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Ethnobotany in the digital age: Opportunities and challenges of traditional knowledge digitization

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Abstract

Digitization of traditional medicinal knowledge bridges the gap between ancient wisdom and modern science, ensuring the preservation and sustainable use of this invaluable cultural heritage. This paper reviews the importance of digitization, highlighting its role in preserving oral traditions, fostering global research collaboration, and promoting biodiversity conservation. It explores the integration of traditional knowledge with bioinformatics tools for drug discovery and sustainable harvesting practices. Furthermore, the review identifies key challenges, such as ensuring data accuracy, ethical concerns, and accessibility for marginalized communities, while proposing solutions through emerging technologies like artificial intelligence and blockchain. By leveraging global databases and tools like TKDL, BOLD, and GBIF, digitization creates a pathway for advancing traditional medicinal knowledge into a universally accessible, scientifically validated resource.

Keywords: Ethnobotany; Digitization; Bioinformatics; Databases

1. Introduction

Traditional medicinal plant and knowledge, often orally transmitted, represents a rich heritage of human interaction with nature. [1] It act as important features of medicinal practice due to its phytochemicals compositions like antioxidant, antibacterial, antifungal activities by their secondary metabolites [2]. However, with globalization, lifestyle changes, and the aging of traditional practitioners, this knowledge faces the risk of being lost. Digitization offers a solution by documenting and preserving this invaluable resource in a structured and accessible format [3], [4]. By bridging traditional practices with modern scientific methodologies, digitization not only ensures cultural preservation but also fosters innovation and collaboration in the fields of pharmacology, ethnobotany, and biodiversity conservation [5], [6].

Traditional medicinal knowledge has historically been transmitted orally from generation to generation, often within communities or families [7], [8]. This reliance on oral transmission makes the knowledge vulnerable to loss due to modernization, globalization, and the passing of traditional practitioners. Digitization offers a robust solution by systematically documenting this knowledge in structured formats. By creating digital repositories, the endangered practices of various cultures are preserved permanently, ensuring they remain accessible for future generations [9]. These repositories serve as a safeguard against the erosion of cultural heritage and provide an enduring record of traditional wisdom[10].

Digital databases significantly enhance the accessibility of traditional medicinal knowledge. Researchers, practitioners, and the public can now access vast amounts of information globally through platforms like the Traditional Knowledge Digital Library (TKDL). These platforms facilitate cross-cultural sharing, breaking geographical barriers and fostering collaboration [7], [11], [12]. For instance, a researcher in Europe can study the medicinal practices of Indian tribes,

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while a practitioner in Africa can adopt herbal remedies from Asia. This accessibility promotes innovation in herbal medicine research and encourages the sharing of knowledge among diverse communities, bridging the gap between traditional practices and global medical advancements.

