peeling of skins of roots and rhizomes, boiling in water, steaming, soaking, pickling, distillation, fumigation (registered chemical agents only authorized by the regulatory bodies), roasting, natural fermentation, treatment with lime, chopping for their further utilization. Therefore, optimal conditions should be followed for processing of medicinal plants after consultations from pharmacopoeias to acquire best results.

5.6.10. Personnel

5.6.10.1. The medicinal plant cultivators should have proper knowledge regarding the medicinal plant species identification, climatic requirements, cultivation, harvest and post-harvest mechanisms.

5.6.10.2. Proper hygiene must be maintained by the medicinal plant cultivators, field workers involved in the different stages of medicinal plants production. Proper training must be given to the medicinal plant cultivators, field workers on hygiene.

5.6.10.3. An individual allergic to any plant material should not be allowed to stay in contact with that specific medicinal plant. The personnel suspected or known to have suffering any disease or wounds should not be allowed in the process of medicinal plant production.

5.6.10.4. Protective clothing such as helmets, face masks, goggles, gloves, and overcoats must be provided to the field workers or medicinal plant cultivators for the application of agrochemicals.

5.6.10.5. Proper training must be given to the medicinal plant cultivators on the need for environment protection, and medicinal plants conservation.

5.6.11. Equipment and Materials

5.6.11.1. The required equipments and utensils must be designed in such a way that should prevent hygienic hazards and are easy to clean, disinfect, and easily assessable for visual inspection. Similarly, the unusable equipments shall be leaf-proof, metal-constructed or impervious material shall be used which is easily cleaned or disinfect.

5.6.11.2. All the materials used for handling of the medicinal plants must not transmit toxic substances, odor, taste, shall have smooth surface with non-adsorbent properties, and must be resistant to corrosion having the capability to undergo repeated cleaning and disinfection.

5.6.11.3. The material required for the storage of medicinal plants must comply with the quality requirements for the selected medicinal plants and must be dry, clean and undamaged.

5.6.11.4. Containers when not in use should be kept clean and in clean area.

5.6.11.5. Cutting devices, harvesters, machines, equipment's should be kept clean and stored in uncontaminated, dry place free from insects, rodents, birds and other pests.

5.6.11.6. The equipment (fertilizer and pesticide applicator) used in the agricultural process must be properly calibrated and calibration certificates and related records must be maintained.

5.6.12. Documentation

5.6.12.1. Documentation related to seeds or propagation materials, cultivation site, cultivation process, fertilization (application of fertilizers, type of fertilizers, dose, etc.), management methods, harvest, post-harvest methods must be documented.

5.6.12.2. Proper auditing shall be conducted by the expert representatives of producers, end users, and authorized regulatory bodies for quality assurance of the medicinal plants and subsequently proper documentation regarding the same shall be maintained.

5.6.13. Comparative Investigation

The comprehensive GACP guidelines mentioned above encompasses all the parameters that are mentioned in the different country-specific GACP guidelines for medicinal plants. Special emphasis has been made regarding the quality of the seeds and propagation material in the different GACP guidelines. The GACP guidelines of America and WHO have described identity, quality, product performance, breeding history of the seeds as an essential parameters. Whereas, India has described the seed/planting material should have pharmacopoeial nomenclature, trade name, botanical name, cultivar selection/phenotype/chemotype/genotype/physico-chemical analysis/marker based analysis. It also lays special emphasis on the marker based analytical confirmation of the seeds for end product used in the industry (Saha *et al.,* 2018). On the other hand, GACP guidelines of Europe, highlighted phenotype, chemotype botanical name, cultivar selection for seeds but excluded genotype and physico-chemical parameters of seeds (Committee on Herbal Medicinal Products, 2006). Similarly, parameters such as identity of planting material obtained from wild sources, obtaining seeds from recent harvest, size uniformity of propagation or root cuttings are specially highlighted in the GACP guidelines of India (National Medicinal Plant Board, 2009). The requirement of species to be resistant or tolerant to diseases is highlighted in the GACP guidelines of Europe as well as WHO and not specifically highlighted in guidelines pertaining Japan and China. The GACP of China has specially highlighted protection of animals from physical and sensory injury during transportation (Organización Mundial de la Salud, World Health Organization, 2003).

The GACP document of Japan highlights one of the unique parameter *viz.* cultivation of plants where the weeds can grow as a good indicator of cultivation conditions. It also highlights avoiding of cows in the cultivation site (Organización Mundial de la Salud, World Health Organization, 2003). Similarly, America's GACP of medicinal plants highlights importance of soil sampling, identification of crops that can be grown in adjoining sites, residual pesticides, heavy metal analysis of site with unknown field history, recording information having relevance to either improving and damaging the crop or site, avoiding areas near by mine tailings, parking lots, golf courses, waterways, underground storage tanks, recent use of pesticides, herbicides, fungicides and information of rate of such pesticide breakdown (American Herbal Products Association and American Herbal Pharmacopoeia, 2006). The India's GACP of medicinal plants focusses on collecting meteorological data for the past three years, provision of artificial shading for shade loving plants, field's proximity to reliable source of water, avoiding salinity, acidity and toxicity, water logging prevention, avoiding site areas near to crematorium, or graveyards, conducting latest soil test report on physico-chemical parameter to decide nature of soil and to do further amendments (National Medicinal Plant Board, 2009).

The WHO guidelines recommend using only the fully composited manure for medicinal plants cultivation. On the other hand, GACP of America recommends use of fertilizers treated through aerobic process and monitor undesirable microbial pathogens through periodic testing. Similarly, it recommends avoiding of lead pipe fitting during irrigation and estimation of pathogenic bacteria in water *viz. E.coli*, coliforms (American Herbal Products Association and American Herbal Pharmacopoeia, 2006). Estimation of total salt concentration, sodium absorption ratio, bicarbonate and boron concentration in water, replenishment of plant population, topping, hoeing, bud nipping, pruning, shading, earthing up, need for adoption of root production enhancement of leafy biomass are highlighted in the India's GACP guidelines for medicinal plants (National Medicinal Plant Board, 2009). The insertion of water soluble foliar fertilizers within 24 hours of preparation, ensuring the quality of water used for mixing fertilizer is highlighted in the GACP of America (American Herbal Products Association and American Herbal Pharmacopoeia, 2006). Providing buffer zones and planting cover crops and green manure to minimize soil erosion are mentioned in the WHO's GACP document. Use of bio-pesticides for crop protection than pesticides in smallest dosage and use of pesticides in smallest effective dosage with low toxicity and low residue pesticide content are mentioned the GACP document of India and China respectively. Optimal time of harvest, consultation of pharmacopoeias and other standards for harvest, avoiding dew, rain or exceptionally high humidity, need for using only clean cutting devices, harvesters, other machines, sorting of raw herbal produce, etc. are mentioned in the WHO GACP guidelines of the medicinal plants (Organización Mundial de la Salud, World Health Organization, 2003).

GACP involves all the steps right from the procurement of seeds to transportation of herbal produce to the herbal industry. Though many stakeholders are involved in the herbal industry, lack of GACP adoption by the farmers, quality of MAP remains the major issue. We strongly recommend implementation of GAP and GACP for medicinal plants to ensure the quality assurance of herbal medicines and also increasing the yield of the crop. Implementing GACP will eventually result in increasing trade of medicinal plants. Therefore, these comprehensive guidelines would address the quality-related issues for promotion of the cultivation of MAP leading to uplifting the economic profile of large, small and marginalized farmers (Singh and Baldi, 2018).

These guidelines can be adopted by different nations or regions in order to achieve quality-rich herbal materials considering the region-specific ecological conditions and following standard agronomic practices of selected medicinal plants. In addition to following standard agronomic practices of selected medicinal plants, these comprehensive GAP guidelines on medicinal plants would ensure safe and quality-rich herbal materials for efficacious herbal formulations. Apart from this, it also encourages to develop monograph on GACP of medicinal plants considering the farmers practices, agro-ecological requirements, and reported literature. The adoption of GACP guidelines provides a safe production system ensuring consumer a right to nutritious, efficacious, affordable herbal medicines.

5.7. CRITICAL VARIABLE ALIGNMENT STUDY TO UNDERSTAND SIGNIFICANT VARIABLES AFFECTING THE CRITICAL QUALITY ATTRIBUTE IN QUESTION BASED ON SCIENTIFIC RATIONALE AND SUGGESTIVE IMPROVEMENTS IN AGRO-PRACTICES FOR QUALITY COMPLIANCE WITH SPECIFIC REFERENCE TO CONTENT OF ACTIVE CONSTITUENT(S), HEAVY METAL RESIDUE AND PESTICIDE CONTAMINATION

5.7.1. Critical Variable Alignment Study

Based on the survey-based study, it was observed that farmers were less aware regarding GAP and some important quality related concerns for medicinal plants. Hence, it became important to analyze critical quality statements of farmers with respect to GAP and suggest comprehensive scientific design for pre-determining the quality of their cultivated produce.

Herbal formulations are intended for human administration, therefore, heavy metals such as lead, cadmium should not be more than 10mg/kg and 0.3mg/kg respectively as per the WHO. Likewise, pesticide residues of Aldrin and dieldrin must not be more than 0.05 mg/Kg. Similarly, *Escherichia coli*, mould propagules, aerobic bacteria, yeasts and moulds, enterobacteria, *Salmonellae* must be in prescribed limits in raw, pre-treated medicinal plants. Aflatoxins, particularly B1, B2, G1 and G2 in plant materials should be avoided (World Health Organization, 2011, 1998). Likewise, crop productivity, microbial load, aflatoxin level, content of active constituents, toxicity indicators (heavy metals and pesticide residues), physicochemical parameters, etc. were the major parameters considered by the herbal industries. Therefore, all these parameters must fall in optimum range for wider industrial acceptance. In this context, it becomes imperative to highlight and map various agricultural materials and processes in order to maintain the desired quality of medicinal plants while also avoiding risks during its production. This has urged us to develop a rationale-based methodical approach to comprehend the quality of medicinal produce in relation to variables and practices involved. The suggestive improvements in terms of optimum agricultural processes are mentioned as descriptive study in 5.7.3. section.

5.7.2. Relationship Between CMA and CQA

Any material is a critical material when it has a high impact on the quality attributes of the medicinal plants. Critical materials are responsible for ensuring right CQA. There are several materials such as soil, water, seeds, site, biological factors, fertilizers, etc. that are used during the agriculture of medicinal plants. All the materials have effects on the quality outcome of the medicinal produce. Therefore, the critical materials were identified based on the inputs drawn from the farmers during the field visits and on sound literature exploration using critical alignment study approach. The critical material and their qualities are represented in Fig. 5.24. The plant stand or plant density has direct effect on the yield of the plant (Verma, *et al.*, 2003). In-adequate plant stand occurring due to poor seed quality is one of the retardants in plant in production areas affecting the yield of the plants (Rajala *et al.*, 2011). The high quality seeds would have higher germination rate, lesser mortality rate making your crop more economic viable. Germination rate, seedling emergence is the process that takes place in few days after sowing the seed; therefore high quality seeds provide vigorous and uniform germination under diverse climatic conditions providing optimum seedling growth resulting in higher yields of the plant (De Ron *et al.*, 2016; Ambika *et al.*, 2014).

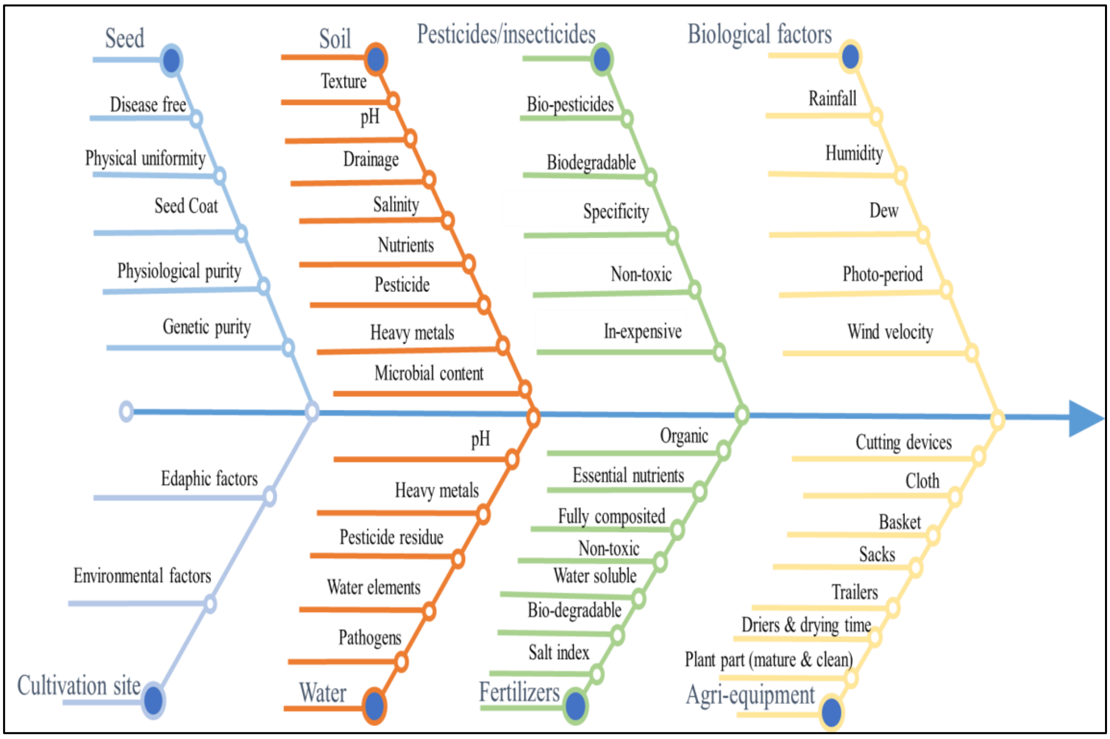


Figure 5.24: CMA and their qualities for medicinal plants cultivation.

The low quality seeds are prone to diseases and attract several types of weeds due to which farmers are forced to apply pesticides, fungicides and weedicides, which increase their input costs as well as increase the pesticide residue limits in the crops that becomes a delimiting factor for the herbal and related industry. Seed coat is other essential parameters responsible for the germination, therefore optimal thick seed coat with proper viability should be considered for the sowing (Culbertson and Kommedahl, 1956). High vigor seed, good germination and emergence are one of the prerequisites for successful sowing that eventually affects the yield of the crop (Tekrony and Egli, 1991). It is suggested to collect genetically, and physically uniform seed having resistant to diseases from the authorized dealer or institution.

Environmental stress which mainly depends on the selection of the site of cultivation increases the vulnerability of the plant to many diseases. Un-ideal climatic conditions weaken the plant growth, distribution and attract many diseases that eventually affect the yield of the crop (Tanaka *et al.*, 2007). Temperature has the direct effect on many plant processes including photosynthesis, transpiration, respiration, germination, seedling emergence, vegetative growth and reproductive growth. Likewise light and duration of light has a greater impact on producing food via photosynthesis and controlling flowering of the plants respectively. If the crops are not provided with optimum climatic conditions it produces low quality, stunted growth, etc. e.g. high temperature conditions cause bitter lettuce (Sandhu and Hodges 1971). Similarly, water and humidity plays great role in the overall growth of the plants. It is a main component in photosynthesis and respiration which directly affects the yield and active constituents of the plants. It also causes the plant to become dehydrated and wrinkled which is not acceptable or fetched lesser price in the herbal industries (Ford and Thorne, 1974). Hazardous site can attract molds such as *Aspergillus flavus* which grows on soil to produce aflatoxins that are carcinogens (Kaaya & Warren, 2005). Therefore, it is suggested to select appropriate site for cultivation offering optimum climatic conditions to the selected plants having no water logging and heavy metal contamination issues.

Soil is a three dimensional substance that covers some of the world's land surface. It provides habitat to bacteria, fungi, insects, mammals and burrowing animals. Soil provides anchorage, oxygen, water temperature modifications and nutrients, etc. Each soil has its own water holding capacity depending on its texture i.e. clayey soil has more water retention capacity as compared to sandy soils. Soil can also reach the permanent wilting percentage in which plant wilts severely and is unable to recover. The soil can be managed to achieve good crop productivity (Seifu and Elias, 2018). In-adequate soils are responsible for crop pathogens and blights which forces farmer to apply excessive pesticides which eventually increase the pesticides residue in the finished crops that is again a limiting factors during analyzing the quality of the medicinal plants.

Similarly, the ideal water used for irrigation has balanced set of salts. The poor quality of water can turn good soil into saline and sodic soils. 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 metabolities and poor aesthetic quality of crops (Tedeschi and Dell'Aquila, 2005). There has been a trend of applying intensive application of insecticides by the farmers to increase the crop yield but this has led the pesticides to exert negative effects on the bio-diversity, soil fertility and quality of water. Excessive use of fertilizers even retards the crop yield by killing important non-target species such as micro-organisms in the soil (Desneux *et al.*, 2007)**.** Similarly, it contaminates the soil surface and underground water which is directly or indirectly taken up by the crops. The excessive deposition of pesticides residues in the crop leads to rejection of crop by the herbal industry as pesticide content is one of the detrimental parameter in context to the quality of the herbal formulations (Rao and KumarMeena, 2011).

Subsequently, fertilizer is an important material derived naturally or chemically that is applied on the soil or the plant to provide one or more nutrients to the plants for their proper growth and yield (Randall and Hoeft, 1988)**.** However, excessive use of chemical fertilizers can retard the crop growth, attract diseases resulting in lesser crop yield (Bremner, 1995). Therefore, optimum use of fertilizers is recommended in the crops, moreover chemical fertilizers are generally not recommended in medicinal plants cultivation (Franz, 1982). Optimum climatic conditions should be followed during harvest of the medicinal plants. In general, biological indicators (rainfall, high wind velocity, high per cent of dew and humidity) are not recommended at the time of harvest. The high per cent of dew and humidity increases the moisture content and attracts several diseases of the collected material. All the equipment, materials, machines involved in harvesting of medicinal plants should be clean and dry. More contact with the soil would lead to larger moisture content, microbial content and physicochemical ranges prone to rejection by the industry (Organización Mundial de la Salud, & World Health Organization, 2003). According to the farmers inputs, and supported literature, the materials (seed, site, soil, water, pesticides, fertilizers, biological indicators i.e. dew, frost, and agricultural equipment) had highest number of consequences or effects on the quality attributes as mentioned in Table 5.10.

Table 5.10: Effect of CMA on CQA of medicinal plants.

Critical quality attributes	Seed	Site	Soil	Water	Pesticides	Fertilizers	Biological indicators	Agricultural equipment's
Crop yield	Very high	Very high	Very high	Very high	High	Moderate	Moderate	Negligible
Microbial load	Moderate	Moderate	High	Moderate	Less	Less	Less	Moderate
Active constituents	High	Less	Very less	High	Negligible	Very less	High	Very less
Physico chemical ranges	Less	Very Less	Less	Very high	Very less	Negligible	Very less	Less
Toxicity indicators	Very less	High	Moderate	Less	Moderate	Negligible	Negligible	Negligible

The alignment study highlighted seed, site, soil, and water had the highest bearing on the crop yield. Similarly, pesticides had a significant relation with crop yield and moderate relation with toxicity indicators. On the other hand, biological indicators, agricultural equipment's had a negligible bearing on toxicity indicators of the plants.

5.7.3. Relationship Between CPP and CQA

Every material used by the farmers for the successful cultivation of the medicinal plants passes through several processes that directly affect the quality of the crop. In general, if the materials pass the quality test but fail optimum processes, it results in poor quality crops (Yan *et al.*, 2014; Qu *et al.*, 2019). The critical processes were divided into three phases *viz.* pre-cultivation: comprising of seed, site, soil, and water treatment processes; agro-practices phase: sowing, plant management, crop nutrition, and harvest; post-harvest phase: comprising of collection, drying, storage, and handling of medicinal plants. The three phases and suggestive improvements in the agricultural processes are mentioned below:

5.7.3.1. Pre-cultivation Phase

Seed treatment: Proper taxonomical authentication with phenotype/chemotype/ genotype and breeding history must be guaranteed for good quality immunity-boosting plants. Similarly, proper inspection should be carried out to control intentional and un-intentional adulteration (Singh *et al.*, 2020b; Chanda, 2014).

Furthermore, seeds must be checked for physical uniformity, should be made disease and pest resistance to get optimum yield (Gahukar, 2012).

Site selection processes: A site should be considered after the analysis of the meteorological data for the past 10 years and the bio-climatic needs of the selected immunity-boosting plants. Sites history in context to heavy metals, pesticide residue should be checked by proper soil sampling (Valipour, 2014; Anderson, 2002). Sites near to mining, crematoriums, golf courses, etc., must be avoided for producing good quality herbs. Feedlot history and domestic animals entry need to be strictly prohibited as it affected the yield of the crop (De Freitas Araújo *et al.,* 2012).

