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Research Paper

Transfer Learning Framework for Precise Multi-Disease Classification in Cauliflower Leaves

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ABSTRACT

Early identification of foliar diseases in cauliflower crops is essential to prevent yield losses and support sustainable agriculture. Traditional methods rely on manual visual inspection, which is subjective, time-consuming, and dependent on expert availability, making large-scale monitoring challenging. With advancements in digital agriculture and Machine Learning (ML), automated disease detection systems offer improved accuracy and faster decision-making. This study proposes Leaf Guard AI, a lightweight and efficient disease detection framework based on a hybrid Inception Residual Network Convolutional Neural Network (IRNCNN) architecture integrated with a Tkinter-based Graphical User Interface (GUI). The system preprocesses input images, extracts hierarchical deep features, and classifies cauliflower leaf diseases into eleven distinct categories with high precision. To evaluate performance, baseline models including Logistic Regression (LR), Decision Tree (DT) Classifier, and Artificial Neural Network (ANN) are implemented for comparison, demonstrating the superiority of the proposed Deep Learning (DL) model. Additionally, the system incorporates a Telegram Bot interface, enabling farmers and agricultural practitioners to upload leaf images via mobile devices. The bot performs real-time analysis and returns classification results along with diagnostic insights, enhancing accessibility and usability. Experimental results show that the proposed model achieves an accuracy exceeding 99%, indicating strong robustness and generalization capability. By combining advanced Deep Learning techniques with user-friendly desktop and mobile interfaces, Leaf Guard AI facilitates automated and real-time disease detection, supporting timely crop management, improved monitoring, and increased agricultural productivity.

Keywords: Cauliflower leaf diseases, foliar disease detection, image preprocessing, feature extraction, classification system, graphical user interface, Tkinter, Telegram bot, real-time analysis, digital agriculture.

1. INTRODUCTION

The amount of arable land all over the world is constantly decreasing due to increasing population and industrialization. Approximately 70% more food is needed to feed the overpopulation [1]. Especially in Asia and Africa, where producers own small lands, agricultural lands are under pressure to produce for human nutrition. As global food demand increases, stricter environmental protection regulations and sustainability rules are put forward to prevent agricultural expansion and deforestation [2]. Today, there is no opportunity to increase the agricultural areas, and the per capita agricultural area is decreasing due to the increase in human population.

To date, many methods such as increasing the yield with breeding techniques, using genetically modified organisms, and application of chemical fertilizers and pesticides are used to provide the food

needed for the increasing world population. While each method has its own advantages and disadvantages, there is still a need for production techniques that are not harmful for ecology and comply with the principles of sustainable agriculture [3]. One of the most effective methods to increase the productivity and use of labor in an area is to use the soil intensively by obtaining more than one product per year, especially in places where the climate is suitable. This can be achieved by cultivation of several annual crops that mature in a short time together or in succession [4].

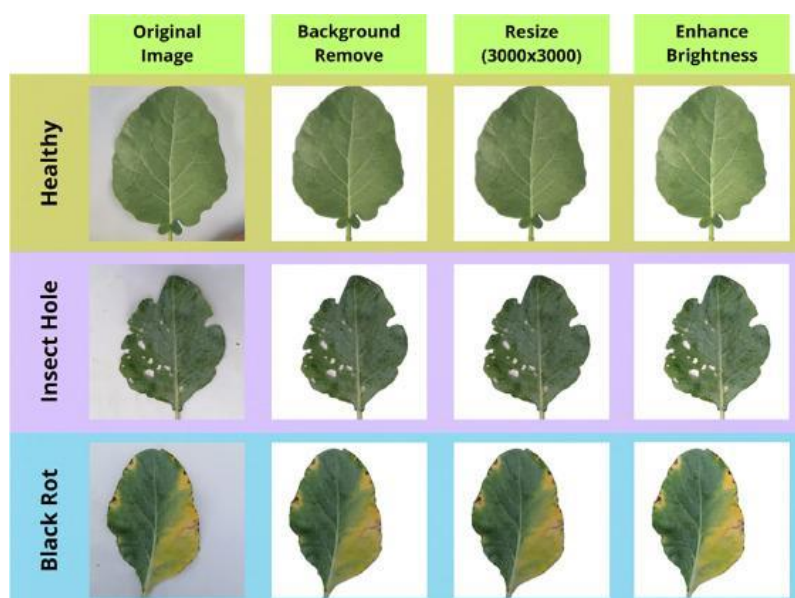


Fig. 1: Cauliflower foliar diseases

Agricultural diversity and its effective management are also of great importance for sustainable agriculture [5]. Sustainable agriculture aims to use nature as a model for designing agricultural systems. Intercropping is a diversified farming practice included in sustainable farming techniques and is a method to increase the diversity in the agro ecosystem [6]. Intercropping refers to the cultivation of two or more plants together in the same place and at the same time. Intercropping has many benefits such as increasing the use of environmental resources, obtaining more efficiency compared to sole cropping, providing disease, pest and weed control, protecting soil fertility that improves product quality, preventing erosion, increasing land use efficiency in low-input agricultural systems. It can also reduce the risk factor for farmers since it provides more stable yields. The species to be grown with intercropping should not adversely affect the growth of the main crop, should not compete with the main crop, and should be a species that provides an advantage in the cultivation of the main crop and generates more income with the main crop from the unit area than the monoculture.

