7. CONCLUSIONS

The area under medicinal plants cultivation in the Indian state of Punjab is less than 1%, which is far less than its potential. Various factors such as high reliability on traditional crops *viz.* rice and wheat due to assured marketing, lack of awareness regarding agro-climatic suitability and GACP of potential medicinal plants, agro-economics, and quality-related issues in context to industrial requirements are key issues that need to be addressed for the promotion of medicinal plants in the state. In the present study, potential medicinal plants such as *A. vera*, *P. emblica*, *W. somnifera*, *G. glabra*, *A. racemosus*, *A. paniculata*, *O. sanctum*, *C. longa*, *C. asiatica*, *A. calamus*, *R. serpentina*, *O. basilicum*, and *C. borivilianum* were selected based on the consumption by the herbal industries, estimated annual trade, expert consultation from industries and prior traces of their cultivation in the state.

At present, no clear guideline is available to suggest which medicinal plants are best suited in the right location in the state of Punjab. In this direction agro-climatic zoning study was conducted to help the policymakers in suggesting optimal regions for the cultivation of selected medicinal plants. Based on international and national available 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.

On developing agro-climatic zoning model for the medicinal plants, it was found that 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*. The agro-climatic suitability of selected plants in various zones of Punjab is represented in Table 7.1.

Table 7.1: Comparative analysis between agro-climatic zones for cultivating medicinal plants.

Plant	Zone-I	Zone-II	Zone-III	Zone-IV	Zone-V
Aloe vera	**	**	**	***	**
Phyllanthus emblica	***	***	**	**	**
Withania somnifera	**	***	***	**	*
Glycyrrhiza glabra	***	***	***	***	***
Asparagus racemosus	***	***	***	**	*
Andrographis paniculata	***	**	**	**	**
Ocimum tenuiflorum	***	***	***	**	**
Curcuma longa	***	***	**	*	*
Centella asiatica	***	***	**	*	*
Acorus calamus	***	***	***	**	*
Rauvolfia serpentina	***	**	**	*	*
Ocimum basilicum	***	***	***	**	**
Chlorophytum borivilianum	***	***	***	**	*

***= Optimally suitable; **= Suitable; *= Less-suitable

This agro-ecological zoning model can act as a baseline study for other medicinal plants, aromatic plants, and spices with same or different bioclimatic indices and can be extrapolated in any part of the world for determining potential growing areas for new crops.

The work was also aimed to enumerate and identify farmers cultivating medicinal plants in Indian state of Punjab. The information regarding medicinal plants is scanty and scattered. Therefore, for the first time different government and private channels were explored to gather the data of medicinal plants cultivators. In the present study, data was successfully collected and subsequently stored on digital map using GIS for the very first time as no such compilation was previously available. Data explored from different channels resulted into identification of 68 farmers cultivating *A. vera, O. sanctum, C. longa, P. emblica,* and *R. serpentina* in Punjab. In the study, digital maps highlighting the five agro-climatic zones of Punjab were also developed to facilitate study related to biophysical potential of specific zone with the selected medicinal plant. It was found that at present *C. longa* was cultivated in every zone of Punjab except western plain. Similarly, *O. sanctum*, *P. emblica,* and *R. serpentina*

were cultivated in western Himalayas, sub humid zone. On the other hand, *A. vera* was dominant on western plain, aried zone corroborating with its suitable agro-ecological requirements, followed by western Himalayas, sub humid zone.

Furthermore, geo-tagging of farmers was done on respective maps using GIS Arc.GIS 10.3 application and relevant data was inserted in such a way that the detailed demographic information on each marking on the map was successfully displayed. The study resulting into the digitalization of farmer's data on respective agro-climatic zone specific maps can be utilized for further studies and generating new hypothesis related to linkage of medicinal plants sector stakeholders for trade and connectivity.

An extrapolatory survey was conducted through personal interviews using a semi-structured, pre-tested reliable questionnaire following purposive sampling technique. A total of 68 farmers were involved in the cultivation of *C. longa, A. vera*, *P. emblica*, *O. sanctum* and *R. serpentina*. The mean percentage score and the Chi-square test were applied for finding significant differences, *i.e.* p-value < 0.05, between the small and large farmers to highlight various technical, marketing, social, and awareness related constraints. It was found that 36.8% of the cultivators were graduates, 23.5 % were large farmers, and 42.6 % belonged to the general caste category.

Few processing units, non-availability of quality planting material, packing and labeling equipment, less knowledge regarding agro-climatic suitability, lack of awareness regarding GAP, NMPB *e-charak* mobile app., and need for agro-technology refinement etc. were some of the constraints faced by the farmers. The significant relationship was found between farmer landholdings in getting sufficient seeds, possessing distillation units, manufacturing herbal formulation, having packaging equipment, willingness for FSSAI approval, channel to sell the produce, availability of internet and subsidy of medicinal plants given by the NMPB.