Soil treatment processes: Soil sampling and physicochemical properties of the soil must be carried out to highlight the nutrient requirements of the plants and to check the water movement in soil layers. There should be proper tillage for the activation of the soil microbes, soil structure, and incorporation of fertilizers and soil amendments (Roger-Estrade *et al.,* 2010). It also helps to reduce soil erosion and releasing minerals from the soil to the plants (Rasmussen, 1999). Similarly, leveling the field must be carried out for the uniform distribution of water, nutrients to the seedlings thereby increasing the yield and good traffic (Agarwal and Goel, 1981). Soil drainage is a natural process that permits water moving across and through the soil because of gravity. In general, poor soil drainage results in a slower germination rate, increase the traffic damage, crop diseases, animal diseases, lesser root development, increase in moulds and weeds affecting the yield of the crops (Seifu and Elias, 2019 and Rhoades, 1974). So, optimum soil drainage must be maintained to avoid deterrent effects on the quality of the produce. In-appropriate soil pH affects plant growth in several ways by leaching the plant nutrients in acidic soil and affecting the bacteria responsible for providing nutrients to plants. Furthermore, to manage heavy metal and pesticide threat, plants such as mustard, marigold, etc., possessing significant phytoremediation properties, must be used (Salt *et al.,* 1998). Nigh soil must be avoided to ensure a lesser vulnerability of microbial and aflatoxin contamination of the plants.

Water treatment processes: The first step to assure the quality of the water is to ensure its compliance with the regional and national qualities (Organización Mundial de la Salud, World Health Organization, 2003). Source of water must be reliable and water should be devoid of pathogens such as *Phytophthora*, 26 of *Pythium*, 8 bacteria species, 27 fungi genera, 10 viruses, and 13 plant-parasitic nematodes species causing diseases, aflatoxins, and extraneous matter (Hong and Moorman, 2005). Good mulch under the crop can prevent the soil salinity by maintaining the optimum moisture to the crop (Pang *et al.,* 2010). Lead which is neither an essential element has a high tendency to get absorbed and accumulate in different parts of the plants leading to stunted growth, chlorosis, blackening of roots, etc. (Nas and Ali, 2018; Sharma *et al*., 2008). Therefore, lead pipe fittings should be avoided to control excessive lead presence in the crop (Singh and Baldi, 2018).

5.7.3.2. Agro-practices Phase

Sowing: Punjab has different growing periods so optimum climatic requirements of the plants at the time of sowing must be followed after consulting official literature and experts (Singh and Rath, 2013; Coventry *et al.,* 1993). During sowing optimal seed to seed and row to row distance, seed depth must be maintained according to the plant requirements. Inappropriate distances affected crop growth, root density, plant height, number of leaves, plant biomass, weeds, and vulnerability to diseases which eventually affects the yield, microbial load, active constituents, physico-chemical ranges, and toxicity indicators (Ngullie and Biswas, 2017).

Plant management: Seeds or material sometimes tend to show mortality in the initial period, so replenishment of the plant population was necessary to get a better yield (Hatfield *et al.*, 2001; Persson, 1980). The plant requires optimum cycles of weeding so that undesired plants do not compete with the principal crops for nutrients especially during the growth period. Similarly, hoeing, topping, pruning, shading must be carried out depending on the plant requirements (Nag and Pradhan, 1992; Aydın and Arslan, 2018). Pruning was essential to remove the dead part of the plant especially Amla, to control, re-direct its growth (Saure, 1987). According to the mapping, the plant management possessed effect on the yield, microbial load, physicochemical and toxicity indicators of the immunity-boosting plants.

Crop nutrition: Optimum use of aerobic organic fertilizers, bio-pesticides is recommended for the medicinal plants. Fully composited organic manures, vermin-compost, poultry manure, green leafy manure must be applied at the initial for phase for a complete breakdown (Organización Mundial de la Salud, World Health Organization, 2003). In some cases, if pesticides were essentially required, the smallest effective dosage with the least toxicity must be used. Human excreta should not be used or mixed with the fertilizers as it attracted pathogens, diseases, and pests lowering the yield of the plant and increasing the microbial load (Strauch, 1991). Fertilizers should be applied by trained personnel only to ensure optimum.

Harvest: The time of the harvest played a critical role in context to the presence of active constituents (Tanko *et al.,* 2005). Only the mature part of the plant should be harvested to attain significant chemical constituents. Good harvesting practices should be carried out to avoid the foreign matter, weeds, and toxic plants adjoining the principal crops. Harvesting must be avoided in high dew, humidity, and rainfall (Organización Mundial de la Salud and World Health Organization, 2003).

5.7.3.3. Post-harvest Phase

Collection: In the case of collecting fruits from the trees such as *P. emblica*, the collectors should follow the optimum time to obtain maximum active constituents in the plants. The collection time (in terms of maturity) of the fruits is essential as it directly impacts the per cent of active constituents, therefore, collection of immature or undersized fruits must be avoided (Tavhare and Nishteswar, 2014). Sorting of the fruits must be carried out to separate damaged fruits which are prone to get microbial contamination. During collection fruits extraneous material must be separated or cleaned in order to avoid higher physico-chemical ranges. Fruits should be collected in a scientific manner after consulting experts and pharmacopoeia to get the desired yield, active constituents, lesser microbial, aflatoxin, moisture content, etc.

Drying: In general, drying should be done in a manner to avoid losing volatile oils, and prevent discoloration of the raw herbs. If drying in not done in optimally, it has chances to increase the moisture resulting in increasing of microbial load. Similarly, if excessive drying in carried out, there are chances of losing volatile oils from the raw herbs affecting the per cent of active constituents. It is recommended that drying of medicinal plants under direct sunlight must be avoided to maintain the volatile contents present in the medicinal plants. Shade drying, solar drying, freeze-drying, etc. must be preferred for medicinal plants (Müller and Heindl, 2007, 2006). During drying, tarpaulin cloth should be used between the cemented floor and the drying material to prevent crop damage and foreign matter which can increase the physico-chemical ranges in the plant samples.

Storage: Storage of medicinal plants impacts the quantity of active constituents present in the medicinal plant. Excessive storage of medicinal plants increases the vulnerability of losing active constituents and increases the chances of retaining moisture leading to higher chances of microbial contamination. Therefore, it is recommended to process or semi-process medicinal plants in due course of time and storage time must not exceed one year for any medicinal plants (Lisboa *et al.,* 2018; Yadav *et al.,* 2013b). Similarly, there must be controlled environmental conditions in the storage room to avoid moisture, microbial, aflatoxin contamination. Proper packing must be carried out for medicinal plants i.e. for hard materials, gunny bags and woven sacks should be preferred, for creeper and leaves, high gauge polythene bags should be used, for fleshy material high gauge High Molecular Weight High-Density Polyethylene (HMHDP) bags should be preferred. An un-authorized person should not be allowed to enter the room (Sumithra and Prasad, 2018)

Handling: Harvested material should be thoroughly cleaned to avoid the presence of foreign matter, high moisture content, microbial content, aflatoxin levels, etc. **(**Rajeshwari and Raveesha, 2016) The processing equipment should be cleaned and free from pathogens to avoid microbial contamination. During transportation, the raw materials should not be overfilled in the sacks, this increases the chances for microbial contamination and damage of produce (Máthé and Franz, 1999). Likewise, unpacking of the material should be carried out immediately on reaching the processing unit for proper sorting to prevent damage to the crops. Inappropriate handling of herbal raw material affects the microbial load, active constituent yield, and physicochemical parameters. The critical process parameters identified in this study are represented in Fig. 5.25.

The present study suggested that from all the critical processes, the pre-cultivation phase has a larger bearing on crop yield. Similarly, sowing had a significant bearing on crop productivity, followed by plant management and crop nutrition in the agro-practices phase. On the other hand, harvesting, collection, drying, storage handling had a negligible effect on crop yield and toxicity but specifically affected constituents and microbial load as mentioned in Table 5.11.

Figure 5.25: CPP for medicinal plants cultivation.

Table 5.11: Effect of CPP on CQA of medicinal plants.

Pre-cultivation phase				
Critical quality attributes	**Seed treatment**	**Site treatment**	**Soil treatment**	**Water treatment**
Crop yield	Very high	Very high	Very high	Very high
Microbial load	Less	Moderate	High	Moderate
Active constituents	High	Less	Less	High
Physicochemical ranges	Very less	Very Less	Very less	Very less
Toxicity indicators	Moderate	High	Moderate	Less
Agro-practices phase				
Critical quality attributes	**Sowing**	**Plant management**	**Crop nutrition**	**Harvest**
Crop yield	Very high	High	High	Negligible
Microbial load	Moderate	Very less	Moderate	Very less
Active constituents	High	Less	Less	Moderate
Physicochemical ranges	Less	Moderate	Negligible	Less
Toxicity indicators	Very less	Negligible	Very less	Negligible
Post-harvest phase				
Critical quality attributes	**Collection**	**Drying**	**Storage**	**Handling**
Crop yield	Negligible	Negligible	Negligible	Negligible
Microbial load	Less	Moderate	Less	Moderate
Active constituents	Moderate	Less	Moderate	Less
Physicochemical ranges	Very less	Very less	Very less	Very less
Toxicity indicators	Negligible	Negligible	Negligible	Negligible

The findings will be helpful to ascertain the systematic method of medicinal plant cultivation and application of suitable measures for obtaining maximum productivity with assured quality. Further, the study lays a fundamental basis for the farmers interested in GAP based cultivation of medicinal plants in a more efficient, cost-effective, and scientific manner. This technique would enable the farmer to fine-tune parameters as all possible interactions have been already evaluated with in-depth understanding. This design would become of greater importance for the herbal industries looking to boost their production and reduce throughput times. Apart from medicinal plants, the study can be extrapolated to other agricultural sciences especially spices, aromatics, etc. for continuous improvement of the quality. Hence, the findings may open a new vista in transforming cultivation practices to an inclusive and holistic approach based on scientific intrigue.

5.8. STANDARDIZATION OF FARMER'S PRODUCE FOR SAME QUALITY PARAMETERS AND GAP VARIABILITY ANALYSIS IN COMPARISON TO INDUSTRIAL STANDARDS

Customers are placing high demands on the industry for high quality of medicinal products. The companies are feeling it difficult to maintain high quality and reliability especially in the case of medicinal plants which are prone to attract microbes, degradation, physicochemical ranges, etc. (Ekor, 2014). Agriculture of medicinal plants is slightly different from that of other crops as their products are intended for human and animal use for carrying various pharmacological activities. Hence, each agricultural process has to be standardized and optimized in order to prevent toxicity indicators, microbial contamination, in-appropriate physicochemical ranges, crop yield and per cent of active constituents (Vlietinck *et al.,* 2009). Each agricultural process starting from the collection of seed to the processing of final medicinal produce needs to be strictly monitored as each step is vulnerable to deteriorate the quality of crops. Conventionally, reliability of medicinal plants has been accomplished using widespread testing of medicinal plants adopting probabilistic reliability modeling. These methods are applied at the delayed phase of improvements. The challenge is to devise in quality and reliability in the early phase of medicinal plants production (Carbone and Tippett, 2004; Dasgupta, 2003). In the present study, FMEA tools were applied to standardize farmers produce based on calculating the RPN of each agricultural step vulnerable to affect the quality of medicinal produce.

5.8.1. Pre-cultivation Phase

Authentication of seed: Proper seed authentication is one of the crucial steps in achieving good quality produce of medicinal plants (Chanda, 2014). In general, most of the farmers rely on oral tradition of local farmers and traders for collecting seeds. This sometimes leads to in-correct identification leading to poor crop yield, active constituents and disease resistance. If its risks are not identified prior to the cultivation, the farmers eventually resort to excessive use of fertilizers and pesticides in order to get high crop yield, disease free plant neglecting the consequences of pesticides and chemical residues in the crop. Hence, proper authentication is pre-requisite and fundamental in medicinal plants cultivation assuring to maintain efficacy and therapeutic property of the herbal preparation. As mentioned in Table 5.12, the toxicity indicators possess the highest severity rankings followed by microbial load, active constituents, crop yield and physico-chemical ranges for medicinal plants. Understanding the potential failure mode, their severity, cause of the failure, occurrence, process controls and detection, it is essential to take suitable concrete steps in fixing the occurrence and detection levels based on the RPN rankings to manage the risks in seed authentication.

In the present study, RPN 72 highlighted lack of awareness (occurrence rate 06) as the major occurrence cause for the failure and process control such as awareness (detection rate 02) could aware farmers to prevent toxicity indicators (severity rate 06) in the authentication process of medicinal plants. Similarly, there are different RPN’s for microbial load, active constituents, crop yield and physicochemical ranges calculated individually with occurrence and detection ratings. As per the validated RPN table, RPN more than 65 suggested quick actions followed by RPN range 38-65 and less than 38 suggesting actions to be taken and acted upon later respectively. In order to bring the RPN value down, the checklists and recommendations are mentioned in Table 5.13.

Table 5.12: Standardization based on authentication of seed.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Authentication of seed	No authentication	Toxicity indicators	06	• No awareness • High costs • No facility nearby	06 03 02	• Awareness programs • Free facility • Giving facility nearby	02 01 01	**72** **18** **12**
		Microbial load	05					**60** **15** **10**
		Active constituents	04					**48** **12** **08**
		Crop yield	03					**36** **09** **06**
		In-appropriate physico-chemical parameters	02					**24** **06** **4**
	Wrong authentication			• Error by an qualified expert • Reliability on fellow farmer or trader or non-expert	01 03	• Detailed authentication by an experienced expert • Consulting local expert	02 04	**12** **72**
								10 **60**
								08 **48**
								06 **36**
								04 **24**

Table 5.13: Checklists for the farmers and recommendations for assuring seed quality.

Some common checklist to assure seed quality	Parameters considered by most of the farmers	Recommendations
Have you carried out proper taxonomical identity consulting an expert? Yes ☐ No ☐	×	Farmers generally rely on oral assurances given by the seed provider and perform self-macroscopic analysis. To circumvent this, here are some recommendations: • Farmers should be made aware regarding the significance of proper seed authentication by frequently conducting farmer's stakeholders meetings by NMPB and RCFC-North. • Concerned organizations of ICAR, state agricultural universities should increase the production of authentic quality planting material and make sure there is adequate material for the farmers to collect from nearby research centres on subsidized rate.
Is the planting material free from pests, diseases, or any adulteration? Yes ☐ No ☐	√	
Is Phenotype/Genotype/Breeding history of the seeds complying with national regulation? Yes ☐ No ☐	×	
Is physicochemical analysis/ marker based analysis of end product carried out for seed? Yes ☐ No ☐	×	
Is the planting material resistant to diseases, biotic, abiotic factors and certified organic Yes ☐ No ☐	×	
Follow seed treatment if any as prescribed on label? Yes ☐ No ☐	×	

Selection of cultivation site: Site selection is the quality determining step before cultivation of medicinal plants (Prakash *et al.*, 2011). It was observed during our field visits that most of the farmers were not considering meteorological data before selection of the site due to lack of awareness or extension services. Critical factors such as non-consideration of the past meteorological data, biotic factors and socio-economic factors related to the site could be the potential cause of the failure which directly affected the toxicity indicators, microbial load, active constituents, crop yield and physicochemical ranges of the medicinal produce. Hence, the FMEA datasheet highlighted RPN for each factor of site selection as mentioned in Table 5.14. Similarly, checklists for assuring proper site selection for the farmers and certain recommendation such as free soil sampling at nearby places, provision of agro-ecological zoning based selection of plants, etc. are mentioned in Table 5.15 for concerned authorities.

Treatment of soil: Soil treatment such as maintaining optimum soil drainage, soil pH, soil nutrients, eliminating pesticides and heavy metal residues, etc. enable optimum sowing conditions (Seifu and Elias, 2018). Therefore, in the present study, we have pre-determined the potential mode of the failures, their severity, causes of failure, occurrence, process controls and detection ratings to obtain RPN of each process involved in treatment of soil. In-appropriate soil pH and presence of pesticides and heavy metals in soil resulted in the higher RPN. Hence, it is important to take quick actions to fix the RPN accordingly. Process controls such as applying sub-surface drainage, mulching for soil drainage; optimum use of fertilizers, crop diversification for pH; phytoremediation techniques for heavy metals and pesticides are also highlighted in Table 5.16 with respective RPN's. Similarly, checklists for the farmers and recommendations are mentioned in Table 5.17 leading to assurance of optimum soil treatment.

One of the key factors in the adoption of medicinal plants is that it should be devoid of chemical fertilizers, pesticides and heavy metals. Most of the farmers of Punjab rely on extensive use of chemical fertilizers and pesticides for gaining maximum yields of wheat and rice. Therefore, a farmer who intends to adopt medicinal plants cultivation must assure that his land should be organic to its maximum capacity. In this context, phyto-remediation techniques play a pivotal role in managing pesticides and heavy metals. Phytoremediation/botanical bioremediation using intercropping with hyper-accumulator plants with capacity to sequester and detoxify large amount of heavy metals based on mechanisms *viz.* a) Phyto-extraction; b) Phyto-accumulation; c) Phyto-stabilization; d) Rhizo-degradation. Plantation of various herbs (Mustard, Methi, Palak), flowering plants (Sunflower, Marigold, Chamomile, Cauliflower, Cabbage), grain (Barley) and tree (Popular, Eucalyptus) along with medicinal plants are reported to significantly obviate the problems of heavy metals and pesticides (Sharma *et al*., 2016). Hence we suggest certain plants based on reported literature for phyto-remediation as mentioned in Table 5.18 and 5.19.

Table 5.14: Standardization based on selection of cultivation site.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Suitable selection of site	In-adequate climate indicators requirements	Toxicity indicators Microbial load Active constituents Crop yield In-appropriate physic-chemical parameters	06 05 04 03 02	• No awareness • Lack of extension services • Lack of data regarding crop-land suitability	06 03 06	• Awareness programs • Interaction between farmers and field officers • Highlight potential agro-ecological zones based on meteorological data for past 03 years	02 01 01	72 18 36 60 15 30 48 12 24 36 09 18 24 06 12
	In-adequate edaphic requirements			• Lack of awareness • Lack of extension services • Higher costs of soil sampling • Lack of labs	06 03 05 04	• Awareness programs • Advancing farmer friendly extension services • Providing free soil sampling • Establish labs in nearby places	02 01 01 01	72 18 30 24 60 15 25 20 48 12 20 16

								36 09 15 12
								24 06 10 08
	In-adequate biotic factors	Toxicity indicators Microbial load Crop yield	06 05 03	• Lack of knowledge regarding site history	02	• Expert consultation. Knowledge from fellow farmers on harmful organisms, weeds, pests and disease infestation	02	24 20 12

Table 5.15: Checklist and recommendations for assuring good site selection.

Checklist to assure good site selection	Parameters considered by most of the farmers	Recommendations
Did you consult meteorological data for at least 10 years? Yes ☐ No ☐	×	In general, the farmers cultivate medicinal plants based on the information passed by oral tradition. Some common parameters such as uniform levels of land, water access, water logging, etc. are generally considered by the farmers before selecting the site. Below mentioned are some recommendations to assure proper site selection: • Potential growing areas for selected medicinal plants should be provided to the farmers based on agro-ecological zoning studies by the
Is your site free from hazardous industrial waste, sludge? Yes ☐ No ☐	√	
Did you carry out pesticide/herbicide and heavy metal analysis and breakdown rate by soil sampling? Yes ☐ No ☐	×	
Are you recording the information regarding improving or damaging crop in the site? Yes ☐ No ☐	×	

Is your site near far from tail mining's, parking lots, waterways? Yes ☐ No ☐	×	research centres through extension services.
Did you identify crops adjoining your site & treatment? Yes ☐ No ☐	×	• A visit of an agricultural expert should be made mandatory to highlight potential biotic and abiotic stress factors to the plants.
Are cows and domestic animals prohibited in your site? Yes ☐ No ☐	×	
Is the site having history of feedlot? Yes ☐ No ☐	×	• Farmers should be made aware through awareness meets regarding the importance of the parameters mentioned in the checklists in order to obtain high quality medicinal plants.
Does the site have optimal water holding capacity & provision of water logging prevention? Yes ☐ No ☐	√	
Does the site have positive ecological, environmental social impact? Yes ☐ No ☐	×	

Table 5.16: Standardization based on treatment of soil.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Soil treatment	In-appropriate soil drainage	Toxicity indicators Microbial load Active constituents Crop yield	06 05 04 03	• Person not attentive • No artificial removal of water from low-lying areas • Surface run-	01 02 03	• None • Surface drainage and sub-surface drainage • Tree-based buffers • Composting of	06 01 02	**36** **12** **36** **48** **48** **30** **10** **30** **40** **40**

		In-appropriate physic-chemical parameters	02	off •In-adequate composting •In-adequate mulching	04 04	organic manure to break clumps and prevent compaction • Mulching for absorption of excess water	02 02	24 08 24 32 32 18 06 18 24 24 12 04 12 16 16
	In-appropriate soil pH			•No awareness •Inherent factors such as climate, soil texture •In-appropriate use of fertilizers •In-adequate cropping practices	03 06 05 04	• Training • Cannot be changed • Applying optimum amount of nitrogen fertilizers, liming • Diversified crop rotation	02 06 04 04	36 216 120 96 30 180 100 80 24 144 80 64 18 108 60 48

								12 **72** **40** **32**
	In-appropriate soil nutrients and organic matter			•No awareness •In-appropriate dose of fertilizers (N,P,K)	03 04	• Training • Consulting agricultural officer on optimum use of fertilizers	02 04	**36** **96** **30** **80** **24** **64** **18** **48** **12** **32**
	Excessive pesticides and heavy metal effected	Toxicity indicators	06	•Lack of knowledge regarding site history •No use of pesticides or heavy metal removal techniques •No soil sampling	03 06 04	• Acquiring prior knowledge on site contamination from the native village farmers or village panchayats • Apply phyto-remediation techniques • Free soil sampling at nearby places	03 05 05	**54** **180** **120**

Table 5.17: Checklist and recommendations to assure soil quality.