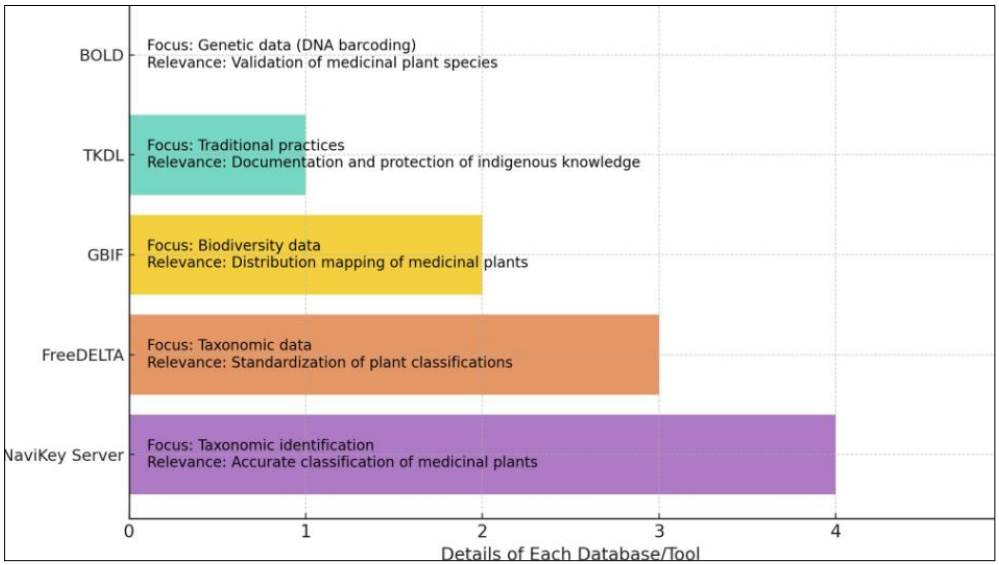

Figure 1 Database and tools for Traditional Knowledge Digitization

1.1. Importance of Digitization of Traditional Medicinal Knowledge

The digitization of traditional medicinal knowledge represents a significant step forward in preserving ancient wisdom, enhancing accessibility, and fostering innovation in the field of medicine. The following sections elaborate on the critical aspects of digitization and its multifaceted impact on society, research, and conservation.

Integration with Modern Science:The digitization of traditional medicinal knowledge creates a bridge between ancient practices and modern scientific methodologies. Through this integration, researchers can analyze traditional remedies alongside pharmacological studies to identify novel medicinal compounds and understand their therapeutic properties. For example, digitized records of traditional remedies have led to the discovery of effective treatments for diseases such as malaria and cancer. This integration not only validates the efficacy of traditional medicine but also expands the scope of scientific research, potentially leading to groundbreaking discoveries in drug development.

Data Analysis and Research: One of the significant advantages of digitized traditional knowledge is the ability to employ advanced bioinformatics tools for analysis. Techniques such as phylogenetic studies, virtual screenings, and in silico modeling allow researchers to identify patterns and relationships between plant species and their medicinal applications. These analyses accelerate the process of drug discovery and development, providing insights into the pharmacodynamics and pharmacokinetics of traditional remedies. For instance, a digitized database can reveal that two plants from different continents have similar bioactive compounds, guiding researchers toward new applications for existing medicines.

Biodiversity Conservation:Digitization plays a vital role in documenting the biodiversity of medicinal plants, which is crucial for conservation efforts. By cataloging the distribution and usage of these plants, researchers can identify species at risk of extinction and develop strategies to protect them[13]. This information is invaluable for creating conservation plans that ensure the sustainable use of resources while preserving ecosystems. For example, a digital repository documenting the medicinal properties of an endangered plant can highlight its ecological importance, motivating efforts to protect its habitat and prevent overharvesting [14].

Education and Trainin: Digital platforms serve as powerful educational tools, providing comprehensive information on medicinal plants and their uses. Students and practitioners of traditional medicine benefit from access to detailed databases that include information on plant species, preparation methods, and therapeutic applications. These platforms democratize knowledge dissemination, allowing individuals from diverse backgrounds to learn about traditional medicine[15]. As a result, the next generation of practitioners can gain deeper insights into traditional practices, ensuring that the knowledge continues to evolve and adapt in modern contexts[16].

Promoting Sustainable Practices: Digitization contributes to sustainability by documenting the ecological impacts of harvesting medicinal plants and promoting responsible practices. By providing data on sustainable harvesting methods, these digital resources guide communities and industries toward more ethical and environmentally friendly practices [17]. For instance, a database might recommend specific harvesting techniques that preserve the plant's ability to regenerate, ensuring that future generations can continue to benefit from its medicinal properties [18]. This balance between utilization and conservation is essential for maintaining biodiversity and the long-term viability of natural resources.

