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Review

Challenges in developing medicinal plant databases for sharing ethnopharmacological knowledge

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ABSTRACT

Ethnopharmacological relevance: Major research contributions in ethnopharmacology have generated vast amount of data associated with medicinal plants. Computerized databases facilitate data management and analysis making coherent information available to researchers, planners and other users. Web-based databases also facilitate knowledge transmission and feed the circle of information exchange between the ethnopharmacological studies and public audience. However, despite the development of many medicinal plant databases, a lack of uniformity is still discernible. Therefore, it calls for defining a common standard to achieve the common objectives of ethnopharmacology.
Aim of the study: The aim of the study is to review the diversity of approaches in storing ethnopharmacological information in databases and to provide some minimal standards for these databases.
Materials and methods: Survey for articles on medicinal plant databases was done on the Internet by using selective keywords. Grey literatures and printed materials were also searched for information. Listed resources were critically analyzed for their approaches in content type, focus area and software technology.
Results: Necessity for rapid incorporation of traditional knowledge by compiling primary data has been felt. While citation collection is common approach for information compilation, it could not fully assimilate local literatures which reflect traditional knowledge. Need for defining standards for systematic evaluation, checking quality and authenticity of the data is felt. Databases focussing on thematic areas, viz., traditional medicine system, regional aspect, disease and phytochemical information are analyzed. Issues pertaining to data standard, data linking and unique identification need to be addressed in addition to general issues like lack of update and sustainability. In the background of the present study, suggestions have been made on some minimum standards for development of medicinal plant database.
Conclusion: In spite of variations in approaches, existence of many overlapping features indicates redundancy of resources and efforts. As the development of global data in a single database may not be possible in view of the culture-specific differences, efforts can be given to specific regional areas. Existing scenario calls for collaborative approach for defining a common standard in medicinal plant database for knowledge sharing and scientific advancement.

Contents

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1. Introduction

From the ancient time, plants are used as an essential component of traditional medicine systems (Fang et al., 2005). Still today medicinal plants remain significant as natural alternatives to synthetic drugs (Kettner et al., 2005) with about 80% of the world population depending upon plants for their primary health care according to WHO estimation (Akerele, 1993). These past and current dependence on plant as a source for medicines gives impetus to the ethnopharmacological studies for studying their efficacy, safety and drug-discovery potentials (Karou et al., 2007). Ethnopharmacology is a multidisciplinary area of research (Etkin and Elisabetsky, 2005) concerned with the observation, description, and experimental investigation of indigenous drugs and their biological activity. The approach of stressing on the importance of plant-derived drugs (Ortega, 2006), assimilation of ethical aspects and anthropological oriented research as well as introduction of historical perspectives of indigenous knowledge systems, thereby makes this field a rich area of multidisciplinary science.

Current view on ethnopharmacology also contextualizes ecology and addresses perception of plants, their use, pharmacology and physiology in human communities (Etkin and Elisabetsky, 2005; Leonti, 2011) all of which are based on traditional medicinal plant use (Heinrich et al., 2006) and natural products. Documenting indigenous medical knowledge and scientific study of indigenous medicines and sharing this knowledge are some of the priorities for the current ethnopharmacological research (http://www.ethnopharmacology.org/ISE_journal.htm). Such efforts of intellectual discovery process require access to all sorts of information and organizing them into systematized knowledge (Chung and Wooley, 2003). Formerly, the process of sharing knowledge was helped by making corresponding journals, manuals and textbooks available in the scientific library (Boehm et al., 2010). Nowadays, application of computerized databases has supplemented new methods for information dissemination. This innovative change in scientific research method has been initiated by the application of Information Technology (Buneman, 2005) which has served a “quiet revolution of Information Technology and bioinformatics” (Bisby, 2000). In view of the quantity and frequency of data generated by the combination of chemical, biological and pharmacological sciences (Reyes-Garcia, 2010), computerized database can provide efficient solution for data management. Database can also contribute towards ethnopharmacological research by facilitating the process of analysis and interpretations (Farnsworth and Loub, 1983; Heinrich et al., 2009). It also brings information generated from diverse fields into a coherent whole (Synge and Heywood, 1988) making them available to researchers, planners and other users. Moreover, web-based databases facilitate knowledge transmission and feed the circle of information exchange between the ethnopharmacological studies and public audience (Leonti, 2011). With the growing popularity of Internet this becomes more significant also for healthcare systems (Eysenbach et al., 2002).

Nowadays, information stored in electronic medium has remarkably increased (Bhat, 1997; Thomas, 2003) with medicinal plant database emerging as one of the trends (Dighe et al., 2010). These databases compiled a wide range of information on plant characteristics, medicinal properties and bioactive compounds along with their images (Deng et al., 2010). Similar to many public, commercial and supplier databases available for natural products (Fullbeck et al., 2006), many medicinal plant databases, diverse in contents and in representations (Allais et al., 2000; Gaikwad et al., 2008; Liu and Sun, 2004; Skoczen and Bussmann, 2006; TradiMed, 2011) have been developed relating this field to information science, such as other disciplines in biology (Morgan et al., 2004).

In spite of the wide use of plants in ethnopharmacology and in modern pharmaceuticals (Farnsworth and Bingel, 1977; Rates, 2001), traditional knowledge of medicinal plant in many communities is yet to be explored. Though there is growing awareness on the role of ontology for shared conceptualizations of the traditional knowledge based systems, where these medicinal plants operate (Jang et al., 2010; Vadivu and Hooper, 2010), the vocabularies of many traditional medicine systems are yet to be standardized and integrated into the database. Consensus is yet to be made for developing database models for integrating and facilitating collaborative ethnopharmacological research (Stepp and Thomas, 2006). Because of the multidisciplinary nature of ethnopharmacology, information compiled by different workers may have diversified perspectives. Establishment of a common standard can help in integrating these subsets into a common pool. In view of this background, need for developing and maintaining a common standard for medicinal plant databases is felt for achieving the objective of representing the complex ethnopharmacological knowledge.

In this review paper, computerized databases developed for compiling ethnopharmacological information of the plants are analyzed with an attempt to address the challenges faced in developing such databases. The broad objective of this review is to gather information on state of the art on medicinal plant databases with reference to their diversity in content and approaches as well as software design so as to suggest minimum methodological standards.

2. Search strategy

An extensive search for articles on the development of databases on medicinal plants was done in the Google Scholar, PUBMED and SCIRUS. The keywords “ethnobotany”, “ethnopharmacology”, "ethnomedicine", "ethnomedicinal plant", "ethnobotanical database", "botanical database", "ethnopharmacological database", "herbal database", "traditional medicine database", "ethnomedicinal plant database" and "database" were used independently and in combination. Literatures related with databases were also searched from the printed materials. The grey literature not listed in the above-mentioned databases was also searched using Google and Yahoo search engines. Bibliographies of the retrieved articles were also searched for additional information and other relevant references. Listed resources were rechecked and updated URLs had been incorporated.

Herbal information resources available in the web have been differentiated by Wootton (2005) into monograph series and databases that are dynamically created and updated using multiple fields. In view of the importance of the interpreted information, both types of resources were collected for this review. In the preliminary survey, 148 records were obtained. After excluding offline databases and websites no longer available, a total of 83 online information resources were listed in Table 1. Selected resources were analyzed according to content type and source, accessibility, language, country, focus area, software technology used, status of the URL, sustainability, update information and compiler information. Information from the unlisted resources was also analyzed to comprehend the challenges.

3. Diversity of databases

The diversity in development and deployment has been reflected by databases like Drug herb interaction database (Cohall et al., 2010), Traditional Medicine Collection Tracking System (Harris et al., 2011), Traditional Chinese medicine information database (Ji et al., 2006), etc. It reveals the diversity in expertise and interests of the groups that maintain them (Stein, 2003). There are several attempts to categorize biological databases including those dealt with medicinal plant following different criteria. Some of them are classification into reference centric or compound centric databases on the basis of design of the database systems (Jagarlapudi and Kishan, 2009); primary, secondary or tertiary information databases on the basis of data source (Bhat, 1997); bibliographic databases or databases combining bibliographic information with numerical and textual information (Loub et al., 1985) on the basis of content type; large-scale public repositories, community-specific database resources and project-specific databases (Rhee and Crosby, 2005) on the basis of scale of the database project, etc. In most cases the demarcating line between these categories is not clear.

In this analysis, major variations in approaches of database development have been observed in source of content, selection of focus area and software technology used. A critical assessment of the approaches adopted and challenges encountered are presented in the following sections.

3.1. Source of content

The content of the databases is derived from either traditional knowledge, scientific research or both, representing the intellectual wealth produced by research and societal investment (Shanmughavel, 2007). Documents reporting current works or reviews provide the content of the primary information databases (Bhat, 1997). Databases like International Ethnobotany database (eBDB) (Skoczen and Bussmann, 2006) and Customary Medicinal Knowledgebase (CMKb) (Gaikwad et al., 2008), Traditional Medicines in the Islands (TRAMIL) (http://www.tramil.net) fall in this category, to some extent, as they can integrate primary data by the users and researchers. On the other hand, contents of the secondary and tertiary information databases depend upon information compiled from published primary information or common knowledge. However, the two differ as secondary information databases reflect original publication (http://www.embase.com; http://www.nlm.mih.gov), while tertiary information databases may or may not indicate the source literature and may also incorporate information from unpublished sources, compiler's comments and graphic materials (http://www.rain-tree.com; http://www.biopark.org/Plants-Amazon.html; http://www.proseanet.org). There are instances of websites displaying online versions of printed books, e.g. A Modern Herbal (Owen, 2002), Botanical Dermatology Database (Schmidt, 2001), International Directory of Specialists in Herbs, Spices and Medicinal Plants (Bhat, 1997), etc.