Checklist to assure soil quality	**Parameters considered by most of the farmers**	**Recommendations**
Are you preventing the use of nigh soil? Yes ☐ No ☐	√	• Soil sampling and physico-chemical analysis of soil should be done to quantify essential soil nutrients prior to planting and decide further amendments. • More soil sampling labs should be established and free soil sampling facilities should be provided to the farmers by the Department of soil and water conservation in Punjab. • Farmers must be made aware regarding the adoption of phyto-remediation plants to circumvent heavy metal and pesticides residues threat as mentioned in Table 5.18 and 5.19. • Create a reliable database and documentation centre related to assess land resources degraded / wastelands or extent of areas subject to soil erosion, deforestation and various types of degradation.
Does the soil have appropriate amount of nutrients? Yes ☐ No ☐	×	
Are you avoiding high soil moisture level for mold and fungal problems? Yes ☐ No ☐	√	
Is there any presence of heavy metals and pesticides residues? Yes ☐ No ☐	×	
Did you consider soil type, pH, drainage, moisture, retention and fertility of the soil through sampling? Yes ☐ No ☐	×	

Table 5.18: Suggestive popular plants used in phytoremediation.

S. No.	**Methodologies and Agents used**	**Heavy metals removed**	**References**
1	**Phytoremediation/Botanical Bioremediation**		
	Brassica spp. (Mainly mustard)	Zn, U, Ni, Cu, As, Pb	Ojuederie and Babalola, 2017; Mandal *et al.*, 2014; Davis *et al.*, 2001; Leblanc *et al.*, 1999
	Helianthus annuus (Sunflower)	Pb, Zn, Cd	Kiran *et al.*, 2007; Antunes *et al.*, 2003; Gupta *et al.*, 2001
	Tagetus erecta (Marigold)	Cd, Ni, Pb	Goswami and Das, 2017
	Trigonella foenumgraceum (Fenugreek/Methi) *Jasminum auriculatum* (Jasmine)	Cr	Mandal *et al.*, 2014

	Eucalyptus		
	Spinacia olearacea (Spinach/Palak)	Ni, Cd, Fe	Mandal *et al.*, 2014
	Chamomilla recutita and *Hypericum perforatum*	Cd	Zarinkamar *et al.*, 2013
	Populus tremula (Poplar)	Cd	Sharma *et al.*, 2016; Kang, 2014
	Psychotria douarre	Ni	Huang *et al.*, 1998
	Iberisinter media	Th	Riddle *et al.*, 2002
	Eichhornia crassipes	Hg	Riddle *et al.*, 2002
2	**Adsorption by plant wastes**		
	Rice husk	Cd	Pilon-Smits, 2005
	Poplar husk	Cd, Cr, Cu, Ni, Zn, Pb	Sharma *et al.*, 2016
	Wheat bran	Cu, Cd	Özer *et al.*, 2004
	Groundnut husk	Cr	Šćiban *et al.*, 2006
	Sugarcane bagasse	Cu, Cd, Pb	Karnitz Jr *et al.*, 2007
3	**Biosorption using microbial agents** (If water is contaminated)		
	Bacillus spp.	Cr, Cd, Ni, U, Th	Ojuederie and Babalola, 2017; Sharma *et al.*, 2016; Mandal *et al.*, 2014; Davis *et al.*, 2001; Leblanc *et al.*, 1999
	Psudomonas putida	Cd, Cu, U, Th, Pb	Kang, 2014; Pardo *et al.*, 2003
	Saccharomyces cerevisiae	Hg, Cd, Cu, Cr, Ni, U, Pb	Zhao and Duncan, 1997

Table 5.19: Suggested means of pesticides removal.

S. No.	Agents used	Pesticides	References
1	Brassica spp. (Mainly mustard)	Phorate	Rani and Juwarkar, 2012
2	*Helianthus annuus* (Sunflower)	Carbofuran residues	Teerakun and Reungsang, 2005
3	*Tagetus erecta* (Marigold)	Chlorpyrifos	Kadian, 2010
4	*Hordeum vulgare* (Barley)	Carbofuran, terbuthylezin	Hussain *et al.*, 2009
5	*Spinacia olearacea* (Spinach/ Palak)	HCH, DDT	Hussain *et al.*, 2009
6	*Brassica oleracea* (Cauliflower)	HCH, DDT	Hussain *et al.*, 2009
7	*Populus tremula* (Popular)	Atrazine	Lee *et al.*, 2012
8	*Daucus carota* (Carrot) peels	Chlorinated pesticides	Hussain *et al.*, 2009
9	*Solanum tuborsum* (Potato) peels	Chlorinated pesticides	Hussain *et al.*, 2009

Water treatment: The poor quality of water can turn good soil into saline and sodic soil having adverse effects on the crops. Irrigation with both saline and acidic water effects 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 deflocculating effect of sodium, crusting of seed beds, water logging, 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. (Khajuria, 2016; Tedeschi and Dell'Aquila, 2005; Hamdy, 1993).

Similarly, important soil flora such as *Azotobacter* is sensitive to high salt concentration. Furthermore poor quality of water can lead to lesser uptake of K^+ and Ca^+ leading to different nutritional deficiencies (Baligar *et al.*, 2001). Water is also sometimes carrier of plant pathogens such as *Phytophthora, Pythium,* bacteria species, fungi genera, viruses, and plant parasitic nematodes species causing diseases (Purushothaman *et al*., 2014; Hong and Moorman, 2005). Therefore, water salinity and in-appropriate water quality was considered as the potential failure mode affecting the quality of product. RPN's were calculated based on severity, occurrence and detection of each factor as mentioned in Table 5.20 and certain checklists for the farmers to avoid water related threats as represented in Table 5.21.

Table 5.20: Standardization based on water quality.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Optimum water treatment	Water salinity or acidity	Toxicity indicators Microbial load Active constituents Crop yield In-appropriate physico-chemical parameters	06 05 04 03 02	•Inherent salinity •Salinity due to human agro-practices activity	02 02	• No control • Water sampling and methods: mulching, sub-surface drainage, minimizing fallow land	05 04	**60** **48** **50** **40** **40** **32** **30** **24** **20** **16**
	In-appropriate water quality (microbial, heavy metal contamination)			•Person at attentive •No reliable source of water •Lead fitting pipes	02 01 02	• None •Water sampling and compliance with national quality •Avoiding lead pipes	06 03 04	**72** **18** **48** **60** **15** **40** **48** **12** **32** **36** **09** **24** **24** **06** **16**

Table 5.21: Checklist and recommendations to assure the quality of water.

Checklist to assure water quality	Parameters considered by most of the farmers	Recommendations
Have you identified the source of water (on-farm well, open irrigation canal, reservoir, municipal supply or other sources)? Yes ☐ No ☐	√	• Farmers should be made aware regarding the significance of quality of water to irrigate medicinal plants through farmer-medicinal plants stakeholders meeting by NMPB in co-ordination with the Soil and Water Conservation Department, Punjab. • Farmer must be made aware regarding water sampling and free water sampling facilities should be provided to the farmers in nearby places by Soil and Water Conservation Department, Punjab. • Specific treatment options to circumvent water salinity, acidity and toxicity should be provided to the farmers by the Soil and Water Conservation Department, Punjab and only tolerant plant species should be advised to the farmers.
Does the water comply with local, regional and national quality standards? Yes ☐ No ☐	√	
Is the irrigation water devoid of salinity, acidity and toxicity? Yes ☐ No ☐	√	
Did you carry out water analysis for heavy metal and residual matter? Yes ☐ No ☐	×	
Did you avoid lead pipe fitting for water? Yes ☐ No ☐	×	
Did you access total salt concentration, sodium absorption ratio, bicarbonate and boron concentration through water sampling? Yes ☐ No ☐	×	

5.8.2. Agro-practices Phase

Sowing: It is the most critical step to ensure quality and quantity of medicinal plants produce. A proper sowing comprises of optimum tillage, levelling, time of sowing, plant and row distances, seeds per acre and seed depth for medicinal plants. Any abnormality in these steps directly affects the quality as well as quantity of the medicinal plants. Before sowing there should be proper tillage for the activation of the soil microbes, soil structure and incorporation of fertilizers and soil amendments (Roger-Estrade *et al.*, 2010). Similarly leveling of field should be carried out for uniform distribution of water, nutrients, and yield and to maintain higher agricultural area and good traffic (Agarwal, 1981). 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). The RPN ratings related to sowing are mentioned in Table 5.22. Process controls such as high manufacturing of state-of-art farm machinery, generating high quality planting materials at research centers, availability of region based agro-practices document for selected medicinal plants are mentioned as recommendations and checklists for the framers to ensure optimum sowing are also mentioned in Table 5.23.

Irrigation*:* A successful crop is the only one that receives optimum level of irrigation. Less or excessive irrigation induces stress to the plants resulting several plant diseases effecting the quality and quantity of the crop (Rinaldi and He, 2014). Hence the potential mode of failure for irrigation would be less or excessive irrigation that can be caused by multiple factors such as lack of attentiveness, poor drainage, in-sufficient supply of water, sudden climatic consequences, etc. having severe effects on the quality of the plants. RPN related to the irrigation is mentioned in Table 5.24 and recommendation to ensure to optimum irrigation is mentioned in Table 5.25.

Crop nutrition: To overcome the fear for stagnant yields, sometimes the farmers resort to un-scientific application of chemical fertilizers leading to plant diseases such as leaf burnt and acidification of soil (Moyin-Jesu, 2019; Painuli and Dev, 1998). Organic manures, vermin-compost, poultry manure, green leafy manure should be optimally used for providing nutrients to the plants. However, excessive use of organic fertilizers can also lead to plant diseases such as leaf burnt and acidification of soil. Human excreta should not be used or mixed with the fertilizers as it attracts pathogens, diseases and pest lowering the yield of the plant and increasing the damaged crop. Fully composited aerobic manure must be applied by trained personnel during the initial phase of the plants for proper breakdown (Singh and Baldi, 2018). Generally, in some cases, local fertilizer traders manage to influence the farmers to use more fertilizers in order to achieve higher yields. In the present FMEA model, processes to control selection of appropriate fertilizers, excessive or lesser application of fertilizers are mentioned in Table 5.26 and checklists are mentioned in Table 5.27 for lowering RPN.

Table 5.22: Standardization based on the process of sowing.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Sowing	In-appropriate tilling	Toxicity indicators Microbial load Active constituents Crop yield Physicochemical parameters	06 05 04 03 02	• Person not attentive • In-effective tillage methods • Surface hardness/ mountainous land	01 02 3	• None • Trainings on best methods of tillage • Awareness on applying "no till farming" and providing mechanized approaches	06 02 02	**36** **24** **36** **30** **20** **30** **24** **16** **24** **18** **12** **18** **12** **08** **12**
	In-appropriate leveling			• Person not attentive • Heavy earth movements • Lack of mechanized equipments • Mountainous land	02 02 04 02	• None • To aware farmers to follow best condition with minimal earth movement and then vary the water supply for the field condition • Provision of more	06 02 04	**72** **24** **96** **48** **60** **20** **80** **40** **48** **16** **64**

						advanced and economical sophisticated leveling equipment • Training and awareness regarding mountain farming	04	32 36 12 48 24 24 08 32 16
	In-appropriate time for sowing			• Lack of awareness regarding optimum time • Shortage of quality planting material leading to delay • Sudden climatic consequences • Delay harvesting of previous crop	02 05 02 03	• Awareness regarding optimum sowing time • Generating sufficient quality planting materials • None • Maintaining proper crop calendar and providing more mechanized farming	02 04 06 03	24 120 72 54 20 100 60 45 16 80 48 36 12 60 36 27 08 40 24 18
	Non-uniform plant and row			• Person not	03	• None	06	108 48

	distance			attentive • No awareness regarding agro-practices • In-appropriate sowing methods • Lack and high costs of mechanized farming	 04 04 05	• Awareness regarding adopting suitable sowing method • Awareness by disseminating agro-practices manual/ training • Providing subsidized machinery	02 02 03	48 90 90 40 40 75 72 32 32 60 54 24 24 45 36 16 16 30
	In-appropriate seed depth and seed per acre			• Person not attentive • Lack of awareness regarding agro-practices • Lack of mechanized farming	02 05 05	• None • More extension services • Providing subsidized machinery	06 03 02	72 90 60 60 75 50 48 60 40 36 45 30 24

								30 20
	No quality planting material			• Lack of generation of QPM in research stations	05	• Increasing the infrastructure to speed the manufacture of QPM	02	60 50 40 30 20

Table 5.23: Checklist and recommendation to assure optimum sowing and site preparation.

Checklist to assure optimum sowing	Parameters considered by most of the farmers	Recommendations
Did you carry out tillage, leveling before the time of sowing? Yes ☐ No ☐	√	• Good agricultural practices methodologies based on state agro-ecological conditions should be drafted by the regional ICAR institutions. • Quality planting material should be generated on high scale at agricultural research centres and be made available to the farmers at nearby places • A simplified version of agro-practices document should be disseminated to the farmers in the native languages. • State-of-art sowing machineries should be manufactured by the research centres and industries and should be given to the farmers on subsidized rates. • Frequent trainings should be conducted by RCFC-North and NMPB to educate the farmers on agro-practices.
Are you considering seedlings per acre? Yes ☐ No ☐	√	
Have you optimally considered plant to plant distance? Yes ☐ No ☐	√	
Are you maintaining proper row to row distance? Yes ☐ No ☐	√	
Is your seeds placed at appropriate depth in moist zone of soil? Yes ☐ No ☐	√	
Are you following all the agro-technique parameters for particular plant as per GAP? Yes ☐ No ☐	×	

Table 5.24: Standardization based on irrigation.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Irrigation	More irrigation	Toxicity indicators Microbial load Active constituents Crop yield In-appropriate physic-chemical parameters	06 05 04 03 02	• Person not attentive • Sudden climatic consequences • Lack of knowledge regarding soil type and water requirement • Poor drainage	01 02 1 02	• None • None • Awareness on optimum use/ more extension services • Surface and sub-surface drainage	06 06 02 02	**36** **72** **12** **24** **30** **60** **10** **20** **24** **48** **08** **16** **18** **36** **06** **12** **12** **36** **12** **08**
	Less irrigation			• Person not attentive • In-sufficient supply of water	02 02	• None Assuring proper supply of water by the	06 04	**72** **48** **36** **60** **40** **60**

				• Sudden climatic consequences	02	government • None	06	**48** **32** **48** **36** **24** **36** **24** **16** **24**

Table 5.25: Checklist and recommendation to assure optimum irrigation.

Checklist to assure optimum irrigation	Parameters considered by most of the farmers	Recommendations
Are you using the water optimally for irrigation? Yes ☐ No ☐	√	• Frequent trainings should be conducted by RCFC-North and NMPB to educate the farmers on agro-practices and planned irrigation by conducting trainings. • Respective state government should assure proper and frequent turns for irrigation in canal water irrigation to the farmers • Government should provide high subsidies on irrigation sprinklers, drip irrigation, etc. • Surface and subsurface motors should be given on subsidized rate to prevent water logging and impounding rain water.
Have you planned irrigation cycle for optimal growth? Yes ☐ No ☐	√	
Do you have provision for water harvesting and conservation methods? Yes ☐ No ☐	×	
Does your site have proper drainage prevention of rain water impounding? Yes ☐ No ☐	√	

Pesticides/insecticides application: The un-scientific application of pesticides exerts negative effects on the bio-diversity, soil fertility and quality of water. Furthermore, this retards the crop yield by killing important non-target species (Desneux *et al.*, 2007)**.** Similarly, it contaminates the soil surface and underground water which is directly or indirectly taken up by the crops. In Punjab, there is heavy usage of pesticides on the traditional crops but in the case for medicinal plants no chemical pesticides or insecticides are recommended as these formulations are intended for human use. Furthermore, developed countries are developing quality checks to avoid excessive presence of chemical pesticides in food grains. Apart from this, exposure to chemical pesticides and insecticides exhibits skin irritation, tumor to birth defects. Therefore, pesticides must be used in smallest effective dosage with least toxicity (Singh and Baldi, 2018; Organización Mundial de la Salud and World Health Organization, 2003). In the present FMEA studies, RPN was calculated considering severity, occurrence and detection ratings of the potential failure modes i.e. excessive, poor and in-appropriate use of the pesticides as mentioned in the Table 5.28. In this context, checklists and recommendations for the farmers and regulatory bodies leading to optimum utilization of pesticides are mentioned in Table 5.29.

Table 5.26: Standardization based on crop nutrition.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Crop nutrition	Excessive use of fertilizers	Toxicity indicators Microbial load Active constituents Crop yield	06 05 04 03	• Application by non-experienced worker • To overcome stagnant yields & economic loss • Lack of knowledge regarding optimum use	02 02 02	• Training • Balanced doses of the fertilizers consulted by block/area agricultural officer • Soil sampling and consulting experts through extension services	02 04 04	**24** **48** **48** **20** **40** **40** **16** **32** **32** **12** **24** **24**
	Lesser use of fertilizers			• Application by non-experienced worker • High costs • Lack of knowledge regarding optimum use	02 03 02	• Training • Availability of cost-effective and subsidized fertilizers • Soil sampling and consultation from area agriculture officer	02 02 04	**24** **36** **48** **20** **30** **40** **16** **24** **32** **12** **18** **24**

	In-appropriate selection of fertilizers			• Use of non-composited manure • Use of chemical fertilizers • Fertilizers not of national quality and poor breakdown	03 04 01	• Proper inspection and manure sampling. • Use only organic mode fertilizers (avoid human sludge); chemical fertilizer only when required • Apply fertilizers during initial	04 02 04	72 48 24 60 40 20 48 32 16 36 24 12

Table 5.27: Checklist and recommendations to assure optimum utilization of crop nutrition.

Checklist to assure crop nutrition	Parameters considered by most of the farmers	Recommendations
Are you using fertilizers for nitrogen fixation and phosphate solubilizing? Yes ☐ No ☐	√	• The department of fertilizers, government of India should devise strict fertilizer policy to reduce the dependency of the farmer on chemical fertilizers • Right combination of doses for government approved fertilizers should be consulted from only the area/block agricultural officer not from local fertilizer trader • Farmers should be made aware regarding the optimum use of only organic fertilizers than chemical fertilizers in order
Do you prefer only organic manure, vermin compost, poultry manure, green leafy manure? Yes ☐ No ☐	√	
Is your manure fully composited? Yes No	×	
Is the fertilizers treated through aerobic process? Yes No	×	

Are you monitoring undesirable microbial pathogens through periodic testing? Yes ☐ No ☐	×	to maintain the fertility of the soil • Free soil sampling facilities must be provided to the farmers to enable them to apply optimum and required fertilizer
Are chemical fertilizers approved by the countries and used to minimize leaching? Yes ☐ No ☐	√	
Are you providing buffer zones for fertilizers and planting cover crops to minimize soil erosion? Yes ☐ No ☐	×	
Are the fertilizers applied by qualified or experienced staff? Yes ☐ No ☐	×	
Are you applying fertilizers at early phase for complete breakdown? Yes ☐ No ☐	√	
Are you using good quality water for fertilizer application? Yes ☐ No ☐	×	
Are you documenting the application of fertilizers? Yes ☐ No ☐	√	

Table 5.28: Standardization based on pesticides/insecticide application.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Crop disease	Excessive use of pesticides	Toxicity indicators Microbial load Crop yield	06 05 03	• Person not attentive • Application by in-experienced	02 05	• None • Training • Awarenes	06 02 02	**72** **60** **60** **54** **60**

		Physico-chemical ranges	02	worker • Fear of lesser yields & economic loss • Influence of local pesticides trader	 05 03	s programs • Consult block agricultural officer and gather pesticides from only the licensed trader	 03	50 50 45 36 30 30 27 24 20 20 18
	No use of pesticides			• Person not attentive • Higher costs • Lack of knowledge regarding optimum use	02 04 05	• None • Availability of cost-effective and subsidy on pesticides • Training on smallest effective dosage with low toxicity	06 04 03	72 96 90 60 80 75 36 48 45 24 32 30
	In-appropriate selection of pesticides			• Use of chemical pesticides	04	• Use only bio-pesticides	04	96 24 80

				• Pesticides not of national quality	01	• Compliance with CIBRC and FSSAI	04	20 48 12 32 08

Table 5.29: Checklist and recommendations for optimum use of pesticides, insecticides.

