International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Design and Development of a Dataset of Indian Rose Plant Leaves for Scientific and Agricultural Applications

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ABSTRACT:

This research presents a high-quality, annotated image dataset of Indian rose plant leaves to support AI-based disease detection. A total of 596 images, including healthy and diseased leaves, were collected from various rose varieties. The dataset is preprocessed and augmented for machine learning use. By addressing the lack of Indian rose-specific datasets, this study aims to improve disease classification accuracy and support advancements in precision agriculture and floriculture research.

Keywords : AI, Agriculture, Data set

1. Introduction:

The cultivation of roses (*Rosa* spp.) has a rich and diverse history that spans across continents and centuries. Originating in ancient Persia, the rose soon spread throughout Asia, becoming one of the most culturally significant and economically valuable flowers. Its aesthetic appeal, therapeutic properties, and symbolic significance have earned it an esteemed place in the cultural, religious, and medicinal traditions of many civilizations.

1.1 Indian History of Rose :

In India, the rose holds a special place in history, tradition, and agriculture. Its earliest references are found in ancient texts like the *Rigveda*, where roses are mentioned for their use in medicine and religious rituals. The *Ramayana* also notes the use of roses in royal adornment. Over the centuries, roses became deeply embedded in Indian culture symbolizing love, devotion, and beauty. They are widely used in weddings, festivals, and spiritual offerings.

India's cultural relationship with the rose extends to practical applications as well. Rose water and rose oil (attar) are essential components of Indian cuisine, cosmetics, and Ayurvedic medicine. Events such as the annual Rose Festival in Chandigarh highlight the enduring popularity and significance of the flower in modern Indian life. In literature and art, the rose frequently appears as a metaphor for divine beauty and romantic expression.

1.2 Historical Roots :

The Mughal era significantly influenced rose cultivation in India. Emperors like Babur and Jahangir were known for their elaborate rose gardens, often filled with imported varieties such as Damask and Bourbon roses. These rulers popularized the rose as a symbol of luxury, refinement, and imperial grandeur**.**

Although the rose's origins trace back to Persia, it has been cultivated in numerous countries including Bulgaria, France, and Italy. In India, rose cultivation thrives in the cooler climates of Kashmir, Bihar, Uttar Pradesh, and Punjab. The unique soil and atmospheric conditions in these regions contribute to the distinctive fragrance of Indian roses.

From a botanical perspective, roses are not only admired for their beauty but also studied for their reproductive biology. The flowers contain both male and female reproductive organs, and pollination is facilitated by insects like bees. Roses exist in numerous species and cultivars, ranging from thorny shrubs to climbers and miniature plants. Their blooms vary widely in color, size, and fragrance.

1.3 Characteristics of Rose Leaves:

Rose leaves play a critical role in the plant's survival and productivity. They are pinnate, meaning they have a central rib with several leaflets arranged on either side. The leaves grow alternately along the stem, optimizing light exposure for photosynthesis. Their sizes typically range from 3 to 20 cm, often with tiny prickles on the underside and symmetrical vein structures.

Throughout the growing season, rose leaves exhibit a spectrum of green hues and may turn golden or red in autumn. In many species, new leaves appear reddish before turning green. The leaf shapes vary across cultivars, with some like the swamp rose (*Rosa palustris*) having elongated leaves. Medicinally, rose leaves have been used in Ayurveda for treating ailments like diarrhea and intestinal ulcers due to their anti-inflammatory and aphrodisiac properties.

1.4 Applications of the Rose Plant

The versatility of the rose plant extends across multiple domains:

- **Cosmetics and Beauty**: Rose extracts and essential oils are key ingredients in perfumes, skincare products, and hair treatments.
- **Culture and Symbolism**: Red roses symbolize love, while roses in general have historical associations with mythology, royalty, and warfare (e.g., the War of the Roses).
- **Food and Drink**: Rose hips are rich in vitamin C and are used in jams, jellies, and teas. Rose water is a staple in Middle Eastern and Indian desserts.
- **Health and Medicine**: Traditional medicine systems, including Ayurveda and Chinese medicine, utilize various parts of the rose plant for their therapeutic properties.

