Harnessing deep learning for medicinal plant research: a comprehensive study

Vidya Hullekere Ananda[1], Narasimha Murthy Madiwala Sathyanarayana Rao[2], Thara Dharmapura Krishnamurthy[3]

[1]Department of Computer Science and Engineering, Kalpataru Institute of Technology, Tiptur, Visvesvaraya Technological University, Belagavi, India
[2]Department of Information Science and Engineering, BMS Institute of Technology and Management, Bengaluru, Visvesvaraya Technological University, Belagavi, India
[3]Department of Information Science and Engineering, Channabasaveshwara Institute of Technology, Gubbi, Visvesvaraya Technological University, Belagavi, India

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ABSTRACT

In today's world, people are more prone to diseases due to food adulteration and pollution in the environment, and people have found a way of using herbal medicine as an alternative to allopathic medicine, especially since coronavirus disease 2019 (COVID-19). Medicinal plants are the source of herbal medicines that increase the immunity of humans. Medicinal plants are used in many applications, like pharmaceuticals, cosmetics, and drugs. Medicinal plants are of great importance, and hence this work presents a review of the medicinal plants grown in Karnataka State, India. The work also highlights species identification and disease detection of medicinal plants employing machine learning and deep learning approaches. The paper provides information about datasets available for various medicinal plant leaf images. The deep learning models used for species identification and disease detection in medicinal plants have been discussed along with the results.

Corresponding Author:

Vidya Hullekere Ananda
Department of Computer Science and Engineering, Kalpataru Institute of Technology, Visvesvaraya Technological University
NH 206, BH Road, Tiptur-572201, India
Email: vidya.ha@gmail.com

1. INTRODUCTION

Medicinal plants play a pivotal role in today's world as they are the main component of Ayurveda. Ayurveda solves health problems through a holistic approach by preventing many diseases and helping face potential challenges in this world [1]. Modern medicine weakens the immunity power of the human body, whereas the Ayurvedic approach to health helps maintain good health by increasing the immunity of the body naturally. Nowadays, we can see that many Ayurvedic therapies treat diseases that are hard to cure in modern medicine. In many cases, Ayurveda avoids surgeries and heals a variety of diseases. Accurate identification and monitoring of medicinal plant species is essential to ensure the quality, efficacy, and safety of herbal products and traditional medicines, as medicinal plants have many uses in medicine. However, the visual similarity and spectrum of medicinal plant biodiversity pose significant challenges for conventional identification methods, often relying on the expertise of human experts. Also, the timely detection of diseases in medicinal plants is crucial to maintaining the potency and integrity of the plants for their intended medicinal applications. Undetected plant diseases can lead to significant crop losses and the production of substandard herbal products, undermining the reliability and trust in traditional medicine.

In this work, we aim to leverage the power of deep learning, a cutting-edge artificial intelligence technique, to address these challenges and revolutionize the way medicinal plants are identified and monitored. Specifically, we seek to develop robust and accurate deep learning-based automated classification systems equipped to handle the identification of a rich assortment of medicinal plant varieties. Explore the implementation of deep learning approaches to the early and precise detection of diseases in medicinal plants, enabling proactive intervention and management. The work emphasizes the significance of leveraging data augmentation approaches to alleviate the limitations of small medicinal plant datasets and enhance the generalization of deep learning models. Investigate the proficiency of the deep learning-based approaches and compare them to conventional machine learning methods, demonstrating the advancements made in this field.

By achieving these objectives, we aim to contribute to the improvement of the medicinal plant industry's efficiency, quality control, and sustainability. The deep learning-powered tools and techniques developed in this study can be integrated into the workflows of cultivators, producers, and healthcare practitioners, empowering them with reliable and scalable solutions for medicinal plant identification and disease monitoring. This research represents a crucial leap in adopting deep learning algorithms in medicinal plant applications, with the potential to transform traditional healthcare practices, enhance the reliability of herbal products, and promote the sustainable management of medicinal plant resources.

The primary motivation of this work is to leverage the power of deep learning to navigate the difficulties of accurate identification and timely detection of diseases in medicinal plants to amplify the efficiency, quality control, and sustainability of the medicinal plant industry and traditional healthcare practices. The problem addressed in this study is to maximize the use of ayurvedic medicines, so we need to identify the medicinal plants and suppress the attack of diseases on medicinal plants to save their community. Deep learning is pivotal in identifying medicinal plant species and detecting their diseases.

India is known as popular for its traditional health systems that include, Ayurveda, Yoga, Unani, Siddha, and Sowa-Rigpa along with Homeopathy. Based on this system, nowadays we can see many policies and systems named AYUSH which is shown in Figure 1. Ancient human civilization used the Siddha system around 800-700 BCE, the Unani system of medicine was used around 460-377 BCE, Ayurveda was used around 900-800 BCE, Homeopathy around 1850 CE, and Yoga and naturopathy was used past many decades which are natural healing systems [2]. The number of plant species used in these systems is shown in Figure 2 [3]. India is one of the reservoirs of biodiversity in the world. Plants are found mainly in the Western Ghats, North-Eastern India, and the Himalayan region. There are around 7,000 medicinal plant species in India, and around 1900 in Karnataka [4]. People below the poverty line cannot afford the expensive healthcare services provided today and they do not even have access to the healthcare services, especially in remote areas. Alternative ways need to be found to meet the challenges faced by these poor people. Medicinal plants offer remedies for this problem and many health issues can be solved if taken care of at the right time with the right medication. The predominant portion of the medicinal plants is found in forests. Medicinal plants provide treatment for the poor people at an affordable price and they also generate income and employment if focused properly. According to the World Health Organization (WHO), about 80% of the global population relies on traditional medicine, which aims to promote the well-being of both people and the planet [5]. 90% of the medicinal plants are used as raw drug material in the Indian medicinal system [6]. 40% of the pharmaceutical industries are using medicinal plants [7].

