ABSTRACT

INTRODUCTION

According to the World Health Organization (WHO) estimate, the global herbal industry is projected to be worth US$ 5 trillion by the year 2050 globally. Punjab is an Indian state which falls under trans-gagentic agro-climatic zone of India. Despite favourable climatic conditions and trade opportunities, Punjab has less than 1% of its total cultivable land under medicinal plants cultivation which is far less than its potential. Non-existence of agro-climatic zoning, standard agro-practices, unawareness about Good Agricultural Practices (GAP), marketing and no quality mapping with industrial standards have made the adoption of medicinal plants complex.

METHODS

The selection of medicinal plants was done on the basis of commercial value, feedback received from local farmers, Government officials along with experts from industry and academia. Agro-climatic study was conducted after collecting the annual temperature and rainfall records from the Indian Meteorological Department (IMD) and Punjab Agricultural University (PAU) and agro-eco-subregion based benchmark soils network was utilized for the preparation of digital base maps. All the base maps were superimposed to highlight optimally suitable zone, suitable zone, and lesser suitable zone using Arc. GIS 10.3. Different government, private channels were explored to identify farmers involved in medicinal plants cultivation for geo-tagging and conduct of survey. The base maps were digitalized online and digital information layers were created. The exact location of farmers was marked on the digitalized maps using their latitude and longitude coordinates using GIS. The farmers were interviewed personally using a questionnaire following the purposive sampling technique. Different constraints related to technical, marketing, social participation, awareness and farmer attitude and policy were studied based on Mean Percentage Score (MPS) and Chi-square test was applied to highlight the significant relationship between the farmer's land holdings (small and large farmers) and various constraints. To supplement quality-rich medicinal plants, drafting of comprehensive Good Agricultural and Collection Practices (GACP) guideline was conducted after critically assessing and comparing the GAP of WHO and other countries like America, Japan,

China, The United Kingdom (UK), and India for selected plants. Critical variable alignment study was conducted to understand significant variables and map Critical Materials Attributes (CMA), Critical Process Parameters (CPP) with Critical Quality Attributes (CQA) for e.g. content of active constituent, crop yield, heavy metal content, pesticide residue, physico-chemical ranges, microbial load and suggest improvements. Standardization of farmer's produce for same quality parameters and gap/variability analysis in comparison to industrial standards was conducted using the Failure Mode and Effect Analysis (FMEA) to get rich-quality herbs and avoid risks that are involved in widespread testing of medicinal plants which is mostly costly. Subsequently, monographs featuring GAP related documentation for on-field cultivation were prepared after conducting field visits, farmer interaction and corroborating the inputs with reported literature. The cost-return analysis for selected medicinal plants was performed following descriptive statistics such as average prices of the crops to calculate total variable costs, yield, gross returns, and return over variable costs. The comparative agro-economics analysis was conducted between traditional crops (wheat and rice) and selected medicinal plants. The GAP based farming manuals have been prepared in English and vernacular language (Punjabi).

RESULTS OBTAINED

Based on industrial demand, pharmacological importance, feasibility of cultivation, and expert consultation, thirteen medicinal plants such as *Aloe vera (A. vera), Phyllanthus emblica* (*P. emblica*), *Withania somnifera* (*W. somnifera*), *Glycyrrhiza glabra* (*G. glabra*), *Asparagus racemosus* (*A. racemosus*), *Andrographis paniculata* (*A. paniculata*), *Ocimum sanctum* (*O. sanctum*), *Curcuma longa* (*C. longa*), *Centella asiatica* (*C. asiatica*), *Acorus calamus* (*A. calamus*), *Rauvolfia serpentina* (*R. serpentina*), *Ocimum basilicum* (*O. basilicum*), *Chlorophytum borivilianum* (*C. borivilianum*) were selected for the agro-climatic zoning studies. Among these thirteen plants, five medicinal plants i.e. *A. vera, O. sanctum, C. longa, P. emblica, R. serpentina* were identified that were presently cultivated by the farmers of Punjab which were included in the survey studies. Among these five medicinal plants, *A. vera, O. sanctum, C. longa* were selected for preparing detailed GAP monographs considering their short crop cycle in terms of first harvest than *P. emblica*, and *R. serpentina*.

