Original Article

Digital herbal pharmacopeia as a solution for herbal plant identification based on computer vision

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ABSTRACT

Pharmaceutical field, especially to ensure the safety, effectiveness, and consistency of plant-based products. In the digital era, digitizing herbal identification is increasingly relevant to improve accessibility and precision, while bridging traditional knowledge with modern pharmaceutical standards. This research aims to develop a Digital pharmacopeia system that includes herbal database features, computer vision technology for plant identification, text search based on a full-text search algorithm, and API integration to support connectivity between components. The system development process uses an image classification technology-based approach that utilizes the Convolutional Neural Network (CNN) algorithm to ensure a high level of accuracy. The results show that the system has successfully improved efficiency and accuracy in herbal plant recognition, with the identification accuracy rate reaching 96% in benchmark testing. In addition, the system also offers a modern solution to support pharmaceutical research, education, and practice. By utilizing digital technology, the system is expected to become a reliable tool for pharmaceutical professionals, researchers, and the general public, while encouraging the preservation and sustainable use of biodiversity. The successful development of this system provides a strong foundation for further innovations in pharmacy and botany.

Keywords: Digital pharmacopeia, Herbal plants, Plant identification, Computer vision, Pharmaceutical technology

Introduction

Medicinal plants are defined as plants that possess substances in one or more of their organs, which are capable of being used for therapeutic applications or serve as precursors for the synthesis of useful drugs [1]. Currently, traditional medicine has attracted a lot of public attention, supported by data that during the pandemic many people use it to increase endurance or to relieve complaints of mild symptoms (mild pain), especially women who are boiled or consumed in the form of spices or other forms of herbal preparations [2]. Accurate identification of herbal plants plays an important role in the pharmaceutical field, as it is the basis for ensuring the safety, effectiveness, and consistency of plant-based medicinal products [3].

A reliable herbal pharmacopeia supports both traditional and modern health practices by providing a standardized reference that guides proper use and dosage. A pharmacopeia is an official, legally binding scientific reference book, compiled by a national or regional authority, that contains quality standards and specifications for medicines used in a country or region. This book contains rules and methods that must be followed nationally and internationally, including qualitative and quantitative analysis methods for active substances and excipients used in pharmaceutical production. An important part of the pharmacopeia is the monograph, which defines various aspects of pharmaceutical ingredients, such as definition, content, morphological properties, physicochemical properties, and biological properties, complete with analytical methods and guidelines for packaging and storage [4]. In the digital era,

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digitizing herbal identification is increasingly relevant as it not only improves accessibility and precision but also bridges traditional herbal knowledge with modern pharmaceutical standards to support the development of more reliable medicines.

In reality, most people today do not recognize or know the benefits of medicinal plants due to the limited storage level of human memory . Errors in the identification of herbal plants can be fatal for those who consume them, and can even result in death. Identifying an unknown plant relies heavily on the inherent knowledge of several botanists [5]. Accurate identification of herbs remains a challenge, mainly due to morphological similarities between species that are often confusing, making traditional methods inadequate to support clinical and pharmaceutical research needs. Traditional pharmacopeias, despite being important references, often lack comprehensive digital resources, making it difficult to meet the demands for accuracy and efficiency in herbal identification. This emphasizes the need for digital innovations that can improve precision and accessibility while bridging the gap between traditional identification methods and modern pharmaceutical needs [6].

Several previous studies have discussed the importance of accuracy in herbal identification to ensure the safety and effectiveness of pharmaceutical products and highlighted the role of digitalization in improving the precision and accessibility of this identification process. A study [5] highlights the critical role of digital technologies in the standardization and accessibility of herbal medicine data. The research discusses the importance of creating a comprehensive digital herbal pharmacopeia that integrates traditional knowledge with modern pharmaceutical practices, aiming to mitigate issues of misidentification and contamination in herbal products. The use of omics technologies and DNA sequencing was also emphasized to ensure product safety and reliability. The study provides insights into how digitized systems can address global demands for standardized herbal medicine.