Checklist to assure insecticides and pesticides application	Parameters considered by most of the farmers	Recommendations
Are you documenting the pesticide application? Yes ☐ No ☐	×	• All the pesticides should comply with the regulation of Central Insecticides Board and Registration Committee (CIBRC) and the FSSAI. • AYUSH testing laboratories should be established in different districts of Punjab to ensure pesticides and heavy metals content in the medicinal plant.
Are you complying with maximum pesticide and herbicide residues limits? Yes ☐ No ☐	×	
Is your pesticide a bio-pesticide mostly? Yes ☐ No ☐	√	
Are you applying pesticides in smallest effective dosage with low toxicity and residue pesticide? Yes ☐ No ☐	×	
Are you following federal, state, local regulations for pesticides and following labels directions? Yes ☐ No ☐	×	

Plant management: Crops especially the medicinal plants require proper management processes for better yields, lesser diseased, microbial and foreign material. Replenishment of the plant population is necessary to get a better yield. Some seeds or material tends to show mortality in the initial period, so replenishment of plants increases the yield by discarding the dead plants (Saha *et al.,* 2018). Plant requires optimum cycles of weeding so that un-desired plants do not compete with the principal crops for nutrients. Plants generally require weeding during the growth period to avoid competence of un-desired material with the principal crops. Similarly, hoeing, topping, pruning, shading are required dependent on the requirement of the plants (Mousavian and Eskandari, 2018). Topping is done to remove the aerial part of the plant to prevent seed formation and distribution in soil (Aydın and Arslan, 2018). Likewise, pruning is done to remove the dead part of the plant, controlling, re-directing the growth, improving or sustaining health of the plant (Saure, 1987). In-adequate weeding cycles, pruning for trees, higher mortality rate etc. are some of the potential failure mode in management of plants effecting the active constituents, microbial load, crop yield and physicochemical ranges (Hatfield *et al.*, 2001). Hence in order to pre-determine the risk factors, FMEA studies in plant management processes highlighted RPN as mentioned in Table 5.30. Similarly, checklists and recommendation to assure proper management are mentioned in Table 5.31.

Harvesting: It is a key process in determining and maintaining the quality of medicinal plants in terms of active constituents, microbial load and physic-chemical ranges. The time of harvest plays a critical role, therefore an optimum time for harvesting the selected medicinal plants should be considered after consulting concerned experts and pharmacopoeia. Harvesting of medicinal plants should be avoided during rainfall, high humidity and dew to prevent excessive moisture level leading to increased vulnerability to microbial contamination of medicinal plants (Tanko *et al.,* 2005). Therefore, FMEA studies suggested RPN based on certain process controls for potential failures mode such as harvesting at in-appropriate time, sudden climatic consequences, and in-adequate harvesting equipment as mentioned in Table 5.32. Accordingly, checklist to ensure the optimum harvesting of medicinal plants and recommendations for the regulatory authorities is mentioned in Table 5.33.

Table 5.30: Standardization based on plant management.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Plant management	In-adequate weeding	Microbial load Active constituents Crop yield Physico-chemical parameters	05 04 03 02	• Person not attentive • Weeding not in appropriate time • Wrong methods of weeding • High labour costs for weeding	04 05 03 02	• None • Weeding in growth period with training to maintain weeding calendar • Weeding using natural and mechanical methods • Providing mechanized subsidized weeding equipment	06 04 03 02	**120** **100** **45** **20** **96** **80** **36** **72** **60** **27** **12** **48** **40** **18** **08**
	No replacements of dead plants	Crop yield	03	• In-appropriate replenishment of plant materials • Shortage of plant materials and seeds	05 04	• Training on suitable time for plant replenishment • Availability of seeds in government institutions	03 04	**45** **48**

	In-adequate pruning	Microbial load	05	• Person not attentive	03	• None	06	**90** **40** **50**
		Crop yield	03	• In-appropriate time for pruning	04	• Training on appropriate time	02	**54** **24** **30**
				• In-adequate methods of pruning	05	• Training and state-of-art equipments for pruning	02	

Table 5.31: Checklist and recommendations to assure proper plant management.

Checklist to assure proper plant management	Parameters considered by most of the farmers	Recommendations
Are you replenishing the plant population to compensate mortality losses? Yes ☐ No ☐	×	• NMPB should make sure that sufficient quantity of quality planting material should be made available to the farmers by providing intensive financial assistance to develop nurseries and Quality Planting Material/Germ Plasm Banks as per operational guidelines. • Subsidies should be provided to the farmers on purchasing mechanized weeding equipment. • More state-of-art farm machinery should be manufactured in India.
Are you pruning, bud nipping, the plant at appropriate time with sustainable methods (if, application to the specific plant) Yes ☐ No ☐	×	
Following optimum weeding cycles especially during the growth period of the principal plant? Yes ☐ No ☐	×	

Table 5.32: Standardization based on harvesting.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Harvesting	In-appropriate time	Microbial load Active Constituents Physicochemical ranges	05 04 02	• Person not attentive • Lack of knowledge regarding optimum time of harvesting	01 01	• None • Visual inspection and expert consultation	6 03	**30** **15** **24** **12** **12** **06**
	In-appropriate climatic conditions			• Person not attentive • Lack of knowledge regarding optimum climatic harvesting conditions • Sudden climatic consequences	01 02 03	• None • Training. Avoid harvesting in high rain, humidity and dew • None	06 02 06	**30** **20** **90** **24** **16** **72** **12** **08** **36**
	In-adequate harvesting equipment	Microbial load Physicochemical parameters	05 02	• Harvesting equipment not clean • Lack of	03 04	• Clean the harvesters before harvest • State-of-art	02 02	**30** **40** **50** **12** **16**

				mechanized harvesters • High costs of harvesters	05	manufacture of harvesters • Providing subsidized harvesters	02	**20**

Table 5.33: Checklist and recommendations to assure proper harvesting.

Checklist to assure proper harvesting	**Parameters considered by most of the farmers**	**Recommendations**
Did you choose optimal time for harvesting? Yes ☐ No ☐	√	• Farmers should be made aware regarding the harvesting cycles for the perennial as well as annual medicinal plants by conducting medicinal plants stakeholders meet by the NMPB. • Frequent trainings sessions regarding the good harvesting practices should be conducted. • More advanced harvesting equipment must be manufactured in order to conduct optimum harvesting.
Did you follow standard procedures for harvesting material? Yes ☐ No ☐	×	
Did you consult pharmacopoeias for active constituents? Yes ☐ No ☐	×	
Did you avoid foreign matter, weeds, during harvest? Yes ☐ No ☐	√	
Are you keeping the cutting devices, harvesters clean, free from insects, rodents, birds and other pests? Yes ☐ No ☐	×	
The cloth used as interface between soil and harvested material is clean and made of muslin cloth, avoiding overfilling of sacks? Yes ☐ No ☐	×	
Did you clean underground parts from soil as soon as harvested? Yes ☐ No ☐	√	
Did you avoid dew, rain and exceptionally high humidity during harvest? Yes ☐ No ☐	√	
Did you transport harvested material to indoor facility if harvesting is done in wet conditions and discarding decomposed material? Yes ☐ No ☐	√	

5.8.3. Post-harvest Phase

Collection: The collection of fruits from the wild fails, if appropriate time, climatic conditions and adequate collecting equipment are not considered. The collection of medicinal plants strictly falls under regional and national governments in order to check the sustained collection and distribution of medicinal plants (Harnischfeger, 2000). Therefore, prior permission should be sought from the concerned government departments before collecting the medicinal plants. Cutting the branches of the tree to ease the collection of desired plant part should be strictly prohibited. Fruits should be collected in such a manner that no damage is done to the fruits during collection. Shaking of trees to collect fruits should be prohibited as it causes damage of fruits unexpected to the industry (Pandey and Das, 2014). RPN was calculated after considering severity of potential failure mode, occurrence and detection for the collection processes as mentioned in Table 5.34. Similarly, checklist and recommendations for collection is mentioned in Table 5.35.

Drying: Due to high investments and energy costs, drying is a large expense in medicinal plant production. There is high vulnerability of losing volatile oils from the medicinal plants, therefore, these should be optimally dried using proper drying equipment and temperature. Generally, they are dried between 30-50°C (Müller and Heindl, 2006). In Punjab, most of the farmers preferred drying under sunlight due to lack of expensive drying equipment, which increases the vulnerability of losing the active constituents. The potential failure mode for drying could be excessive drying, lesser drying or contaminated drying. Rodents and pests must be prevented during the drying process by maintaining proper inspections. The failure mode directly affects the microbial load, active constituents and physicochemical ranges of the medicinal produce. The FMEA studies suggested that lack of knowledge regarding the optimum time for drying was the potential cause of failure having high occurrence rate that could be fixed by proper training and resorting to automated advanced drying equipment as mentioned in Table 5.36. As per the RPN ratings scale, the processes having RPN more than 65 needs to acted quickly followed by RPN range from 38-65. Therefore, necessary checklists and recommendations must be taken to ensure optimum drying of medicinal plants as mentioned in Table 5.37.

Table 5.34: Standardization based on collection of medicinal plants.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Collection	In-appropriate time	Microbial load Active Constituents Physicochemical ranges	05 04 02	• Person not attentive • Lack of knowledge regarding optimum time of collection	01 01	• None • Visual inspection and expert consultation	6 03	30 15 24 12 12 06
	In-appropriate climatic conditions			• Person not attentive • Lack of knowledge regarding optimum climatic collection conditions • Sudden climatic consequences	01 02 03	• None • Training. Avoid collection in rain, high humidity and dew • None	06 03 06	30 30 90 24 24 72 12 12 36
	Collection of immature and damaged plant part			• Collection using un-conventional methods • Lack of mechanized harvesters	04 04	• Follow regional guidelines. Avoid shaking of plants • State-of-art manufacturing	02	40 40 50 40 32 32 40

				• High costs of harvesters	05	of fruit collectors	02	**32** **16** **16** **20** **16**
				• No sorting of collected part	04	• Providing subsidized collection equipment	02	
						• Sorting the plant part based on industrial requirement	02	

Table 5.35: Checklist and recommendations to assure optimum collection.

Checklist to assure proper collection	Parameters considered by most of the farmers	Recommendations
Do you know RET status of the plant species and are you adhering to legal and ecological prescriptions preventing threat to species? Yes ☐ No ☐	×	• Collectors should be made aware by the forest officials that forests in India are regulated by both central and state governments. So, forests being a concurrently regulated, one should adhere to all the laws regulated by central and state governments. Indian Forest Act 1927, The wildlife (Protection) Act 1972, The forest (Conservation) Act 1980, The Biological Diversity Act 2002, The Scheduled Tribes and Other Tradtional Forest-Dwellers Act 2006 must be consulted as they contain provisions for collection of medicinal plant produce from forests. • Frequent trainings sessions regarding the good collection practices should be conducted.
Are you collecting the medicinal plants from areas where its frequency of occurrence is sustainable and allowing its population to regenerate? Yes ☐ No ☐	√	
Did you collect the plant part on optimal time? Yes ☐ No ☐	√	
Did you maintain minimum damage to plant during collection? Yes ☐ No ☐	√	

Are you avoiding fruit damage caused by rudimentary collection techniques such as shaking of plants? Yes ☐ No ☐	√	• More advanced and subsidized collection equipment must be manufactured in order to conduct optimum collection of medicinal plants.
Are you transporting the collected medicinal plant in clean and dry conditions? Yes ☐ No ☐	√	
Did you avoid overfilling of sacks? Yes ☐ No ☐	×	

Table 5.36: Standardization based on drying of medicinal plants.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of this failure cause	Current process controls	Detection	RPN (Risk priority number)
Drying	Excessive and under drying	Microbial load Active Constituents Physico-chemical ranges	05 04 02	• Person not attentive • Lack of knowledge regarding optimum time and drying temperature • Lack of knowledge regarding choosing appropriate drying equipment • Fault in drying machine • High costs of drying equipment	01 05 04 01 04	• None • Automated drying equipment. Training on drying • Provide extension services to aware farmer • Automated fault detector • Providing subsidized drying	06 02 02 01 02	**30** **50** **40** **05** **40** **24** **40** **32** **04** **32** **12** **20** **16** **02** **16**

						equipments		
	Contaminated drying	In-appropriate physico-chemical parameters	02	• Drying on cemented/open floor • Higher vulnerability to pests and rodents	05 05	• Use tarpaulin cloth between floor and produce • Visual inspection during open drying	02 03	**20** **30**

Table 5.37: Checklist and recommendations to assure optimum drying of medicinal plants.

<table>
<tr><th>Checklist to assure proper drying</th><th>Parameters considered by most of the farmers</th><th>Recommendations</th></tr>
<tr><td>Are you avoiding open drying in sunlight?
Yes ☐ No ☐</td><td>×</td><td rowspan="7">Drying is one of the costly mechanism in management of medicinal plants, below are some recommendations:
• Common drying facilities such as bulk poly-houses should be provided to the small farmers by the government via support of NMPB.
• There is lack of state-of art drying equipments for drying specific medicinal plant part. Hence, more drying options (advanced drying equipments) should be provided to the farmers for optimum drying besides solar dryers and freeze drying, etc.
• Training on proper drying mechanisms should be provided to the farmers through extension services from agricultural institutions, RCFC and NMPB.</td></tr>
<tr><td>Are you using open air drying, freeze drying, wire screened rooms, solar dryers, etc. for drying?
Yes ☐ No ☐</td><td>×</td></tr>
<tr><td>Did you consider duration of drying, temperature (30 to 50°C is recommended)?
Yes ☐ No ☐</td><td>√</td></tr>
<tr><td>Did you avoid overfilling of tray load during drying?
Yes ☐ No ☐</td><td>×</td></tr>
<tr><td>Did you avoid smoke and medicinal plant contact?
Yes ☐ No ☐</td><td>×</td></tr>
<tr><td>Did you use tarpaulin cloth or sheeting during drying on cemented floor?
Yes ☐ No ☐</td><td>√</td></tr>
<tr><td>Are you avoiding rodents, insects during drying?
Yes ☐ No ☐</td><td>√</td></tr>
</table>

Storage: 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 (Fennell *et al.*, 2004). Higher costs for controlled environment conditions, lack of knowledge regarding optimum storage time for medicinal plants among the farmers influenced the failure mode resulting to effect microbial load, active constituents and physicochemical ranges as mentioned in Table 5.38. Subsequently, checklist and recommendations would lead to optimum storage of medicinal plants are mentioned in Table 5.39.

Table 5.38: Standardization based on storage of medicinal plants.

Process	Potential failure mode (How the "X" fails)	Potential effects of the failure on product	Severity of the failure rating	Potential cause of failure	Occurrence of failure cause	Current process controls	Detection	RPN (Risk priority number)
Storage	Improper time of storage	Microbial load Active Constituents Physico-chemical ranges	05 04 02	• Person not attentive • Lack of knowledge regarding storage time	01 04	• None • Training on optimum storage conditions	06 02	30 40 24 32 12 16
	Un-controlled environment conditions			• Person not attentive • Higher costs	01 05	• None • Providing free storage facilities to the farmers	06 03	30 75 24 60 12 30
	Contaminated storage			• Person not attentive • No measures for pests and rodents • Free access of persons • No cleanliness cycles • Un-suitable storage bags	02 05 04 05 04	• None • Identification of source, sanitation and fumigation • Access restricted to only handlers • Frequent cleaning to prevent insect breeding • Selecting un-contaminated bag	06 02 02 02 02	60 50 40 50 40 48 40 32 40 32 24 20 16 20 16

Table 5.39: Checklist and recommendations to assure optimum storage of medicinal plants.

Checklist to assure proper storage	Parameters considered by most of the farmers	Recommendations
Are you storing the harvest above one year? Yes ☐ No ☐	√	• Small farmers have the storage issues, they generally do not have sufficient space to store their collected produce, hence following should be considered: • Collection centres should be established in villages through the support of panchayats. Similarly, collection centres should be established in every district of Punjab. • Funds are provided by the NMPB to establish collection centres, therefore farmers should be made aware and co-operative collection centres can be established. • Farmer Producer Organizations (FPO) and Self-help groups having good strength of medicinal plants cultivators should be provided with funds to develop collection centres in their native places.
Did you choose gunny bags for hard materials and high gauge polythene bags for creeper and leaves and high gauge HMHD bags for fleshy material? Yes ☐ No ☐	×	
Do you have controlled storage conditions? Yes ☐ No ☐	×	
Are you maintaining cleanliness in conjunction with proper fumigation? Yes ☐ No ☐	×	
Did you apply mechanical methods for controlling rodents and pests? Yes ☐ No ☐	×	
Did you prohibit entry of un-authorized persons? Yes ☐ No ☐	×	
Do you have different compartments for filling, processing in storage room? Yes ☐ No ☐	×	

Standardization of medicinal plants based on these parameters will help the farmers to produce quality-rich produce based on the parameters required by the herbal industry. This standardization methodology not only highlighted the important qualitative parameters, but also highlighted risk control and risk communication to the farmers during agricultural process. Each agricultural process having risks of failures on the quality of the medicinal plants in terms of the quantity of active constituents, crop yield, microbial load, toxicity indicators and physicochemical ranges was validated using FMEA tools. This standardization methodology identified potential failure, their cause, occurrence, process control and detection to highlight the RPN and suggested checklists and recommendations for the farmers to enable them to get standardized produce as per industrial standards.

5.9. DRAFTING OF MONOGRAPH OF SELECTED MEDICINAL PLANTS FEATURING GAP RELATED DOCUMENTATION FOR ON-FIELD CULTIVATION

It is a fact that GAP enhances the quality of medicinal plants, but GAP is subject to agro-ecological condition of the selected region, agro-techniques followed by the farmers, etc. It is not necessary that GAP for specific medicinal plants would be same in all the climatic conditions of the world. Therefore, the regulatory bodies suggest development of GAP monographs of specific medicinal plants based on the region's agro-ecological conditions (Jayashree *et al.*, 2015; Jat *et al.*, 2014; World Health Organization, 2006). There are success stories of progressive farmers that have benefitted from the cultivation of medicinal plants in the state. In this context, on field-cultivation of medicinal plants based study was conducted. The agro-practices of selected medicinal plants *viz. A. vera, O. sanctum*, and *C. longa* followed by the progressive farmers of the state was reported for the first time. This on-field cultivation analysis was conducted to develop GAP monographs after conducting field visits, farmer interaction, reporting farmer's agro-practices and corroborating the inputs with reported literature (Jayashree *et al.*, 2015; Jat *et al.*, 2014 a,b,c; World Health Organization, 2006). The monographs were divided into three parts *viz.* botanical and pharmacological characteristics, good agricultural practices, and standard quality parameters/certifications prescribed by the API, ICMR, FSSAI, and WHO. The monographs for the selected medicinal plants are described in subsequent sections:

5.9.1. Monograph on GAP for *A. vera*

5.9.1.1. Botanical and Pharmacological Characteristics

5.9.1.1.1. Name of the plant

5.9.1.1.1.1. *Scientific name*

Latin botanical name: *Aloe vera* (Linn.) Burm.f.

Family: Xanthorrhoeaceae

5.9.1.1.1.2. *Vernacular names*

English: Indian aloe

Hindi: Kunvar pathu

Punjabi: Kamaar

Tamil: Thazahai

Malayalam: Chenninayakam

Kannada: Lolesara

Kashmiri: Musabbar

Figure 5.26: *A. vera* plant.

5.9.1.1.2. Plant part used in traditional medicine

Leaves

5.9.1.1.3. Part to be used as raw material for the extraction of aloe-emodin

Leaves

5.9.1.1.4. Geographical distribution and the major areas of cultivation

5.9.1.1.4.1. *Geographical distribution*

A. vera originated in Africa due to dry climate. It also grows in dry regions of Asia, Europe, America and it can withstand constant drought except in temperate region (Eshun and He, 2010).

5.9.1.1.4.2. *Major areas of cultivation*

In India it is widely cultivated in Rajasthan, Andhra Pradesh, Gujrat, Maharastra and Tamil Nadu (Jat *et al.*, 2015b).

5.9.1.1.5. Morphological characteristics of *A. vera*

The API and other standard literature mentioning the morphological characteristics of *A. vera* are described in Table 5.40.

Table 5.40: Morphological characteristics of *A. vera.*

Macroscopic	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Tandon, 2011; Indian Herbal Pharmacopoeia, 1998)
Dried Juice	Surface dull, opaque with slightly vitreous appearance	Brittle and solid

Fresh leaves	--	Flat or slightly concave on the upper surface and tapering towards the apex where a strong spine is located and smaller ones at the margins

5.9.1.1.6. General description of characteristics of plant material

5.9.1.1.6.1. *Organoleptic characteristics*

The organoleptic characteristics of *A. vera* highlighted in the API and other standard literature is mentioned in the Table 5.41.

Table 5.41: Organoleptic characters of *A. vera.*

Characters	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Tandon, 2011; Indian Herbal Pharmacopoeia, 1998)
Shape	Dried juice: Compact irregular masses	Dried juice: Opaque pieces of varying shapes. Fresh leaf: Simple, sessile, succulent, subulent, flat or slightly concave on the upper surface and strongly rounded on the lower, broad at base
Size	Dried juice: Irregular	Dried juice: Opaque pieces of varying sizes Fresh leaf: 20-30 cm in length, 5 to 10 cm in width
Color	Dried juice: Dark chocolate brown to black	Dried juice: Dark brown to blackish color Fresh leaf: Dark green occasional white blotches at places, white base. When broken colorless mucilaginous mass, when exposed becomes yellowish
Odor	Dried juice: Characteristic	Dried juice: Unpleasant
Taste	Dried juice: Nauseous and bitter	Dried juice: Nauseating and extremely bitter Fresh leaf: Bitter fluid

5.9.1.1.6.2. *Microscopic characteristics*

The microscopic characteristics of *A. vera* highlighted in the API and other standard literature is mentioned in the Table 5.42.