1.5 Horticulture in India

India is one of the major producers of roses globally, cultivating several varieties across diverse climatic regions. Among the most commonly grown rose varieties in India are the Edward Rose, Andhra Red Rose, Button Rose, and Paneer Rose. These varieties thrive particularly well in the plains of Tamil Nadu, where optimal horticultural conditions—such as daytime temperatures around 26°C and nighttime temperatures around 15°C—are naturally available. The ideal soil for rose cultivation is well-drained sandy loam with a pH of 6–7, coupled with a minimum of six hours of bright sunlight daily. These conditions are prevalent across several southern states, making them favorable zones for large-scale rose cultivation.

Northern Indian states such as Himachal Pradesh, Uttar Pradesh, Kashmir, and Rajasthan are also significant contributors to the country's rose production. In Kashmir, common cultivars include the Kashmiri Rose, Dhar Rose, and Bulgarian Rose, predominantly used in rose oil (attar) production. In Uttar Pradesh, the Edouard Rose—used in cosmetic formulations—and Paneer Rose—popular in garlands—are widely cultivated. Rajasthan, with its rich soils and water availability in specific regions, also supports rose farming. The Himalayan Musk Rose, a wild variety with distinctive five-petalled flowers and yellow-tinged branches, is found at altitudes ranging between 1200–1400 meters. Its petals are traditionally used in attar production.

Despite favorable growing conditions, rose plants are susceptible to numerous diseases and pests that severely affect yield and quality.

Common Diseases :

- **Black Spot Disease:** Caused by the fungus *Diplocarpon rosae,* black spot is one of the most destructive rose diseases. It typically thrives during warm, wet conditions in spring. Symptoms include circular black lesions surrounded by yellow halos, leading to premature leaf drop and stunted plant growth.

- **Powdery Mildew:**This disease is caused by *Podosphaera pannosa* and appears as a white or gray powdery coating on young leaves, shoots, and buds. It results in leaf curling, discoloration, and deformation. The disease is especially prominent in areas with high nighttime humidity and poor air circulation.

Major Pests

- **Rose Chaffer Beetle :** These beetles, about ½ inch long, emerge in early summer and feed on rose foliage in large groups. Though short-lived, their impact is significant, particularly in regions with sandy soils like parts of Uttar Pradesh and Rajasthan.

- **Flower Caterpillar (*Lozotaenia forsterana*) :** The green larvae bore into buds and hide within curled leaves. Their feeding creates "shot holes" in the leaves and damages flowers, often leading to significant aesthetic and commercial loss.

1.6 Need for Digital Monitoring

Given the variety of diseases and pests affecting rose plants, accurate and timely diagnosis is essential. Conventional monitoring methods are labor-intensive and often inconsistent. In this context, a structured digital dataset of rose leaves can facilitate automated disease detection, species classification, and plant health assessment using machine learning and computer vision techniques.

This study aims to develop a comprehensive image dataset of Indian rose plant leaves, labeled by domain experts. The dataset comprises **600 images** captured using smartphones (12–13 MP resolution) at different growth stages, under varying conditions and distances. Each image is annotated with metadata such as plant condition, disease type, and leaf maturity, forming a robust resource for AI-based agricultural applications.

1.7 Motivation

Recent advancements in artificial intelligence, particularly in machine learning and computer vision, have significantly enhanced the capabilities of automated plant disease detection. However, the performance of these technologies heavily depends on the quality, diversity, and specificity of the training datasets.

Most existing datasets used in plant pathology research are limited in scope—focusing on select crops, standard lighting conditions, and generic disease categories. They rarely address the **region-specific challenges**, disease prevalence, and cultivar diversity present in Indian horticultural environments, particularly in rose cultivation.

India, being a major producer and exporter of roses, cultivates a wide range of species that are vulnerable to a host of fungal, bacterial, and insect-borne diseases. Despite this, there is a notable **lack of curated datasets** that focus exclusively on **Indian rose leaves**. This absence poses a significant obstacle to developing accurate AI tools for disease detection and rose variety classification.

This research is motivated by the need to fill this critical gap by designing and developing a **specialized dataset** that captures the unique features, environmental conditions, and disease profiles of **Indian rose plants**. The resulting dataset aims to support advanced diagnostic models, precision agriculture tools, and further research in floriculture.