Figure 1. Traditional medicine system AYUSH

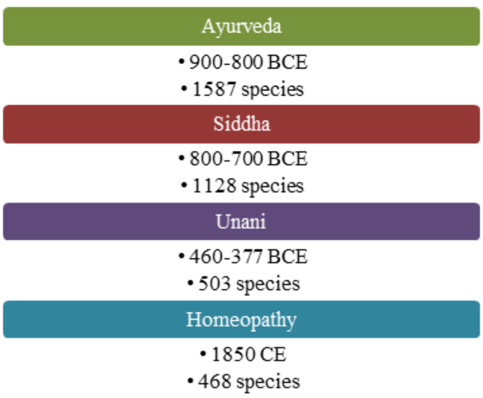

Figure 2. Indian traditional medicine system with history and number of plant species

Unfortunately, the sector of medicinal plants in our country is not well organized and potentially utilized. National and state-level organizations have to design policies related to the medicinal plant sector. The medicinal plant growing habitats have to be increased with great supervision, and the rare medicinal plant species that are extinct need to be protected. So that India can export natural medicines to international markets [8]. We can find the application of medicinal plants in various fields. Figure 3 shows the application of medicinal plants in various fields in the market.

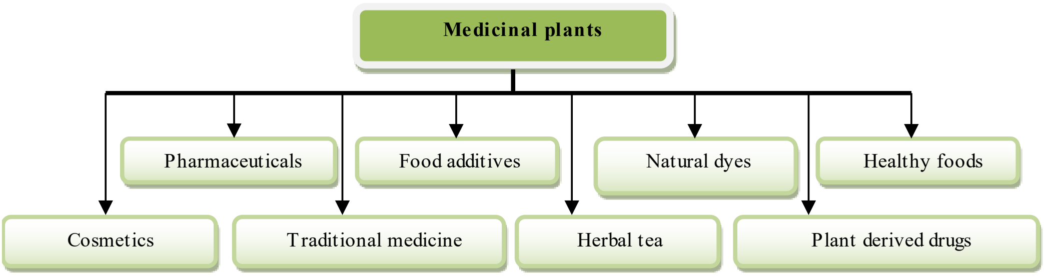

Figure 3. Medicinal plants in various fields

Artificial intelligence is a new technology of computer science that evolved 67 years ago. Artificial intelligence was invented in 1956 by John McCarthy [9]. But it has become popular in the past few decades. It is widely used in almost all applications today. Machine learning (ML) and deep learning (DL) are the subfields of Artificial Intelligence and are finding great application in many fields like healthcare, agriculture, banking, social media, cyber security, robotics, e-commerce, education, and gaming. In this work, deep learning techniques used in species identification and disease identification in medicinal plants are discussed.

Nature offers us a remarkable method of naturally healing various illnesses and injuries through medicinal plants. Medicinal plants play a remarkable role in reducing the use of toxic substances in drug production. Medicinal plants have antimicrobial, antibiotic-resistant, and antibacterial properties. The medicinal properties of plants come from various parts of the plants such as leaves, stems, bark, root, flowers, fruit, gum, rhizome, seed, tuber, and wood. Medicinal plants can be used to increase immunity, especially in children. We can use them in treating common diseases like colds, coughs, fever, dysentery, vomiting, and many others. This sub-section summarizes various diseases treated using medicinal plants.

One of the key diseases treated using medicinal plants is related to skin. Many allopathy drugs especially related to skin are made of natural components available from medicinal plants. The five most used plant families in Indian Ethnodermatology are Euphorbiaceae, Fabaceae, Apocynaceae, Asteraceae, and Zingiberaceae. These families are used to cure diseases such as cuts and wounds, ringworm, skin diseases, eczema, sores, scabies, leukoderma, burning areas, warts, herpes, infective hepatitis, carbuncle, itching, pimple, sole on legs, leprosy, psoriasis, skin infection, inflammatory diseases, astringent, boils, dandruff, dermatitis, skin allergies, swelling on hands and legs, ear ache, abdominal cramps, rash, snake bites, syphilis, acne, bites, white spot of skin, wormy skin sores, hyperpigmentation, leukoderma, premature skin wrinkle, skin allergy caused by insect, bites or microbes [5]. They are also used to treat diseases related to endocrine disorders, diabetes mellitus, thyroidal and hormonal imbalances. Once the plant is used for medicinal purposes, the other parts of plants form residual biomass used as renewable energy resources on the earth [10].

The medicinal plants of the Cucurbitaceae family contain rich phytochemicals that give therapeutic effects. These plants exhibit the properties of antihyperglycemic, antidiabetic, anticancer, antimicrobial, antioxidant, analgesic, anti-inflammatory, anti-stress, and immunomodulatory effects. These plants are nutritional, economical, and ethnoveterinary in nature [11]. The medicinal plants namely *Licania macrophylla* (leaf, bark), *Manilkara elata* (bark), and *Vouacapoua Americana* (bark) efficiently fight against herpes and chikungunya diseases available in the Amazonian region [12]. Medicinal plants have the benefits of reducing respiratory infections, antidiabetic potential, improved immunity, antiviral properties, anti-inflammatory, improved sleep quality, normalized pulmonary functioning, antioxidant, mucociliary clearance, and augmenting phagocytosis [13].