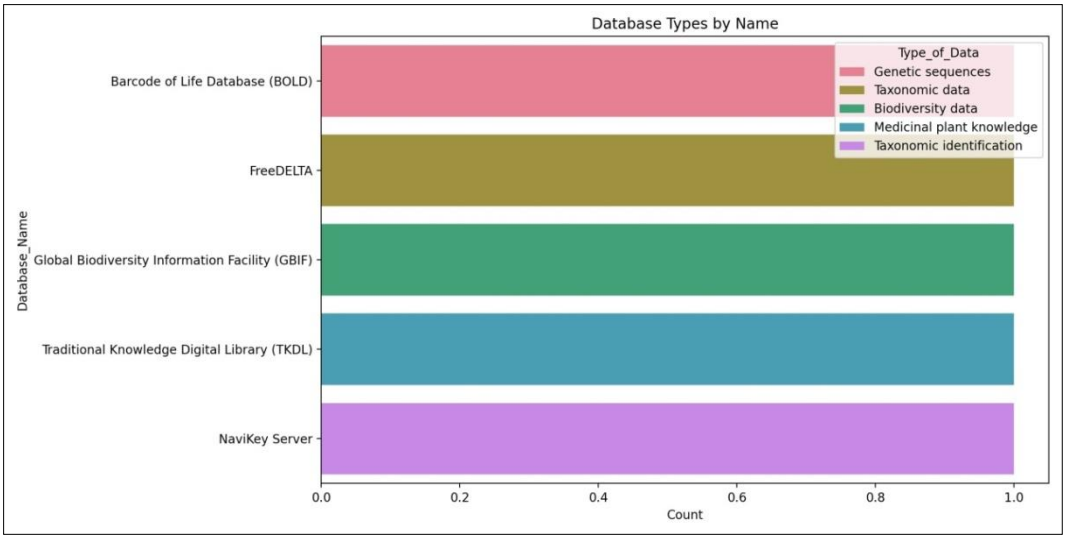

Figure 2 Database for Traditional Knowledge

1.2. Current Databases and Tools in Digitizing Traditional Medicinal Knowledge

The digitization of traditional medicinal knowledge relies on robust databases and tools that store, analyze, and share valuable information [6]. These platforms facilitate species identification, conservation, research, and the prevention of intellectual property theft [20]. Below is a detailed of some key databases and tools essential for this endeavor:

Table 1 Major Digitized Databases

Database Name	Type of Data	Number of Entries/Details	URL/Access Link
Barcode of Life Database (BOLD)	Genetic sequences	5,339,196 barcode sequences	BOLD
FreeDELTA	Taxonomic data	68 datasets	FreeDELTA
Global Biodiversity Information Facility (GBIF)	Biodiversity data	Millions of records (varies by species)	GBIF
Traditional Knowledge Digital Library (TKDL)	Medicinal plant knowledge	Specific to India (varies)	TKDL
NaviKey Server	Taxonomic identification	22 datasets	NaviKey

1.2.1. Barcode of Life Database (BOLD)

The Barcode of Life Database (BOLD) is a comprehensive repository dedicated to genetic information, with over 5 million barcode sequences available for species identification and biodiversity research [19]. The database aims to create a standardized framework for identifying species using DNA barcoding [20], [21], [22]. Each barcode sequence represents a unique identifier for a species, enabling precise classification. BOLD is invaluable for biodiversity conservation, ecological monitoring, and identifying new or cryptic species. It is extensively used by taxonomists, ecologists, and conservationists to assess species diversity in various ecosystems.

Significance in Traditional Knowledge: By providing genetic data for medicinal plants, BOLD aids researchers in validating species used in traditional medicine. This ensures the correct identification of plants and minimizes errors in documentation and application

The global reach of BOLD makes it an indispensable tool for integrating genetic data into the study of traditional medicinal practices.