The agro-climatic zoning model highlighted that zone-I was optimally suitable for most of the selected medicinal plants, followed by zone-II, III, IV, and V. Geo-tagging enabled assessing of farmers on different agro-climatic zones of Punjab and representing their demographics. It was found that 05 medicinal plants such as *C. longa, A. vera, O. sanctum, P. emblica*, and *R. serpentina* were cultivated by 68 farmers across Punjab. It was found that 95.72% of the farmers were not involved in signing contract farming, 78.4% had no processing units, 58.4% lacked knowledge of potential agro-climatic zone to cultivate medicinal plants, 74.47% lacked awareness regarding GAP. The comprehensive drafted GAP guidelines resulted in 12 GAP parameters with 108 sub-parameters. The variable alignment study highlighted seed, site, soil, and water had the highest bearing on the crop yield. Furthermore, in pre-cultivation phase, seed treatment, site treatment, soil treatment, and water treatment had very high impact on crop yield and very less impact on physicochemical ranges. In agro-practices phase, sowing had high impact on crop yield, and very less effect on toxicity indicators. Subsequently, in post-harvest phase, collection has moderate effect on active constituents, drying has moderate effect on microbial load, and storage has moderate effect on active constituents. FMEA successfully enabled standardization of farmers produce in context to crop yield, toxicity indicators, microbial load, active constituents, and physicochemical ranges. Highest severity was given to toxicity indicators followed by microbial load, active constituents, crop yield, and physicochemical ranges. Each agricultural process (authentication, site selection, soil, water, cultivation, crop fertilization, harvest, drying, storage, etc.) and its effect on the critical standardization criteria was evaluated and checklists were suggested to lower the Risk Priority Number (RPN) in order to get good standardized herbal produce. The monograph represented three sections *viz.* botanical and pharmacological characteristics of plants, good agricultural practices, and Standard Quality Certifications (SQC's) tests that were mentioned in Ayurvedic Pharmacopoeia of India (API), Indian Council of Medical Research (ICMR), WHO, and Food Safety and Standards Authority of India (FSSAI). Based on our agro-economics study, *A. vera* has INR. 92,876/- profitability per annum/acre, *O. sanctum* has INR. 35,515/-, and *C. longa* has a profitability of INR.73,725 per annum/acre. The pictorial farming manuals were prepared in local language (Punjabi) for wider dissemination among the farmers.

DISCUSSION

A comprehensive roadmap was required to identify potential growing zones and medicinal plants cultivators in the state, digitalize their information in order to map the farmers on the agro-ecological specific map using GIS. In developing countries like India there is scanty information related to medicinal plants cultivators so digitalization of farmers information would also help to link clients, farmers, industries, and concerned officials to plan strategies for improved access, trade, and outreach in the future studies.

It also highlighted *O. sanctum*, *W. somnifera* as alternate crops for paddy during *kharif* season. Different technical, trade, social, awareness, and policy related constraints highlighted in the study would help the policymakers to devise appropriate solutions to promote medicinal plants cultivation in the state. In agro-economics study, the selected medicinal plants had more annual profitability than wheat and paddy, hence these crops can be adopted by the farmers after following GAP, and market assessment.

Maintaining consistency is one of the major hurdles in agriculture due to several interfering biological and other factors, hence variability alignment study technique would enable farmer to fine-tune parameters by evaluating possible interactions with in-depth understanding. Conventionally, reliability of medicinal plants has been accomplished using widespread testing of medicinal plants adopting probabilistic reliability modeling. These methods were applied at the delayed phase of improvements. Therefore, FMEA would help to standardize the farmers produce in order to avoid quality related issues in the later stages. Experience of a farmer plays a vital role in the success of the crop. The WHO has recommended drafting of region specific GAP monographs of medicinal plants. In accordance to it, monographs were prepared considering the farmers practices, ecological conditions of the state and corroborate the inputs with supportive literature. These monographs can be adopted by the farmers interested in cultivation of medicinal plants at commercial scale.

CONCLUSIONS

The study was designed to promote the medicinal plants cultivation in the state keeping in view the economic sustenance of farmer based on integrative knowledge of optimum zone and condition, financial feasibility analysis, suitable agro-practices, collection methodologies, quality evaluation and related documentation. The study

successfully identified medicinal plants cultivators in the state, digitally mapped farmers and also embedded their demographic profile using GIS. Agro-ecological zoning successfully highlighted potential growing zones for medicinal plants across Punjab. It also highlighted various constraints faced by the farmers. Subsequently, comprehensive GAP guidelines were drafted, the study also identified critical materials and processes effecting quality of medicinal plants. FMEA approach was successfully applied for standardization of farmers produce in order to prevent late stage risks in plant production. The monographs of GAP of selected medicinal plants based on the farmers practices and literature support were drafted and the agro-economics study suggested that *C. longa, A. vera,* and *O. sanctum* has more profitability per annum than the traditional crops.

As no policy exists to regulate right medicinal plant in right area, the rationale and findings of the present study can be used in other parts of the country to ascertain potential growing zones for other medicinal plants based on the region's ecological conditions. The geo-spatial approach used in the present study can provide a luminous light to link consumers and industries directly with the farmers throughout the country. Subsequently, successful farmer's practices in corroboration with the literature can be reported in the form of monographs and disseminated throughout the region using vernacular languages in different parts of the country. This study can be a baseline study for integration of scientific methodologies, successful agro-practices, and documentation as per international norms leading to inputs for future policies for farmer's benefit.