Another important application of medicinal plants includes synthesizing silver nanoparticles. Silver nanoparticles (AgNPs) are biosynthesized from herbal plants and act as therapeutic agents for bacteria, fungi, and tumors [14]. Medicinal plants play an important role in reducing inflammation in memory cognitive diseases like Alzheimer's disease, vascular dementia, Parkinson's disease, traumatic injury in the brain, stroke, and cerebral malaria [15]. Recently it has been observed that bioactive components in medicinal plants have an impact on ocular disorders like infections in the eye, eye disorders, and vision damage which includes glaucoma and diplopia [16]. Colon cancer is a disease caused by gut microbiota. The disease can be treated in Ayurveda with the use of plants mainly with polyphenolic compounds in curcumin (Curcuma longa/Turmeric). It has chemoprevention properties; it is antioxidant and anti-inflammatory. Aloe vera helps prevent the growth of harmful bacteria clostridium perfringens. The Glycyrrhiza glabra (licorice), Portulaca oleracea, and Euphorbia lathyrism are the other plants used in the treatment of colon cancer [17]. Paralysis is another important disease that is found in common nowadays and the medicinal plants distributed over 25 families are used to treat different types of paralysis [18].

Over 200 plant species in the Tibeto-Burman ethnic group are used for treating various health issues specifically in women, like urinary problems, prepartum care, genital problems, constipation, maternal diet, increased appetite, breast milk stimulant, beauty, blood circulation, blood pressure, baby health care, uterus involution, blood nourishment, childbirth, dizziness, menstrual cycle, and fertility. The three plants used extensively included Blumea Balsamifera of the Asteraceae family, Cleroddendrum Colebrookianum of the Lamiaceae family, Buddleja Asiatica of the Scrophulariaceae family [19]. Consuming medicinal plants treats fatigue caused due to post-coronavirus disease (post-COVID) [20]. Crude extracts of medicinal plants are also used in curing many neurological disorders like epilepsy which is found in low-income countries [21]. Medicinal plants also find application in veterinary practices in many parts of India. One such case study is done in Meghalaya in North East India [22]. Medicinal plants improve animal health and reduce the need for synthetic antibiotics and hormones used in animals for their growth and reduce the mortality rate [23].

In this view, medicinal plants still need to be explored more to find the potential of medicinal plants in curing humanitarian diseases. With this exploration and integration of traditional medicine with the modern medicine system, the existing healthcare system will be improved with the best results and have fewer side effects. Traditional medicine aids in conserving harmonic conformity in nature.

Plants are the major sources of preserving biodiversity in nature. India contributes 7% of biodiversity in the world. Medicinal plants prioritize biodiversity conservation too, along with the discovery of future life-saving compounds [24]. There are 17,000 to 18,000 flowering plant species in India, out of which around 7,000 are used as medicinal plants [25]. There are around 1,900 species of medicinal plants found in natural forests in Karnataka according to Karnataka state medicinal plants authority (KaMpA) [4]. The list of various medicinal plants available in Karnataka [26] and the plants used to treat different diseases is made available in the link *https://github.com/vidyaha18/Medicinal-plants* using the references [5], [11], [18], [27] with the file name "List of various medicinal plants of Karnataka used in curing human diseases." The table in the link shows medicinal plants in Karnataka that can be found easily around us to treat common diseases.

2. LITERATURE REVIEW

This subsection of the paper provides a comprehensive overview of the existing research and scholarly work on two main areas-species identification and disease detection of medicinal plants. Species identification is crucial in medicinal plants to ensure the safety and efficient use of medicinal plants. Disease detection is important, as we need to conserve medicinal plants against different bacterial and fungal diseases. Species identification and disease detection helps in proper utilization of medicinal plants.

2.1. Species identification in medicinal plants

Species identification is crucial in medicinal plants to ensure the safety and efficient use of medicinal plants. Different medicinal plants contain different compounds and are used to treat a variety of diseases. Accurate identification of medicinal plants ensures the correct usage of medicinal plants to treat the disease and the risks of side effects can be reduced. It also helps in knowing the extinct medicinal plants and the conservation of such medicinal plants and thus helps in ensuring the availability of medicinal plants to a long extent. Many deep learning models are used in the species identification of various plants. Some work done in this field and the deep learning models used in this application are listed here.

The models used for identifying medicinal plant species in the work given by Borkatulla *et al*. [28], include ImageNet pre-trained ResNet50, DenseNet201, VGG16, and InceptionV3 with RMSprop optimizer. The experiment is carried out for 10 epochs with a learning rate of 0.0001. The measure of accuracy of the models includes 72%, 97%, 96%, and 95% respectively. Islam *et al*. [29], use two convolutional neural network (CNN) pre-trained models namely DenseNet201 and InceptionResNetV2. The accuracy for the training dataset of both the models is 98.46% and 92.93%, validation accuracy is 96.30% and 90.10%, test accuracy is 80.69% and 90.09%, validation precision is 96.81% and 90.83%, validation recall is 95.43% and 87.72% and validation F1-Score is 96.10% and 88.94% respectively, for both the models.

Azadnia and Kheiralipour [30], employ artificial neural networks in their work. The training, testing, and validation data are 60%, 20%, and 20% respectively. The model was able to identify six medicinal plants, hence there were six neurons in the output layer. The model uses 6,000 Ayurvedic plant samples. 10 neurons were used in the hidden layer. The performance measures of the model are correlation coefficient-1, 100% classification rate, and 2.35×10^{-6} mean square error which is optimal. A deep CNN is used by Pushpa and Rani [31], to classify 40 Ayurvedic plant species. The model here is named AyurPlantNet, also the pre-trained models ResNet50 and DenseNet121 are compared with ResNet34, VGG16, MobileNetV3_Large, and EfficientNetwork_B4 and the model recorded an accuracy of 92.27%.