1.8 Hypothesis:

This research hypothesizes that a well-organized and specifically labeled dataset focused on Indian rose plant leaves can significantly improve the performance of machine learning models in disease detection and classification. Existing datasets often lack specificity and do not comprehensively represent the unique disease profiles found in Indian cultivars. By creating a high-quality dataset with annotated images detailing disease types and severity levels, it is expected that trained models will exhibit higher precision, recall, and overall accuracy compared to those trained on generic plant datasets. The anticipated outcome is an increase in diagnostic accuracy, facilitating more reliable automated tools for use in agriculture and floriculture.

1.9 Significance of the study :

The dataset's development will be a valuable asset for plant pathology and computer vision researchers and professionals. It will allow for the development of more precise and sturdy models for identifying and categorizing diseases, ultimately contributing to improved plant health management practices. Furthermore, this dataset can serve as a benchmark for future research and developments in agricultural technology. By filling in the gaps in current data and concentrating on the specific requirements of Indian rose plants, this study aims to advance the current state of plant disease diagnostics and promote the sustainable growth of India's floriculture industry. By filling in the gaps in current data and concentrating on the specific requirements of Indian rose plants, this research aims to advance the current state of plant disease diagnostics and promote the sustainable growth of India's floriculture industry.

2. Literature Review :

The primary objective of this literature review is to conduct a comprehensive examination of existing research related to plant disease detection and dataset development, with a special emphasis on rose plants. This review helps in understanding previous methodologies, identifying research gaps, and informing the development of a high-quality dataset specific to Indian rose plant leaves.

Swetharani and Prasad (2020) presented a study titled *"Design and Implementation of Efficient Rose Leaf Disease Detection Using K-Nearest Neighbors"*, where they emphasized the early detection and classification of rose leaf diseases to reduce agricultural losses. Traditional methods for disease identification are acknowledged as time-consuming and knowledge-intensive, prompting the development of an automated detection system. Their model integrated feature extraction with supervised learning, particularly the k-nearest neighbors (KNN) classifier, to accurately classify plant diseases. The researchers employed datasets from Kaggle and UCI repositories, although these were not specific to rose leaves. Despite computational limitations and moderate accuracy, the study demonstrated the efficacy of supervised learning for precise disease identification in rose plants.[1]

Ashok Kumar, Pankaj Kumar, and Kalpana Suman (2023) developed an artificial intelligence-based framework titled *"Automated Plant Disease Diagnosis Using Deep Learning Model"*. This research focused on early disease detection in rose plants using robotic imaging and computer vision. The system utilized texture features through Grey Level Co-occurrence Matrix (GLCM) and applied fuzzy logic for disease classification and grading.

Techniques such as K-means clustering and image segmentation were employed to isolate and diagnose affected leaf regions. Although the model achieved an accuracy of 70%, limitations remain in generalizability across diverse environmental conditions. The study significantly contributed to the field by combining fuzzy logic with AI and GLCM for enhanced disease recognition.[2]

Sazzad et al. (2022) introduced a dataset-centric study titled *"RoseNet: Rose Leave Dataset for the Development of an Automation System to Recognize the Diseases of Rose"*. Their work focused on developing an extensive rose leaf dataset encompassing both healthy and diseased samples categorized into Blackspot, Downy Mildew, and Fresh Leaf. The dataset was constructed through a systematic image acquisition and preprocessing pipeline, including color space transformations, segmentation, feature extraction, ranking, and classifier application. The use of natural and artificial lighting under varying conditions increased the dataset's robustness. The open-access nature of the dataset and comprehensive guidelines for its usage position this work as a key resource in rose plant disease detection.[3]

Malik et al. (2022) explored classification algorithm performance in the study titled *"A Performance Comparison of Classification Algorithms for Rose Plants"*. Their research involved capturing high-resolution rose leaf images and applying various classification algorithms including Naive Bayes, Generalized Linear Model, Multilayer Perceptron, Decision Tree, Random Forest, Gradient Boosted Trees, and Support Vector Machine (SVM). After preprocessing the images using tools like CVIP and performing statistical feature extraction, SVM yielded the highest accuracy (72%). This study highlights the superiority of ensemble classifiers and optimization of parameters such as tree depth and splitting criteria for enhanced classification performance.[4]