Another [7] study employed a Convolutional Neural Network (CNN)-based web system for medicinal plant identification. The research demonstrated high accuracy in classifying medicinal plants by leveraging image preprocessing and CNN's robust architecture for feature extraction. The model was validated with multiple folds of cross-validation, achieving an accuracy exceeding 98%. This work underscores the feasibility of integrating machine learning algorithms in digital solutions for herbal plant identification. Recent studies highlight the transformative role of computer vision in medicinal plant identification, a critical step toward developing digital herbal pharmacopoeias.

Adzdnia *et al*. [8] introduced a CNN-based system that achieved 99.3% accuracy in identifying medicinal plants, demonstrating its reliability for real-time applications. This innovative approach underscores the integration of digital tools for accurate and efficient plant identification. Similarly, a study utilizing transfer learning with pre-trained models, including Inception v3 and ResNet50, achieved high accuracy in identifying medicinal plant species from the Indonesian Medicinal Plant Dataset. This adaptation of advanced machine learning methods underscores their effectiveness in handling diverse and complex datasets [9]. Another study focused on designing an automated system for identifying medicinal plants in real-time using EfficientNet-B1 as the deep learning backbone. The system incorporated a dynamic knowledge base and a mobile application interface, achieving up to 87% Top-1 accuracy on private datasets. This real-time application highlights the practical implementation of machine learning techniques in the identification and classification of medicinal plants, emphasizing its potential in real-world scenarios [10].

As a solution to the challenges in herbal plant identification, the development of a technology-based herbal dictionary that integrates image classification features offers a modern approach to support the recognition of medicinal plants more accurately and efficiently. This system is expected to not only help the general public in recognizing the types and benefits of herbal plants, but also become a reliable tool for pharmaceutical professionals and researchers to ensure safety, effectiveness, and consistency in their use. By utilizing image classification technology, this innovation can bridge the gap between traditional knowledge and modern pharmaceutical needs, while encouraging the preservation and sustainable use of biodiversity.

Materials and Methods

The development process of the digital pharmacopoeia system follows a structured methodology, starting with a literature study to establish a theoretical foundation, a needs analysis to identify user requirements and define the system's key features, system development to design and implement core functionalities, and testing and validation to evaluate the system's performance, accuracy, and usability in **(Figure 1)**. The flowchart provides a clear representation of the sequential and iterative nature of the process.

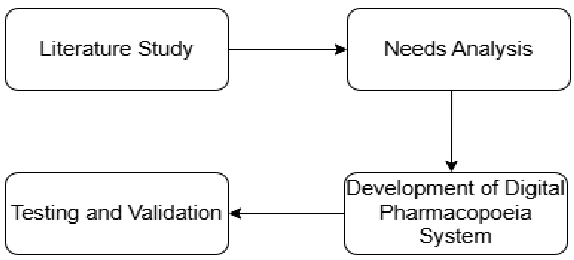

Figure 1. Flowchart of Digital Pharmacopoeia System Development Process

Literature study

A literature study was conducted to explore theories, methods, and previous findings relevant to the development of digital pharmacopeia. This research aims to provide a strong scientific basis and justification for the development of modern technology-based applications. One of the aspects studied was the format and functionality of traditional pharmacopeias, which are generally available in printed or PDF form. Although traditional pharmacopeias provide important reference standards, their limitations lie in the lack of interactivity and difficulties in accessibility. In addition, significant challenges also arise in the process of herbal plant identification using traditional references, especially as botanical expertise is often required to understand complex morphological descriptions. This emphasizes the need for innovative solutions to overcome such shortcomings.

On the other hand, digital technologies have shown great potential in supporting the pharmaceutical and botanical fields through the application of web applications, search engines, and computer vision technologies. In this context, computer vision technology can be used to simplify the process of herbal identification quickly and accurately, while web-based applications can increase the accessibility of pharmacopeias for a wide range of users. Further review highlights the relevance of digital pharmacopeias in meeting the needs of modern pharmacy, particularly for clinical practice and research purposes. A fast, accurate, and interactive digital pharmacopeia can be a solution that supports drug development, pharmaceutical analysis, as well as the preservation of traditional knowledge in a more accessible and user-friendly format.