In this review, it was observed that one of the major approaches for collecting information is bibliographic source (Bothmer et al., 1997; Liu and Sun, 2004; Roberts, 1995; Schoonbaert, 1996). Bibliographic source as the most frequently encountered category has been reported by other researchers also (Bhat, 1997; Loub et al., 1985). Databases specified on related areas also serve as important resource for ethnopharmacological knowledge, e.g. Agricultural Online Access (http://agricola.nal.usda.gov/), International Information System for Agricultural Sciences and Technology (http://agris.fao.org/), Allied and Complementary Medicine Database (http://www.bl.uk/services/stb/amed.html), Chemical Abstracts Service (http://www.cas.org), etc. Bibliographic resource is usually the preferred source for reaffirming the properties of the medicinal plants before any analytical works. Although large numbers of collection are there in such databases, the content remains still inadequate. It is because they represent a regressive view which can only be updated by regular revision (Kettner et al., 2005). Literatures from local or regional publications, in spite of their immense contribution to conserving traditional knowledge, could not be fully assimilated in many of the global level bibliographic databases. There had been some attempts to retrieve information on medicinal plants from regional publications and non-indexed journals (Manha et al., 2008; Soetjipto and Rosario, 2003).

In addition to bibliographic databases, the necessity for primary source from users and healers is felt for compiling information on traditional knowledge. It is because practice of traditional knowledge is usually encountered in remote areas rich in biodiversity but poor in modern scientific amenities (Edwards and Heinrich, 2006). The necessity is also compounded when certain lab-based biomedical researchers tried to obtain data from secondary sources thereby raising the chance of distortion of the original information from primary source (Andrade-Cetto and Heinrich, 2011). As the traditional knowledge system contained within a particular culture is changing under the impact of globalization and urbanization, the situation calls for rapid incorporation of available knowledge in addition to articles from peer-reviewed journals or findings from lab-based research. Approaches in this line have been noticed in development of Native American Ethnobotany Database (Moerman, 1998) through systematic exploration of scientific literature, ethnographic accounts and historical documents. Similarly, Historical Estonian Herbal Medical Database (Historislik Eesti Rahvameditsiini Botaaniline Andmebaas) came into existence by digitizing handwritten pages of folklore that include local plant knowledge and plant lore (Sõukand et al., 2010).

Collection and incorporation of primary data demand rigorous methodologies for systematic evaluation, checking quality and authenticity of the data. Secondary and tertiary information, also, are not free from the problem of data quality. Occurrence of unreliable data and questionable research methodology without detailed reference (Thomas, 2003) make some online resources unsuitable for sound scientific research. For instance, presence of

Table 1
List of the online databases providing information on medicinal plants.

Name of the database	Compiler	Country	Language	Website	Year of launch	Comments	Citation
A Guide to Medicinal and Aromatic Plants	Center for New Crops and Plant Products, Purdue University	USA	English	http://www.hort.purdue.edu/newcrop/med-aro/default.html	1995	Compilation from different sources; open access	Thomas (2003)
A Modern Herbal	Mrs. Margaret Grieve		English	www.botanical.com/botanical/mgmh/mgmh.html	1995	Online version of book of the same name; contains disclaimer.	Owen (2002)
ADONIS	Group of European Publisher	UK	English		1992	Service absorbed into Elsevier in 1997; now part of Science Direct; URL changed.	Bothmer et al. (1997)
AGRICOLA (*Agricultural Online Access*)	US National Agricultural Library, Maryland	USA	English	http://agricola.nal.usda.gov/	1970	Organized into two datasets—NAL Public Online Access Catalog and Article Citation Database; does not contain the text of articles cited; URL changed; provides information on agriculture and related fields.	Farnsworth and Loub (1983)
AGRIS (*International Information System for Agricultural Sciences and Technology*)	Library and Documentation Systems Division, FAO, Rome	International	English	http://agris.fao.org/	NA	Records from 1975; contains citations from scientific journals; URL changed; efforts are given for better interlinked information collection and services	
Alticopeia Herbal Medicine Database	David I. Rappaport			http://www.ddhsoftware.com/gallery.html?show=number&record=527	2001	Downloadable database on herbal and non-herbal dietary supplements; run on HandBase software in mobile computing environment.	Reynolds and Strayer (2005)
AMED (*Allied and Complementary Medicine Database*)	Health Care Information Service, British Library	UK	English	http://www.bl.uk/services/stb/amed.html	1985	Bibliographic database of complementary medicine; URL changed; subscription based.	Roberts (1995)
ASTIS (*The Arctic Science and Technology Information System Database*)	University of Calgary	Canada	English, French	http://www.aina.ucalgary.ca/astis/	NA	Project began from 1974; covers all aspects of northern Canada including life science; emphasizes on grey literature; however could not cover all publications on northern Canada.	WIPO (2011)
BACIS (*Boelens Aroma Chemical Information Service*)	Bacis	The Netherlands		http://www.leffingwell.com/bacis/bacispdi.html	1985	Downloadable; depends on proprietary software; focussed mainly on perfumery and fragrance.	

BGCI—Plants for the Planet	Botanic Gardens Conservation International	UK/International	English, Spanish, Japanese	http://www.bgci.org	1987	Documented plants in cultivation in botanic gardens including 12,000 threatened plants; linked with other resources.	
BIOSIS Previews	Thomson Reuters	USA	English	http://thomsonreuters.com/products_services/science/science_products/a_z/biosis/	1926	Now part of Thomson Reuters; information on published literatures and non-journal coverage including reports, reviews, meetings, etc.; updated weekly.	Farnsworth and Loub (1983)
BoDD (*Botanical Dermatology Databases*)	John Mitchell & Arthur Rook	UK	English	http://www.botanical-dermatology-database.info/	1994	Online version of the book—*Botanical Dermatology*; URL changed; updated frequently.	Schmidt (2001)
CAB Direct	CAB International	UK	English	www.cabi.org	2003	Computerized since 1973; turn online in 2003; bibliographic records with news articles, reports; covers CAB Abstract and CAB global health.	Aalai et al. (2009)
CAM on PubMed	The National Center for Complementary and Alternative Medicine and the National Library of Medicine	USA	English	http://nccam.nih.gov/research/camonpubmed/	2001	Complies with the HON code standard for trustworthy health information.	Muscat (2001)
Chemical Abstracts Service	American Chemical Society, Columbus	USA	English	www.cas.org	NA	Chemical information; also contains biochemical information.	Baker et al. (1980); Dittmar et al. (1976)
China National Knowledge Infrastructure Database	Tsinghua University	China	English, Russian, German, Chinese	http://www.cnki.net	1988	Information for different disciplines; also includes medicinal plant information.	Xia et al. (2008)
China TCM Patent Database	State Intellectual Property Office, China	China	English, Chinese	http://chmp.cnipr.cn/englishversion/login/index.asp	2002	Covers bibliographic data related to TCM from 1985 to present.	Liu and Sun (2004)
CHMIS-C	University of Michigan	USA	English	http://sw16im.med.umich.edu/chmis-c/	NA	Disease-specific; information on cancer-related molecular targets, anticancer herbal recipes.	Fang et al. (2005)
CIEER	Centre for International Ethnomedicinal Education and Research	USA	English	http://www.cieer.org	NA	Ethnobotanical resource directory divided into 12 areas; contains disclaimers.	

Table 1 (*Continued*)

Name of the database	Compiler	Country	Language	Website	Year of launch	Comments	Citation
Cochrane Library	Cochrane Collaboration	International	English	http://www.cochranelibrary.com	1996	Collection of databases in medicine and other healthcare specialties; originally published by Update Software, now part of Wiley Online System; subscription-based, partly free.	Chalmers (1993)
CMKb (*Customary Medicinal Knowledge Base*)	Macquarie University	Australia	English	http://biolinfo.org/cmkb/index.php	NA	Online relational database; focusses on customary medicinal plants; linked to other online resources; contains disclaimers.	Gaikwad et al. (2008)
Datadiwan	Bernhard Harrer Wissenstransfer	Germany	English, German	www.datadiwan.de/index_e.htm	1995	Emphasizes on medicinal aspect; began as flat html text website; now reorganized into structured database; contact required for data accessibility.	Allais et al. (2000)
Dictionary of Chinese Herbs	Complementary and Alternative Healing University		English, Chinese	http://alternativehealing.org/chinese_herbs_dictionary.htm	NA	Last updated in 2007.	
DNP (*Dictionary of Natural Products*)	Chapman and Hall, London	UK	English	http://dnp.chemnetbase.com	1992	Phytochemical information; URL changed; subscription based; part of Taylor & Francis Group	Ji et al. (2009)
Dr. Duke's Phytochemical and Ethnobotanical Database	Dr. Jim Duke	USA	English	http://www.ars-grin.gov/duke/	NA	Phytochemical information; new website at www.greenpharmacy.com; old website still exists; data gathered from the literature.	Duke (2011)
Dr. G. Madaus Medicinal Plant Database	Dr. G. Madaus	Germany	English, German	http://www.madaus.de/Plants-Database.82.0.html	NA	Contains information collected from 1938; updated regularly.	
EBBD (*Economic Botany Bibliographic Database*)	Centre for Economic Botany, Royal Botanic Gardens, Kew	UK	English	http://kbd.kew.org/kbd/searchpage.do	NA	Replaces three separate web resources.	
eBDB (*International Ethnobotany Database*)	Foundation for Open Ethno Botanical Research	USA	English	http://ebdb.org	NA	Multilingual; ethnographic information; covers Ecuador, Perú, Kenya and Hawai'I; location information; non-commercial.	Skoczen and Bussmann (2006)