Viet *et al*. [32], in their work, used a large dataset of medicinal plant images. The study assessed and optimized the federated learning framework using two federated learning approaches, FedAvg and FedProx, and four state-of-the-art deep learning networks for the task of categorizing medicinal plants. The training set was distributed in two forms: independently and identically distributed (IID) and non-independently and identically distributed (non-IID). The optimal federated learning system achieved an accuracy of 94.51% and 82.65% over the baseline on IID data and Non-IID data, respectively. Future research could investigate the use of other, more complex federated learning algorithms.

Govindaprabhu and Sumathi [33] proposed ensemble EfficientNet and Xception with ResNet (EEXR) model and employed the Mendeley dataset that contains 1,800 images of 18 medicinal plant species in their work. The model achieved an accuracy of 96.71% and error rate of 3.24% for the plant dataset. Dey *et al*. [34] trained and evaluated the performance of seven deep learning models VGG16, VGG19, DenseNet201, ResNet50V2, Xception, InceptionResNetV2, and InceptionV3 to identify and classify inter-family and inter-species variations of medicinal plants. DenseNet showed promising results with 99.64% accuracy. The future work addresses the challenges of automatic plant identification in diverse regions, expanding the dataset, enhancing the robustness of the approach, and translating the research findings into practical real-world identification solutions.

Wang *et al*. [35] identified and quantified two medicinal plant species, and the authors used a combination of deep learning and unmanned aerial vehicle remote sensing (UAVRS) to achieve quantitative detection of the flowers of these two plant species. YOLOv7 and YOLOv5n were employed in the work where YOLOv7 showed best results of 97% accuracy and YOLOv5n with 93.40% accuracy.

Sharma and Vardhan [36] proposed the MTJNet model to evaluate an Indian medicinal leaf dataset in their study. The proposed MTJNet achieved a precision of 99.60%, recall of 99.62%, accuracy of 99.71%, and F1-Score of 99.58%. The experimental results showed that the MTJNet statistically outperformed prevalent models. Future work includes deploying the model in real-world applications and exploring transfer learning and domain adaptation.

From the current state-of-the-art, it is evident that deep learning models are widely used in species identification which overcomes the conventional machine learning techniques [37]. The popular deep learning models used in this area include ANN, CNN, and pre-trained models like ResNet, DenseNet, VGG, InceptionV3, MTJNet, Xception, and MobileNet out of these DenseNet shows promising results. The state-of-the-art pre-trained deep learning model EfficientNetB0, EfficientNetV2-S, vision transformer, and bidirectional encoder image transformer are also used [38]. According to the survey, we found that the lack of datasets is the gap identified and other models like federated learning, and transfer learning can be used other than pre-trained models.

2.2. Disease detection in medicinal plants

Even though medicinal plants are used to treat many diseases, they are prone to diseases like humans. Medicinal plants are majorly affected by fungal diseases [39]. There are many other diseases caused by pests in medicinal plants, information about important medicinal plants that are grown in Karnataka state in India along with pests that cause the disease and parts of the plant that are affected is given in the link *https://github.com/vidyaha18/Medicinal-plants* with the file name "List of important medicinal plants of Karnataka attacked by various pests".

It is important to manage these diseases to ensure the health and productivity of medicinal plants and to protect the bioactive compounds in them. Identification of diseases in plants is very important; especially in the category of medicinal plants. By detecting the disease in medicinal plants, we can take appropriate measures to control the same and save the plant from being damaged or dying. Also, as medicinal plants are used in many applications as discussed in the introduction section, the quality of the plant is of great importance to preserve the quality of the products like herbal medicines and other products like cosmetics. Early detection of disease helps in avoiding the spreading of the disease to other parts of the plant. It also helps in avoiding the use of fertilizers to control plant disease by using biologically available manures like cow dung and other products from neem plants. Thereby, the quality of the plant as well as the soil is also preserved. Deep learning technology has its effect in the field of plant disease detection nowadays. Few works that have been done in identifying plant diseases and the deep learning models used in disease detection of plants are discussed here.

Andrew *et al*. [40] in their study used the publicly available PlantVillage dataset, which contains 54,305 image samples of different plant disease species in 38 classes. The researchers used DenseNet-121, ResNet-50, VGG-16, and InceptionV4. The DenseNet-121 model achieved the highest classification accuracy of 99.81% and F1-Score of 0.998, outperforming the other pre-trained models. The ResNet-50 model achieved an accuracy of 99.83% and a model loss of 0.027. In comparison, the InceptionV4 model reached 97.59% accuracy, and the VGG-16 model had a lower accuracy of 84.27%.

Diykh *et al*. [41] used RGB drone imagery data from Prince Edward Island, Canada to predict the normalized difference vegetation index (NDVI). The researchers proposed a novel framework that integrates empirical curvelet transform and a DenseNet deep learning model. The proposed DenseNet-based model achieved the highest structural similarity index (SSIM=0.98) and the lowest mean squared error (MSE=120) in NDVI prediction. The model also showed an accuracy of 97% in predicting NDVI from the RGB drone imagery. The drawback is that the model was only tested on a small dataset.

Alom *et al*. [42] in the work, used Brassica Napus rapeseed species, collected from agricultural fields. The study adopted five contemporary deep learning-based CNN models: DenseNet201, VGG19, InceptionV3, Xception, and ResNet50. The DenseNet201 model has the highest accuracy of 100% for flowers and 97% for both packets and leaves. The system is a binary classification and cannot specify multi-class species. Aishwarya and Reddy [43] in the study, created a comprehensive dataset of groundnut leaf images. The study utilized a tri-CNN architecture consisting of DenseNet169, Inception, and Xception, which are pre-trained on the ImageNet dataset. The proposed method achieved an accuracy rate of 98.46%. On the potato leaf dataset, the accuracy rate was 96.05%, and on the grape leaf dataset, it was 99.32%. The proposed ensemble strategy demonstrated superior performance compared to traditional techniques.