Needs analysis

A needs analysis was conducted to identify the specific needs of potential users of digital pharmacopeia, including pharmacy practitioners, researchers, and students. The aim is to ensure that the proposed solution is relevant and directly beneficial to users. This process involved several approaches, such as user surveys using questionnaires to understand what information is needed regarding herbs, desired search features, and optimal user experience. In addition, interviews with pharmaceutical or botanical experts were conducted to obtain input on important data that should be included in the digital pharmacopeia, such as plant benefits, contraindications, dosage, and other relevant information.

As a complement, a needs observation was conducted by analyzing how traditional pharmacopeias are used in pharmacy practice. These observations helped understand the processes that could be improved through digital technology. By integrating insights from surveys, interviews, and observations, the development of digital pharmacopeias can be designed to meet the needs of users practically and improve the efficiency of use compared to traditional formats.

Development of digital pharmacopeia system

Data collection

Data collection is the process of collecting, measuring, and analyzing various types of data using several methods [11]. The data collection stage aims to gather comprehensive information about herbal plants. The information collected includes plant images, scientific names, benefits, and other pharmaceutical information such as contraindications and dosage. To ensure the accuracy of the data, reliable sources should be used, such as scientific journals, pharmaceutical reference books, or recognized botanical databases. This data will be the main basis for the development of a digital pharmacopeia that is informative and relevant to user needs.

Data preprocessing

Once the data has been collected, the next step is data preprocessing to ensure that the format is uniform and ready for use in digital applications. Plant names must be written consistently according to scientific nomenclature standards, while plant images need to be adjusted to a similar size and resolution so that they can be easily recognized by the system. To improve the quality of the dataset, image augmentation, such as rotation, lighting changes, or zooming, is performed so that the computer vision system used has a better ability to recognize plants from various visual conditions. This process ensures that the digital pharmacopeia can function optimally [7].

Key feature development

Updateable herbal plant list

This application provides a database that lists herbal plants complete with scientific information, such as scientific name, local name, pharmacological benefits, botanical description, contraindications, and dosage. The information in the database can be updated regularly by administrators or authorized users, ensuring that the data available is always current and relevant. The update mechanism is designed with an intuitive interface, making it easy to add or modify data according to the latest scientific developments.

Computer version feature

Computer vision is a branch of artificial intelligence (AI) that focuses on how computers can understand and analyze images or videos. In computer vision, there are various problems, including object detection and image classification, which aim to recognize and categorize objects in images or videos automatically [10]. Deep learning-based image recognition features, such as those used in herbal plant identification, utilize models such as MobileNet or EfficientNet trained with herbal plant image datasets, allowing users to upload plant images and obtain identification information automatically.

Text search

This feature allows users to quickly search for herbal plant information using specific keywords. The system is equipped with a full-text search algorithm to produce accurate search results. In addition, there is a filtering feature based on categories, such as benefits, plant parts used, or dosage forms, making it easier for users to find relevant information.

API integration

The backend system is equipped with APIs that serve as a link between various application components, such as text search, database management, and computer vision models. These APIs are designed to ensure seamless integration so that interactions between the user interface and backend functions can run efficiently and seamlessly.

The output of the developed system includes text-based search features, plant recognition through images, as well as a database of herbal plants that can be updated regularly. This combination of features is designed to provide a comprehensive solution in presenting accurate, relevant, and easily accessible herbal information to users.

Testing and validation

App effectiveness

This digital pharmacopoeia app was evaluated through usability testing methods to assess the extent to which it can assist practitioners and researchers in utilizing herbal information efficiently. As part of the evaluation, a survey was conducted among 20 respondents from various backgrounds, including pharmacy practitioners, researchers, students, and related staff. Testing was conducted by having respondents use the application according to their roles, followed by answering a System Usability Scale (SUS)-based questionnaire. SUS is a user test method that provides a “quick and dirty” but reliable measurement tool [12], which was chosen in this study because it allows respondents to quickly and easily complete questions designed to assess user experience, such as ease of use, menu integration, and comfort in accessing information [13].