Table 5.42: Important microscopic characters of *A. vera.*

Type of microscopy	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Hendrawati, 2015; Tandon, 2011; Indian Herbal Pharmacopoeia, 1998)
Transverse section	--	TS of leaf is boat shaped showing outermost chlorenchymatous region. Important descriptors in the TS of leaves should include acicular crystal of calcium oxalate, cuticle, epidermis, juice cells, mesophyll, mucilage, pericycle, phloem, stomata, spine, vascular bundle and xylem
Powder	Shows innumerable crystalline, yellowish brown to chocolate, colored particles of varying size	Fine crystalline powder having beige white to yellowish colour

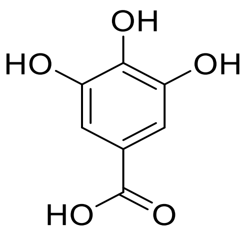
5.9.1.1.7. Chemical composition

5.9.1.1.7.1. *The major chemical constituents of A. vera*

The major chemical constituents investigated in the plant are emodin, aloe-emodin, aloin, emodin, aloesin (Sánchez *et al.,* 2020).

5.9.1.1.7.2. *Physical and chemical properties of emodin*

Chemical structure:



Molecular formula: $C_{15}H_{10}O_5$

Chemical name: 1,3,8-trihydroxy-6-methylanthracene-9,10-dione

Molecular weight: 270.24 g/mol

Description: Orange powder or needles

Solubility: It is soluble in alcohol, insoluble in water

Melting point: 257.0 °C

[Detailed quality specifications of emodin, see compound summary of emodin[‡]].

[‡]Compound summary of emodin with Pubchem CID: 3220 in *Pubchem* database, https://pubchem.ncbi.nlm.nih.gov/compound/Emodin

5.9.1.1.8. Pharmacological activity

5.9.1.1.8.1. *Traditional pharmacological activity of A. vera*

Traditionally, it is used to treat wounds, burns, and inflammation. The plant possesses anti-cancer, anti-diabetic, and anti-microbial properties. Apart from this, it provides protection against skin problems, digestive diseases, bone related and cardiac problems. It acts as laxative, aphrodisiac, stomachic, astringent, antidotal, cathartic, anthelmintic and hepatic stimulant. Its gel is used in various skin ailments, gonorrhea, piles, jaundice, menstrual suppressions and treatment of burns and bruises (Sánchez *et al.*, 2020; Eshun and He, 2010).

5.9.1.1.8.2. *Pharmacological activity of emodin*

Emodin possesses anti-viral, anti-allergic, anti-diabetic, anti-bacterial, anti-osteoporotic, neuro-protective, immunosuppressive, anti-cancer, and hepato-protective properties. It also possesses good laxative property (Dong *et al.*, 2016).

5.9.1.2. Good Agricultural Practices

5.9.1.2.1. General description

Therefore, it can be grown in almost all part of India. Its water requirement is low therefore; it can be cultivated in arid to semi-arid areas.

5.9.1.2.2. Preferred growing conditions

5.9.1.2.2.1. *Ecological conditions*

Some studies suggest that *A. vera* can tolerate -3°C minimum and 40°C maximum temperature. It can tolerate excessive draught conditions, except in temperate climate (Bahmani *et al.*, 2016; Jat *et al.*, 2015b).

5.9.1.2.2.2. *Climatic conditions*

The climatic conditions of India, suits the plant. For the ideal growth, annual temperature range of 20-40°C and 350-400 mm annual rainfall is required (Cousins and Witkowski, 2012).

5.9.1.2.2.3. *Soil conditions*

Growth is faster under medium fertile soils such as cotton soils. It can also be grown in marginal to sub-marginal soils having low fertility. Loam to coarse sandy loam soil is preferred. It can be preferably grown up to pH 8.5 with high sodium and potassium salts (Jat *et al.*, 2015b).

5.9.1.2.2.4. ***Nutrient conditions***

Crop requires specific amount of N, P, K doses depending upon the varying soil test values. Use of farm yard manure, vermi compost, green manure and poultry manure shall be used to fulfill the requirements of nutrients.

5.9.1.2.2.5. ***Water conditions***

It requires less irrigation but irrigation at critical points of cultivation must be given. Water used for irrigation must comply with national requirements of water used for irrigation (Organización Mundial de la Salud and World Health Organization, 2003).

5.9.1.2.2.6. ***Agro-climatic suitability in Punjab***

Considering the above-mentioned agro-ecological parameters, the growing areas of *A. vera* in Punjab is represented in Fig. 5.27. *A. vera* is highly suitable in agro-climatic zone-IV, which is called as western plain aried zone comprising of Mukstar, Bathinda, Mansa and some part of Faridkot districts of Punjab.

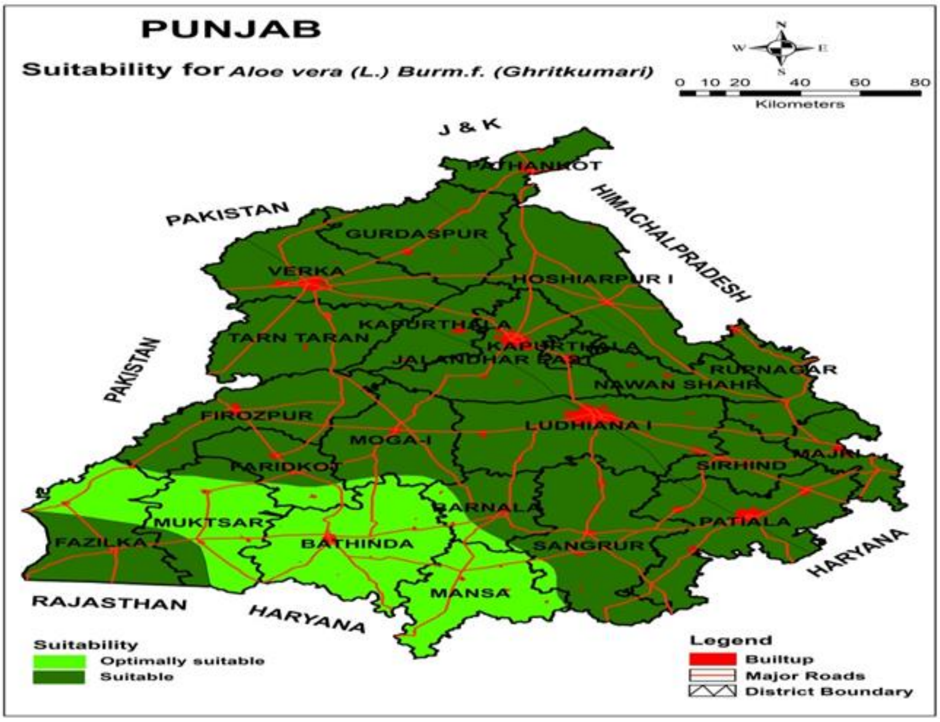


Figure 5.27: Agro-climatic suitability of *A. vera* in Punjab.

5.9.1.2.3. Seeds

5.9.1.2.3.1. ***Seeds and cultivar***

Generally, for commercial cultivation, India has released varieties of aloe for commercial cultivation. The genotypes with high level of aloin such as IC 111267, IC 111269, IC 111271, IC111279, IC 111280, IC 112532, IC 112521, IC 111273, IC

112531, IC 112517, IC 112527, INGR 06023, INGR 13043 and INGR 06024 released by ICAR-Delhi can be used as planting source (Jat *et al.*, 2015b).

5.9.1.2.3.2. *Morphology of the suckers of A. vera*

Suckers should have 4-7 leaves with height up to 20-30 cm.

5.9.1.2.3.3. *Propagation*

The plant is mostly propagated through suckers (lateral shoots). The mother plant produces 3-4 suckers in the growing period. The propagation material used by the farmers of Punjab is represented in Fig. 5.28.

Figure 5.28: Size of *A. vera* during sowing.

5.9.1.2.4. Cultivation method

5.9.1.2.4.1. *Selection and preparation of cultivation site*

Site should be selected after consulting meteorological and edaphic data. The roots of *A. vera* do not penetrate much deep, therefore land should not be disturbed deeper. Depending upon the type of soil 2-3 ploughing should be done followed by leveling. Divide the field according to the field pattern or slope for drainage of water. Initial flush of weeds should be avoided to ensure weed free young plant for initial 20-30 days. Suckers should be planted in the month of July to August, for irrigated land it can be cultivated anytime in the year except the months of winter November-February. The field of *A. vera* in the Mansa district of Punjab is represented in Fig. 5.29.

Figure 5.29: *A. vera* field in Mansa district of Punjab.

5.9.1.2.4.2. *Transplanting*

Rate of suckers per acre: 17,000-19,000

Plant to plant distance: 40-50 cm

Row to row distance: 40-50 cm

Sowing depth: 12-15 cm

5.9.1.2.4.3. *Fertilization*

Compost or farm yard manure approximately 15 tonne/acre is applied during the soil preparation by the farmers of Punjab. Subsequently, 10tonne/acre of farm yard manure is applied in the second, third, fourth year of planting. Wood ash can be applied in the pits during field preparation for good growth.

5.9.1.2.4.4. *Field management*

- **Irrigation:** Irrigation is required just after transplantation of suckers. However, 3-5 irrigations are required in a year except monsoon season. If monsoon is abundant one-time irrigation is also sufficient.

- **Weeding and intercultural operations:** Field should be devoid of weeds during the entire period of growth. Initial weeding should be done during land preparation and first hoeing should be followed in a month after weeding. Subsequently 3-5 weeding are required manually with light hoeing for beneficial outputs. Regular inspections should be made so that diseased or dead plants are removed regularly.

5.9.1.2.5. Prevention and control of plant diseases and pests

Plant is not much prone to diseases in India. But due to efficient water holding capacity of soil, plants are prone to get fungal infections in the roots. For this, some farmers of the Punjab use Trichoderma: a bio control agent for the treatment. However, leaf spots, mealy bug are reported in some parts of the India. Termite problem can be eradicated by light irrigation. Fig. 5.30, represents leaf spot disease in the *A. vera*.

Figure 5.30: Leaf spot disease on *A. vera* leaf.

5.9.1.2.6. Harvest and post-harvest processing

5.9.1.2.6.1. *The best collection/harvest time*

A. vera harvesting is labour intensive job. The leaves of aloe are cut from its base by the workers. First harvesting is done after 10-11 months of planting. The first harvesting yields from 25-35 ton per acre. Subsequently, three harvesting are taken from second, third, fourth and fifth year. On average, 60 ton per acre is the yield of the plant from second to fifth year. The best time to harvest plant is during morning and evenings at early flowering to get good active constituents. Fig. 5.31 and 5.32 represent harvesting of *A. vera* leaves in the Punjab.

Figure 5.31: Farm women worker harvesting *A. vera* in Punjab.

Fig. 5.32: Farmer with harvested *A. vera* leaves in Mukstar Sahib district of Punjab.

5.9.1.2.6.2. *Post-harvest processing method*

The plant is required to be processed immediately so immediate transport is required to avoid thermal degradation and microbial contamination. Fig. 5.33, represent washing of *A. vera* leaves in the herbal unit in Punjab. The *A. vera* leaves are transported to processing unit and dried aloe juice as a medicine is prepared by transversely cutting the leaves at the bases and allowing gel to drain out in a vessel. The collected juice is allowed to concentrate by evaporation or by boiling. Similarly, the pulp of the leaf is used particularly in cosmetics industry, so the left over leaves after exudation are cut open and gel is removed by using blunt knives. The gel is stirred vigorously in a blender to make a homogeneous mixture, which is then filtered using muslin cloth and allowed to centrifuge to get gel.

Figure 5.33: A worker washing fresh *A. vera.* leaves at a herbal industry in Punjab.

5.9.1.3. Standard Quality Certifications

5.9.1.3.1. Basic quality specification for herbal materials of *A. vera*

5.9.1.3.1.1. *Physicochemical parameters*

The physicochemical parameters mentioned in the API and other standard literature is mentioned in Table 5.43.

Table 5.43: Physico-chemical parameters of *A. vera.*

Physico-chemical parameters	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Tandon, 2011)
Foreign matter	Dried Juice: n.m.t. 2 %	Dried juice: Nil Leaf: Nil
Total ash	n.m.t. 5 %	Dried juice: n.m.t. 3.5 % Leaf: n.m.t. 1.0%
Acid insoluble ash	Dried juice: n.m.t. 2 %	Dried juice: n.m.t. 0.4% Leaf: n.m.t. 0.002%
Alcohol soluble extractive	Dried juice: n.l.t. 80 %	Dried juice: n.l.t. 83.0% Leaf: Not less than 0.45 %
Water soluble extractive	Dried juice: n.l.t. 60 %	Dried juice: n.l.t. 60.0 % Leaf: n.l.t. 1.5 %
Moisture content	Dried juice: n.m.t. 10 %	--

n.m.t: not more than; n.l.t: not less than

5.9.1.3.1.2. *Qualitative and quantitative estimation of A. vera*

The qualitative (R_f) and quantitative ranges of emodin mentioned in the API and other standard literature are mentioned in Table 5.44.

Table 5.44: Qualitative and quantitative ranges of emodin in *A. vera*.

Analytical method	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other reported literature** (Tandon, 2011)	**General method of experimentation**
TLC	--	TLC of leaf: Emodin spot at R_f at 0.61 (Green color) TLC of dried juice: Aloin spot at R_f at 0.63 (Reddish orange)	Solvent for extraction using Soxhlet apparatus: Alcohol as solvent Solvent system: Toluene: Ethyl acetate: Formic acid (5:1:0.5) Visualization: Under UV light at 254 nm For detailed method, refer "*Quality Standards of Indian Medicinal Plants*" [§]
HPTLC	--	Aloin was found to be 0.521 % in dried juice. Emodin was found to be 0.0131 % in leaves	Dried juice: extraction using Soxhlet apparatus: Alcohol as solvent. Solvent system: Ethyl acetate: Methanol: Water (10:1.35:1) Visualization: Spraying TLC plate with 10% ethanolic potassium hydroxide reagent For detailed method, refer "*Quality Standards of Indian Medicinal Plants*" [**]

5.9.1.3.1.3. *Ranges of toxicity indicators in A. vera*

The toxicity indicators mentioned in various standard literatures are mentioned in Table 5.45.

Table 5.45: Toxicity indicators of *A. vera*.

Toxicity indicators	**Ranges**
Food additives: Fresh leaves (FSSAI, 2015)	Not permissible
Surface treated leaves: Phosphates	1,760 mg/Kg

[§] *Quality Standards of Indian Medicinal Plants* (2011), Vol-IX, Indian Council of Medical Research, New-Delhi, India. pp. 36-39.
[**] *Quality Standards of Indian Medicinal Plants* (2011), Vol-IX, Indian Council of Medical Research, New-Delhi, India. pp. 40-43

(FSSAI, 2015)	
Peeled, cut, shredded: Phosphates Sulfites Lauric arginate ethyl ester (FSSAI, 2015).	 5,600 mg/Kg 50 mg/Kg 200 mg/Kg
Pesticide residues (World Health Organization, 2011, 1999, 1998)	Aldrin and dieldrin: Not be more than 0.05 mg/Kg
Metal contamination (World Health Organization, 2011, 1999, 1998)	Lead: n.m.t. 10 mg/Kg Cadmium: n.m.t. 0.3 mg/Kg
Microbial contamination (World Health Organization, 2011, 1999, 1998)	• *Salmonella spp*.: Nil **Decoction:** • Aerobic bacteria: n.m.t. 10^7/g • Fungi: n.m.t. 10^5/g • *Escherichia coli*: n.m.t. 10^2/g **Internal use**: • Aerobic bacteria: n.m.t. 10^5/g or mL • Fungi: n.m.t. 10^4/g or mL • Enterobacteria gram negative bacteria: n.m.t. 10^3/g or mL

n.m.t.: not more than; n.l.t.: not less than

5.9.2. Monograph on GAP for *O. sanctum*

5.9.2.1. Botanical and Pharmacological Characteristics

5.9.2.1.1. Name of the plant

5.9.2.1.1.1. *Scientific name*

Figure 5.34: Twig of *O. sanctum*.

Latin botanical name: *Ocimum sanctum* L.

Family: Lamiaceae

5.9.2.1.1.2. *Vernacular names*

English: Holy basil

Hindi: Tulasi

Punjabi: Tulasi

Tamil: Tulasi, Thulasi, Thiru

Malayalam: Tulasi, Tulasa

Kannada: Tulasi, Shree tulasi, Vishnu tulasi

Urdu: Raihan

5.9.2.1.2. Plant part used in traditional medicine

Leaves, and whole plant.

5.9.2.1.3. Part to be used as raw material for the extraction of eugenol

Leaves, and whole plant.

5.9.2.1.4. Geographical distribution and the major areas of cultivation

5.9.2.1.4.1. *Geographical distribution*

O. sanctum is found in the entire Indian subcontinent from Himalayas (1800 m) to Andaman and Nicobar islands. It can be found in the Southeast Asian tropics (Singh *et al.,* 2021a,b,c).

5.9.2.1.4.2. *Major areas of cultivation*

Traditional cultivation of the plant can be traced around Mathura to fulfill the need of Vrindavan temple. It is widely cultivated in Uttar Pradesh and in southern India (Jat *et al.,* 2014).

5.9.2.1.5. Morphological characteristics of *O. sanctum*

The API and other standard literature mentioning the morphological characteristics of *O. sanctum* are mentioned in Table 5.46.

Table 5.46: Morphological characteristics of *O. sanctum.*

Macroscopic analysis	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Gupta *et al.,* 2008; Indian Herbal Pharmacopoeia, 1998)
Leaves	Petiolate and thin petiole is 1.5-3 cm long, hairy on surface	Both surfaces pubescent; venation reticulate, veins more prominent at lower side. Slightly grove on upper surface, slender hairy
Whole plant	Erect, 30-60 cm high, much branched, annual herb. Flowers are crimson or purplish color	Biennial or triennial plant, reaches heights upto 30-77 cm. Flowers purplish or crimson, fruits are sub-globose with small black markings

5.9.2.1.6. General description of characteristics of plant material

5.9.2.1.6.1. *Organoleptic characteristics*

The organoleptic characteristics of *O. sanctum* highlighted in the API and other standard literature is mentioned in Table 5.47.

Table 5.47: Organoleptic characters of *O. sanctum.*

Organoleptic analysis	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Gupta *et al.,* 2008; Indian Herbal Pharmacopoeia, 1998)
Shape	Shape of leaf is Elliptic-oblong, obtuse or acute, entire or serrate, pubescent on both surface, thin petiole	Shape of the leaf is elliptic and oblong
Size	2.5-5 cm long, 1.6-3.2 cm wide	2 to 2.5 cm long, 1 to 1.5 cm wide
Color	Green to yellowish	Upper surface green and lower pale green
Odor	Aromatic	Aromatic
Taste	Characteristic	Slightly pungent and mucilaginous

5.9.2.1.6.2. *Microscopic characters*

The microscopic characteristics of *O. sanctum* highlighted in the API and other standard literature is mentioned in Table 5.48.

Table 5.48: Important microscopic characters of *O. sanctum.*

Microscopic analysis	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Gupta *et al.*, 2008; Wallis, 2004)
Transverse section	Petiole shows number of covering and glandular multicellular trichomes. Layers of collenchymatous and parenchymatous cells and three vascular bundles consisting of xylem and phloem. Midrib has epidermis trichomes and vascular bundles. Lamina has epidermis and presence of trichomes, anomocytic stomata, palisade layers, closely packed parenchyma with chloroplast and oleo-resin	T.S. of leaf comprises of collenchyma, epidermis, glandular trichomes, lower epidermis, obliquely cut vascular bundles, palisade, phloem, upper epidermis and xylem
Powder microscopy	Polygonal and wavy walled epidermal cells in surface view, glandular trichomes, palisade and spongy parenchyma and anomocytic and diacytic stomata	Powder shows covering trichomes, glandular trichomes, sessile glandular trichomes, cupshaped trichomes, fragments of spiral, annular, reticulate and pitted vessel. Cicatrix, obliquely cut vascular bundles, palisade, stomata are also present

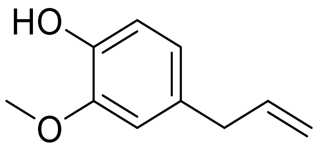
5.9.2.1.7. Chemical composition

5.9.2.1.7.1. *The major chemical constituents of O. sanctum*

The major chemical constituents investigated in the plant are eugenol, and urosolic acid (Gupta *et al.*, 2008).

5.9.2.1.7.2. *Physical and chemical properties of eugenol*

Chemical structure:



Molecular formula: $C_{10}H_{12}O_2$

Chemical name: 2-methoxy-4-prop-2-enylphenol

Molecular weight: 164.2 g/mol

Description: Colourless or pale yellow or amber-color liquid. It has a clove like odour

Solubility: It is soluble in glacial acetic acid, miscible in chloroform, alcohol, and oils.

Boiling point: 253.889 ° C at 760 mm Hg

Melting point: -9.222222 °C

[Detailed quality specifications of eugenol, refer compound summary of eugenol[††]].