To summarize, machine learning algorithms used for disease detection include support vector machines, random forests, artificial neural networks, deep belief networks, and deep CNN with trained models such as VGG16, InceptionV4, ResNet50, ResNet101, ResNet152, AlexNet, GoogleNet, DenseNet [40], [44], [45]. Recently, transfer learning emerged as a new field to enhance the performance of deep learning models [46]. New technology in DL like attention mechanisms can be used and these attention mechanisms were integrated into MobileNetV2, EfficientNetV2, and ShuffleNetV2 [47]. The work in the field of plant disease detection has been carried out on many available datasets like plant village dataset, PlantDoc, and Kaggle, and done for many other crops, but not specifically done for medicinal plants. It is good to develop more efficient solutions by evaluating the model on a larger and more diverse dataset with different crops.

However, the work in the field of medicinal plants is minimal and requires attention. Previous studies show that there are limited datasets for medicinal plants especially for disease detection. Additional datasets need to be built to accelerate the research in the fields of medicinal plants. Data augmentation techniques may be used to enhance the dataset size available for medicinal plants, which improves the generalization of deep learning models. By applying the deep learning technology, we can maximize the use of medicinal plants as they have ample use in the field of medicine. Beyond deep learning techniques, phytochemical analysis could be used to get accurate results for disease detection but, it takes more time and effort to implement. By leveraging the capabilities of deep learning for species identification and disease detection, medicinal plant-based industries can enhance their efficiency, quality, and sustainability, ultimately benefiting both the producers and the consumers of herbal medicines and products. In the future, we may work on models like graph-based deep learning and long short-term memory networks (LSTM).

3. METHOD

This section provides an experimental setup that consists of different steps used for species identification and disease detection of medicinal plants. Figure 4 provides the overview of the process. The workflow model for the proposed system containing species identification and disease detection is shown in Figure 4. The model starts with the data collection stage, the data can be taken from the standard public datasets and also real-time data can be used hence data can be collected from multisource. The next step is data preprocessing which includes data augmentation, normalization, and segmentation. The third step is the model selection phase, any neural network model can be employed here. The fourth step is the training phase which includes training the selected neural network model by splitting the dataset into training and validation datasets. The fifth step is the evaluation phase where the trained neural network model is tested and evaluated for good performance using metrics like confusion metrics, F1-Score, and area under curve. On successful testing, the model can be used for species identification and disease detection. If the model performance needs to be improved further, the training of the model is required and hence we have the loop from the evaluation phase to the training phase.

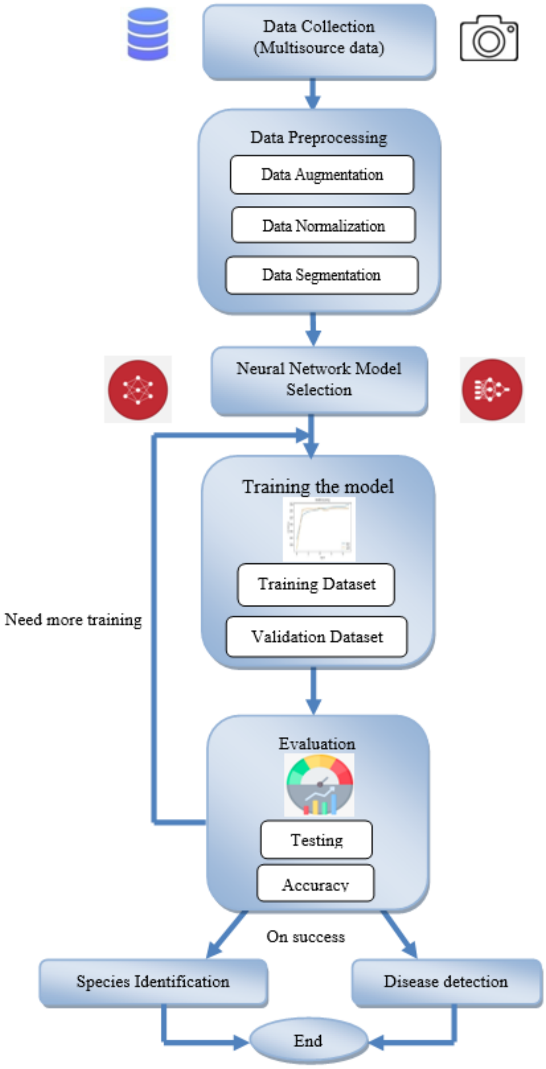

Figure 4. Workflow diagram

3.1. Datasets for medicinal plants

It is very hard and requires a lot of time and effort to collect the data required to train the machine learning and deep learning models. Few researchers have worked on this and contributed to the datasets for medicinal plants. This section gives details about the datasets that are exclusively available for medicinal plants.

3.1.1. Kaggle dataset

This dataset contains images of medicinal plant species Catharanthus Roseus, Kalanchoe Pinnara, Longevity Spinach, Terminalia Bellirica, Terminalia Chebula, Centella Asitica, Azadirachta Indica, Ocimum Tenniflorum, Cymbopogon Citratus, Euphorbia Tithymaloides. The dataset contains 5,000 images of which 70% is used as training data containing 3,500 images, 20% of data is used as testing data containing 1,000 images, and 10% as validation data containing 500 images [28].