Accuracy of herbal plant identification

The digital pharmacopeia application uses CNN-based computer vision models such as MobileNetV2 [14, 15], InceptionV3 [16, 17], and ResNet50V2 [18, 19] to identify herbal plants. The image data is divided into Rhizome, Leaf, and Fruit categories, filtered, and augmented to increase the variety and quality of the dataset. After training and testing using separate datasets, the model showed high accuracy, precision, and recall, ensuring accurate and reliable plant identification capabilities [20, 21]. This supports pharmaceutical and research needs with technology-based solutions.

Validity of pharmaceutical information

The digital pharmacopeia app ensures the validity of information through the involvement of 10 pharmacy experts who directly evaluate the accuracy and relevance of the data. Information such as scientific names, pharmacological benefits, contraindications, and dosages are verified to ensure accuracy. Expert feedback is used to update and improve the database, making the app a trusted source for pharmaceutical and research needs.

Applications in pharmaceutical research and clinical practice

To evaluate the applicability of the app in supporting pharmaceutical research, education, and services, a test was conducted involving 10 pharmacy experts. The test aimed to assess how the app could provide practical benefits in various contexts. In research, the app was used to provide quick access to scientific information on herbs, supporting species identification for experimental purposes. In education, the app became an interactive learning tool that complemented traditional references for pharmacy students. Meanwhile, in clinical practice, the quick search and plant identification features facilitate decision-making regarding the selection of appropriate herbal medicines.

Results and Discussion

The *Results and Discussion* section contains a description of the results obtained during the research and development process, as well as an analysis of the findings. The discussion is conducted to provide a deeper understanding of the results achieved and relevance to the objectives set.

Accuracy of herbal plant identification

The following presents the results of the development of the Digital pharmacopeia system which includes several main stages, starting from data collection, and data processing, to the development of main features. Each of these stages is carried out systematically to ensure the resulting system can meet user needs and support efficiency in managing pharmacopeial information.

Data collection results

The data collection results include comprehensive information on various herbal plants, scientific names, benefits and other pharmaceutical information.

Data collection results

This data processing includes image augmentation performed to increase the variety of the dataset by applying transformations such as 30° and 330° rotations, 1.5 times increase in brightness and contrast, and horizontal inversion. This technique is applied to images from classes less than the target, which are randomly selected to generate new variations. The augmented results are uniquely named and stored in their respective class directories until the number of images per class reaches 100 for *training* and 40 for *validation*. This process ensures a more diverse dataset to support more robust model training. The details of the image augmentation process, including the applied transformations and the distribution of images for training and validation.

Main feature development results

Updatable herbal plant list

In this development result, a database is created that contains a list of herbal plants along with their scientific information. The information includes scientific name, local name, pharmacological benefits, botanical description, contraindications, and dosage. The database is designed to be updated regularly by administrators or users with special access. The update system is equipped with an intuitive interface, making it easy for users to add or update data according to the latest findings in the scientific field.

Computer vision feature

The implementation of the *computer vision* feature allows the system to automatically identify herbal plants through user-uploaded images. This technology uses deep learning models such as MobileNetV2, InceptionV, and ResNet50V2, which have been trained with herbal plant datasets. With this feature, users can easily obtain information about plants by simply taking a picture, making the identification process faster and more practical. The interface displaying the results of herbal plant identification using the computer vision feature is shown in **(Figure 2)**.

Figure 2. Herbal Identification Result Interface

Text searching

The developed text search feature provides convenience for users in finding specific herbal plant information. With the *full-text* search algorithm, search results become more accurate and relevant. In addition, the system also supports more targeted searches through filters based on benefits, plant parts, or dosage forms. In fact, the text generated from the image recognition feature can be directly used as search keywords, allowing users to access information in an integrated manner. The plant identification results interface, as illustrated in **(Figure** 3**)**, showcases detailed information about the identified herbal plant.

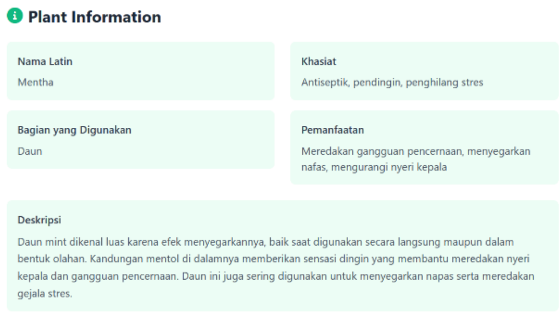

Figure 3. Interface of herbal plant identification results with detailed information

API integration

To support good integration between various functions in the application, the backend of the system is equipped with an API . These APIs connect modules such as text search, data management, and *computer vision* features. Thus, each component of the system can interact efficiently, creating a coordinated workflow and enhancing the user experience.