The critical alignment study identified critical materials such as seed, soil site, water, fertilizers, pesticides, biological indicators and equipments had significant relation with the quality attributes of medicinal plants. Similarly, processes *viz.* authentication of seed, maintaining optimum soil drainage and pH, soil sampling, levelling, tillage, water-logging prevention, the optimum time of sowing, seed-row distances, harvesting time, aerobic treated, fully composited and early application of

fertilizers, phytoremediation, drying time, drying temperature, storage time, etc. had a significant effect on critical quality attributes of the medicinal plants. The study successfully developed a relationship between Critical Material Attribute, Critical Process Parameter and Critical Quality Attribute to enlighten the farmers to pre-determine the quality and subsequently avoid the risks involved in the cultivation of medicinal plants. The suggested strategy of encompassing quality in concern with every critical material and process parameter by aligning independent and dependent variables with desired quality attributes, establishing their significance level and deep insights of quality risk assessment ensure quality medicinal produce, an essential pre-requisite for its commercial acceptance. The findings will be helpful to ascertain the systematic method of medicinal plant cultivation and to apply 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.

In the present study, comprehensive GACP guidelines for medicinal plants were drafted in order to develop more holistic and robust guidelines after inclusion of all the unique parameters mentioned in the GACP guidelines of different countries. Point-wise comparisons were made for 12 parameters such as seeds, site selection, soil, water, cultivation, crop management, crop nutrition, harvest, post-harvest, personnel, and equipment. Documentation described in various GAP guidelines were analyzed to develop robust GACP guidelines by including 12 heads and 108 sub-heads. 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. These guidelines will encourage *ex*-situ conservation of medicinal plants through

sustainable cultivation of medicinal plants. Apart from this, it also encourages to develop monograph on GAP 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. These comprehensive guidelines can be a baseline for the formation of country-specific GAP guidelines in the future studies.

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 (Dasgupta, 2003).

In the present study, Failure Mode and Effect Analysis (FMEA) tools were applied to standardize farmers produce based on calculating the Risk Priority Number of each agricultural step vulnerable to affect the quality of medicinal produce. Overcoming the delayed phase of improvements associated with probabilistic reliability testing modeling, FMEA was utilized to assure quality and reliability in the early phase of medicinal plants production. This standardization technique highlighted risk assessment, 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. Furthermore, remediation techniques were suggested for quality compliance and heavy metal residue and pesticides contamination. Each agricultural process during pre-cultivation phase, agro-practices phase and post-harvest phase was studied and suggestive checklists and recommendations were drafted for the farmers to enable them to get standardized medicinal plants as per the industrial standards.

Following GAP practices and adopting standard agro-technique for specific medicinal plants enhance the quality of medicinal plants. But, 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. In this context, on-field cultivation study of medicinal plants adopted by the progressive farmers 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 in corroboration with the standard literature. The monographs were divided into three parts *viz.* botanical and pharmacological characteristics, good agricultural practices, and standard quality certifications for herbal materials. The Standards for Quality Certifications (SQC's) of *A. vera, O. sanctum,* and *C. longa* comprising of morphological, microscopical, physico-chemical, qualitative, quantitative, microbial load, toxicity indicators, etc. along with their acceptable limits prescribed by API, ICMR, FSSAI, and WHO have been drafted as an intuitive document for the farmers involved in the commercial utilization of these medicinal plants.

The agro-economics of selected medicinal plants, *A. vera*, *O. sanctum*, and *C. longa* was carried out. The agro-economics inputs were processed after collecting the primary data through personal interviews using a semi-structured, pre-tested questionnaire from the farmers. The cost A1 concept considering actual expenses in cash and kind incurred in production by owner, which included human labour, machine labour, value of seeds, insecticides, pesticides, manures, fertilizers, irrigation, miscellaneous expenses, was followed in the present study. The cost-return analysis was processed to calculate total variable costs, yield, gross returns, returns over variable costs. Furthermore, the agro-economics of most prevalent crops in Punjab i.e. wheat and rice was compared with that of selected medicinal plants. As per the study, *A. vera* had INR.92,876/- returns per acre annually on average for five years, *O. sanctum* had INR.35,515/- returns over variable cost and *C. longa* had INR. 73,725/- returns over variable returns per acre. The selected medicinal plants had more returns than the traditional crops *i.e.* (wheat and rice).

The most prevalent marketing channel was found directly between the farmers and the consumers/industry. Cultivation of *O. sanctum* can be a good alternative to *kharif* crop paddy (which is high water consuming crop) after assured marketing. Cultivation of *A. vera* can be carried out in Punjab especially in arid areas only after signing contract agreement assuring guaranteed 100% buyback. Multilayer farming of medicinal plants with different types of vegetables, pulses and fruits must be explored by the agricultural research institutions in order to generate maximum returns to the farmers. The suggestive recommendations: A policy document has been submitted to

the Forum on Indian Traditional Medicine (FITM) and Ministry of AYUSH for deliberations and wider dissemination.

Historical evidence shows that apart from providing health values, the adoption of medicinal plant cultivation has improved the livelihood status of the cultivators in many countries by generating high-income sources. Subsequently, medicinal plants have an important ecological role that helps check runoff, erosion, purify water, controls flooding. The adoption of medicinal plant cultivation could be fruitful if the constraints highlighted in the study are comprehensively addressed and quality-related measures as suggested in the study are implemented by the farmers in conjunction with the concerned policymakers.

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