Title: Medicinal plant raw
URL: https://www.kaggle.com/dsv/4510170
DOI: 10.34740/KAGGLE/DSV/4510170

3.1.2. Mendeley dataset

The dataset consists of two classes, the medicinal leaf dataset, and the medicinal plant dataset with 80 plant species, 6,900 images, and 40 plant species, 5,900 images respectively. The plants include Aloe barbadensis miller, Phyllanthus Emblica, Morinda Citrifolia, Tinospora Cordifolia, Ficus Religiosa, Euphorbia Hirta, Bambusoideae, Piper Betle, Bacopa Monnieri, Eclipta Prostrate, Cinnamomum Camphora, Ricinus Communis, Citrus Medica, Coffea, Murraya Koenigii, Costus Igneus, Artocarpus Heterophyllus, Jasminum, Zingiber Officinale, Psidium Guajava, Lawsonia Inermis, Hibiscus and many others. The data was collected in Mysuru and Kerala regions [48].

Title: Indian medicinal leaves image datasets
URL: https://data.mendeley.com/datasets/748f8jkphb
DOI: 10.17632/748f8jkphb.3

3.1.3. MED117_Medicinal plant leaf dataset

The dataset contains 117 different species of 77,500 total medicinal plant images. The U-Net model was used for the segmentation of the images in the preprocessing stage. Watershed segmentation techniques were also used along with U-Net. The class of each plant contains 179 to 1,300 species [49].

Database names: MED117_Leaf Species I the database which has two subfolders namely, Raw leaf image set of Medicinal plants_v2 and Segmented leaf set using U-NET segmentation.
URL: https://data.mendeley.com/datasets/dtvbwrhznz/4
DOI: 10.17632/dtvbwrhznz.4

2.1.4. Medicinal leaf dataset

The dataset consists of 30 species of medicinal plants such as Santalum Album, Muntingia Calabura, Amaranthus Viridis, Azadirachta Indica, Citrus Lemon, Ficus Auriculata, and many more. Each species has 60 to 100 images of high quality. It is available on the Mendeley platform [50].

URL: https://data.mendeley.com/datasets/nnytj2v3n5/1
DOI: 10.17632/nnytj2v3n5.1

3.1.5. BDMediLeaves: a leaf images dataset for Bangladeshi medicinal plants identification

The dataset consists of 2,029 original images and 38,606 augmented images of the leaves of commonly found ten medicinal plants in Bangladesh. The dataset is in the Mendeley platform. It contains two categories namely BDMediLeaves augmented dataset and BDMediLeaves original dataset for training, testing, and validation. The plants include Hibiscus Rosa-Sinensis, Centella Asiatica, Phyllantuhus Emblica, Kalanchoe Pinnata, Mikania Micrantha, Azadirachta Indica, Terminalia Arjuna, Justicia Adhatoda, Ocimum Tenuiflorum, and Calotropis Gigantean [29].

URL: https://data.mendeley.com/datasets/gk5x6k8xr5/1
DOI: 10.17632/gk5x6k8xr5.1

3.2. Deep learning models

Deep learning was proposed by Rina Dechter in 1986. The first deep-learning algorithms were published by Ivakhnenko and Lapa in 1967 [51]. It consists of three layers, an input layer, a hidden layer, and an output layer, and operates with input and weights. Nowadays, deep learning has become increasingly prevalent and is being applied in almost all applications. Plant species identification and plant disease detection are vital applications that use deep learning models. There are many deep learning architectures designed by various pioneers who are working in this field. The top deep learning architectures include: i) convolutional neural networks (CNN), ii) artificial neural networks (ANN), iii) long short-term memory networks (LSTM), iv) recurrent neural networks (RNN), v) generative adversarial networks (GAN), vi) radial basis function networks (RBFN), vii) multilayer perceptron (MLP), viii) self-organizing maps (SOM), ix) deep belief networks (DBN), x) restricted Boltzmann machines (RBM), and xi) autoencoders (AE).

Many machine learning and deep learning algorithms are used, to name a few supports vector machine (SVM), random forest (RF), perceptron, backpropagation algorithm, regression techniques, Bayesian classifier, and neural networks. The neural networks gained high importance and convolutional neural networks are popularly used in species identification and disease detection in plants. Many models work based on the above-mentioned architectures. In this work, we have considered medicinal plants and discussed work done in species identification and disease detection in medicinal plants. The majority of the papers involved in the study have used CNN models [52]. A few of the CNN models used in deep learning and their years of invention are given in Figure 5. Among the models identified from the study, DenseNet is more popular as it obtains good results for our objectives.

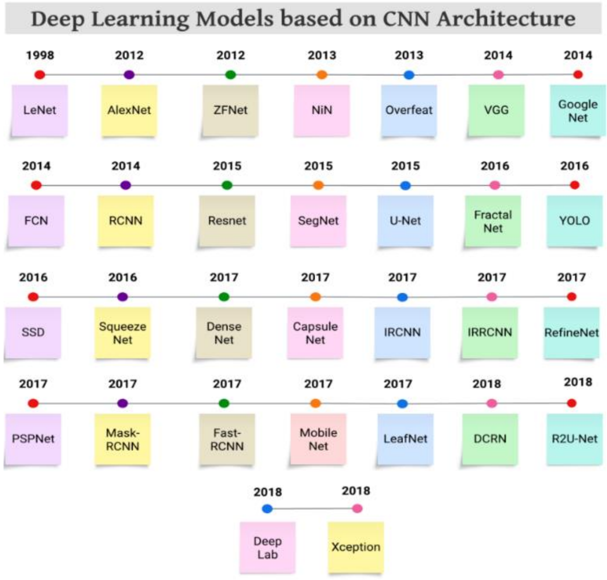

Figure 5. Deep learning models based on convolutional neural networks

4. RESULTS AND DISCUSSION

In this section, we discuss the results of various machine learning and deep learning models used in species identification and disease detection of medicinal plants. Many conventional machine learning techniques like random forest, support vector machine, and others have been used. However, deep learning models give promising results compared to machine learning models, particularly neural networks. The study found that models like ResNet, DenseNet, VGG16, InceptionV3, ANN, and AyurPlantNet are majorly employed for plant species identification. Among these DenseNet outperforms all other models with 99.64% accuracy, and MTJNet with 99.71% accuracy. For plant disease detection various deep learning approaches like InceptionV4, ResNet, VGGNet, AlexNet, GoogleNet, Overfeat, VGG, and DenseNet are employed. In these models, DenseNet outperforms all other models with 99.8% accuracy.