Cauliflower (*Brassica oleraceae* var. *botrytis*) belongs to the Brassicaceae family and is a good source of minerals, vitamins, phytochemicals, and carbohydrates (Fig. 1). Similarly, leaf lettuce (*Lactuca sativa* L. var. *crispa*) also contains necessary elements for human nutrition. Both cauliflower and lettuce are cool climate vegetables and are grown widely in Turkey with a total annual production of 235,000 tons (9100 ha) and 234,000 tons (9600 ha), respectively. It is necessary to increase the yield to be obtained from the unit area due to the limited or even decreasing possibilities of expanding the agricultural lands.

2. LITERATURE SURVEY

Singh, et al. [7] Indicated that cauliflower showed a wide adaptability to temperature and humidity. Regarding the application of Arg, the data show that the foliar application did not produce significant differences in any parameter, except for L*. These results are like the results found by other authors. Considering that Singh et al. Collado-González, et al. [8] Reviewed cauliflower consumption has

increased due to its observed beneficial effects on human health, especially on chronic diseases. Furthermore, the use of arginine has been shown to improve the heat stress tolerance of plants by increasing the polyamine content. Thus, we aimed to investigate the effects of the exogenous application of arginine on the physical and chemical quality parameters of cauliflower florets under heat stress.

Turan, et al. [9] Presented the Intercropping systems are one of the sustainable agricultural models as they play an important role in protecting soil fertility, efficient use of resources, maintaining stable yields, and reducing the effectiveness of diseases and pests. The aim of this study was to investigate the effects of intercropping (IC) cauliflower (*Brassica oleracea* L. var. botrytis) with leaf lettuce (*Lactuca sativa* L. var. crispa) on the yield and quality parameters of cauliflower and to evaluate the overall productivity of the system under different nitrogen fertilization rates (160, 200, and 240 kg N ha⁻¹). Our results showed that the leaf chlorophyll value (SPAD), plant weight, leaf weight, head diameter, head height, head weight, and total yield of cauliflower were found to increase as the nitrogen dose increased in both the monocropping (MC) and IC systems.

Olsen et al. [10] Focused on Electrical conductivity (EC) was measured in saturation extracts according to Rhoades. Soil pH was determined in 1:2 extracts, and calcium carbonate concentrations were determined according to Soil organic matter (OM) was determined using the Smith Weldon method according to Nelson and Sommers. Ammonium acetate buffered at pH 7 was used to determine exchangeable cations. Microelements in the soils were determined by diethylenetriaminepentaacetic acid (DTPA) extraction methods. Nimkar, S.A. et al [11] Reviewed Cauliflower is an important vegetable crop of the family Brassicaceae and is grown in many countries across the globe. The name cauliflower originated from the Latin words 'Caulis' and 'Floris', which means cabbage and flower, respectively. It has been rightly described as the "Aristocrat of cole crops" and is grown throughout the world for tender white curds.

Akter, et al. [12] Presented the world's cauliflower production and consumption in 2020 were 25.50 million metric tons. Asia is the biggest producer of cauliflower accounting for 75% of the world's production. In 2020, the cauliflower cultivation area of Bangladesh was 54.25 thousand acres, and its production was approximately 283.16 thousand metric tons. Prodhan, et al. [13] Aimed to evaluate the influence of gibberellic acid on both concentration and time of application on the seed production ability of BU cauliflower-1. The experiment was conducted to determine seed production ability at five concentrations of GA₃: G₀ = Control, G₁ = 100 ppm, G₂ = 200 ppm, G₃ = 300 ppm, G₄ = 400 ppm, along with four application times at different growth stages including T₁ = Foliar application at 3 weeks after planting, T₂ = Foliar application at 4 weeks after planting, T₃ = Foliar application at 5 weeks after planting and T₄ = Foliar application at 6 weeks after planting.