Table 2 Distribution of Life Forms in BOLD

Life Form	Number of Entries
Animals	176,400
Plants	65,732
Fungi and Other	20,838

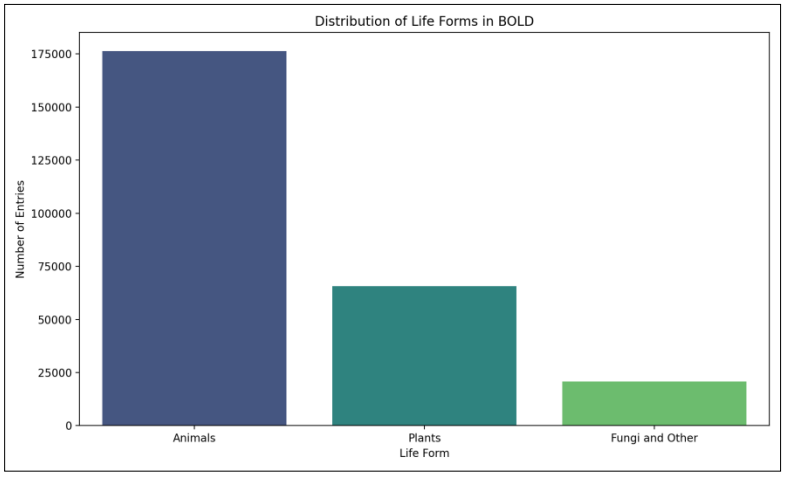

Figure 3 Distribution of Life Forms in BOLD

1.2.2. Traditional Knowledge Digital Library (TKDL)

The Traditional Knowledge Digital Library (TKDL) is an Indian initiative designed to document traditional medicinal practices and safeguard them against biopiracy. The library contains information from ancient texts such as Ayurveda, Siddha, and Unani systems of medicine. By digitizing this knowledge, TKDL protects indigenous intellectual property rights and prevents unauthorized patents [7] . The TKDL is shared with patent offices worldwide to ensure that traditional knowledge is recognized as prior art. This step significantly reduces instances of biopiracy where corporations might exploit indigenous practices without consent [23]. TKDL also serves as a research tool, offering detailed insights into traditional formulations, plant species, and preparation methods. It fosters collaboration between traditional medicine practitioners and modern researchers. The TKDL is a pioneering effort in bridging traditional knowledge with modern legal and scientific frameworks, making it a global model for preserving and protecting indigenous heritage.

1.2.3. Global Biodiversity Information Facility (GBIF)

The Global Biodiversity Information Facility (GBIF) is an international network that provides open access to biodiversity data to support research and conservation. GBIF aggregates data from various sources, including museum collections, field observations, and citizen science contributions. Its database encompasses millions of records covering diverse life forms, including plants used in traditional medicine. The platform is instrumental in identifying endangered species and devising conservation strategies. Researchers and policymakers use GBIF data to track changes in biodiversity and assess the impact of human activities on ecosystems (Secretariat of the Convention on Biological Diversity) [36]. By providing detailed distribution data, GBIF helps document the habitats of medicinal plants. This information is critical for conserving species that are overharvested or threatened by habitat loss. GBIF's commitment

to open data sharing makes it a valuable resource for integrating biodiversity information into the study and application of traditional medicinal knowledge [24].

1.2.4. FreeDELTA

FreeDELTA is an open-source software platform designed for the compilation and analysis of taxonomic data, with a primary focus on plant sciences. The platform supports dataset creation, management, and analysis, making it a preferred tool for researchers documenting plant species. FreeDELTA allows users to generate detailed taxonomic descriptions and classifications. As an open-source tool, FreeDELTA is customizable, enabling researchers to tailor it to their specific needs. Its user-friendly interface and comprehensive analytical capabilities make it a practical choice for taxonomists [24]. FreeDELTA aids in standardizing the classification of medicinal plants, ensuring consistency in documentation. This is particularly important for creating databases that align with international taxonomic standards. The versatility and accessibility of FreeDELTA contribute to its widespread use in documenting and analyzing traditional medicinal plants.

1.2.5. NaviKey Server

NaviKey Server is a taxonomic identification tool that facilitates accurate classification of plant species based on morphological and other characteristics. The server enables users to input specific traits of a plant and receive potential matches from its database [25]. This interactive identification process is highly efficient for field researchers and taxonomists. NaviKey is also a valuable educational tool, helping students and practitioners understand plant taxonomy and improve their identification skills. By providing precise identification of medicinal plants, NaviKey minimizes errors in the documentation and application of traditional remedies. Accurate classification is crucial for ensuring the efficacy and safety of traditional medicines. [26]. NaviKey's intuitive approach to species identification makes it an essential tool for researchers working at the intersection of taxonomy and traditional knowledge.

Table 3 Types of Data in Biodiversity Databases

Database Name	Taxonomic Data	Ecological Data	Genetic Data	Ethnobotanical Data
BOLD	Yes	No	Yes	No
GBIF	Yes	Yes	No	No
TKDL	Yes	No	Yes	Yes
FreeDELTA	Yes	No	Yes	No

While digitization offers significant benefits in preserving and utilizing traditional medicinal knowledge, several challenges must be addressed to ensure its success and sustainability. Additionally, future directions highlight the potential for technological advancements and inclusivity to enhance the scope and impact of digitization efforts [13].