Many works have been done on species identification but the above study lists some of the work carried out on species identification of various medicinal plants. The comparative analysis of various deep learning models in medicinal plant species identification is given in Table 1 and Figure 5. Table 1 shows the models and dataset used, the number of epochs, the accuracy achieved, and the references used to summarize the analysis of various models.

Figure 6 shows the graphical representation of the comparative analysis of various models used in the study. From this, it is evident that ANN and DenseNet models outperform other models with 100% and 97% accuracy respectively. The comparative analysis of the models used for disease detection is given in Table 2 which contains information like models, datasets, number of epochs, test and validation accuracy, and references. The work needs to be extended for medicinal plant species to protect them from diseases that are being attacked. Figure 7 shows the graphical representation of the comparative analysis given in Table 2.

Table 1. Comparative analysis of various deep learning methods in plant species identification

Model used	Dataset	Epochs	Accuracy	References
ResNet50	Bangladeshi medicinal plant dataset	10	72	[28]
DenseNet201	Bangladeshi medicinal plant dataset	10	97	[28]
VGG16	Bangladeshi medicinal plant dataset	10	96	[28]
InceptionV3	Bangladeshi medicinal plant dataset	10	95	[28]
DenseNet201	BDMediLeaves	20	80.69	[29]
InceptionResNetV2	BDMediLeaves	20	90.09	[29]
ANN	Real time data	20	100	[30]
Ayur-PlantNet	Real time data	-	92.27	[31]
Federated learning	IID and NON IID	5	94.51	[32]
EEXR	Mendeley dataset	50	96.71	[33]
DenseNet201	Medicinal plant dataset	20	99.64	[34]
YOLOv7	Custom dataset	-	97	[35]
YOLOv5	Custom dataset	-	93.4	[35]
MTJNet	Indian medicinal leaf dataset	-	99.71	[36]

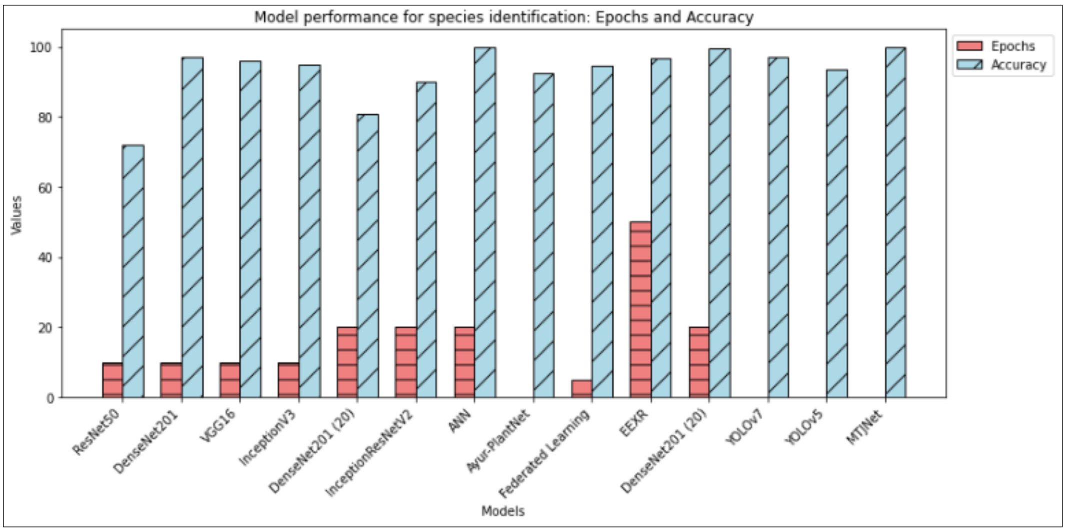

Figure 6. Comparison of different deep learning approaches for plant species identification

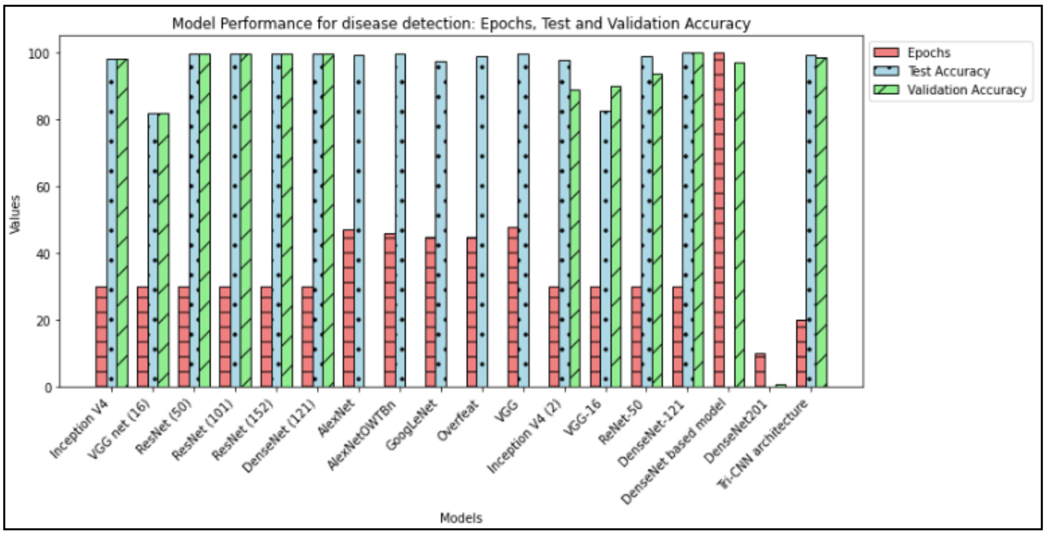

Figure 7. Comparison of different deep learning approaches for plant disease detection