5.9.2.1.8. Pharmacological activity

5.9.2.1.8.1.Traditional pharmacological activity of *O. sanctum*

In Ayurveda, *O. sanctum* is mentioned as “Mother medicine of nature”, “The Queen of herbs”. It is considered to prevent diseases, stress, and promote wellbeing, general health and longevity in an individual (Kumar *et al.*, 2013).

5.9.2.1.8.2. Pharmacological activity of eugenol

Eugenol has potent anti-oxidant and free radical scavenging properties. It shows dose-dependent anesthetic affects at concentration of 50-60 mg/Kg intravascular (i.v). It possesses inhibitory activity against both gram positive and negative bacteria’s. Eugenol at concentration of 1000 µg/mL inhibits the growth of *P. aeruginosa*. It is reported to have strong anti-inflammatory effect because of its property to block COX-2 enzyme (Nejad *et al.*, 2017).

5.9.2.2. Good Agricultural Practices

5.9.2.2.1. General description

Tropical and sub-tropical climate is suitable for its cultivation; therefore, it can be grown in the entire Indian sub-continent tropics (Jat *et al.*, 2014).

5.9.2.2.2. Preferred growing conditions

5.9.2.2.2.1. *Ecological conditions*

It can grow on vast range of soils with tropical and sub-tropical climate. The plant is moderately tolerant to drought and frost. It can also be grown on partially shaded areas (Makri and Kintzios, 2008).

5.9.2.2.2.2. *Climatic conditions*

It grows optimally, in an annual temperature range of 15-35°C with 700-7600 mm annual rainfall (Jat *et al.*, 2014).

[††] Compound summary of eugenol with Pubchem CID: 3314 in *Pubchem* database, https://pubchem.ncbi.nlm.nih.gov/compound/Eugenol

5.9.2.2.2.3. ***Soil conditions***

It grows best in well-drained sandy-loamy soil. However rich loam, saline, alkaline to moderately acidic soils and poor laterite are also suited. Water-logged soil can lead into root-rot disease. It can be preferably grown at a pH range of 5-8.5 (Jat *et al.*, 2014; Makri and Kintzios, 2008).

5.9.2.2.2.4. ***Nutrient conditions***

The approximate recommended dose of fertilizers required this crop is 30 Kg of K_2O, P_2O_5 and 60 Kg N per hectare. Cobalt and manganese at 50 and 100 ppm concentration respectively is said to increase the oil content (Jat *et al.*, 2014).

5.9.2.2.2.5. ***Water conditions***

Water requirement depend on the soil's moisture content and season. In *kharif* season, it requires 3-4 irrigations while the plant may require up to 15-20 irrigations per year. Water used for irrigation must comply with national requirements of water used for irrigation.

5.9.2.2.2.6. ***Agro-climatic suitability in Punjab***

Considering the above-mentioned agro-ecological parameters, the growing areas of *O. sanctum* in Punjab is represented in Fig. 5.35. Observing the agro-ecological suitability of *O. sanctum*, it is found to be highly suitable for agro-climatic zones I,II and III comprising from *Kandi* belt to Pathankot, Hoshiarpur, Gurdaspur, Jalandhar and extending towards Moga, Barnala, Ferozpur and Sangrur districts of Punjab.

Figure 5.35: Agro-climatic suitability of *O. sanctum* in Punjab.

5.9.2.2.3. Seeds

5.9.2.2.3.1. *Seeds and cultivar*

There are seven *Ocimum* species and there are nine varieties named CIM Ayu, CIM Saumya, CIM Angana, CIM Jyoti, CIM Kanchan, CIM Surabhi, CIM Sharada, and CIM Snigdha provided by the CSIR-CIMAP.

5.9.2.2.3.2. *Morphology of the seeds of O. sanctum*

The seeds must be fresh from the stock of pedigree. Seeds of *O. sanctum* are brownish-reddish-yellow in color with shining globose-subglobose seed coat which becomes mucilaginous when wet (Jat *et al.,* 2014).

5.9.2.2.3.3. *Propagation*

The plant is mostly propagated through seeds which must be fresh.

5.9.2.2.4. Cultivation method

5.9.2.2.4.1. *Selection and preparation of cultivation site*

Land is prepared by ploughing, and leveling. It is essential to remove weeds during the initial periods. The land must be free from heavy metals, and excessive chemical fertilizers.

5.9.2.2.4.2. *Sowing and nursery management*

Sowing: The seeds are scattered on the nursery beds manually with 2 cm depth. As seeds are small in size, it can be mixed with the sand for sowing.

Nursery management: Nursery is raised in the starting month of June. Beds are formed for raising the nursery and must be supplied with farm yard manure or vermi-compost. 50-100 g of seeds is sufficient to raise seedlings for 1 acre land. The Fig. 5.36. and 5.37. represent the farmers preparing nursery for *O. sanctum* in the Punjab. The Fig. 5.38., represent the germination of seeds on the nursery beds.

Fig. 5.36: Preparation of *O. sanctum* nursery in Punjab.

Fig. 5.37: Farmers preparing nursery beds for *O. sanctum* in Punjab.

Fig. 5.38: Germination of *O. sanctum* seeds on nursery beds.

5.9.2.2.4.3. *Transplanting*

Transplanting is done in the month of August or when seedlings are six weeks old having 4-6 leaves. Fig. 5.39. and 5.40. represent the farmers transplanting seedlings of *O. sanctum*. The transplanting details are mentioned below:

Rate of seedlings per acre: 8000-12000

Plant to plant distance: 40-45 cm

Row to row distance: 40-45 cm

Sowing depth: 5 cm

Fig. 5.39: Farmers of Punjab transplanting *O. sanctum* seedlings.

Fig. 5.40: Spacing between the seedlings of *O. sanctum*.

5.9.2.2.4.4. *Fertilization*

Compost or farm yard manure approximately 9-11 tonne/acre is applied during the soil preparation by the farmers of Punjab.

5.9.2.2.4.5. *Field management*

Irrigation: Generally, 3-4 irrigations are sufficient if only one harvest is required. If plant is grown for a year, then 15-20 irrigations per year are required.

Weeding and intercultural operations: Field should be devoid of weeds during the entire period of growth. Three weeding are required and first weeding is done after 30 days of planting when the weeds start to compete with the principal crop for nutrition and sunlight. Second weeding can be done after one month followed by third weeding based on visualizing the weeds. Hoeing is required at two months after planting.

5.9.2.2.5. Prevention and control of plant diseases and pests

No serious pests or diseases have been observed for this plant by the selected cultivars in Punjab. However, there can be chances of root rot due to water logging. Therefore, proper drainage of soil must be maintained. Some of the reported pests, diseases, symptoms of *O. sanctum* are mentioned in Table 5.49. and represented in Fig. 5.41. (Jat *et al.*, 2014).

Table 5.49: Diseases of *O. sanctum.*

Insect pests	**Indications**	**Treatment**
Leaf roller	Roller stick to the under surface of leaves causing them to roll back length wise	Boil neem leaves for spraying or spray Azadirachtin 10,000 ppm
Tulsi lace wing	Caused by *Cochlochila bullita*	
Diseases	**Causing organism**	**Treatment**
Powdery mildew	*Oidium spp*	Spraying wet sulphur 4 g/L
Seedling blight	*Rhizoctonia solani*	Drenching the nursery bed with Bavistin 1%
Root rot	*Rhizoctonia batalicola*	

Fig. 5.41: Common diseases of *O. sanctum.*

5.9.2.2.6. Harvest and post-harvest processing

5.9.2.2.6.1. *The best collection/harvest time*

First harvesting is done after 80-90 days of transplanting. In Punjab, this is considered as a *kharif* plant and only one harvesting is carried out. The harvest is done at a full bloom stage during sunny day as represented in the Fig. 5.42. Harvesting is avoided in the next day after rainfall. Plant are cut 15-20 cm above the ground level. If the plant is cultivated for the whole year, then the first harvesting is done at the end of third month after planting and subsequent harvesting after 60-80 days interval.

Figure 5.42: Matured bushy *O. sanctum* ready to harvest in Punjab.

5.9.2.2.6.2. *Post-harvest processing method*

The harvested crop is allowed to wilt in the clean area for 4-6 hours to reduce the moisture. The leaves are dried for further processing. Oil is extracted from the leaves and the whole plant using steam distillation. The distillation unit should be cleaned and the collected oil should be passed from anhydrous sodium sulphate 15-20 g per litre to remove the moisture. The oil should be stored in amber colored glass bottles or stainless steel containers to avoid degradation of oil (Jat *et al.,* 2014).

5.9.2.3. Standard Quality Certifications

5.9.2.3.1. Basic quality specification for herbal materials of *O. sanctum*

5.9.2.3.1.1. *Physicochemical parameters*

The physicochemical parameters mentioned in the API and other standard literature are mentioned in the Table 5.50.

Table 5.50: Physico-chemical parameters of *O. sanctum.*

Physico-chemical parameters	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Gupta *et al.,* 2008; Indian Herbal Pharmacopoeia, 1998)
Foreign matter	n.m.t. 2 %	n.m.t. 2.0 %
Total ash	n.m.t. 19 %	n.m.t. 17.7 %
Acid insoluble ash	n.m.t. 3 %	n.m.t. 2.8 %
Alcohol soluble extractive	n.l.t. 6 %	n.l.t. 8.0 %
Water soluble extractive	n.l.t. 13 %	n.l.t. 19.0 %

n.m.t: not more than; n.l.t: not less than

5.9.2.3.1.2. *Qualitative and quantitative estimation of O. sanctum*

The qualitative (R_f) and quantitative ranges of eugenol mentioned in the API and other standard literature are mentioned in Table 5.51.

Table 5.51: Qualitative and quantitative ranges of eugenol and urosolic acid in *O. sanctum*.

Method	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Gupta *et al.*, 2008)	**General method of experimentation**
TLC	Carvacarol, Caryophyllene, Nerol and camphene with violet to blue color	Urosolic acid and eugenol spot at R_f 0.50 and 0.74 respectively. (Urosolic acid: Purple; Eugenol: Brown)	**API:** TLC of alcoholic extract of drug. Solvent system: Toulene: Ethyl acetate (9:1) on exposure to Iodine solution, and spraying vanillin-sulphuric acid reagent For detailed method, refer, *The Ayurvedic Pharmacopoeia of India* ‡‡ **ICMR** (Gupta *et al.*, 2008): Reflux powdered drug with methanol on water bath. Solvent system: Toulene: Ethyl acetate: Formic acid (7:3:0.3) Visualization with spraying plate with anisaldehyde-sulphuric acid reagent with heating the plate at 100 °C For detailed method refer, *Quality Standards of Indian Medicinal Plants* §§
HPTLC	--	Eugenol (4.0 % w/v) and Urosolic acid (0.91 to 2.0 % w/v)	Solvent system for HPTLC of Eugenol: Toulene: Ethyl acetate: Formic acid: Methanol (3: 2: 0.4: 0.4). Scanning at 280 nm. Solvent system for HPTLC of Ursolic acid: Toulene: Ethyl acetate: Formic acid: (7: 3: 0.3). Scanning at 530 nm and derivatization with anisaldeyde-sulphuric acid reagent by heating 100°C till colored bands appears For detailed method, refer, *Quality Standards of Indian Medicinal Plants******

‡‡ *The Ayurvedic Pharmacopoeia of India* (1989a). Part-I, Vol-II, Government of India, Ministry of Health and Family Welfare, Department of AYUSH, New-Delhi. pp.170-176

§§ *Quality Standards of Indian Medicinal Plants* (2010). Vol-V, Indian Council of Medical Research, New-Delhi, India. pp. 278-279.

*** *Quality Standards of Indian Medicinal Plants* (2010). Vol-V, Indian Council of Medical Research, New-Delhi, India. pp. 280-282.

5.9.2.3.1.3. *Ranges of toxicity indicators in O. sanctum*

The toxicity indicators mentioned in various standard literatures are mentioned in Table 5.52.

Table 5.52: Toxicity indicators of *O. sanctum*.

Pesticide residues (World Health Organization, 2011, 1998)	Aldrin and dieldrin n.m.t. 0.05 mg/Kg. Total residue consumed should be n.m.t. 1 % from the medicinal plant material
Microbial contamination (World Health Organization, 2011, 1998)	**For crude plant:** *Escherichia coli*, maximum 10^4 per gram Mould propagules, maximum 10^5 per gram **For pre-treated plant:** Aerobic bacteria, maximum 10^7 per gram Yeasts and moulds, maximum 10^4 per gram *Escherichia coli*, maximum 10^2 per gram Other *Enterobacteria*, maximum 10^4 per gram *Salmonellae*, none **Plant materials for internal use:** Aerobic bacteria, maximum 10^5 per gram Yeasts and moulds, maximum 10^3 per gram *Escherichia coli*, maximum 10 per gram Other *Enterobacteria*, maximum 10^3 per gram Salmonellae, none
Heavy metal residue (World Health Organization, 2011, 1998)	Lead: n.m.t. 10 mg/Kg Cadmium: n.m.t. 0.3 mg/Kg
Aflatoxins (World Health Organization, 2011, 1998)	Avoid aflatoxins B1, B2, G1 and G2 in plant materials

n.m.t.: not more than; n.l.t.: not less than.

5.9.3. Monograph on GAP for *C. longa*

5.9.3.1. Botanical and Pharmacological Characteristics

5.9.3.1.1. Name of the plant

Figure 5.43: Rhizomes of *C. longa*.

5.9.3.1.1.1. *Scientific name*

Latin botanical name: *Curcuma longa* L.

Family: Zingiberaceae

5.9.3.1.1.2. *Vernacular names*

English: Turmeric

Hindi: Hardi

Punjabi: Haldi

Malyalam: Manjal

Tamil: Manjal

Telugu: Pasupu

Kannada: Arishina

Kashmiri: Ledar

5.9.3.1.2. Plant part used in traditional medicine

Rhizomes

5.9.3.1.3. Part to be used as raw material for the extraction of curcumin

Dried rhizomes

5.9.3.1.4. Geographical distribution and the major areas of cultivation

5.9.3.1.4.1. *Geographical distribution*

The plant is found in diverse tropical regions from sea level to 1500 m above sea level. It is speculated to be originated in South-East Asia, while the epicentre of its domestication is certainly Indian subcontinent. The use of turmeric as culinary spice and can be traced back to approximately 4000 years to the Indian Vedic culture. It is likely to have reached China by 700 AD, East Africa by 800 AD, and West Africa by 1200 AD. At present, India is a leading producer and exporter of *C. longa* in the world (Prasad and Aggarwal, 2011).

5.9.3.1.4.2. *Major area of cultivation*

C. longa is cultivated in the tropics and found almost every part of India. Andhra Pradesh is the leading state in India to produce *C. longa*. It is also widely cultivated in Orissa, Tamil Nadu, West Bengal, Karnataka, Maharastra, Assam, Meghlaya, Gujrat (Jayashree *et al.,* 2015; Prasad and Aggarwal, 2011).

5.9.3.1.5. Morphological characteristics rhizomes

The API and other standard literature mentioning the morphological characteristics of *C. longa* are mentioned in the Table 5.53.

Table 5.53: Morphological characteristics of *C. longa.*

API (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Tandon and Sharma 2010; Indian Herbal Pharmacopoeia, 1998)
Rhizomes half as broad as long. Short branched, root scars and annulations of leaf bases, fractured horny, fractured surface, and central cylinder twice as broad as cortex	Primary rhizomes are condensed swollen. Longitudinally wrinkled and marked with circular rows. 3 to 5 large depressions scars. Rhizomes are hard, heavy with short fracture. Secondary rhizomes are longitudinally wrinkled exhibiting encircling leaf scars

5.9.3.1.6. General description of characteristics of plant material

5.9.3.1.6.1. *Organoleptic characters*

The organoleptic characteristics of *C. longa* highlighted in the API and other standard literature is mentioned in Table 5.54.

Table 5.54: Organoleptic characters of *C. longa.*

Characters	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Tandon and Sharma 2010; Indian Herbal Pharmacopoeia, 1998)
Shape	Oblong, ovate, pyriform, cylindrical, generally short branched	Primary rhizomes: Ovate-oblong, conical, pear shaped. Secondary rhizomes: Cylindrical curved, tapering bluntly at both ends, occasionally branched
Size	2-5 cm long and 1-1.8 cm thick	Primary rhizome: 3 to 7 cm long, 2 to 3 cm wide Secondary rhizome: 4 to 10 cm in length 1 to 1.5 cm in diameter
Color	Externally yellow to yellowish brown. Cracked surface orange to reddish brown	Yellowish orange, internally uniformly dull yellowish
Odor	Characteristic	Aromatic and somewhat pungent
Taste	Characteristic	Bitter

5.9.3.1.6.2. *Microscopic characteristics*

The microscopic characteristics of *C. longa*, highlighted in the API and other standard literature are mentioned in Table 5.55.

Table 5.55: Important microscopic characters of *C. longa*.

Type of microscopy	**API** (The Ayurvedic Pharmacopoeia of India, 1989).	**Other standard literature** (Tandon and Sharma 2010; Indian Herbal Pharmacopoeia, 1998).
Transverse section	Epidermis is thick-walled, different dimensions of cubical cells. Cortex has presence of slim walled rounded parenchyma cells, collateral vascular bundles. Has disperse oleo-resin cells with brownish content, thin walled cork cells having 4-6 layers, ground tissue cells containing starch grains of 4-5µ in diameter, oil cells containing orange- yellow globules of volatile oils or resinous matter. Presence of spirally thickened vessels	Presence of cork, cortex, cortical vascular bundle, endodermis, oleoresin cells, stellar vascular bundle. Inner region with endodermis consists all the above mentioned characters including pericycle, phloem, starch grains, stellar vascular bundle, xylem
Powder	--	Presence of cortical parenchyma cells with starch grains and oleoresin cells, cork in surface view, group of spiral and annular vessels, fragment of reticulate vessel, starch grains

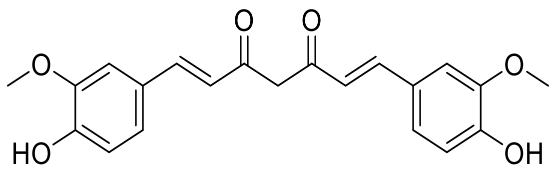
5.9.3.1.7. Chemical composition

5.9.3.1.7.1. *The major constituents of C. longa*

The major chemical constituents present in the rhizomes of *C. longa* are volatile oil, consisting of turmerone, and colouring agents known as curcuminoids. In standard form, curcumin is varied between 5-6.6 %, moisture more than 9%, volatile oils less than 3.5 %. The volatile oil contains cinol, zingiberene, d-α-phellandrene, borneol, d-sabinene, and sesquiterpenes (Jayashree *et al.*, 2015; Prasad and Aggarwal, 2011; The Ayurvedic Pharmacopoeia of India, 1989).

5.9.3.1.7.2. *Physical and chemical properties of curcumin*

Chemical structure:



Molecular formula: $C_{21}H_{20}O_6$

Chemical name: (1*E*,6*E*)-1,7-bis(4-hydroxy-3-methoxyphenyl)hepta-1,6-diene-3,5-dione

Molecular weight: 368.4 g/mol

Description: Orange-yellow needles.

Solubility: Insoluble in water, ether, and soluble in alcohol, acetic acid, and glacial acetic acid.

Melting point: 183.0 °C or 361 °F

[For detailed quality specifications of curcumin, refer compound summary of curcumin[†††]].

5.9.3.1.8. Pharmacological activity

5.9.3.1.8.1.*Traditional pharmacological activity of C. longa*

In Ayurveda, *C. longa* is known to strengthen the body energy, dispelling worms, regulation of menstruation, expelling gall stones, and relieving gas and arthritis. It is also known to purify blood, and has anti-inflammatory, anti-microbial properties (Labban, 2014; Prasad and Aggarwal, 2011).

5.9.3.1.8.2. *Pharmacological activity of curcumin*

Curcumin is reported to suppress the formation of edema, decrease the proliferation of cells in a mouse induced with prostate cancer cells, it also exhibit choretic effects. Curcumin also possess anti-inflammatory effects by blocking the cyclooxygenase enzymes (Beevers and Huang, 2011).

5.9.3.2. Good Agricultural Practices

5.9.3.2.1. General description

C. longa is harvested in seven-nine months depending upon the variety and time of sowing if managed properly. The sprouting of rhizomes is difficult below 10°C and above 40 °C. Mostly, the optimum range of temperature is responsible for the regulation of seeds and propagules of *C. longa* plants for good germination (Jayashree *et al.,* 2015).

[†††]Compound summary of curcumin with Pubchem CID: 969516 in *Pubchem* database, https://pubchem.ncbi.nlm.nih.gov/compound/Curcumin

5.9.3.2.2. Preferred growing condition

5.9.3.2.2.1. *Ecological conditions*

The plant can be found at altitudes ranging from sea level to 1500 m above sea level. The optimum annual temperature required for the plant ranges from 20-35°C (Sandeep *et al.,* 2016; Sharma and Sharma, 2012; Ishimine *et al.,* 2004).

5.9.3.2.2.2. *Climatic conditions*

It can be grown in diverse tropical conditions. However, annual temperature below 10°C and above 40 °C is not suitable for its cultivation. It requires an annual rainfall ranging from 800 to more than 1500 mm (Jayashree *et al.,* 2015; Ishimine *et al.,* 2004).

5.9.3.2.2.3. *Soil conditions*

It grows best in well-drained sandy and clay loam soils. It can be preferably grown at a range of pH 4.5-7.5 with good organic status (Sandeep *et al.*, 2016).