ECOPORT	University of Florida, the Food and Agricultural Organization, UN, the National Museum of National History, the Smithsonian Institution.	USA	English	http://ecoport.org/ep	NA	Provides service of aggregating different data sources.	Ecoport (2011)
EMBASE	Elsevier Science, Amsterdam	The Netherlands	English, French, Spanish, German, Chinese, Korean	http://www.embase.com	NA	Bibliographic database; covers international biomedical literature since 1947.	Stone et al. (1998)
Encyclopedia on Indian Medicinal Plants	Foundation for Revitalization of Local Health Tradition	India	English	http://envis.frlht.org/indian-medicinal-plants-database.php	NA	Regional focus; URL changed; includes features for vernacular name search.	
ETHMED	Traditional Sino Japanese Medicines, Toyama University	Japan		http://ethmed.u-toyama.ac.jp/search_Eng/	NA	Based on traditional medicine; URL changed; now under the supervision of Institute of Natural Medicine.	Bhat (1997)
Ethnobotany of the Peruvian Amazon	Otorongo Blanco			http://www.biopark.org/Plants-Amazon.html	1997	Flat text; information on medicinal and useful plants in the Amazonian region of Peru; with bibliographic inputs.	
Ethnomedicinals for Research and Development	Catalyst Consultants			http://www.ethnomedicinals.com	NA	Background information not available.	
EXTRACT Database	University of Exeter	UK	English	http://www.plant-medicine.com/herbdatabaseoverview.htm	NA	Conceived in 1990; online; URL changed; clinical evidence on the use of herbal remedies; website last updated in 2008.	Mills and Willoughby (1996)
FDA Poisonous Plant Database	Food and Drug Administration, US	USA	English	http://www.accessdata.fda.gov/scripts/plantox/index.cfm	NA	Webpage updated in 2008; contains disclaimers.	FDAPPD (2011)
Fitomedicina Base de Datos	Asociación Argentina de Fitomedicina	Argentina	Spanish	http://www.plantasmedicinales.org	NA	Focusses on medicinal plants and phytomedicines in Latin America; subscription based;	
GBIF (*Global Biodiversity Information Facility*)	The Secretariat of the Global Biodiversity Information Facility	Denmark	English	http://www.gbif.org	2001	Advocate of data standard provides information publishing, integrating and using data.	
GlobinMed (*Global Information Hub on Integrated Medicine*)	Ministry of Health, Malaysia	Malaysia	English	http://www.globinmed.com	2003	Prototype launched in 2003; continuously updating.	

Table 1 (*Continued*)

Name of the database	Compiler	Country	Language	Website	Year of launch	Comments	Citation
HERBA (*Historical Eesti rahvameditsiini Botaaniline Andmebaas*)	Estonian Literary Museum	Estonia	Estonian	http://herba.folklore.ee	2008[a]	Herbal medicine based on folk uses; includes plants used in cosmetics; includes disclaimers	Sõukand et al. (2010)
Herbalist	Hopkins Technology, Minnesota	USA	English	http://www.hoptechno.com/herbmm.htm	NA	Focusses on herbal medicine; subscription based.	Bhat (1997)
Herbasin	Dasherb Corp.		English	http://www.dasherb.com	1992	Professional company specializing in herb, herbal extracts and natural herbal remedies.	WIPO (2011)
HerbMed	Alternative Medicine Foundation Inc.	USA	English	www.herbmed.org	1998	Managed by the American Botanical Council; provides free information for 20 plants; focus on use of herb for health; HerbMedPro, advanced version is subscription based.	Wootton (2002)
IBIDS (*The International Bibliographic Information on Dietary Supplements*) Database	Office of Dietary Supplements, National Institute of Health, US	USA	English	http://ods.od.nih.gov/health_information/ibids.aspx	1986	URL changed; covers information from 1986; literature on dietary supplements; now changed into "*Dietary Supplements*".	Ferruggiaro et al. (1999)
ILDIS (*International Legume Database & Information Service*)	Biology Department, University of Southampton	International	English	www.ildis.org	2001	Online version released in 2001.	Synge and Heywood (1988)
International Directory of Specialists in Herbs, Spices and Medicinal Plants	Prof. Lyle Craker, University of Massachusetts, Amherst	USA	English		1998	E-book version of the book of the same name.	Bhat (1997)
IOPI (*International Organization for Plant Information*)	International Organization for Plant Information	International	English	http://plantnet.rbgsyd.nsw.gov.au/iopi/iopihome.htm	1991	Focusses on creating and linking databases of plant taxonomic information.	WIPO (2011)
IT IS (*Integrated Taxonomic Information System*)	Partnership of IT IS-North America, other organizations and taxonomic specialists	International		http://www.itis.gov	1996	Provides taxonomic information	WIPO (2011)
IPNI (*International Plant Name Index*)				http://www.ipni.org	1999	Provides service for checking plant name and authors name.	
MAPPA (*Medicinal and Aromatic Plants Program in Asia*)	International Centre for Integrated Mountain Development	Nepal	English	http://mappa.icimod.org/	1998	Regional focus on Asia	
MAROWINA Database	TROPILAB Inc.	USA	English	http://www.tropilab.com/medsupp.html	NA	Herbal medicines used in Suriname; contains disclaimers	WIPO (2011)

Medicinal and Poisonous Plant Database	Michael C. Tims			http://www.biologie.uni-hamburg.de/b-online/ibc99/poison	NA	URL changed;	
MEDLINE (*Medical Literature Analysis and Retrieval System Online*)	National Library of Medicine	USA	English	http://www.nlm.mih.gov	NA	Covering literature on biomedicine and health from 1950.	Saxton and Owen (2005); WIPO (2011)
MEDPHYT	Beilstein Institute, Germany and University of Klagenfurt, Austria	Austria, Germany	English, German	http://www-itec.uni-klu.ac.at/~harald/medphyt/	2003	Project begin in 2003; background information not available.	Kettner et al. (2005)
MMPND (*Multilingual Multiscript Plant Name Database*)	The University of Melbourne	Australia	English	http://www.plantnames.unimelb.edu.au/	1995	Multiscript and multilingual search of different uses of plants; data from bibliographic input along with compiler's study;	
MPBD (*Medicinal Plants Database of Bangladesh*)	Dr. Shaikh Bokhtear Uddin	Bangladesh	English	www.mpbd.info	NA	Regional focus on medicinal plants of Bangladesh; features of vernacular name.	
MMPD (Myanmar Medicinal Plant Database)	Tun Institute of Learning	Myanmar	English	www.tuninst.net	NA	Offline versions more extensive; last updated in 2008; emphasized on vernacular name.	
NAPRALERT (*Natural Product Alert*)	Department of Medicinal Chemistry and Pharmacognosy, University of Illinois, Chicago	USA	English	www.napralert.org	1975	Subscription-based; bibliographic and other related information on natural products.	Loub et al. (1985)
Native American Ethnobotany Database	Museum of Anthropology, University of Michigan	USA	English	http://herb.umd.umich.edu/	1977	Technologically continuously updated; information based on extensive field and literature survey; regional and cultural focus on Native Americans.	Moerman (1998)
Natural Medicines Comprehensive Database	Therapeutic Research Faculty	USA	English	www.naturaldatabase.com	1999	Includes PDA version; information on herb interaction and effectiveness; phytochemical information	Clauson *et al.* (2008)
Natural Standard		USA	English, Spanish	http://www.naturalstandard.com	2000	Reviews scientific evidence on complementary and alternative medicine; data from clinical trials and other resources.	Tomasulo (2003)
Northern Ontario Plant Database	Algoma University College	Canada	English	www.northernontarioflora.ca	2002	Information herbarium specimens stored in institutions; linked to other data sources.	

Table 1 (*Continued*)

Name of the database	Compiler	Country	Language	Website	Year of launch	Comments	Citation
PAM (*Plantas Aromáticas e Medicinais*)	Universidade de Trás-os-Montes e Alto Douro	Portugal	Portuguese	http://www.infoherbs.com/front.html	NA	Searchable by plant name, uses,medicinal properties and active compounds.	WIPO (2011)
PASCAL	Institut de l'Information Scientifique et Technique	France	French, English	www.inist.fr	1973	Bibliographic database; specialized on searching a topic across several disciplines.	Bhat (1997)
PFAF (*Plants For A Future*)	Plants For A Future	UK	English	http://www.pfaf.org/user/default.aspx	NA	Online free; download fee based; regional focus on edible and useful plants of temperate regions.	WIPO (2011)
PHARMEL	Universite Libre de Bruxelles	Belgium	French	http://www.ulb.ac.be/sciences/bota/pharmel.htm	1994	Downloadable;	Lejoly (1995)
Phytotherapies	Herbworx Corporation, Australia	Australia	English	www.phytotherapies.org	2000[a]	Subscription based; emphasized on phytochemicals; targetting the herbalists for relevant information;	
Plant-antivenom	Universidade de São Paulo—Faculdade de Medicina de Ribeirão Preto - Departamento de Genética			http://gbi.fmrp.usp.br/plantantivenom	NA	Disease-specific; information from scientific literatures; features amino acid sequence;	Amui et al. (2011)
PLANTS Database	United States Department of Agriculture	USA	English	http://plants.usda.gov/java/	NA	Advanced search with boolean logic; new feature compatible with Geographic Information System; information confined to US and its territories.	WIPO (2011)
PRELUDE	Catholic University of Louvain	Belgium	English, French	http://www.metafro.be/prelude	1996	Plants used in traditional veterinarian and human medicines in Africa; data collected from scientific literatures including grey literatures or directly by the Prelude Sub-Network.	
PROSEA (*Plant Resources of South East Asia*)	PROSEA Network	Indonesia, Netherlands,	English	www.proseanet.org	1991	Regional focus on South East Asia; URL changed; data from published literature, photo and compilation by experts; online version through E-Prosea.	Danimihardja (1995)

Table 1 (*Continued*)

PROTA Databank	Plant Resources of Tropical Africa Programme	International	English	http://www.prota.org/uk/	2000	Regional focus; primary data of priority species; secondary data from literatures; bilingual features; current phase involves changing static webpages to interactive ones.	Siemonsma and Lemmens (2009)
Rainforest Tropical Plant Database	Raintree Nutrition, Inc.	USA	English, French, German, Italian, Norwegian, Portuguese, Spanish	http://www.rain-tree.com	1996[a]	Focus on Amazon rainforest; information from independent sources and publications; HTML based; include disclaimers; last updated in 2010.	WIPO (2011)
SEPASAL (*Survey of Economic Plants for Arid and Semi-Arid Lands*)	Royal Botanic Garden, Kew	UK	English	www.kew.org/ceb/sepasal	1990s	Provides information wild and semidomesticated tropical and subtropical plants; target species for germplasm collection and storage for research, biodiversity conservation and utilization; remote data entry facility through Global Editing software; Though project was initiated in 1981, PC version of database began in 1990s.	Tan et al. (1995)
TCM Herb Database	Rocky Mountain Herbal Institute, US	USA	English	www.rmhiherbal.org/ai/pharintro.html	NA	URL changed; includes downloadable software with feature of e-content.	
TCM-ID (*Traditional Chinese Medicine Information Database*	National University of Singapore	Singapore	Latin, English, Chinese	http://tcm.cz3.nus.edu.sg/group/tcm-id/tcmid.asp	NA	Based on Traditional Medicine; compiled from published literature; website last update in 2005.	Chen et al. (2006); Ji et al. (2006); Wang et al. (2005)
TCMLARS (*Traditional Chinese Medical Literature Analysis and Retrieval System*)	China Academy of Traditional Chinese Medicine Information Institute	China	Chinese, English	http://www.cintcm.ac.cn/	1992	Include a separate Chinese medicine database; papers published in domestic and foreign journals.	Fan (2001)