Testing and validation result

Application effectiveness

Usability testing was conducted by evaluating the product through a hands-on testing process. This method involved distributing surveys to various respondents, which included service officers at WKJ, visitors, plant maintenance staff, and software developers, totaling 20 people. Each respondent was asked to operate the WKJ website application according to their respective roles and access levels. Based on the evaluation results, the average *System Usability Scale* (SUS) score obtained from all questions is 82**.**

The results of the usability testing are summarized **(Table 1)**. The table below shows the results of usability testing conducted on 10 respondents. Each respondent was asked to answer 10 statements related to the use of the website, such as ease of use, availability of features, and others. This data is used to evaluate the system's usability and overall user experience.

The table displays the Usability Scale (SUS) assessment results of the 19 respondents involved in the testing. Each respondent was given a SUS score from 0 to 100, with higher scores indicating better usability levels. Based on the table, the average SUS score of the 19 respondents is 82, which means that the overall user experience of the tested website is at a good level. In addition, the table also provides individual scores for each respondent, allowing for further evaluation to identify respondents with scores above or below the average. **(Table 1)** shows the System Usability Scale (SUS) scores for each respondent, with an average score of 82, indicating a good level of usability. This data provides valuable insights into the overall effectiveness of the website and highlights areas where improvements could be made based on user feedback.

Table 1. System Usability Scale (SUS) Scores for Each Respondent

No	Respondent	Score	No	Respondent	Score
1	Participant 1	83	11	Participant 11	83
2	Participant 2	85	12	Participant 12	83
3	Participant 3	85	13	Participant 13	78
4	Participant 4	83	14	Participant 14	83
5	Participant 5	83	15	Participant 15	80
6	Participant 6	83	16	Participant 16	80
7	Participant 7	80	17	Participant 17	83
8	Participant 8	83	18	Participant 18	78
9	Participant 9	80	19	Participant 19	78
		Average = 82			

Accuracy of herbaceous plant identification

This stage aims to ensure that the computer vision model and website have achieved the expected goals, especially in terms of the accuracy of herbaceous plant identification. The model built to identify herbal plants consists of three models, namely a model for identifying the rhizome category, a model for identifying the fruit category, and a model for identifying the leaf category. The model for the rhizome category is able to classify 10 types of rhizomes, while the model for the fruit category can classify 7 types of fruit, and the model for the leaf category can classify 9 types of leaves. In the process of building image processing models, each type or label consists of 100 images. The dataset used to build the image processing model consists of 100 images for each type or label. The model was tested again using new plant data to check its ability to identify plant with a satisfactory level of accuracy. In addition, the website was tested to ensure that supporting features, such as the medicinal plant catalog and WKJ contact, were functioning optimally. This test includes an evaluation of the interface, user navigation, and ease of use of the plant identification features. This evaluation is an important part of ensuring the system is ready to use and can meet user expectations. A summary of the results of the accuracy of herbaceous plant identification is described in the following **(Table 2)**.

Table 2 . Accuracy of Herbaceous Plant Identification Models

Classification Label	Accuracy of MobileNetV2	Accuracy of InceptionV3	Accuracy of ResNet50V2
Rhizome			
Ginger, Ginger Emprit, Red Ginger, White Kunir, Turmeric, Galangal, Black Temu, Mango Temu, White Temu, and Temulawak.	0.99	1.00	1.00
Leaf			
Guava Leaf, Basil Leaf, Kepel Leaf, Turmeric Leaf, Mint Leaf, Papaya Leaf, Betel Leaf, Red Betel Leaf, and Mango Ginger Leaf.	0.99	1.00	1.00
Fruit			
Java Chili, Duwet, Guava, Lime, Kaffir Lime, Kepel, and Papaya.	0.98	0.89	0.97