Varsha Sawarkar and Seema Kawathekar (2018), in their review paper *"A Review: Rose Plant Disease Detection Using Image Processing"*, focused on image processing techniques for early disease detection. The research detailed steps such as image acquisition, preprocessing, segmentation, feature extraction, and classification. The authors analyzed multiple classifiers, including neural networks, SVM, fuzzy logic, and KNN, but found SVM to be the most effective despite its complexity. The review pointed out limitations in current methodologies and emphasized the need for further exploration of hybrid and ensemble techniques for improved performance.[5]

Paper No./ Parameters	1	2	3	4	5
Methods Used	1. Feature extraction process and supervised learning mechanism are used to classify diseases. 2. Formulation of a novel automated system for plant disease detection.	Utilizing a deep learning and image processing approach, the system incorporates segmentation techniques, textures, colors, and deep learning methods for disease detection.	Image Acquisition, Preprocessing, Feature Extraction, Data Balancing, and Classifiers are used.	The study analyzed the performance of classification algorithms: Naive Bayes, GLM, MLP, Decision Tree, Random Forest, Gradient Boosted Trees, and SVM.	ANN, SVM, back propagation algorithm, Gabor filter, SGDM, KNN, neural networks, fuzzy classifier, color analysis, and feature-based rules are employed for plant disease classification and detection.
Contributions	Introducing an automated system for plant disease detection utilizing advanced learning mechanisms, with a particular focus on identifying rose plant diseases such as anthracnose, mildew, rust, and leaf spot.	It introduces the use of computer vision technology combined with fuzzy logic for disease detection and grading, utilizing texture features extracted through GLCM and	Dataset usage guidelines, open access datasets, supervised by Shamim Kaiser, with no competing financial interests declared.	Proposes ML-based rose type identification via leaf features, optimizing Random Forest parameters for accuracy, and showing ensemble classifiers superior	Detection of rose plant diseases using digital image processing techniques, application of image processing for plant disease diagnosis with high accuracy, and utilization of

		enhancing system accuracy with SURF, DENSE, and Bag of Visual Words.		performance.	SVM and KNN methods for plant disease
Limitations	Current solutions are ineffective and suffer from computational complexity problems. There is currently no solution that offers high accuracy when it comes to classifying plant diseases.	There could be restrictions in effectively identifying and classifying plant diseases in various situations, even when utilizing segmentation techniques and machine learning models.	The research does not specifically mention any limitations regarding the dataset or methodology used in the research.	The paper does not explicitly mention any limitations or constraints of the study.	The complexity of SVM compared to KNN in plant disease detection highlights the need for further exploration of other classification methods beyond SVM and KNN.
Results	The new system effectively identified diseases in rose plants with great precision by using a supervised learning KNN classifier for disease classification.	There could be restrictions in effectively identifying and classifying plant diseases in various situations, even when utilizing segmentation techniques and machine learning models.	Dataset FlowerNet is utilized for disease recognition with machine learning models. The images were captured with the help of natural and artificial light from various perspectives and backgrounds.	Results indicate that SVM obtains the highest accuracy of 72% on feature set FS1, suggesting that the performance of ensemble classifiers is superior to that of individual models.	In this paper, SVM and artificial neural network are used for rose plant disease detection, with the SVM classifier aiming for more accurate results in saving rose plants.

In conclusion, prior research has progressively improved methods of disease detection in rose plants through AI, image processing, and machine learning. However, there remains a pressing need for region-specific, high-quality datasets particularly for Indian rose varieties which this study aims to address.

3. Objective:

The main aim of this study is to develop a comprehensive, labeled image dataset of Indian rose plant leaves for disease detection and classification. The objectives include:

- To collect high-quality images of rose leaves from diverse regions, species, and varieties across India.
- To annotate each image with disease type, severity, leaf condition, and related metadata, in collaboration with plant pathologists.
- To preprocess the dataset by applying normalization and augmentation techniques (e.g., rotation, scaling, color correction).

- To create a clean and noise-free dataset to ensure better machine learning model performance.

4. Data Collection and Methodology :

This section provides a comprehensive explanation of the dataset construction process for Indian rose plant leaf disease detection. The dataset was curated by collecting images of rose plant leaves from a local botanical garden, under the supervision of an expert cultivator. All images were captured in a controlled environment to ensure uniformity in lighting and background conditions, which enhances the quality and reliability of the dataset.

The geographical characteristics of the collection site have been documented (see Table 3.1), as these factors significantly influence the variety of rose plants and the prevalence of specific diseases. Recognizing this, the researchers included location-specific information to provide contextual relevance to the dataset.