Table 2. Comparative analysis of various deep learning methods in plant disease detection

Model used	Dataset	Epochs	Test accuracy	Validation accuracy	Reference
Inception V4	PlantVillage	30	98.08	98.02	[45]
VGG net (16)	PlantVillage	30	81.83	81.92	[45]
ResNet (50)	PlantVillage	30	99.59	99.67	[45]
ResNet (101)	PlantVillage	30	99.66	99.66	[45]
ResNet (152)	PlantVillage	30	99.59	99.68	[45]
DenseNet (121)	PlantVillage	30	99.75	99.76	[45]
AlexNet	Realtime data	47	99.06	-	[44]
AlexNetOWTBn	Realtime data	46	99.44	-	[44]
GoogLeNet	Realtime data	45	97.27	-	[44]
Overfeat	Realtime data	45	98.96	-	[44]
VGG	Realtime data	48	99.48	-	[44]
Inception V4	Plantvillage	30	97.59	88.7	[40]
VGG-16	PlantVillage	30	82.75	90.1	[40]
ReNet-50	PlantVillage	30	98.73	93.5	[40]
DenseNet-121	PlantVillage	30	99.81	99.8	[40]
DenseNet based model	RGB Drone image data	100	0	97	[41]
DenseNet201	Brassica Napus data	10	0	0.98	[42]
Tri-CNN architecture	ImageNet dataset	20	99.39	98.46	[43]

5. CONCLUSION

In this study, the remarkable potential of deep learning techniques in revolutionizing the identification and monitoring of medicinal plant species has been demonstrated. The overall system discussed in the study can be helpful for farmers and forest managers in monitoring crop growth, and plant health and identifying issues related to diseases and water shortages. From the comparative analysis of the deep learning models in species identification and disease detection of medicinal plants, it is evident that DenseNet, VGG16, and InceptionV3 show better results compared to other models, particularly DenseNet shows unprecedented accuracy in classifying a diverse range of medicinal plant species, outperforming traditional approaches. Beyond species identification, our findings have also highlighted the power of deep learning in the early and precise detection of diseases in medicinal plants. The ability to rapidly identify disease symptoms can enable to empower cultivators, producers, and healthcare practitioners with advanced yet accessible technologies. We can drive a paradigm shift towards more efficient, data-driven, and environmentally responsible practices in the medicinal plant industry.

The implications of our work extend far beyond the immediate benefits to the medicinal plant industry. By integrating deep learning-powered identification and monitoring systems, we envision a future where the sustainable cultivation and conservation of medicinal plant species can be greatly enhanced. The traceability and quality control enabled by these technologies can also contribute to the transparency and accountability of the medicinal plant supply chain, building trust and confidence in traditional herbal products. Moreover, the dissemination of the deep learning-based tools and techniques developed in this study can support capacity building within the medicinal plant community. In the future, we believe that the continued advancement of deep learning research in this domain holds immense potential. Exploring multimodal data integration, transfer learning, few-shot learning techniques, GANs, and the development of interpretable deep learning models can further expand the capabilities and versatility of these technologies for medicinal plant applications. Also, new datasets can be constructed with healthy and diseased leaf images of medicinal plants which are helpful in disease detection of medicinal plants.

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BIOGRAPHIES OF AUTHORS

Vidya Hullekere Ananda received a B.E. degree in computer science and engineering, Visvesvaraya Technological University, India, in 2009, M.Tech. in computer science from Sri Siddhartha Institute of Technology, India and pursuing a Ph.D. degree in the domain of deep learning from Visvesvaraya Technological University, India. Currently, she is an Assistant Professor of the Department of Computer Science and Engineering, Kalpataru Institute of Technology, Tiptur, Karnataka, India. She has 12 years of teaching experience. Her research interests include machine learning and deep learning in agriculture and healthcare. She can be contacted at email: vidya.ha@gmail.com.

Narasimha Murthy Madiwala Sathyanarayana Rao completed his B.E in CSE, M.Tech. in VLSI design and embedded systems, and holds PhD in software engineering and cloud computing from a reputed University, in India. He is currently working as an Associate Professor of the Department of Information Science and Engineering, BMSIT, Bengaluru, Karnataka, India. He has 19 years of teaching experience in the engineering program. He has received the Education Excellence Award and has NPTEL Elite certification. His research interest is in the domain of cloud computing, microcontrollers, software engineering, and machine learning. He has published articles in various national and international journals indexed in Scopus and Web of Science. He has both administrative experience and teaching experience. He can be contacted at email: narasimhamurthyms@bmsit.in.

Thara Dharmapura Krishnamurthy graduated from Sri Siddhartha Institute of Technology with a bachelor's degree in the branch of Computer Science and Engineering. She secured post-graduation with a Master of Technology from AMC College Bangalore in the branch of Computer Science and Engineering. Awarded with Ph.D. degree in the field of machine learning and deep learning in the year 2022 from Visvesvaraya Technological University, Belgaum, India. She is also serving as Professor and Head of the Department of Information Science Engineering at Channabasaveshwara Institute of Technology, Tumkur, Karnataka, India. She has 15 years of teaching experience and has published articles in various national and international journals indexed in ACM, Scopus, and Web of Science. Her research interests include data mining, data analytics, machine learning and deep learning. She can be contacted at email: thara.dk@cittumkur.org.