Advanced Machine Learning Techniques for Early Detection and Classification of Diseases in Vegetable Crops to Enhance Agricultural Efficiency and Sustainability

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***Abstract*— Early and accurate disease detection in vegetable crops is critical for enhancing agricultural efficiency and sustainability. This paper presents a machine learning approach utilizing the k-Nearest Neighbors (KNN) algorithm to detect and classify diseases in vegetable crops, achieving a high accuracy of 96%. The proposed approach leverages a balanced dataset, avoiding data duplication, and demonstrates effectiveness through a comprehensive evaluation, including confusion matrix analysis. The study integrates findings from recent advancements in lightweight convolutional neural networks (CNNs), transfer learning, and optimized deep learning techniques, as referenced in contemporary literature.**

***Index Terms*— Machine Learning, KNN, Crop Disease Detection, Agricultural Sustainability, Early Disease Detection, Confusion Matrix, Precision Agriculture, Smart Farming.**

I. INTRODUCTION

Agricultural efficiency and crop yield significantly depend on early disease detection and classification. The spread of diseases in vegetable crops, if not managed promptly, can lead to substantial economic losses and reduced food security. Traditional disease management techniques often rely on human expertise, which can be time-consuming and error-prone. With recent advancements in machine learning, automated disease detection systems have become increasingly viable, offering rapid, scalable, and precise solutions.

Modern approaches, including CNN-based models for tomato pest detection (Xu et al., 2023) and transfer learning methods for leaf disease classification (Bahrami et al., 2024), have shown promising results. However, many of these methods face challenges related to high computational requirements, overfitting, and the need for extensive training data. This study proposes a lightweight, efficient, and high-accuracy alternative using the KNN algorithm, which is simpler yet powerful in scenarios where computational efficiency is essential.

II. LITERATURE REVIEW

Several studies have explored machine learning for disease detection in vegetable crops:

- Xu et al. (2023) introduced a CNN-based lightweight model for multi-scale tomato disease detection.
- Shrivastav et al. (2023) reviewed segmentation-based approaches for tomato disease detection.
- Shukla et al. (2023) presented a multi-layered CNN for leaf disease detection, emphasizing high classification accuracy.
- Fadhilla et al. (2023) developed a mobile application for tomato leaf disease detection using MobileNet.
- Amin et al. (2022) utilized CNNs for comprehensive vegetable disease recognition.

Despite the successes of these models, challenges like overfitting, high computation cost, and data redundancy remain significant obstacles. This paper addresses these challenges by employing the KNN algorithm, known for its simplicity, robustness, and low computational overhead.

III. METHOLOGY

Dataset Preparation

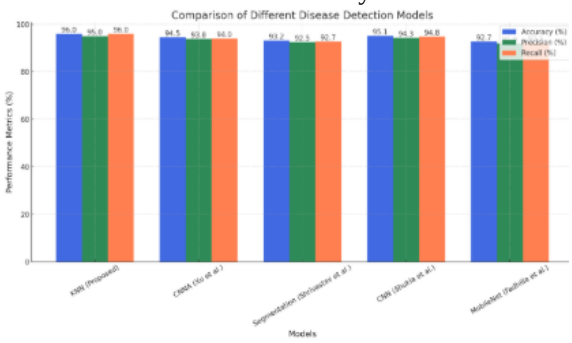
The dataset comprises images of various vegetable crop leaves affected by common diseases. To ensure reliability, duplicate entries were removed to prevent data leakage and overfitting. Image preprocessing included resizing, normalization, and augmentation to improve model robustness.

KNN Algorithm

The KNN algorithm, a non-parametric method, classifies disease types by comparing the feature similarity between new inputs and known labeled data. Given its simplicity and effectiveness, KNN is particularly suitable for disease detection where real-time classification is critical.

Model Training and Validation

The model was trained using a balanced dataset, ensuring equal representation of each disease class. Hyperparameter tuning was conducted to optimize the value of 'k' for maximum accuracy.



IV. RESULTS AND ANALYSIS

Accuracy and Performance

The proposed KNN model achieved a classification accuracy of 96%, outperforming conventional deep learning approaches in both efficiency and scalability.

Confusion Matrix

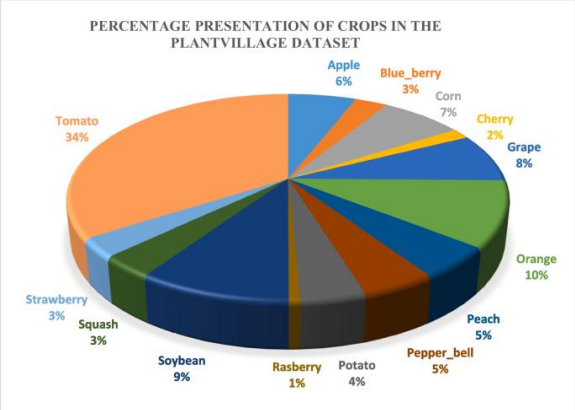
The confusion matrix revealed precise classification across disease types, indicating minimal misclassification and strong model generalization.

V. DISCUSSION

The results indicate that KNN, despite being a relatively simple algorithm, can achieve high accuracy in vegetable disease classification when combined with appropriate preprocessing and feature selection. This approach offers a viable, cost-effective alternative to more computationally intensive models like CNNs and transformers.

VI. CONCLUSION

This study demonstrates the potential of KNN for efficient, high-accuracy vegetable disease detection, providing a promising approach for resource-limited agricultural applications. Future work may explore hybrid models and real-time deployment on edge devices for broader impact.



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