Table 1 (*Continued*)

Name of the database	Compiler	Country	Language	Website	Year of launch	Comments	Citation
TCMP (*Taiwan's Compendium on Medicinal Plants*)	Department of Industrial Technology, Ministry of Economic Affairs, Taiwan	Taiwan	English	http://www.tcmp.com.tw/index.asp	2005[a]	Both subscription and open access to limited information; focusses on Chinese herbal medicine;	
TradiMed	Natural Products Research Institute, Seoul National University	South Korea	Chinese, English, Japanese, Korean	www.tradimed.com/index.asp	2001	Based on Chinese and Korean traditional medicine; information on prescription, chemistry and image of medicinal plants; subscription based; free preview for selected plants; now under company TradiMed Inc.	Chang (2001)
Traditional Medicinal Plants of Samoa	Centre for International Ethnomedicinal Education and Research	Germany	English, German	www.dittmar.dusnet.de/english/esamoa.html	NA	Regional focus; information provided by Samoan healers; plants without known scientific names are also included; HTML with search script; vernacular name included.	WIPO (2011)
TRAMED *(South African Traditional Medicines Database)*	University of Cape Town	South Africa	English	http://www.mrc.ac.za/Tramed3/	NA	URL changed; regional focus on Africa; contains disclaimers; capability of boolean search;	Sharma et al. (2011)
TRAMIL (*Traditional Medicines in the Islands*)	TRAMIL Network	Latin America, Caribbean	English, French, Spanish	http://www.tramil.net/	1984	Primary data through participative ethnopharmacological survey; qualitative and quantitative approach; voucher specimen collection; regional focus on medicinal plants of Carrabean. URL changed; old website still existing.	
USDA-Iowa State Database of the Isoflavone Content of Foods	U.S. Department of Agriculture, Agricultural Research Service	USA	English	http://www.nal.usda.gov/fnic/foodcomp/Data/isoflav/isoflav.html		Database downloadable as ZIP file; phytochemical database; primary data from laboratory analysis; secondary data from refereed journal; updated periodically; open access.	

URL—uniform resource locator, NA—not available.

[a] Year of copyright.

incomplete, incorrect and irregular data was reported in the data source of Chinese *Materia Medica* (Lin et al., 2008). Such situations demand authentication for standardization of Chinese medicines (Zhao et al., 2006).

Website providing information on quality evaluation is very limited. The CAM on PubMed (http://nccam.nih.gov/research/camonpubmed) shows compliance with evaluation standard of the Health on the Net Foundation (HON, 2011). Selection of credible herbal Internet sites had been done by Owen (2002) using criteria consisting of source, accuracy, referenced information, content, currency, depth, uniqueness, bias, design, audience, stability, reputation and interactivity of the database. The World Health Organization (WHO) has also provided efforts for defining the minimum standards for evaluations that can be achieved by information-gathering on efficacy and safety, observational studies, standard clinical and sharing of the information with traditional healers and other stakeholders (Homsy et al., 2004). More efforts can be given for development of standard criteria for evaluation and their applications.

Since the emergence of the Internet as powerful medium for health communication (Cassel et al., 1998; Eysenbach et al., 2002), there is a chance of applying online information as a guide for personal healthcare. As such, segregation of ethnomedicinal information without proper validation from medical prescription has become more than an ethical issue. Posting Disclaimers stating that the data should not be seen as medical tool but intending only for exchange of scientific views is a means to overcome the problem. This mechanism has been applied in few databases such as FDA Poisonous Plant Database (FDAPPD, 2011), Customary Medicinal Knowledge Base (Gaikwad et al., 2008), Rainforest Tropical Plant Database (http://www.rain-tree.com).

Herbal treatment may be associated with some adverse reactions (Elvin-Lewis, 2001) that may arise from various factors such as toxic constituents (Calixto, 2000), dose (De Smet, 1995), age (Ernst, 1999), drug-use etc. In view of the scope of the problem and to bring the issue forward to public, proposals for conducting herbal surveillance service (De Smet, 1995) are there. Such efforts can be fully achieved by collaborative works of healthcare officials, pharmacologists, industry and other stakeholders (Winslow and Kroll, 1998). Cross linking or integrating information elicited from Internet resources like the National Centre for Complementary and Alternative Medicine (http://nccam.nih.gov/), American Botanical Council (http://www.herbalgram.org), US Food and Drug Administration (http://www.fda.gov), US Pharmacopeia (http://www.usp.org) (Elvin-Lewis, 2001; Murphy, 1999) could contribute immensely in such endeavour.

3.2. Thematic databases

Many databases were found to be providing attention to specialized content. In this section, databases focussed on specialized area such as traditional medicine system, regional aspect, disease-specific and phytochemical information are analyzed. Specialized databases have some advantages as compared to comprehensive approaches. One of the comprehensive approaches as suggested by a meeting convened by UNIDO recommended that medicinal plant databases should contain information such as botanical aspects, ethnopharmacological aspects, chemical aspects, agrotechnological aspects, chemotaxonomic aspects, market aspects and other relevant aspects (Synge and Heywood, 1988). Except in public-funded large database project, such comprehensive approaches have limitations (Synge and Heywood, 1988), because data collection from a wide geographical area and different disciplines in a single database is impractical (Gaikwad et al., 2011) with the chance of inconsistencies and compromises (Stein, 2003). Many of the existing independent databases, thus developed, are variable in their content and quality with regional or cultural focus (Thomas, 2003). In the following sub-sections, databases differing in thematic content are assessed.

3.2.1. Databases on traditional medicine system

Many drugs have entered the international pharmacopoeia through the study of ethnopharamcology and traditional medicine (Patwardhan, 2009). Importance of plants in traditional medicine is reflected in Ayurveda and other indigenous medicines in South Asia with a record of about 1800 plant species (Kumar and Gupta, 2004). Likewise, the Chinese *Materia Medica* also has described many prescriptions, with the first record dating from about 1100 BC followed by works such as the Shennong Herbal and the Tang Herbal (Newman et al., 2000). Thus, databases targetting traditional medicine system provide a good chance for storing and archiving information on medicinal plant. Examples can be cited from the database on Oriental Medicine derived from the knowledge of TCM (TradiMed, 2011), Traditional Medicine in the Island database (TRAMIL, 2011), CMKb (Gaikwad et al., 2008) and many others.

Medicinal plant databases based on traditional knowledge system have various objectives like archiving of traditional knowledge (Gonzalez-Tejero et al., 2008; Upadhya et al., 2010), application of herbal knowledge for screening (Ye et al., 2010) and protection of intellectual property rights (Liu and Sun, 2004; Upadhya et al., 2010). Codified and non-codified knowledge on traditional medicinal systems (WHO, 2002) disappeared with the experts and could not be carried forward from generation to generation (Anami et al., 2008). Gradual loss of indigenous knowledge of medicinal plants from demographic changes (McCarthy, 1992) demands urgent need to preserve the existing traditional medicine (Upadhya et al., 2010). Development of medicinal plant database, apart from other methods, serves as a tool for archiving traditional knowledge on medicinal plants (Gonzalez-Tejero et al., 2008). When the databases are based on a specific cultural context, they can contribute towards conserving traditional knowledge and also serve as medium for complementing transmission of the knowledge (Edwards and Heinrich, 2006; Leonti, 2011).

Providing information on traditional knowledge through databases is one of the approaches for protection of traditional knowledge. Databases like Traditional Knowledge Digital Library (TKDL) of India (Das et al., 2007) and the China TCM Patent Database (Liu and Sun, 2004) act as a bridge between the traditional knowledge of the respective countries and the patent examiners at the International Patent Offices. EthnoMedicinal Plants of Western Ghats (EMPWG) database project in India safeguards the claims of the local community on Intellectual Property Right issues (Upadhya et al., 2010). From these aspects, databases storing traditional knowledge are seen as medium for legal protection. However, archiving of medicinal information needs to be looked beyond the legal framework as the prime objective of such databases is to put traditional knowledge in the service of humanity. Databases on traditional knowledge therefore, should be the medium for hybridization of scientific and indigenous knowledge (Edwards and Heinrich, 2006) for sustainable use of bioresources.

Medicinal efficacies of biological organisms and minerals are well understood if studied within broad domain of cultural knowledge of the community or group concerned (Reyes-Garcia, 2010). Databases, also, should have the capability to represent ethnographic information and associated traditional knowledge. Attempts in this aspect have been observed in databases like eBDB (Skoczen and Bussmann, 2006) and MEDFLOR (Beecher and Gyllenhaal, 1993). At the same time, segregation of valid practices and remedies from ineffective and unsafe practices (Akerele, 1984) is also necessary. As the traditional medicine system has two universal categories of disease aetiology namely natural and unnatural (supernatural) causes (Williams, 2006), magico-religious practices remain part and parcel of practice in many of these systems. Whether these aspects of traditional knowledge should be incorporated, distilled or rejected depends on the nature of the study. From the perspective of the social sciences, these practices represent a significant component of the culture of the society. Some scholars have advocated inclusion of spiritual healing for HIV/AIDS prevention initiative by defining it as entirely distinct from witchcraft, however, based on certain criteria, such as, the acceptability by the community, absence of negative social or physical connotations (Homsy et al., 2004). If the objective of a particular project is inclined more towards the drug discovery, emphasis may be given on plants having psychoactive drug inducing properties.