Balibrea, et al. [14] Followed a brief, 50 mg of inner and outer leaves was lyophilized and finely ground in a Moulinex grinder (AR110830); incubated twice with 1.5 mL of extraction buffer (MeOH/water (80:20, v/v) at 4 °C, for 30 min each time; and centrifuged for 15 min at 3500× g, at 4 °C. Then, each sample supernatant was filtered through an activated C18 Sep-Pak cartridge (Waters Associates, Milford, MA, USA) that had been previously activated. The activation of that cartridge was carried out by washing with 20 mL of methanol/water (80%/20%, v/v). Santos et al. [15] Reported that excessive heat stress in broccoli crops was specifically harmful in the differentiation phase of flower buds. However, this damaging effect was reduced when heat stress was applied after the flower buds were already formed. The effect of temperature gradient on the growth of Brassicas depends mainly on several important factors, such as the crop and variety used, the exposure time, the intensity of stress, and the growth stages when heat stress is applied.

3. PROPOSED SYSTEM

This research presents an intelligent and automated system designed to detect and classify cauliflower foliar diseases using advanced computational techniques. The system addresses the challenges of manual disease identification by integrating ML, DL, and image processing within a unified desktop application. It enables efficient analysis of leaf images, ensuring accurate recognition of multiple disease categories that commonly affect cauliflower crops. The design focuses on handling real-world agricultural datasets, improving diagnosis consistency, and supporting timely disease management practices.

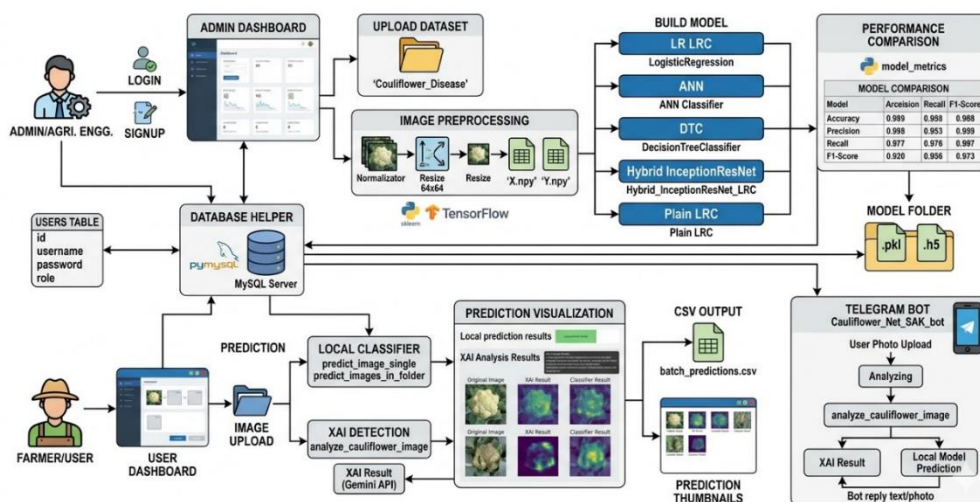


Fig. 2: System architecture for cauliflower foliar diseases

The application is developed using a Tkinter-based GUI, allowing users to seamlessly interact with various modules, including dataset loading, preprocessing, model training, evaluation, and prediction as shown in Fig. 2. It incorporates multiple classification models such as LR, DT, ANN, and a hybrid IRNCNN based, each contributing to a comprehensive understanding of disease patterns. Through structured training and performance measurement, the system evaluates each model using accuracy, precision, recall, F1-score, confusion matrices, and ROC curves, offering a complete analytical view of the disease detection process.

In addition to its processing capabilities, the system supports role-based access for administrators and general users. Admins can manage datasets, train models, and monitor performance, while users can perform batch predictions on new leaf images. This makes the application suitable for agricultural researchers, quality control teams, and field consultants who require reliable tools for large-scale leaf analysis. By combining automation, scalability, and visual output generation, the research contributes to enhancing disease monitoring efficiency and aligns with the growing trend of data-driven agriculture.

4. RESULTS ANALYSIS

The results description section presents the key findings of the study in a clear and organized manner. It highlights the outcomes obtained after analyzing the collected data, often using tables, graphs, or summaries for better understanding. This section focuses on factual observations without interpretation or bias. It helps readers see patterns, trends, or relationships identified during the research. The results directly relate to the objectives or hypotheses of the study. It provides a concise overview of what the research discovered.

Fig. 3 IRNCNN: The confusion matrix exhibits perfect diagonal dominance with all classes correctly classified. There are no misclassifications, demonstrating that the IRNCNN effectively extracts

hierarchical and subtle leaf features. This confirms the model's superior capability for multi-class disease detection, ensuring reliable and real-time support for farmers and agricultural experts.