A primary challenge lies in ensuring data accuracy during collection and documentation. Traditional medicinal knowledge often originates from oral traditions, which can be susceptible to errors in translation, interpretation, or recording [7], [12]. Rigorous data collection methodologies must be employed to capture this knowledge faithfully. This includes working closely with traditional practitioners to verify information and cross-referencing data with reliable sources such as ancient manuscripts or published research. Ensuring accuracy is critical to maintaining the credibility and scientific utility of digitized databases.

Table 4 Summary of Digitization Tools for Natural Products

Tool Name	Type of Natural Product	Brief Description	URL
FreeDELTA	Plant, animal	A tool for taxonomic data compilation	FreeDELTA
NaviKey	Plant	A server for taxonomic identification	NaviKey

Another pressing issue is improving accessibility for marginalized communities. Many traditional practitioners and indigenous healers lack the resources or technical expertise to engage with digital platforms [27], [28]. To address this, databases must be designed with user-friendly interfaces and support for multiple languages. Efforts should also be made to train practitioners and community members in using digital tools, empowering them to contribute to and

benefit from these resources. Inclusive accessibility ensures that digitization efforts do not alienate the very communities that are the custodians of traditional knowledge.

Table 5 Comparison of Key Features

Database/Tool	Primary Focus	Applications	Relevance to Traditional Knowledge
BOLD	Genetic data (DNA barcoding)	Species identification, biodiversity research	Validation of medicinal plant species
TKDL	Traditional practices	Biopiracy prevention, research collaboration	Documentation and protection of indigenous knowledge
GBIF	Biodiversity data	Conservation, ecological studies	Distribution mapping of medicinal plants
FreeDELTA	Taxonomic data	Dataset management, taxonomic analysis	Standardization of plant classifications
NaviKey Server	Taxonomic identification	Interactive identification, education	Accurate classification of medicinal plants

Ethical concerns are another significant challenge in the digitization process. Proper acknowledgment and equitable benefits must be provided to the communities that share their traditional knowledge [12], [16], [29]. This includes recognizing their intellectual property rights and ensuring they receive fair compensation or other forms of support. Transparent mechanisms should be established to involve these communities in decision-making processes and prevent exploitation. Ethical digitization practices are essential for building trust and fostering collaboration between researchers and indigenous groups.

Expanding database coverage is a crucial future direction for digitization. Many existing databases focus on well-documented medicinal plants and practices, often overlooking lesser-known remedies or those from remote regions. To ensure inclusivity, efforts must be made to document diverse knowledge systems, including those from underrepresented cultures. This expansion not only enriches the scope of digitized knowledge but also provides a more comprehensive resource for researchers and practitioners globally [30], [31]. Finally, leveraging emerging technologies such as artificial intelligence (AI) and blockchain presents exciting opportunities for the future of digitization. AI can be used to analyze large datasets, identify patterns, and predict potential medicinal applications of plants . Blockchain technology, on the other hand, offers robust solutions for authenticating data and protecting intellectual property rights [32], [33], [34], [35]. By incorporating these technologies, digitization efforts can become more efficient, secure, and impactful.

2. Conclusion

The digitization of traditional medicinal knowledge is pivotal for preserving cultural heritage and fostering innovation in medicine and conservation. By systematically documenting oral traditions, digitization safeguards invaluable practices from the risks posed by modernization and the loss of traditional custodians. Databases such as BOLD, TKDL, and GBIF serve as critical repositories, enabling researchers to validate species, prevent biopiracy, and promote sustainable resource management. Despite its many advantages, digitization faces challenges such as data accuracy, inclusivity, and ethical considerations. Addressing these requires rigorous methodologies, user-friendly platforms, and equitable frameworks to acknowledge and benefit indigenous communities. Future directions point toward expanding database coverage and leveraging emerging technologies like artificial intelligence and blockchain to enhance data analysis, authenticity, and intellectual property protection.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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