3.2.2. Regional level databases

In this category, information of the databases has been exclusively based on traditional usage confined to a particular geographical area, though the information can be accessed globally. Several attempts have been made to develop information system for collecting and managing ethnomedicinal plant knowledge at different geographical areas (Babac, 2004; Manha et al., 2008; Natale et al., 2009).

In the Asian countries where traditional medicinal systems with rich legacy of plant medicines (Dighe et al., 2010), many national level database such as Medicinal Plants Database of Bangladesh (MPDB, 2011), Myanmar Medicinal Plant Database (MMPDB, 2011), Medicinal and Aromatic Plants Database of Nepal (http://www.forestrynepal.org/website/), databases of Foundation for Revitalisation of Local Health Tradition (FRLHT) in India etc. have compiled widely dispersed data along with their vernacular names and associated literature. Regional Networks such as the Asian Pacific Information Network on Medicinal and Aromatic Plants (APINMAP) (Dayao, 1995; McCarthy, 1992) and the Plant Resources of South East Asia (PROSEA) Foundation (Soetjipto and Rosario, 2003) have contributed to the sharing of medicinal plant data. In other regions, efforts like the Database for North African Medicinal and Aromatic Plant (http://data.iucn.og/places/medoffice/nabp/database/NA_Plant.htm), MEDUSA (Skoula et al., 2003), Rubia Project (Pieroni et al., 2006) etc. have contributed to the collection and dissemination of traditional knowledge.

Selection of plants for medicinal usage by the indigenous population followed their own criteria as culturally specific plants in one community may not be significant in another (Edwards and Heinrich, 2006; Heinrich, 2003). Apart from tendency to use native and perennial resources (Alburquerque, 2010), indigenous people also incorporate many exotic and weeds (Stepp and Moerman, 2001) in their traditional medicinal systems. Locally developed databases based on a country or a district's need (Deng et al., 2010) have greater advantage in compiling the local and culture-specific knowledge systems and the newly introduced medicinal plants through field-based studies.

From the perspective of scientific knowledge sharing, sharing of information in regional database is of utmost importance (Heinrich et al., 2009). It can be achieved by aggregating the data at different levels by employing standard meta-data, appropriate protocol and technology. A conceptualized framework for developing and sharing local data with the global database repository is depicted here (Fig. 1).

Lack of unified system for recording ethnopharmacological data in regional databases is discernible. Many of regional databases exist as stand-alone applications (Bhattacharyya et al., 2006; Upadhya et al., 2010) following their own customized technical standard. Content of many of these databases could not be accessible on the Internet, e.g., AFlora (Ichikawa et al., 2001), Indian Medicinal Plants National Network of Distributed Databases (Chander, 1995; Geevan, 1995), Medicinal Plants of Malta (Bhat, 1997), Plants for Life Database (Gachathi, 1995), etc. Linguistic barrier in the regional database also restricts sharing of information with the large scientific community. For instance, dominancy of Chinese language in most of the medicinal plant databases developed in China (Deng et al., 2010) hinders information sharing at global level. For making data interoperability and sharing of information with large scientific community, development of regional database needs to adhere to common unified standard as discussed in the later sections.

3.2.3. Disease-specific databases

In the last few years, some of the medicinal plant databases are found to be dedicated only to a particular disease (Jarayaman, 2000). In this review, many disease-specific databases are observed. Databases for storing medicinal plant information used in asthma (Kasirajan et al., 2007), in diabetes (Arulrayan et al., 2007; Babu et al., 2006; Middha et al., 2009; Singh et al., 2009), in cancer (AAMD, 2011; Fang et al., 2005; Vetrivel et al., 2009), in anti-arthritic plants (Siddiqui et al., 2011) are some of the examples.

Approaches for targetting a particular disease thrived as a convenient means for study of recipes, ingredients and individual compounds. However, approach of prioritization of the most effective species through quantitative methods is yet to be applied in many of the databases observed even though this approach has become an emerging trend in ethnobotany (Hoft et al., 1999). Though descriptive listing also finds its relevance in recording traditional knowledge (Verpoorte, 2008), quantification methods such as disease-consensus index (Andrade-Cetto et al., 2006) are equally important for studying the nature of information collection and analysis for disease-specific studies. Mere listing of plants used in a particular disease is not a sufficient way for selecting potentially effective plants, because indigenous people may use plants in remedies according to their beliefs other than biochemical activity (McClutchey et al., 2009; Williams, 2006). Therefore, expected potential of the disease-specific databases include providing sufficient ethnopharmacological knowledge for searching clues to bioactivity from the traditional medicine.

For classification of disease, ethnopharmacological databases need to look beyond the disease aetiology of the western medicine system. The International Classification of Diseases (ICD) of the WHO, which is globally recognized standard for generating statistics on morbidity (Heinrich et al., 2009), has the potential for applicability in ethnopharmacological databases. However, inconsistencies are observed between ICD and traditional medicine system as knowledge between these two systems differ (Jang et al., 2010). While the modern western medicine attempts to identify the individual factors contributing to illness, the TCM views disease as the result of abnormal interactions or imbalances in human systems (Lukman et al., 2007). In Ayurveda, harmonious state of three *doshas* (forces) creates balance and health, while an imbalance manifests as a sign or symptom of a disease (Patwardhan et al., 2005). In spite of these different viewpoints, symptoms are practically identical in both the medicine systems from the perspectives of patient. By selecting such common feature, different medicine systems can be interlinked through development of ontology (Jang et al., 2010). An initiative has been set to bridge the traditional medicine and modern pharmaceutical research by using open linked data for depressive disorders (Samwald et al., 2010).

3.2.4. Phytochemical databases

Some of the databases under review are observed to focus on the phytochemical information of the medicinal plants, e.g., database on pharmacophore analysis of active principles from medicinal plants (Pitchai et al., 2010), the Indian Medicinal Plants Protein Dataset (IMPPDS) (Anandakumar et al., 2008) and herbal

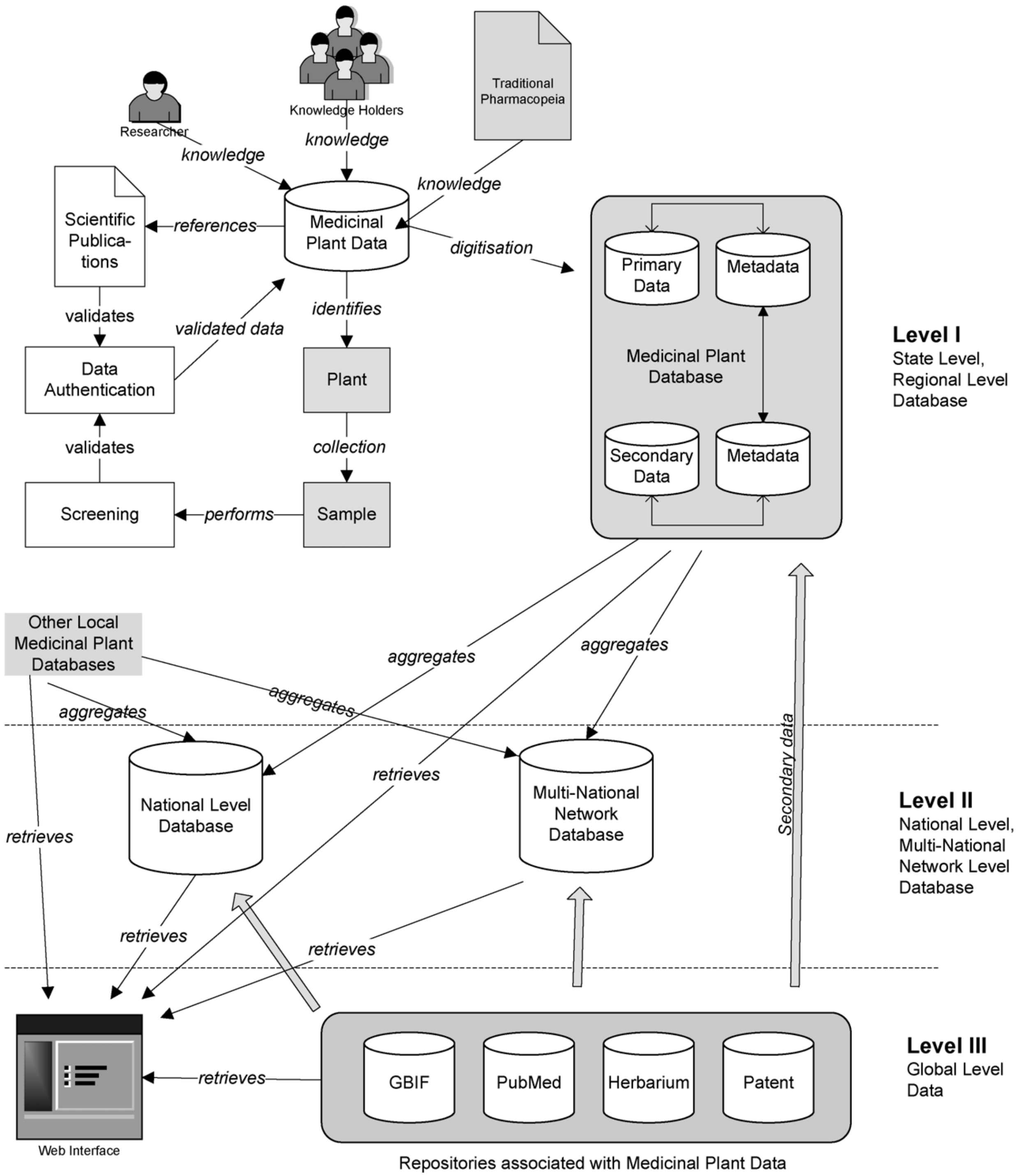

Fig. 1. Conceptualized framework for developing Medicinal Plant Database at local level and sharing the data at global level.

constituents and bioactive plant compounds with known target specificities (Ehrman et al., 2007a), etc.

Effectiveness of a herbal medicine may be attributed to one or a few bioactive compounds or synergistic effects of all of its constituents (Ehrman et al., 2007b). It has been argued that lack of these phytochemical information has prevented wide acceptance of medicinal plants (Fang et al., 2005). Databases providing phytochemical information are acting as the medium for filling these lacunae. However, despite presence of lot of interest in pharmaceutical databases (Horace, 1985), many of them are found providing very basic information on medicinal plants and tend to focus on drug discovery (Kettner et al., 2005).