5.9.3.2.2.4. *Nutrient conditions*

Crop requires specific amount of N,P,K doses depending upon the varying soil test values. It is reported that 60 Kg Nitrogen, 120 Kg K_2O and 50 Kg P_2O_5 per hectare is the recommended nutrient dosage in Kerala (Jayashree *et al.,* 2015).

5.9.3.2.2.5. *Water conditions*

Crop requires 12-13 irrigations in Punjab; it can even extend up to 30 irrigations depending upon the region. There should be optimum drainage for the water to prevent excessive water-logging. Water used for irrigation should match national quality standards.

5.9.3.2.2.6. *Agro-ecological suitability in Punjab*

Considering the above-mentioned agro-ecological parameters, the growing areas of *C. longa* in Punjab is represented in Fig.5.44. *C. longa* is optimally suited for agro-climatic zone-I and II corresponding to western plain and northern Plain, and dry subhumid regions of Punjab. The zones cover Pathankot, Hoshiarpur, Gurdaspur, Kapurthala, Roopnagar, Sirhind districts of Punjab.

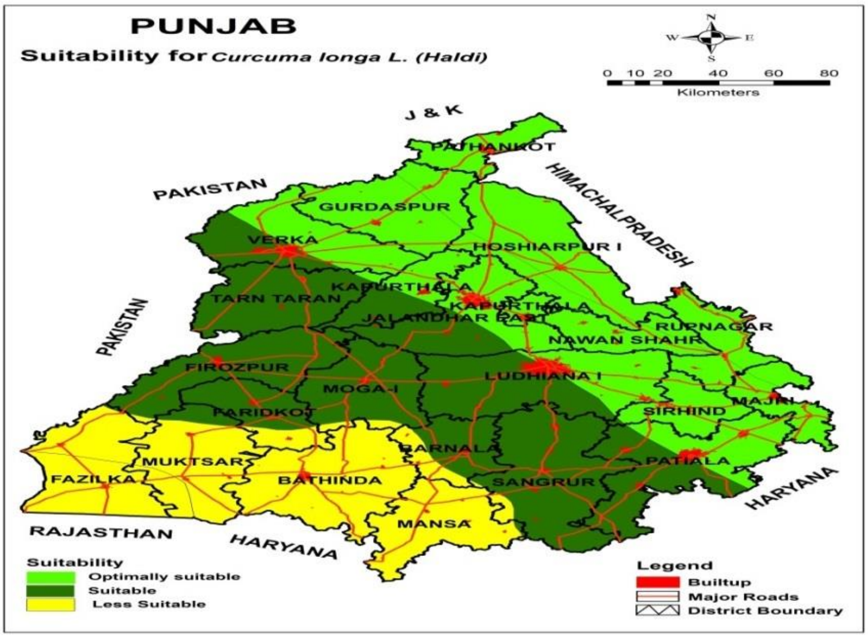


Figure 5.44: Agro-ecological suitability of *C. longa* in Punjab.

5.9.3.2.3. Seeds

5.9.3.2.3.1. *Seeds and cultivars*

Generally the cultivator is known by the name of the locality where it is cultivated. Some important cultivators are Allepey, Duggirala, Tekkurpet, Sugandham, Erode local, Amalapuram, Moovattupuzha, Lakdong and Salem. There are certain improved varieties also released by the ICAR-Indian Institute of Spices Research, Kerala, India (Jayashree *et al.*, 2015)**.**

5.9.3.2.3.2. *Morphology of the suckers of C. longa*

The seeds should be healthy from the recent harvest. The size of the seed should be at least 5-10 cm long and 1-1.8 cm thick. Seeds should be oblong, ovate, pyriform as represented in Fig. 5.45.

Figure 5.45: Size of turmeric seed during sowing.

5.9.3.2.3.3. *Propagation*

C. longa can be grown by direct sowing as well as by transplanting. However, transplanting in *C. longa* is not conventional. Therefore, direct sowing is preferred by the farmers. Recently harvested healthy and disease free whole or split mother, and fingers of rhizomes are used for the planting of the turmeric. It is also reported that seed rhizomes should be treated with mancozeb 0.3 % for half an hour and dried in shade for 3-4 hours and planted (Jayashree *et al.,* 2015). The germination of seeds is observed in 30-45 days after sowing the seed.

5.9.3.2.4. Cultivation method

5.9.3.2.4.1. *Selection and preparation of cultivation site*

Site should be selected after consulting meteorological and edaphic data. Depending upon the type of soil 3-4 ploughing should be done followed by tilthing and leveling. Soil should be brought to desired tilth for growing seed and seedling. Initial flush of weeds should be avoided to ensure weed free young plant. The field should be divided according to the field pattern or slope for drainage of water. Generally ridge and furrow method is used for the sowing of *C. longa* seeds. However, few farmers preferred sowing of seeds on beds. Each bed is made 100 cm wide, 30 cm in height with spacing of 50 cm between the two beds. Automatic potato planter consisting of a hopper for each row and cups with chain drive mechanism is used for sowing by some farmers as represented in Fig. 5.46, 5.47, and 5.48. The graded seeds are picked up by the cups and carried to opener spout and released. If a cup is found empty, seed is released from compensating tray ensuring uniform seed spacing with no missing. The seed depth during sowing is represented in Fig. 5.49.

Figure 5.46: Raised beds preparation for cultivation of turmeric by a farmer of Punjab in Hoshiarpur district.

Figure 5.47: Farm workers preparing land for turmeric cultivation in Punjab.

Fig. 5.48: Sowing of turmeric seeds by a farmer of Punjab using potato planter.

5.9.3.2.4.2. *Sowing*

- Rate of seedlings per acre: 6-7 quintals (q) seeds
- Plant to plant distance: 20-25 cm
- Row to row distance: 30-40 cm
- Sowing depth: 2.5-3 cm
- Sowing time: In the month from May to June.

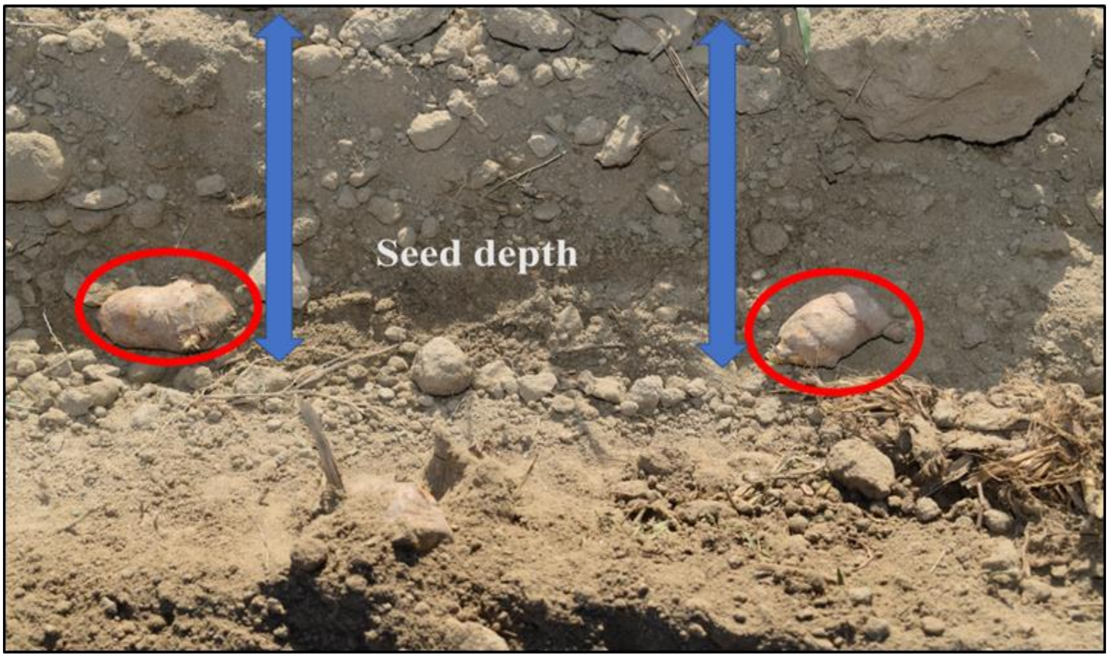


Figure 5.49: Depth of turmeric seed before getting covered by soil during sowing.

5.9.3.2.4.3. *Fertilization*

Compost or farm yard manure approximately 20 tonne/acre is applied during the soil preparation by the farmers of Punjab. Based on the pH, hydrated lime 500-1000 Kg/ha can also be applied for laterite soils. Farmers also used 50-60 Kg Urea, 50 Kg DAP and 20 Kg muriate of Potash in one acre of land to fulfill required N.P.K level depending upon the type of soil. India has different soil type and agro-ecological conditions throughout, so crop maintenance can be done according to the needs of the soils. Depending upon the soil test reports, there should be supplying of N, P and K as per the requirements, which depends upon agro-ecological conditions. The fertilizers must be applied in 2-3 split dosages. In poor zinc soils, zinc fertilizer (25 Kg of zinc sulphate/ha) can be applied to get good yield (Jayashree *et al.,* 2015).

5.9.3.2.4.4. *Field management*

- **Mulching:** The crop can mulched with green leaves or with straw of the paddy 40 q/acre just after planting to avoid weeds and reduce evaporation. Mulching can be repeated using lesser proportion of straw after 40 and 90 days after planting. Fig. 5.50 represent mulching of turmeric with paddy straw by a farmer of Punjab.

Figure 5.50: Farmer of Punjab mulching turmeric using paddy straw.

- **Irrigation:** Farmers of Punjab followed 12-14 irrigations in case of clayey soil and up to 30 irrigations in case of sandy loam soils are required. Irrigations should be frequent in the initial stages of sowing.
- **Weeding and intercultural operations:** Field should be devoid of weeds during the entire period of growth. Weeding is generally done 2-3 times after planting the seed with gap of 60, 90 and 120 days. Regular inspections should be made so that diseased or dead plants are removed regularly.
- **Intercropping**: It was found that some farmers were involved in intercropping of turmeric with *Populus deltoids* (poplar tree) due to its shade tolerance. However, intercropping with chillies, colocasia, onion, brinjal and cereals like maize, ragi etc. are also reported in literature. Fig. 5.51 represent a farmer of Punjab following intercropping of turmeric with Poplar.

Fig. 5.51: Intercropping of *C. longa* with poplar trees by a farmer of Punjab.

5.9.3.2.5. Pest and disease management

Plant is generally less prone to disease attack. Some pest related disease affecting the leaves of the turmeric post monsoon was observed in Punjab during our study. The infested leaves were rolled up, turned pale yellow and eventually dried. The infested pest can be seen in Fig. 5.52.

Figure 5.52: Pest infected turmeric leaves of *C. longa* in Punjab.

However, some of the diseases and their symptoms reported in the literature are as mentioned in Table 5.56. and Fig. 5.53.

Table 5.56: Diseases of *C. longa.*

Disease	Causing species	Characterization	Prevention
Leaf blotch	*Taphrina maculans*	Irregular brown spots on either side of the leaves	Mancozeb (0.2%)
Leaf spot	*Colletotrichum capsici*	Brown spots of different sizes on the upper surface of the young leaves	Carbendazm (0.5 Kg/ha) or copper oxychloride (0.2 %)
Rhizome rot	*Pythium aphanidermatum*	Lower leaves of the infected pseudo stem show yellowing, becomes soft eventually collapse of plant and decaying of rhizomes	Mancozeb (0.3%) for 30 mins before storage and at the time of sowing
Leaf blight	*Rhizoctonia solani*	Necrotic patches with papery white center spreading on whole surface with blighted appearance	Bavistin (0.2 %) alone or in mixture with Bordeaux 1%
Nematode pests Root knot	*Meloidogyne spp.* *Radopholus similis* *Pratylenchus spp.*	Damage to turmeric	*Pochonia chlamydosporia* applied to the beds

			at the time of sowing (20 g/bed).
Insect pests Shoot borer	*Conogethes punctiferalis*	Presence of bore-hole on the pseudo stem. The adult is medium sized moth with a wingspan of 20 mm, the wings are orange-yellow with minute black spots	Malathion (0.1%) Lamda-cyhalothrin (0.0125%) at 21 days interval during July to October
Rhizome scale	*Aspidiella hartii*	Adult females are circular with light brown to grey (1 mm diameter) appearing on encrustations on the rhizomes. They feed on sap of the rhizomes making the rhizome shriveled	Timely harvest of rhizomes. Discard severely infested rhizomes before storage. Treat seed with quinalphos (0.075% for 20-30 mins)
Minor pests Leaf feeding beetles	*Lema* spp.	Feed on leaves during monsoon and makes feeding marks on the leaves	Malathion (0.1%)
Lacewig bug	*Stephanitis typicus*	Infests foliage making them turn pale and dry up. It is most common post monsoon period in drier regions	Dimethoate (0.05%)
Sucking pests	--	Infests the leaves affecting their structure	Neem leaves boiled in water for treatment (azadirachtin 2 mL/l of water)
Turmeric thrips	*Panchaetothrips indicus*	Affects leaves causing them to roll and turn pale yellow and dry up. It is also most common post monsoon period in drier regions	Dimethoate (0.05%)

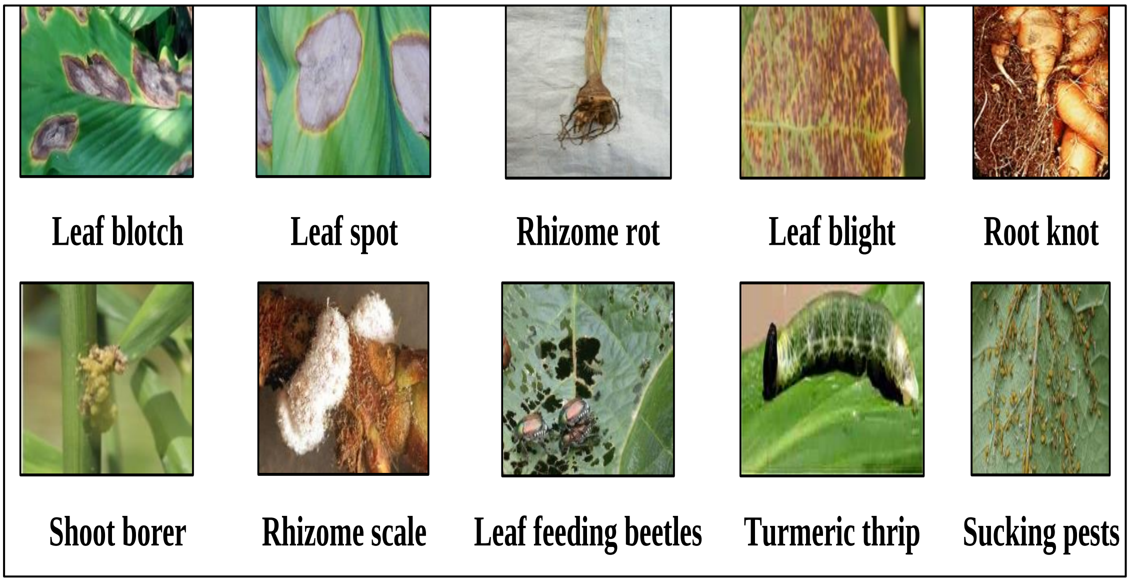


Figure 5.53: Common diseases of *C. longa.*

5.9.3.2.6. Harvest and post-harvest processing

5.9.3.2.6.1. *The best harvesting time, and quality evaluation prior to harvest*

Harvesting is done in 7-9 months after planting seeds. On maturity, the leaves of the plant become dry and light brown. Harvesting is preferred in dry conditions from January to March. In Punjab, harvesting generally starts from second week of February to March. The harvesting is done either manually or by using a tractor. In manual harvesting the land is ploughed, the rhizomes are lifted with spade and collected by hand picking. In case of harvesting using tractor, turmeric harvester is used to take the raised beds. The rhizomes are collected manually and collected at a place and extraneous matter adhering the crop is removed. The seeds to be utilized in next cultivation are preserved and stored by heaping in well ventilated rooms. To avoid fungi and scale infestations, 0.3% of mancozeb and 0.075% quinalphos are used respectively (Jayashree *et al.,* 2015).

5.9.3.2.6.2. *Post-harvest processing method*

Turmeric has to be passed through multiple post harvesting processes such as washing, boiling, drying, polishing, grading and storage to enter market.

- **Boiling:** It is done before the rhizomes are dried. Boiling is essential in removal of raw odour of turmeric, reduces drying time and demolish vitality of the fresh rhizomes. Traditional methods of boiling are, putting the raw turmeric in a vessel made of galvanized iron sheet and boiling it with water (40-60 minutes for fingers and 90 minutes for mother rhizomes) until froth is formed and white fumes are formed with a characteristic odour. The turmeric is considered to be fully boiled when rhizomes pressed between the finger and thumb is easily broken down and its interior becomes yellow instead of red. It was observed during our study that turmeric growers in Punjab used different boiling vessels for boiling the raw produce as represented in Fig. 5.54 to 5.56.

Figure 5.54: Traditional boiling vessel with pressure gauge at farmer's field in Punjab.

Figure 5.55: Boiling assembly devised by a farmer using drums and connecting vessels.

Figure 5.56: Furnace and inner view of vessel of improved turmeric boiler.

The improved turmeric boiler has trough, inner perforated four drums and lid. The inner drum is provided with hooks for lifting and inspection door. The capacity of the drum is 100 Kg and about 55-70 Kg of washed rhizome is taken in each drum for boiling. Turmeric boiler has a furnace to produce steam and boil the batches. It takes around 25 minutes to boil the initial batch and about 10-15 mins for the subsequent batches. The furnace has two opening, one for feeding the fuel and other one for removing the ash. The fuel requirement is 7-75 Kg of agricultural waste or leaves of turmeric.

- **Drying:** The cooked finger and balls were dried up seprately under the sunlight. Thick layer of turmeric (5-7 cm) was spread from drying as thin layer adversely affects the colour of the rhizome. During night time the layer was heaped and covered. It takes around 10-15 days for complete drying of rhizomes. Mould growth should also be checked and avoided. The drying of turmeric by farmers are represented in Fig. 5.57 and 5.58.

Figure 5.57: A farmer drying his turmeric fingers in Punjab.

Figure 5.58: Inner yellowish appearance of turmeric after drying.

Drying can also be done using solar tunnel driers covered by stabilized semi-transparent polyfilm sheet of 200 microns thickness.

- **Polishing and Coloring:** Polishing is done to smoothen the rough surface of the dried turmeric comprising of roots bits. The smoothening is done either manually or mechnically. Manually it is achieved by rubbing the surface of the turmeric with hard surface. Now a days, farmers of Punjab used automatic polishing of rhizomes in which the dried turmeric rhizomes are put into the rotating drum mounted on central axis leading to abrasion of the surface against each other as they roll inside the drum as represented in Fig. 5.59. and 5.60. Polishing is done till recommended 7-8% is achieved. Usually 5-8 % of the weight of the turmeric is the polishing waste. Sometimes undiserable coloring agent is added to the turmeric for polishing, which is not recommended. It takes around one hour per batch for polishing turmeric. During the last phase of the turmeric polishing, turmeric powder was sprinkled over the rotating rhizomes for attractive appearance of turmeric.

Fig. 5.59: Polishing of turmeric in process by a worker in Punjab.

Fig. 5.60: Interior view of polishing machine for turmeric.

Cleaned and graded turmeric was packed in gunny bags and stored in cool, dry places protected from light and kept free from extraneous material. Turmeric being a natural product is prone to be affected with contaminants during different stages of processing. As, it is not recommended to apply pesticides on dried produce, so proper inspection should be made and material should be sorted and kept free from pests and other contaminants.

5.9.3.3. Standard Quality Certifications

5.9.3.3.1. Basic quality requirements for herbal materials of *C. longa*

5.9.3.3.1.1. *Physicochemical parameters*

The physicochemical parameters mentioned in the API and other standard literature are mentioned in the Table 5.57.

Table 5.57: Physico-chemical parameters of *C. longa.*

Physicochemical parameters	**API** (The Ayurvedic Pharmacopoeia of India, 1989)	**Other standard literature** (Tandon and Sharma, 2010).
Foreign matter	n.m.t. 2 %	n.m.t. 1% by weight
Total ash	n.m.t. 9 %	n.m.t. 9-12 %
Acid insoluble ash	n.m.t. 1 %	n.m.t. 1.5-1.8 %
Alcohol soluble extractive	n.l.t. 8 %	n.l.t. 10 %
Water soluble extractive	n.l.t. 12 %	n.l.t. 11 %
Volatile oil	n.l.t. 4 %	--
Moisture	--	n.m.t. 12 % by weight
Total starch	--	n.m.t. 60% by weight

n.m.t: not more than; n.l.t: not less than

5.9.3.3.1.2. *Qualitative and quantitative estimation of C. longa*

The qualitative (R_f) and quantitative ranges of curcumin mentioned in the API and other standard literature are mentioned in Table 5.58.