The collected images were categorized into two primary classes: **diseased** and **healthy**. This classification forms the basis for training machine learning models aimed at early disease detection. Such predictive systems are intended to support cultivators by minimizing crop losses through timely intervention.

Table 3.1

Subject	Computer Science
Specific subject area	Image processing, Image classification, Image detection, and computer vision.
Type of data	Images
How the gathered data were	First, the rose garden is chosen by examining the areas in India where these gardens are most commonly found. A consummate in the field have chosen the specific garden which has plenty of rose production and containing the plant's leaves which are healthy and disease affected. In a time period from February to April, by using smartphone's 12MP camera and the captured image's resolution is 720*1440 IPS. All the images were captured under the supervision of a expert.
Data format	Raw
Description collection of data	The collected data were not pre-treated in any way with the help of domain specialist and the cultivator of the plant. The images were meticulously obtain from the rose garden.
Data source location	**Nursery:** Ajay Nursery **City:** Bhadgaon Road, Chalisgaon, Maharashtra 424101 **Country:** India
Location's Geographical details	**Longitude:** 75.0063° E , **Latitude:** 20.4619° N **Sea Level:** 344 meters above mean sea level. **Climate Zone :** 1) **Average Temp (°C/°F) :** 29.92/85.86 2) Precipitation (mm/in) : 109.3/4.3 3) Humudity : ~43%
Data accessibility	**Repository name:** Mendeley Data Data identification number (permanent identifier, i.e., DOI number): Direct link to the dataset:https://data.mendeley.com/preview/rh3ms8ddh8

4.1. Image Collection

We have created a photo gallery that highlights rose leaves, whether they are diseased or healthy. The majority of the photographs were taken in the local nurseries and botanical gardens. All the images were captured in geographical conditions with a humidity of about 43%, an average temperature of 29.92

°C, and a height of 344 meters above sea level. All the related geographical details are elucidated in a more detailed way in **Table3.1.** There are 596 photographic photos in this collection as a whole. The total images of healthy leaves are 414 and disease-affected leaves are 182, respectively. Sample images from each category are shown following images**.**

			
Healthy Leaves		**Unhealthy Leaves**	

4.1.1 Data Acquisition :

The RGB color pictures of the leaf are shot with smart phone cameras with pixel sizes of 1480 x 720 pixels for a clean image. Each of the captured pictures is 225KB to 1MB in size. These pictures have been cropped into smaller ones of 300×300 pixel size. Using the python image analysis library, images are saved in JPEG format.

4.1.2 Image Pre-processing:

The work of image preprocessing entails noise removal and image enhancement. A leaf picture with a resolution of 300×300 pixels is utilized. The RGB images are converted to gray scale to enhance accuracy. Converting to gray scale helps eliminate unnecessary information from the images and aids in computational processing. Filtering the image's noise is done before any further processing. In this case, a smoothing filter is applied. To improve contrast, use contrast enhancement techniques such as histogram equalization and contrast modification.

4.1.3 Data Augmentation

The images we captured were not sufficient to create a dataset. That's why we have enhanced our images by rotating, scaling, flipping, color adjustments, cropping, and enlarging them. In addition to this, we have also rotated and zoomed in and out high-resolution images, and thus the process of augmentation is complete.

4.2 DATA COLLECTION :

In this section, we gathered the data because machine learning algorithms learn from the available data or evidence. Mistakes in data collection are easily propagated to the training phase of the data and affect the performance of classifiers. That's why we collected the data very carefully. By using the two devices, the first one is a Samsung SM-J600G Galaxy J6 J600G, and the second is a Redmi 6 Dual-SIM 64GB Smartphone with cameras of 13MP and 12MP, respectively. Also, the remaining features of both of the devices are discussed in **Table 3.2.** The images that are captured have a resolution of 1480 x 720 pixels. All the images were in a controlled environment, keeping the light condition the same for every image. And in this, we have captured images of the Orange, Pink, Red, Yellow, and White and their respective varieties colored rose plant leaves (please see **Fig. 3.4**). Also, we have calculated their measurements, and according to those measurements, researchers have categorized the captured images into three types - small, large, and medium. During the research, after calculating the sizes of the gathered rose leaves, we found that the average size for large leaves is 7 cm x 4 cm, the average size for medium leaves is 3.5 cm x 2 cm, and the average size for small leaves is 1.5 cm x 1 cm. Researchers have further categorized them into diseased and healthy categories. And the collected data is elucidated in a more detailed way in the following **Table 3.3, Table 3.4**, and **Table 3.5**, respectively.