A commendable work on phytochemical database is observed in Dr. Duke's database (Duke, 2011). The main feature of this database is the compilation of the chemical information of the plants along with bibliographic records. However, Dr. Duke's database has limited support for a variety of ethnobotanical data (Skoczen and Bussmann, 2006) and could not encompass all the phytochemical data in spite of its global perspective.

Problems of trivial names for biochemical compounds are not free in biological databases also. These problems are encountered when comparing biochemical data from different sources or automatically parsing chemical compound names (Aguilar et al., 2003). Inconsistencies can be minimized by checking the

IUPAC names with resources like *Dictionary of Natural Products* (http://dnp.chemnetbase.com) or other resources along with the CAS Registry Number.

Plants of the same species collected from different locations are known to possess different chemical compositions. Traditional healers also put geographical location as important criterion for efficacy of the medicinal plant. Tibetan healers believed that presence of bioactive compounds differ according to altitude (Liu et al., 2009). Traditional healers in Nigeria prefer the mistletoe growing on cocoa tree for treatment of hypertension as opposed to the same plant growing on oil palm or any other tree (Mafimisebi and Oguntade, 2010). Such 'apparently insignificant' information is very critical from the point of ethnopharmacology. Moreover, approaches like incorporating datasets about structure, nomenclature, compound class, chirality, pharmacology, targets, traditional medicine categories, botanical name along with vernacular name etc. (Ehrman et al., 2007a) could contribute immensely in our understanding of herbal medicine.

Genetic and genomics information of the concerned species also have the potentiality for utilization in developing medicinal plant databases (Deng et al., 2010), e.g. the Medicinal Materials DNA Barcode Database (MMDBD) incorporating the DNA sequences of medicinal plants (Lou et al., 2010) and Plant Antivenom database incorporating amino acid sequences of the compound (Amui et al., 2011). Integration of sequence data into the database for proper identification of the medicinal plant is a feature that needs to be stimulated having a lot of potential.

4. Design of DBMS

Online resources on medicinal plants are found to be represented either as (a) flat HTML texts, e.g. A Modern Herbal (Owen, 2002), Botanical Dermatology Database (Schmidt, 2001), (b) downloadable databases, e.g. Boelens Aroma Chemical Information Service (http://leffingell.com/bacis/bacispdi.html), TCM Herb Database (http://www.rmhiherbal.org/ai/pharintro.html), (c) relational databases, e.g., CMKb (Gaikwad et al., 2008), MEDPhyt (Kettner et al., 2005) and NAPRALERT (Gyllenhaal et al., 1993), or (d) object-oriented databases (Thomas et al., 2001). Databases specially designed for mobile computing environment are also there (Clauson et al., 2008; Reynolds and Strayer, 2005). Wide ranging variation of online resources from simple file directories to object-oriented database software (Rhee et al., 2006; Thomas et al., 2001) indicates lack of benchmark database available for researchers or practitioners in medicinal plant (Anami et al., 2008).

Issues pertaining to general bioinformatics community in designing databases also exist in designing information system for medicinal plants. One of the problems in computer-aided biology is difficulty in communication between life scientists and computer scientists (Lacroix, 2003). Most of the papers on databases describe the content and user functionality with little information on the design and implementation of the software (Nelson et al., 2003; Rhee and Crosby, 2005). Only a few guidelines (Chadha, 1990; Frost-Olsen and Holm-Nielsen, 1986) are there to direct database development. Guideline proposed by Frost-Olsen and Holm-Nielsen (1986) and extended by Synge and Heywood (1988) provides the following recommendations for developing databases: keep it simple, design it first, build up the expert knowledge needed, work out the objectives and scope of the database before choosing the hardware, use standard hardware and software, allow for future expansion, let the machine do the hard work, plan for good quality output, plan for networking and follow the data standards that have been agreed upon.

Basically, objectives of a database management system (DBMS) are to provide means to store and retrieve information that is both convenient and efficient (Silberschatz et al., 2006). For achieving these objectives, these systems need to be well designed (Nelson et al., 2003). Unlike sequence-centric databases used in molecular biology (Galperin, 2006), in which queries are based on nucleic acid or amino acid sequences, medicinal plant databases would need to handle disparate types of data. Designing of a perfect DBMS requires systematic analysis and consideration of characteristics of the plants such as taxonomy, phytochemistry, medicinal usage etc. which will form the basic components of information system. Data structures should be customized for each data type and overall schema should be made flexible and scalable. As required in nutrition databases (Lemay et al., 2007), the database structure must be able to handle meta-data for enhancing integration of various databases (Tan et al., 1995).

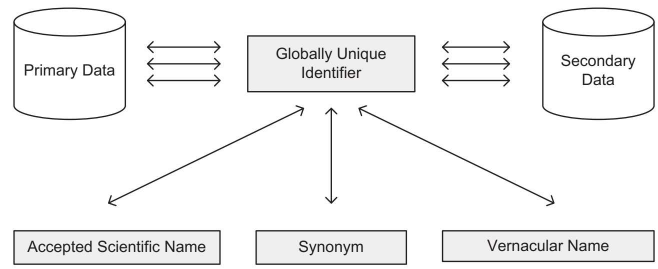

Fig. 2. Globally Unique Identifier can be used for unique identification and sharing of resources between primary data and secondary data.

Development of biological database, including ethnobotanical database, is complex because such applications differ significantly from the commercial software applications both in their modelling and processing requirements (Vidya and Haritsa, 1996). Software development process needs to address the ground reality of the traditional knowledge and practices of indigenous people that are working to ensure intergenerational transmission of knowledge traditions (Christie, 2006).

4.1. Unique identification of plants

Most of the databases reviewed in this paper employed taxonomic name as unique identification of plants. The core of any medicinal plant database should include a shared identifier to serve as the natural link between different databases for sharing information (Patterson et al., 2006). The approach of representing taxonomic names as identifiers in databases (Sarkar, 2007; Synge and Heywood, 1988) has serious limitations as they are not completely stable, nor they are globally unique (Kennedy et al., 2005). Occurrence of different classification systems and several alternate names make development of single, common reference taxonomy difficult. Chances are there that software using Linnean binomial may aggregate data about different taxonomic concepts (Berendsohn, 1995). DBMS should have the capability of handling multiple taxonomies arising from the combination of legacy data, newly described taxa, modern revisions and conflicting opinions (Raguenaud et al., 1999).

Application of globally unique identifiers (GUI) is one of the methods for integration of biological information from diverse source (Fig. 2). These identifiers are valuable because they expose information in a standard way to other software (Godfray et al., 2007). Though there are numerous schemes for generating such identifiers, current focus is given mainly on three alternatives, HTTP URIs (Uniform Resource Identifiers), Digital Object Identifiers (DOIs) and Life Science Identifiers (LSIDs) (Page, 2008). Software clients can access the data associated with the LSIDs using a protocol called Simple Object Access Protocol (Box et al., 2000).

Need for a global ethnobotanical plant name index that can capture scientific names from primary and secondary ethnobotanical datasets (Gaikwad et al., 2011) has been felt by many researchers. Such index will serve as a catalogue for determining the plant species having medicinal value while assisting in the validation of the scientific names and in biodiversity conservation (Sarkar, 2007).

Another problem that needs attention is inaccurate identification (Synge and Heywood, 1988) which is one of the problems in ethnobotanical works (Łuczaj, 2010). Even in common and easily distinguishable plants high proportion of misidentification is found when identifications are done by non-taxonomists. Obvious misidentification problem is compounded by the prevalence of variation in vernacular name (Lawrence and Hawthorne, 2006). Misidentification problems are reflected in many journals (Kholia and Fraser-Jenkins, 2011) and databases along with outdated taxonomy (Soberon and Peterson, 2004). Traditional knowledge is usually associated with vernacular name known to the particular culture. When misidentified species have been rectified, the associated ethnobotanical attributes need to be assigned to the correct scientific taxon. Such flexibility in the database structure can be implemented by application of unique identifiers as the reference point.

4.2. Data aggregation

Growth of Internet and the availability of biological data sources on the Web have opened up tremendous opportunity for biological research (Chung and Wooley, 2003) including ethnopharmacological research. Ability to access data from many different databases (Jagadish and Olken, 2004) is one of the requirements of the biomedical database. Integrating diverse sources of digital information is a major challenge as the desired information is diverse (Page, 2006; Stein, 2003). There are different approaches of data aggregation. Websites like EcoPort (Ecoport, 2011) integrate different data sources through meta-search engine. The Natural Product Alert (NAPRALERT) compiles information on natural products including medicinal properties by survey of the current literature and selective retrospective indexing (Gyllenhaal et al., 1993; Stepp and Thomas, 2006). The electronic Plant Information Centre (ePIC) of the Kew provides a single point of search across all Kew's major specimen, bibliographic and taxonomic databases on the Internet (ePIC, 2011). The TCMGeneDIT integrates information about TCMs, genes, diseases, effects and ingredients by using text mining approaches (Fang et al., 2008). Heterogeneous origin of web-assembled databases makes quality control an important exercise to be followed (Soberon and Peterson, 2004).

Integration of biological databases can be achieved by link integration, view integration and data warehousing approaches (Stein, 2003). In the link integration query from one database can follow hypertext links to related information in other data sources. This type of integration has been observed in some of the online resources (http://www.hort.purdue.edu/newcrop/med-aro/default.html; http://www.bgci.org). View integration which builds an environment for viewing data from other sources is resource intensive and can be implemented by large-scale project. Data warehousing approach brings all the data in a single database, an effort which is very difficult to create. Probability of depositing standardized ethnopharmacological survey data into a common repository for future comparison in the line of metabolomics databases (Verpoorte, 2008) for future reference also has been discussed.

One of the approaches to harness available ethnopharmacological resources is incorporation of primary data by the users into the database. Contributors may belong to either research scholars, traditional knowledge holders or common users (Skoczen and Bussmann, 2006). If the databases have multilingual features (http://www.plantnames.unimelb.edu.au; http://www.prota.org/uk/; http://www.tradimed.com/index.asp) data sharing will be more effective.