Table 5.58: Qualitative and quantitative ranges of curcumin in *C. longa.*

Major active constituent	**API**	**Other standard literature** (Tandon and Sharma, 2010)	**General method of experimentation**
Curcumin	--	R_f at 0.54 (Reddish brown color) Percentage of curcumin range from 2.85 to 6.5 %	Solvent for extraction using Soxhlet apparatus: Ethanol Solvent system: Toluene: Ethyl acetate: Formic acid (5:1.5:0.5) Visualization: Under UV light at 254 nm For detailed method, refer "*Quality Standards of Indian Medicinal Plants"* ‡‡‡

n.m.t: not more than; n.l.t: not less than; ppm: parts per million; ppb: parts per billion

5.9.3.3.1.3. *Ranges of toxicity indicators in C. longa*

The toxicity indicators mentioned in standard literatures are mentioned in Table 5.59.

Table 5.59: Toxicity indicators of *C. longa.*

Toxicity indicators	**Ranges** (FAO and WHO, 2019; Sharangi and Pandit, 2018; Plotto, 2004; World Health Organization, 2011, 1998)
Aflatoxin	Aflatoxin B1: 5 ppb Aflatoxin Total: 10 ppb
Pesticide residues	Iprobenfos: < 0.01 ppm Profenofos: < 0.05 ppm Triazophos: < 0.01 ppm Ethion: < 0.30 ppm Phorate: < 0.10 ppm Parathoin: < 0.60 ppm Chlorpyrifos: < 1.00 ppm Methyl parathion:< 3.00 ppm
Metal contamination	Lead: n.m.t. 10.0 ppm by weight Copper: n.m.t. 5 ppm by weight Arsenic: n.m.t. 0.1 ppm by weight Zinc: n.m.t. 25 ppm by weight Tin: Nil Cadmium: n.m.t. 0.1 ppm by weight Lead chromate: Nil

n.m.t: not more than; n.l.t: not less than; ppm: parts per million; ppb: parts per billion.

‡‡‡ *Quality Standards of Indian Medicinal Plants* (2010), Vol-VIII, Indian Council of Medical Research, New-Delhi. pp. 142-145.

5.9.3.3.1.4. *C. longa standards mentioned in ASTA, ESA, and Agmark*

The standard requirements of *C. longa* as per American Spice Trade Organization (ASTA), European Spice Association (ESA) and Agmark are mentioned in Table 5.60 and 5.61.

Table 5.60: Standard requirements for *C. longa* as per ASTA, ESA, and Agmark.

ASTA cleanliness specification of turmeric (Plotto, 2004)	• Whole insect, dead: 3 by count • Excreta, Mammalian: 11.1 mg/Kg • Excreta, Other: 11.1 mg/Kg • Mold: 3% by weight • Insect Defiled/Infested: 2.5% by weight • Extraneous Foreign Matter: 0.5% by weight
ESA quality minima for turmeric (Plotto, 2004)	**Whole turmeric** • Total ash (% w/w) max: 8 • Acid insoluble ash (% w/w) max: 2 • Moisture (% w/w) max: 12 • Volatile oil (%v/w): 2.5 **Ground turmeric** • Total ash (% w/w) max: 9 • Acid insoluble ash (% w/w) max: 10 • Moisture (% w/w) max: 10 • Volatile oil (v/w): 1.5
Agmark standards for turmeric powder (Plotto, 2004)	**Powder (passed 300 micron sieve)** • Moisture (% w/w) max:10 • Total ash (% w/w) max: 7 • Acid insoluble ash (% w/w) max: 1.5 • Lead max (ppm): 2.5 • Starch max (% w/w): 60 • Chromate test: Negative **Coarse ground powder (passed 500 micron sieve)** • Moisture (% w/w) max: 10 • Total ash (% w/w) max: 9 • Acid insoluble ash (% w/w) max: 1.5 • Lead max (ppm): 2.5 • Starch max (% w/w): 60 • Chromate test: Negative

%w/w: per cent weight by weight; %w/v: per cent weight by volume; ppm: parts per million.

Table 5.61: Agmark specifications of different grades of Turmeric (Plotto, 2004).

Parameters	**Limits of Alleppey fingers (Good grade)**	**Limits of Alleppey fingers (Fair grade)**	**Fingers other than Allepey (Special grade)**	**Fingers other than Allepey (Good grade)**	**Fingers other than Allepey (Fair grade**	**Rajapore fingers (Special grade)**	**Rajapore fingers (Good grade)**	**Rajapore fingers (Fair grade)**	**Bulbs (Special grade)**	**Bulbs (Good grade)**	**Bulbs (Fair grade)**
~Flexibility:	Hard to touch	Hard	Hard to touch, metallic twang on break	Hard to touch, metallic twang on break	Hard	Hard to touch, metallic twang on break	Hard to touch, metallic twang on break	Hard	-	-	-
~Broken pieces, fingers<15 mm (not more than % by weight):	5	7	2	3	5	3	5	7	-	-	-
~Foreign matter (not more than % by weight)	1	1.5	1	1.5	2	1	1.5	2	1	1.5	2
~Defectives (not more than % by weight)	3	5	0.5	1	1.5	3	5	7	1	3	5
~Percentage of bulbs by weight, max.	4	5	2	3	5	2	3	5	-	-	-
~Flexibility:	Hard to touch	Hard	Hard to touch, metallic twang on break	Hard to touch, metallic twang on break	Hard	Hard to touch, metallic twang on break	Hard to touch, metallic twang on break	Hard	-	-	-

5.10. ECONOMIC FEASIBILITY STUDIES OF SELECTED MEDICINAL PLANTS

The agro-economics inputs were processed after collecting the primary data through personal interviews and Cost A1 concept considering actual expenses in cash and kind incurred in production by owner which included seeds, seed treatment, fertilizers, plant protection, machine labour costs, irrigation, human labour, post-harvest to estimate gross returns per acre, variable cost per acre, and return over variable cost/acre. In Punjab, the average labour cost per day is Indian Rupee (INR) 320/day and each labour works for 8 h/day which costs him around INR.40/h. Similarly, the average cost of the fertilizer is estimated to be INR 250/tonne. The machine labour which mainly exercise tillage, sowing, harvesting costs INR.450/h on average. In Punjab, irrigation is a free process that is supported by the government, however, INR 250/acre has been allocated to this subhead for wear and tear of the motors and bore wells. The cost-return structure of selected medicinal plants was also compared with the traditional crops *i.e.* wheat and rice for providing detailed insights into the adoption of feasibility of medicinal plants in the state.

5.10.1. Cost-return Structure of *A. vera*

A. vera is a five year crop and the first cutting of the crop is taken after 10-11 months of the plantation (Jat *et al.*, 2015b). From second year to fifth year three cuttings per annum are done by the farmers. On average, one cutting yields 20-30 tonnes of leaves from 1 acre of land. At present, most of the farmers of Punjab received INR 2.5/kg rate of *A. vera* leaves from industries. The farmers cultivating *A. vera* directly sell the produce to the interested industries such as the Unati co-operative Marketing-cum-Processing Society Ltd. situated at Talwara, Hoshiarpur and Herbal Trends, Gidderbaha, Punjab. The cultivation of *A. vera* is hugely labour extensive as approximately 50-77% is the share of labour cost in the whole agricultural process. The gross returns of the crop is INR 75,000/- out of which INR 45,619/- is the variable cost and INR 29,381/- is the return over the variable cost for the first year. On average, 60 tonnes of leaves are harvested in three cuttings in one acre of land for the second year with INR 1,08,750/- as returns over variable cost. The cost-return analysis for the second year remains same for the third, fourth and fifth years as mentioned in Table 5.62. It is advisable to cultivate *A. vera* on optimum agro-ecological conditions, adopting standard agricultural practices and assuring marketing before its cultivation for generating economic benefits (Jat *et al.*, 2015b).

5.10.2. Cost return structure of *O. sanctum*

O. sanctum is cultivated in the month of July and harvested in the month of October or November. Nursery is raised and the saplings are transplanted in the field. *O. sanctum* requires three manual weedings, 3-4 times irrigation depending upon the rainfall. One acre of *O. sanctum* yields 3.5 q. of dried leaves whereas 15 q. is the yield of dried whole plants. At present, dried leaves of *O. sanctum* are sold at INR 150/kg and whole plant is sold at INR 50/kg. Generally, there is no major disease attack on the crop so no insecticides or pesticides are required during its cultivation. The gross returns of *O. sanctum* are INR 52,500/- out of which INR 16,985/- is the variable cost after deducting subsidy amount provided by the NMPB. The returns over the variable cost is INR 35,515/- from one acre. The farmers cultivating *O. sanctum* in Punjab sell *O. sanctum* directly to industries such as Aimil Pharmaceuticals situated at Nalagarh. The cost-return structure for *O. sanctum* is mentioned in Table 5.63.

5.10.3. Cost return structure of *C. longa*

The costing structure of *C. longa* involved cost of seeds, sowing, machine, fertilizers application, cost of plant protection, irrigation, weeding, harvesting. After harvesting, post-harvest management of *C. longa* also have significant share in the production costs of *C. longa*. During the survey, it was found that 98% of the farmers sold *C. longa* in processed form (powder) directly to the costumers. Only three farmers, out of the total 24 *C. longa* cultivators sold raw *C. longa* to local *mandi* or processing units like Fapro, Hoshiarpur at INR 8-10/kg; while the processer sold *C. longa* for INR 120-180/Kg in retail. Therefore, it can be concluded that the farmer cultivating as well as processing the *C. longa* have more returns on the variable cost than the one selling raw *C. longa*. In the present study, the agricultural as well as the post-harvest cost-returns have been analyzed as mentioned in Table 5.64. On average, 110 q. of *C. longa* is the total wet yield out of which 17.6 q. is the dry yield from one acre of land. From the total production cost, 53% is the share of post-harvest management of *C. longa*. The selling price of the produce ranges from INR 100/kg to INR 200/Kg depending upon the demand and quality of the produce. The farmers earned net profit of INR 73,725/- by incurring INR 1,02,275/- as variable cost.

Table 5.62: Agro-economics of *A. vera.*

S. No.	Particulars	Quantity	Value (INR)	Share in agricultural process
A	**Income estimate**			
	Gross return/acre	INR 2.5/Kg selling price of fresh leaves × yield	75,000/- (1st year)	**--**
B	**Expenditure estimate**			
1	**Physical input**			
First year				
	Suckers/acre	18,000	18,000×1= 18,000/-	40.9%
	Fertilizers (farm yard manure)/acre (tonnes)	15	15×250= 3750	
2	**Machine labour** • Field preparation (h)	4.5	450/h=2025/-	3.81%
3	**Human labour** • Fertilizer application • Sowing • Weedings • Harvesting (h/acre)	24 h 160 h 320 h (4 times/year and 10 labours/acre) 160 h	960/- 6400/- 12,800/- 6400/-	50.03%
4	**Irrigation (h)**	5 irrigations/year= 62.5 h	250/-	0.47%
5	**Transportation**	--	2000/-	3.76%
6	**Miscellaneous**		500/-	
	Yield (tonne/acre)	30		**--**
	Subsidy by NMPB per acre (30% of 24889 production cost)		7,466.7/-	
	Variable cost/acre		45,619/-	
C	**Profit (INR)**			
	Return over variable cost/acre		29,381/-	
Second year				
A	**Income estimate**			
	Gross returns/acre	INR 2.5/Kg selling price of fresh leaves × yield	1,50,000/-	
B	**Expenditure estimate**			

1	**Physical input**			
	Fertilizer (farm yard manure)/acre (tonnes)	10	10×250= 2,500/-	6.0%
2	**Irrigation**	62.5 h	250/-	0.60
3	**Human labour** • Weedings (h/acre) • Cuttings (h/acre)	 320 h (4 times/year and 10 labours/acre) 480 h (3 cuttings/year and 20 labours/cutting)	 12,800/- 19,200/-	77.57%
4	**Transportation**	**--**	6,000/-	14.5%
5	**Miscellaneous**		500/-	1.21%
	Yield (tonne/acre)	Approximately 60 tonnes leaves from three cuttings in one year		
	Variable cost for second year/acre		41,250/-	
C	**Profit (INR)**			
	Return over variable cost/acre/annum		1,08,750/-	
The cost-return structure for second year remains approximately same for the year three, four and five.				

Table 5.63: Agro-economics of *O. sanctum*.

S.No.	**Particulars**	**Quantity**	**Value (INR)**	**Share in agricultural process**
A	**Income estimate**			
	Gross return/acre	INR 150/Kg selling price of dried leaves × yield	INR 52,500/-	
B	**Expenditure estimate**			
1	**Physical input**			
	Seed/acre	300 g	500/-	13.48%
	Fertilizers (farmyard manure)/acre (tonnes)	10	10×250= 25,00/-	
2	**Machine labour** • Field preparation	 4.5 h	 2,025/-	9.09%
3	**Human labour** • Nursery preparation • Fertilizer application • Transplantation • Weeding	 32 h (4 labours) 16 h (2 labours) 82 h (10 labours) 72 h (three times, 9 labours) 80 h (10 labours)	 1,280/- 640/- 3,280/- 2,880/- 32,00/-	65.0%

	• Harvest • Leaf drying	80 h (five days, 10 labours)	32,00/-	
4	**Irrigation**	3-4 times	250/-	1.12%
5	**Transportation**	**--**	2,000/-	8.98%
6	**Miscellaneous**		500/-	2.24%
	Yield/acre (dry leaves)	3.5 q		
	Subsidy by NMPB per acre (30% of 17569.2 production cost)		5,270.7/-	
	Variable cost/acre		16,985/-	
C	**Profit**			
	Returns over variable cost/acre		35,515/-	

Table 5.64: Agro-economics of *C. longa.*

S.No.	**Particulars**	**Quantity**	**Value (INR)**	**Share in agricultural process**
A	**Income estimate**			
	Gross return/acre	INR 100/Kg selling price of powder × dry yield	1,76,000	**--**
B	**Expenditure estimate**			
1	**Physical input**			
	Seed/acre (q)	6.5	6.5×3600= 23,400	30.85%
	Seed treatment	--	400	
	Fertilizers Farm yard manure)/acre (tonnes) Urea, DAP, and Potash fertilizers/acre	 20 Less than 50 Kg	 20×250=5,000 2,250	
	Plant protection/acre (mostly bio-pesticides, fungicide, weedicide)	--	1200	
2	**Machine labour** • Tillage/acre (h) • Sowing/acre (h) • Harvesting/acre (h)	 3.5 h 4.5 h 2.5 h	 450/h=1,575/- 450/h= 2,025/- 450/h= 1,125/-	4.52%
3	**Irrigation (h)**	13 irrigations= 32.5 h	250/-	0.23%
4	**Human labour** • Fertilizer application	 16 h	 640/-	11.93%

	• Sowing • Weedings • Harvesting (h/acre)	64 h 160 h (2 times, 10 labours one time) 72 h (9 labours)	2,560/- 6,400/- 2,880/-	
Post-harvest				
1.	Wet yield (q/acre)	110	--	52.44%
2.	Dry yield (q/acre)	17.6	--	
3.	Cleaning	48 h (6 labours)	1,920/-	
4.	Boiling	200/q	22,000/-	
5.	Polishing	500/q	88,00/-	
6.	Grinding	1000/q	17,600/-	
7.	Transportation	--	3,000/-	
8.	Packing cost	--	1,000/-	
	Miscellaneous		500/-	
	Variable cost/acre		1,02,275	
C	**Profit (INR)**			
	Return over variable cost/acre		73,725/-	

5.10.4. Cost return analysis of prevalent traditional crops in Punjab

Two-third of the total production of the food grains are contributed by Punjab and is a leading producer of wheat in India (Thakur *et al.,* 2016). The major reason behind dominance of wheat and paddy monoculture in the state is the zero risk in crop production, and its marketing. Besides this, there is 100% assured procurement of these crops in the *mandis* providing farmers a Minimum Support Price (MSP) (Ali *et al*., 2012). Punjab has the best marketing system for wheat and paddy crops which is developed by strengthening the infrastructure of the *mandi's*. There are *mandis* every five to six kilometres in Punjab. These *mandis* employ up to 300,000 labourers in transportation, sorting and packing. These *mandis* procure from about 2 million farmers[§§§]. The department of economics and sociology, Punjab Agricultural University, Punjab has prepared an executive brief on the district wise cost of cultivation of important crops in Punjab (Kaur *et al.,* 2018a). The average cost-return analysis of wheat and paddy is mentioned in Table 5.65 and 5.66 respectively. The present study emphasized on the agro-economics of the selected medicinal plants and recommends adoption of these medicinal plants in the suitable agro-ecological area after assuring or generating market. The comparative agro-economics analysis between the traditional crops and selected medicinal plants in described in the Table 5.67.

[§§§] *Inputs: Article by Arvind Shukla, Gaon Connection, 15/Dec./2020*.

Table 5.65: Cost return analysis of wheat in Punjab.

S.No.	Particulars	Quantity	Value (INR)	Share in agricultural process
A	**Income estimate**			
	Gross return/acre	INR 17.50/Kg selling price of wheat × yield	INR 31,150/-	
B	**Expenditure estimate**			
1	**Physical input**			
	Seed/acre	56 Kg	981/-	43.78 %
	Fertilizers (Urea, DAP, etc.)/acre	165 Kg	2090/-	
	Pesticides and Insecticides/acre Stomp/Dost/Markpendi Awkira/Momiji 85 Platform 385 SE	 1.5 L 60 g 1.0 L	723/-	
2	**Labour** Machine labour (field preparation) Human labour	 4.8 h 21.5 h	 2198/- 856/-	35.24 %
3	**Irrigation**	3-4 times	234/-	2.70 %
4	**Transportation**	11 L	968/-	11.17 %
5	**Miscellaneous**		616/-	7.10 %
	Yield/acre (q)	17.8		
	Variable cost/acre		8666/-	
C	**Profit (INR)**			
	Returns over variable cost/acre		22,484/-	

Table 5.66: Cost Return analysis of rice in Punjab.

S.No.	Particulars	Quantity	Value (INR)	Share in agricultural process
A	**Income estimate**			
	Gross return/acre	INR 14.477/Kg selling price of rice × yield	INR 37,611/-	
B	**Expenditure estimate**			
1	**Physical input**			
	Seed/acre	10 Kg	690/-	31.82 %
	Fertilizers (Urea/DAP, etc.)/acre	127 Kg	1596/-	

	Pesticides, Insecticides, weedicides/acre Pendimathalin Metsulfuron Zineb	 1 L 30 g 500 g	 1396/-	
2	**Labour** Machine labour (field preparation) Human labour	 3 h 77.75 h	 1324/- 3110/-	38.32 %
3	**Irrigation**	3-4 times	1459/-	12.611 %
4	**Transportation**	11 L	1343/-	11.60 %
5	**Miscellaneous**		651/-	5.62 %
	Yield/acre (q)	25.98		
	Variable cost/acre		11,569/-	
C	**Profit (INR)**			
	Returns over variable cost/acre		26,042/-	

Table 5.67: Comparative cost-return analysis between traditional crops and medicinal plants.

Particulars	**Wheat (Rabi)**	**Paddy (Kharif)**	***C. longa* (9 month crop)**	***A. vera***		***O. sanctum* (Kharif)**
				1st yr.	**2nd to 5th yr.**	
Yield (q/acre)	17.8	25.98	17.6 (dry yield)	300	600/annum in three cuttings	3.5
Gross return	31,150	37,611	1,76,000	75,000/-	1,50,000/-	52,500/-
Variable cost	8666	11,569	1,02,275	45,619/-	41,250/-	16,985/-
Return over variable cost	22,484	26,042	73,725/-	29,381/-	1,08,750/-	35,515/-
Profitability per annum	**48,526/-**		**73,725/-**	**92,876/-**		**35,515**

This objective behind this study was to highlight cost-return analysis of these medicinal plants, so that they can be a strong competitor to the traditional crops in context of feasibility of cultivation and economics. Cultivation of paddy requires intensive irrigation for its cultivation leading to huge underground water exploitation. In general, the selected medicinal plants required less irrigation and are lesser prone to disease attack as compared to paddy. Medicinal plants such as *O. sanctum* can replace paddy in the *kharif* season with more returns on variable costs than paddy if proper marketing channel is established. Similarly, *C. longa* that was cultivated in the month of May and harvested in the month of January can be rotated with the maize crop that is cultivated in the month of February and harvested in June. The cultivation of *A. vera* has annual returns over variable cost of INR 1,08,750/- for consecutive five years if cultivated on suitable land and assuring its market. This can be potential crop having good opportunities in agribusiness for the farmers especially the farmers that can own processing units or have processing units nearby their agricultural fields. Alternatively, in order to get confidence of the farmers in initial phase, farmers should be motivated to partially adopt cultivation of these medicinal plants on a part of land. Upon successful cultivation and financial benefits to the farmers, large scale cultivation of medicinal plants will easily be adopted by farmers in self-motivated manner.

5.11. DRAFTING OF FARMING MANUAL FOR SELECTED PLANTS IN LOCAL LANGUAGE FOR WIDER BENEFITS

The GAP based farming manuals were translated in vernacular language (Punjabi) for wider translation of the study among the farmers, are attached as Annexures IV, V, VII.

5.12. SUBMISSION THE PROPOSED COMPREHENSIVE GAP FOR SELECTED MEDICINAL PLANTS TO REGULATORY AGENCIES

Developed training manuals, monographs, and other relevant material related to the present work have been submitted to the FITM/Ministry of AYUSH/RIS in form of book chapters, and policy recommendations for wider implementation.