	Table 3.2
Samsung Phone:	Samsung **SM-J600G Galaxy J6 J600G DUOS 32GB** Smartphone. The Galaxy J6 features a 5.6" HD (1480 x 720 pixels)+ Super AMOLED Infinity Display, 13MP Rear Camera, 8MP Front Camera with 3-Level LED Flash, Rear f/1.9 Aperture
Redmi Phone:	The Data was collected with a **Redmi 6 Dual-SIM 64GB** Smartphone,which features dual rear 12MP + 5MP Cameras and front-facing 5MP Camera. It has a depth sensor for better portraits. 5.45" 720 x 1440 IPS LCD display; 2.0 GHz ARM Cortex-A53 Octa-Core CPU

Table 3.3 Size Distribution of Leaves Dataset (Device 1)

Sr.No	**Rose Color**	**Size**				**Total**
		Small	**Medium**	**Large**	**Diseases**	
1	Light Pink	7	4	9	7	27
2	Orange	10	16	20	17	63
3	Pink	6	6	7	13	32
4	Red	11	8	17	18	54
5	White	7	8	12	11	38
6	Yellow	3	3	4	4	14
7	Yellow Blend	2	3	3	5	13

Table 3.4 Size Distribution Of Leaves (Device 2)

Sr.No	**Rose Color**	**Size**				**Total**
		Small	**Medium**	**Large**	**Diseases**	
1	Light Pink	7	4	9	7	27
2	Orange	10	16	19	17	62
3	Pink	11	9	13	18	51
4	Pink French Rose	4	2	4	2	12
5	Pink Miniature Rose	5	6	8	10	29
6	Red	11	10	19	19	59
7	Red Miniature Rose	4	3	4	4	15
8	White	7	8	12	11	38
9	Yellow	13	9	13	14	49

Table 3.5 Detailed Description of Datasets Collected according to Devices

Lens	**Type of Leaves**		**Total**
	Healthy Leave	**Disease Leave**	
Samsung Galaxy J6	166	75	241
Redmi 6	248	107	355
			Total= 596

We have collected a sample size of 596 to create a dataset with the objective of recognizing diseases on rose plant leaves, and the dataset is easily accessible at {https://data.mendeley.com/preview/rh3ms8ddh8}. Also, this dataset can be used for further research. While creating a dataset, we captured at least 10–20 pictures of every major species from the locality under the same climate conditions and under the same light exposure. Then we have categorized them into disease and healthy leaves and also categorized them size-wise, which makes it easier to recognize the disease of the respective leaves.

4.3 DATASET DESCRIPTION

This article presents an extensive dataset of rose leaf images, both disease- affected and disease-free are classified into various species classes like Orange, Pink, Red, Yellow, White and their respective varieties (please see **Fig. 3.4**).

Fig. 3.4 Leaves of different colored roses, (a) Orange rose, (b) Pink rose, (c) Red rose, (d) Yellow rose, and (e) white rose. The leave images are from the dataset

4.4 RESEARCH GAPS AND LIMITATION

Limitations:

- The geographic scope of data collection may not capture all environmental conditions and disease variations across India.
- Reliance on manual annotation introduces the risk of human error and subjectivity in disease classification.

Gaps:

- Need for longitudinal data to understand disease progression over time.
- Limited exploration of advanced machine learning techniques like deep learning and transfer learning.
- Need for more user-friendly tools and mobile applications for real-time, on-field diagnostic support

5. CONCLUSION AND FUTURE WORK :

In conclusion, this research has successfully developed a comprehensive and annotated dataset of Indian rose plant leaves, significantly contributing to the field of plant disease detection. The dataset's high-quality images and precise annotations will facilitate the training of accurate machine learning models for diagnosing rose plant diseases.

For future work, it is recommended to expand the dataset to include more diverse samples from various regions and seasons. Additionally, integrating non-visual data, such as soil health and climate information, could enhance the diagnostic accuracy of the models. Exploring advanced machine learning techniques like deep learning and creating user-friendly diagnostic tools for real-time field use would further increase the practical utility of the dataset.

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