A different model for collaborative authoring of taxonomic work is done through community-based projects called the wikis (Godfray et al., 2007). Remote data entry by registered users is implemented in SEPASAL database (http://www.kew.org/ceb/sepasal) through Global Editing software. Collaborative and community-based model when implemented in the medicinal plant databases can accelerate the data aggregation process. Probable insertion of false information in the wiki type of database is minimized by using the Captcha module (*Completely Automated Public Turing test to tell Computers and Humans Apart*) in Plant antivenom database (Amui et al., 2011).

Heterogeneity in data formats and structures, lack of standard terminology along with cultural and linguistic differences complicated the data integration (Cheung and Chen, 2010). For developing a system that enables biological data sharing, the fundamental prerequisites are compatibility of data definitions and a common access protocol.

4.3. Data standard

Only a few databases emphasized the application in data standard e.g. AGRICOLA (http://agricola.nal.usda.gov), Global Biodiversity Information Facility (http://www.gbif.org), etc. Standardization and nomenclature are important so as to provide a consistent view of data available in a particular field (Brusic et al., 2000) as the lack of uniform data standard creates problems in data mining and integration of data (Ehrman et al., 2007b; Schloman, 2006). Standardization of terms to describe medicinal plant can contribute (Cook, 1995) immensely in sharing data content. For interchange of data between databases, obstacles of data compilation standards (Cao et al., 1995) and compatibility of data definitions should be addressed. Compatibility of data definitions includes both structural compatibility and semantic compatibility (Berendsohn, 2003). Full structural compatibility i.e. the use of the same fields and relations, the same database schema etc. is impossible to achieve in most of the cases. Semantic compatibility i.e. adherence to a definition of the contents of a data element needs to describe and define data elements for the entire domain.

There are efforts to provide a common standard of data at global level. The Economic Botany Data Collection Standard (EBDCS) developed by the International Working Group on Taxonomic Databases for Plant Sciences (TDWG) is one of such efforts. The objective of the TDWG (now Biodiversity Information Standards) is to promote common use and interpretation of terminology, data fields, dictionaries and common logical rules (Bisby, 1994). During implementation, EBDCS was found to lack flexibility as the standard does not translate into relational structure easily (Cook, 1999) and it also contains many inconsistencies. It also lacks option to incorporate local terminologies (Heinrich et al., 2009).The standard was designed with the emphasis on development of independent databases (Thomas, 2003).

At present, the data standards endorsed by the TDWG include Plant Names in Botanical Databases, and Authors of Plant Names and World Geographical Scheme for Recording Plant Distributions. Access to Biological Collections Data (ABCD), another standard for support exchange and integration of data on living specimens, preserved specimens and observations, was ratified by TDWG in 2005, and is under constant review by the ABCD Task Group (ABCD, 2011). Current work of the TDWG includes Applicability of the GUID and Life Sciences Identifiers, Darwin Core, TAPIR (TDWG Access protocol for Information Retrieval), etc. On the other hand, the CEEB (Collections for Ethno- and Economic Botany) Project, a joint initiative of the Missouri Botanical Garden, the New York

Botanical Garden, the Field Museum of Chicago and the Society for Economic Botany, is working to develop and publish curatorial standards (CEEB, 2011) on its website (http://ceeb.econbot.org). Advances in these fields could contribute immensely in sharing data.

4.4. Ontology

Ontology has become the backbone technology for knowledge-based systems. It has been defined as 'specification of a conceptualization' (Gruber, 1995). Ontologies applied to the online resources create semantic web (Vadivu and Hooper, 2010), the architecture of which consists of machine understandable languages such as XML (Extensible Markup Language), RDF (Resource Description Framework) and OWL (Web Ontology Language).

Ontologies can be applied in data selection, data aggregation, decision support, natural language processing and knowledge discovery (Bodenreider, 2008). Ontologies support data integration in two ways: warehousing and mediation (Hernandez and Kambhampati, 2004). Initiative to create, maintain and facilitate the use of a controlled vocabulary for plants has been started by the Plant Ontology Consortium (Avraham et al., 2008).

As compared to classical technologies (e.g. non-semantic web pages, SQL databases, SOAP application interface), several advantages of semantic web technology and ontologies are there (Samwald et al., 2010) in ethnopharmacology in the way data and knowledge are accessed and exchanged (Heinrich et al., 2009). As non-codified traditional medicine is transmitted orally through generations, the knowledge may become adulterated or deteriorated, thus changing meaning and concept. Standardization of disease concept is of utmost importance for preserving and validating the information. Ontology is a means to reduce or eliminate the conceptual inconsistencies and to achieve a shared understanding so as to improve communication, sharing, interoperability and reusability.

Conceptualization of disease knowledge through ontologies can enable representation of knowledge in a computer-comprehensible way as well as interoperability across databases. As different ontologies can be mapped on each other and interlinked to develop an ontological network, a user working in one area can access information from another different area (Baird and Rhee, 2004). For example, a user having knowledge of TCM can access information about a particular disease, say diabetes, from another knowledge domain represented by western medicine or Ayurveda. Initiative for application of ontology in traditional medicine system has been started with the development of the Unified Traditional Chinese Medical Language System (UTCMLS) (Zhou et al., 2004), ontology for Traditional Korean Medicine (TKM) (Jang et al., 2010), ontology for African Traditional Medicine (ATM) (Atemezing and Pavon, 2008).

Success of applicability of ontology depends on the quality, installed base and governance (Bodenreider, 2008). Knowledge presented in the ontology has to be interpreted with an understanding of the concerned medicine system (Jang et al., 2010). Ontologies do not by themselves lead to the integration of biological databases. They serve as facilitators. In the absence of organized common hierarchy of common concepts, integration through ontology becomes a tedious and error-prone work (Stein, 2003).

The potentials and capabilities of ontology and semantic web will need to be explored in the ethnopharmacological databases for exchanging domain-specific ideas between different fields. This endeavour can be achieved through community-based efforts from different sections of the ethnopharmacological researchers and knowledge holders.

5. Applications

Medicinal plant databases allows quick recovery of multidisciplinary information (Chen et al., 2011; Manha et al., 2008) making them information bank (Upadhya et al., 2010) for future research in ethnopharmacology. Expected potentials of such databases include capability of analysis (Kumar and Gupta, 2004) and exporting relevant data for analysis (Skoczen and Bussmann, 2006), irrespective of the amount of information contained. Values of data contained in the databases are illustrated by the applicability of the analysis in different parameters. Application of the NAPRALERT database for searching information related to human reproduction (Farnsworth et al., 1981), application of database for computational screening of medicinal plants (Vyas et al., 2008), application of Random Forest for virtual screening of Chinese herbs (Ehrman et al., 2007c), docking methods for screening against hepatitis C virus (Srinivasan et al., 2011), screening of bioactive molecules utilizing information of medicinal and aromatic plants database in India (Masood and Shafi, 2005) and validation of prescription of TCM by developing artificial intelligence (Chen et al., 2006) are examples of the different applications.

The applications are not limited to providing information for drug discovery and conserving traditional knowledge. A unique application has been observed in the Aurukun Ethnobiology Database, where Wik community used the database as a means of promoting traditional knowledge in eco-tourism initiative (Edwards and Heinrich, 2006).

Another important utility of medicinal plant database is its contribution towards plant conservation research (Bhattacharyya et al., 2006). Information collated in databases may become relevant for influencing decision makers at any level, but the quality and efficiency of this documentation is directly associated with the amount of the available information (Pupulin, 2007; Smith et al., 2000).

Though different types of applications of medicinal plant databases have been reported, full applicability and potentiality of these databases are yet to be explored.

6. Challenges

Challenges encountered in developing medicinal plant databases include issues related to ethnobotanical issues and technical issues as represented in Fig. 3.

Similar to other biological databases, sustainability issue is observed with many websites become inaccessible or relocated to other sites (Galperin, 2006; Wren and Bateman, 2008). It has been commented that such issue is common in many project-funded databases specified for project data during the funding period (Rhee and Crosby, 2005). However, some changes in websites have been associated with evolution of the databases when they are absorbed into other services, e.g. ADONIS, BIOSIS Previews, (Table 1) etc. Other limitations like lack of frequent update (Wren and Bateman, 2008) and non-disclosure of year of creation are also noticed. Maintenance of digital data in long term basis is associated with many challenges including evolution of hardware and software, and the risk of systems becoming obsolete (Canhos, 2004). Since maintenance in long-term basis is costly (WHO, 1993) and possible only in major institutions and government agencies (Hussey et al., 2006), aggregation of information stored in different databases will become one of the options.