Table 3. Pharmaceutical Plant Evaluation Results

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Plant 1	3	3	3	3	3	3	3	3	3	3
Plant 2	2	3	3	2	2	3	3	3	2	3
Plant 3	2	3	3	2	2	3	3	3	3	3
Plant 4	2	2	2	2	2	2	2	2	2	2
Plant 5	3	3	3	3	3	3	3	3	3	3
Plant 6	3	3	3	3	3	3	3	3	3	3
Plant 7	3	3	3	3	3	3	3	3	3	3
Plant 8	3	3	3	3	3	3	3	3	3	3
Plant 9	3	3	3	3	3	3	3	3	3	3
Plant 10	3	3	3	3	3	3	3	3	3	3
Plant 11	3	3	3	3	3	3	3	3	3	3
Plant 12	3	3	3	3	3	3	3	3	3	3
Plant 13	3	2	2	2	2	2	2	2	2	2
Plant 14	2	2	2	3	3	2	2	2	2	2
Plant 15	2	2	2	3	3	2	2	2	2	2
Plant 16	2	2	3	3	3	3	3	3	3	3
Plant 17	3	2	3	2	2	3	3	3	3	3
Plant 18	3	2	3	2	2	3	3	3	3	3
Plant 19	2	2	3	2	2	3	3	3	3	3
Plant 20	2	2	3	2	2	3	3	3	3	3
Plant 21	3	3	3	3	3	3	3	3	3	3
Plant 22	3	3	3	3	3	3	3	3	3	3
Plant 23	3	3	3	2	3	3	2	3	3	3
Average per plant	2.6	2.6	2.8	2.6	2.6	2.8	2.7	2.8	2.7	2.8
Average					**2.74**					

Pharmacy information validity results

To evaluate the validity of the pharmaceutical plant data based on the responses from 10 participants (P1 to P10) regarding each plant, we computed the average scores per plant. The scores range from 2.61 to 2.83 across all plants, with the overall average score across all plants being 2.74. These results offer insight into the general perception of the plants' relevance or effectiveness, where a higher average score indicates a more favorable perception. Plants with average scores closer to 3, such as Plant 1, Plant 5, and Plant 6, reflect a stronger consensus among participants, suggesting that these plants are considered valuable or relevant. On the other hand, plants with lower average scores, like Plant 4, Plant 13, and Plant 14, show more disagreement or a less favorable perception, indicating that they may require further validation or adjustments based on more specific criteria to improve their perceived significance. As shown in **(Table 3)**, the distribution of scores further highlights the differences in participant perceptions of each plant.

Probability of application results

Based on the results of the application trial by 10 pharmacy experts, the probability of application in each field can be seen in **(Table 4)**. For the field of pharmaceutical research, the application was considered applicable by 50% of the participants. In the field of education, the application was applied to 90% of the participants, indicating excellent acceptance. Whereas in the area of pharmaceutical services, the app was applied to 70% of participants, reflecting good potential although there is room for further improvement. These results suggest that the app has great potential in supporting pharmacy education and pharmacy services, and has a moderate possibility in supporting pharmacy research.

Table 4. Application Implementation Probability

	Pharmacy Research	Education	Pharmacy Service
participant 1	NO	NO	YES
participant 2	YES	YES	YES
participant 3	NO	YES	YES
participant 4	YES	YES	YES
participant 5	YES	YES	YES
participant 6	NO	YES	YES
participant 7	NO	YES	YES
participant 8	YES	YES	YES
participant 9	NO	YES	YES
participant 10	YES	YES	YES
Probabititas	50%	90%	70%

Conclusion

This research successfully developed a Digital pharmacopeia system that includes innovative features such as an updatable herbal plant database, *computer vision* technology for plant identification, *full-text* search algorithm-based text search, and API integration to support connectivity between components. The system provides a modern and efficient solution for the management of herbal plant information, thereby improving data accessibility and accuracy for users. The success of this development not only demonstrates the potential application of technology in the pharmaceutical and botanical fields but also provides a solid foundation for further development in the future. The system is expected to be a useful tool in supporting research, education, and practice in the field of herbs and pharmacology.

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Conflict of interest: None

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Ethics statement: None

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