Consideration of open accessibility of traditional knowledge is usually encountered in sharing medicinal plant data. Restriction on using biodiversity data is common mainly in developing countries, based on interpretations of Convention on Biological Diversity with regard to access and benefit-sharing (Chavan and Krishnan, 2003). When the traditional knowledge is openly accessible, there

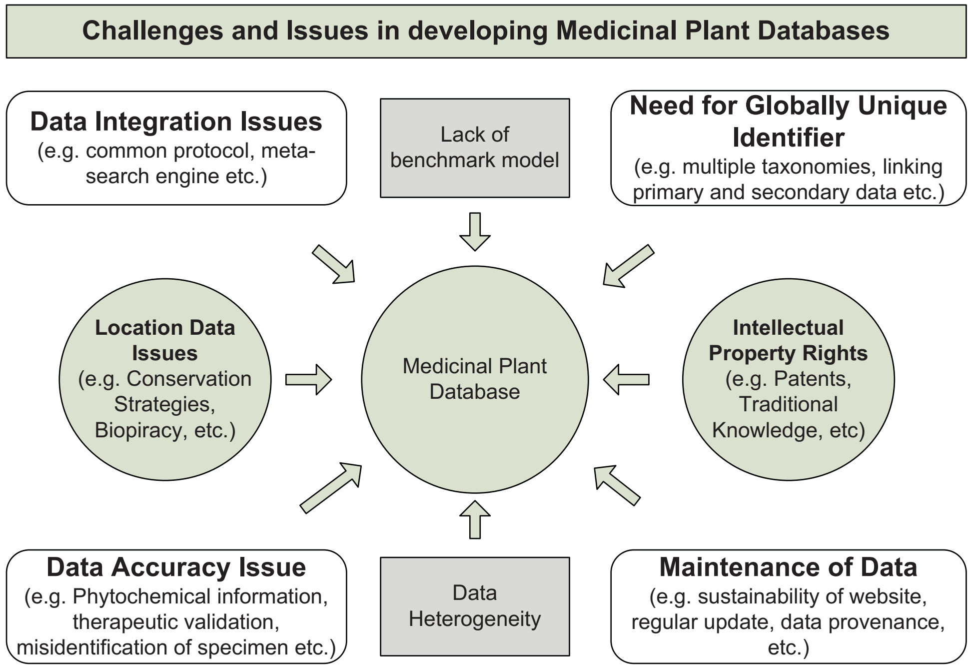

Fig. 3. Challenges facing the utilization of databases for medicinal plant research.

are arguments that it may be used as a modern commodity like any form of intellectual property (Brush, 1993). However, commodification of the traditionally used plants have occurred even in spite of limited or negative scientific information to support to their use, e.g. Euterpe oleracea (Heinrich et al., 2011), Salvia hispanica (http://naturalstandard.com/monographs/herbssupplements/chia.asp). While the databases can prove useful in preventing patents from being granted on the assets of traditional communities, unrestricted access to these databases may well give rise to biopiracy (Dutfield, 2002). All the academic research based on traditional knowledge does not lead to patent filings and commercial exploitation. However, there are arguments that such research are not free from biopiracy realm and get benefitted from the scientific use of traditionally used plant material (Mahop and Mayet, 2007). Another view is that the existence of sensitive data should not be used as an excuse for restriction of data (Canhos, 2004). Indigenous community needs to adapt to novel methods for protecting the traditional knowledge (Aguilar, 2001) and associated plant materials.

In view of the occurrence of diversified approaches and associated issues, need for development of common standards for application of database technology in ethnopharmacological research is felt. Need for such standards and conceptual contributions had also been expressed in many papers (Heinrich et al., 2009; Homsy et al., 2004; Mosihuzzaman and Choudhary, 2008). Standardization can be achieved by collective, integrative and collaborative approaches from many sectors. In the light of the above analyses and existing trends, some of the issues that need to be addressed for the development of a sound approach are discussed here.

- Botanical nomenclature: It can be checked through internationally recognized databases like the International Plant Name Index (http://www.ipni.org) which is considered as 'authority data server' for plant names (Lughadha, 2004), the W3TROPICOS (http://www.mobot.org), the Index Nominum Genericorum (http://botany.si.edu/ing/), the Species 2000 (http://www.sp2000.org), the International Organization for Plant Information (http://plantnet.rbgsyd.nsw.gov.au/iopi/iopihome.htm) and The Plant List (http://www.theplantlist.org). To achieve "minimum standard for names in botanical databases", the standard of "Plant Names in Botanical Databases" endorsed by the TDWG (TDWG, 1994) can be referred.
- Identification: Accurate identification of the botanical species can be achieved by collecting voucher specimens and depositing them in herbaria (Heinrich et al., 2009) and making them available for future comparisons. Inclusion of separate field for Voucher Number in the database table is a practicable approach in field-based studies. However, this field could not be mandatory when the information is retrieved from published literature, historical texts or published pharmacopeia. There have been discussions about the deposit of the plant materials in the germplasm banks (Cordell and Colvard, 2005) and application of DNA barcoding of the collected species (Newmaster and Ragupathy, 2010) for proper identification of the plant.
- Geographical location: Standard for representing geographical location has been provided by TDWG under the title of World Geographical Scheme for Recording Plant Distributions, and can be downloaded from the website (http://www.tdwg.org). But incorporation of this data should be in accordance with the Convention of Biological Diversity which recognizes national and international regulations.
- Ethnographic information: Collection of ethnographic information is essential as the traditional usage of the plant is usually culture-specific. Methodologies for ethnographic and ecological information collection have been discussed in several papers. Since qualitative research can produce culturally specific and contextually rich data (Mack et al., 2005), greater flexibility in database design is demanded.
- Ethnic taxonomy: Apart from scientific taxonomy, traditional taxonomy including vernacular name (Heinrich et al., 2009) is important because it is the connecting link between the traditional knowledge holders and the plant specimen.
- Personal information: Collection of information about the knowledge holders also becomes relevant. It will allow the scholars in conducting quantitative methods such as consensus index, user value indices, relative cultural importance, etc. (Hoffman and Gallaher, 2007). For ensuring respect for persons (NCPHSBBR,

1979) and respect for communities (Weijer et al., 1999), the mechanism of prior informed consent should be incorporated.

- Traditional medicine system: It is important to mention the type of medicinal system along with the source of the traditional knowledge, for instance whether the knowledge is transmitted knowledge, or acquired from some other sources. Such information is relevant in countries like India where different traditional medicine systems (e.g. Ayurveda, Unani, Siddha etc.) exist. Integration of traditional knowledge for codified system can be done by following published pharmacopeia or standardized publication. This approach may not be applicable in non-codified traditional medicine. In view of difference in cultural context, a common standard for describing traditional medicine can be attempted for integration into the databases.
- Disease classification: In addition to traditional classification, modern classification of disease should be followed for sharing information at global level. The current version of *International Classification of Diseases* (ICD-10) which is available on WHO website (http://www.who.int/classifications/icd10/) can be used as reference for the ethnopharmacological works.
- Ontology: With many tools available for ontological development in the web, development and sharing of concept and vocabularies through ontology will become common feature in the coming years. Collaborative efforts of the Plant Ontology Consortium (http://www.plantontology.org) have developed controlled vocabulary that describes anatomical and morphological structures along with growth and developmental stages for all plants. Biomedical ontologies can be accessed from resources like Open Biological and Biomedical Ontology (http://www.obofoundry.org), Gene Ontology (http://www.geneontology.org), RxNorm (http://www.nlm.nih.gov/research/umls/rxnorm/), the Medical Subject Headings (MeSH) (http://www.ncbi.nlm.nih.gov/mesh), etc. Along with these efforts, development of standard ethnopharmacological ontology at global level can contribute a lot in sharing knowledge.
- Collection information: Plant parts used, stage of the collection, storage condition, drying process should be highlighted. The WHO has provided guidelines on Good Agricultural and Collection Practices (GACP) to individual countries, which has been applied in countries like India (NMPB, 2009). Regional level databases need to be made conformed to the guidelines prescribed by the respective countries.
- Non-botanical components: Chemical constituents can be referred to by correct IUPAC along with CAS Registry Number(s) that can be implemented by cross-checking from resources such as LIGAND (www.genome.jp/kegg/ligand.html), UM-BBD databases (http://umbbd.msi.umn.edu), etc. Biochemical reactions, if required, can be checked and integrated from different databases such as BRENDA (www.brenda-enzymes.org), MetaCyc (http://metacyc.org), etc. as reaction data differs among the databases (Lang et al., 2011). When zoological names have to be cited, it can be done by checking through resources like Index to Organism Names (http://www.organismnames.com/), Nomenclator Zoologicus Online Information (http://ulo.mbl.edu), etc.
- Pharmacological information: For ethnopharmacological research, characterization of the range of pharmacological actions of herbal medicines and determination of the chemical characteristics of bioactive compounds are relevant. So, data generated from pharmacodynamics, general pharmacological and toxicological investigations need to be incorporated in the database. Guidelines for conducting these studies have been provided by the WHO (WHO, 1993), and can also be a source of database designers to determine type of information to cover.
- Authenticity of information: One of the functionality of the databases should be towards evaluation of traditional medicine. While collating the information some standard should be maintained by the curator for incorporating the authentic knowledge. Use of certificate of authenticity (Mosihuzzaman and Choudhary, 2008) and information extraction from reputed peer-review journals are some of the methods.
- Informatics: Type of database (whether offline or online), software platform to be used and database schema to be followed will depend on the objective of the project. As discussed above, strict adherence to standardized protocol is demanded when the need of data sharing arises. It can be implemented through either including capability to export datasets in a standard common format or following standard database schema. With Economic Botany Data Collection Standard could not fully comprehend the expectancy from ethnopharmacological research, development of more specialized standard is required. Some other efforts of the TDWG can be studied for applicability. For instance, Darwin Core intending for sharing information about biological diversity by providing reference, definitions, examples, and commentaries, and TAPIR (TDWG Access Protocol for Information Retrieval) need to be analyzed in view of their applicability in ethnopharmacological research. Apart from these aspects, applicability of the GUIDs and Semantic Web Technologies need to be considered for data sharing and interoperability. While disseminating scientific data, evaluation from the legislative perspective is also relevant. Proposal set by the International Council for Science (ICSU) and the Committee on Data for Science and Technology (CODATA) is an approach towards setting principles in data sharing (http://www.codata.org). Collaborative and community-based approaches are required for setting the trends and standard in this area.

7. Conclusion

In this review electronic databases on medicinal plants are identified and categorized according to different criteria. Even when a particular database is focussing on a particular area, features and characteristics of other types of databases are also observed. For avoiding unnecessary duplication of research and for efficient utilization of resources, sharing of content of medicinal plant databases is necessary. It can be achieved by optimization of data and development of common minimum standard for sharing such resources.

As the development of global data in a single database may not be possible in view of the culture-specific differences, efforts can be given to specific regional areas. However, the compiler should address the issues of authenticity and validation of the data, multilingual and semantic issues as well as the applicability of the data for further medicinal plant research. Adopting and incorporating similar and parallel techniques and methodology already implemented in allied and interrelated disciplines can provide a dimension in the medicinal plant research.

For the integrative and scalable potential of the database, thorough understanding of the discipline of ethnopharmacology along with its current scenario and future vision becomes relevant. In spite of many efforts, still there is no standard protocol for developing medicinal plant database that caters to a specialized area. Such endeavour can be fulfilled by collaborative works of institutes concerned, international organizations, academicians and stakeholders. A continuous critical assessment in this field and dialogue among the academicians and programmers will contribute immensely in knowledge sharing and scientific advancement.

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