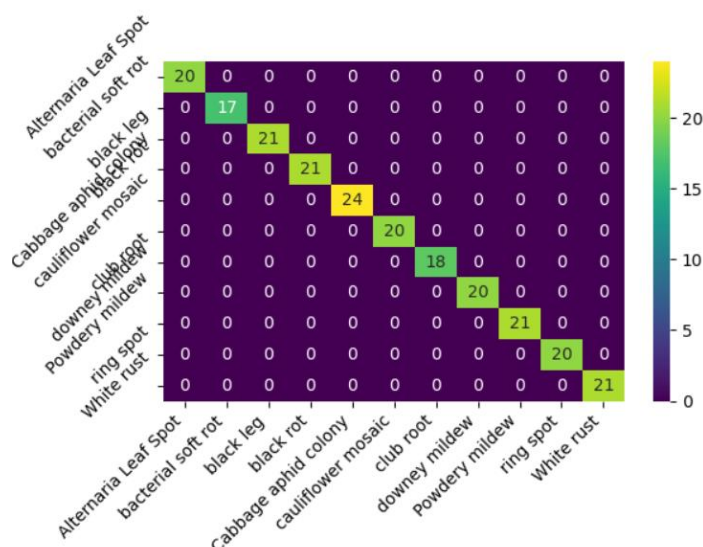


Fig. 3: Obtained confusion matrix of IRNCNN

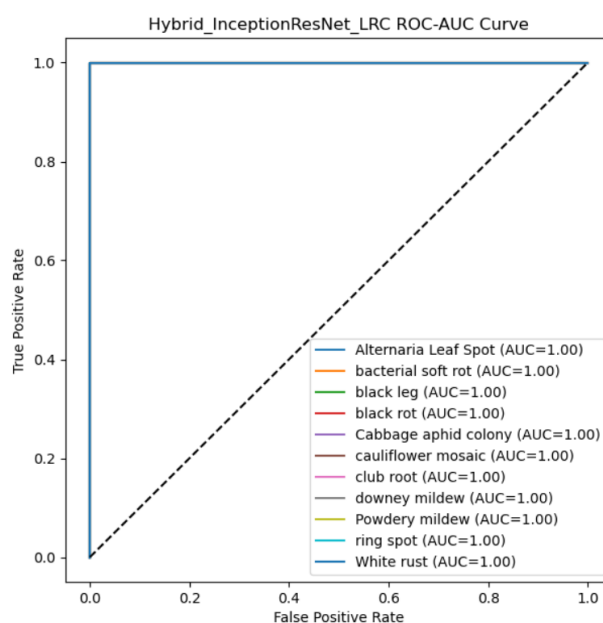


Fig. 4: Obtained ROC-AUC curve of IRNCNN

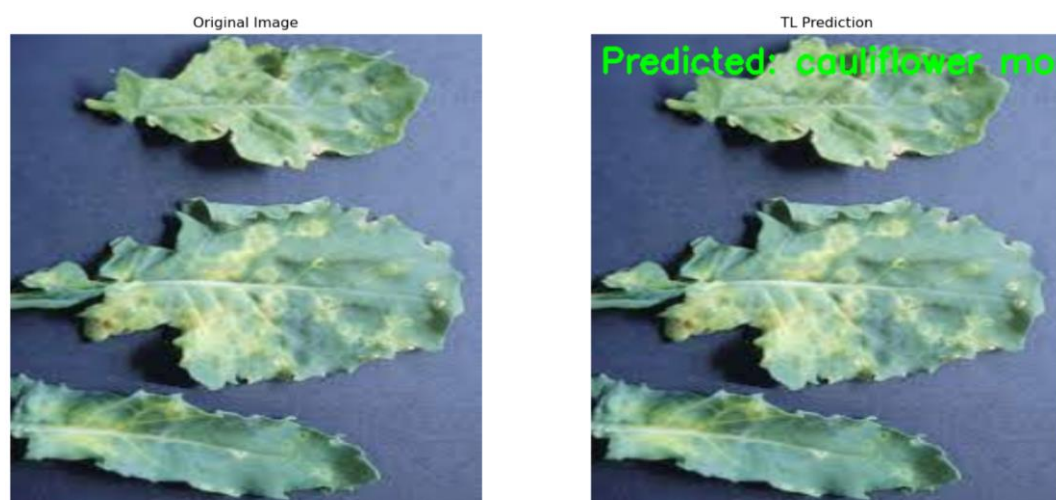
Fig. 4 hybrid IRNCNN: The ROC-AUC curves reach the maximum value of 1.0 for all eleven disease classes. This indicates flawless discrimination between classes, demonstrating that the IRNCNN successfully extracts high-level hierarchical features from cauliflower leaf images. The results confirm the model's robustness and suitability for real-time disease detection, enabling precise decision-making for farmers and agricultural practitioners.



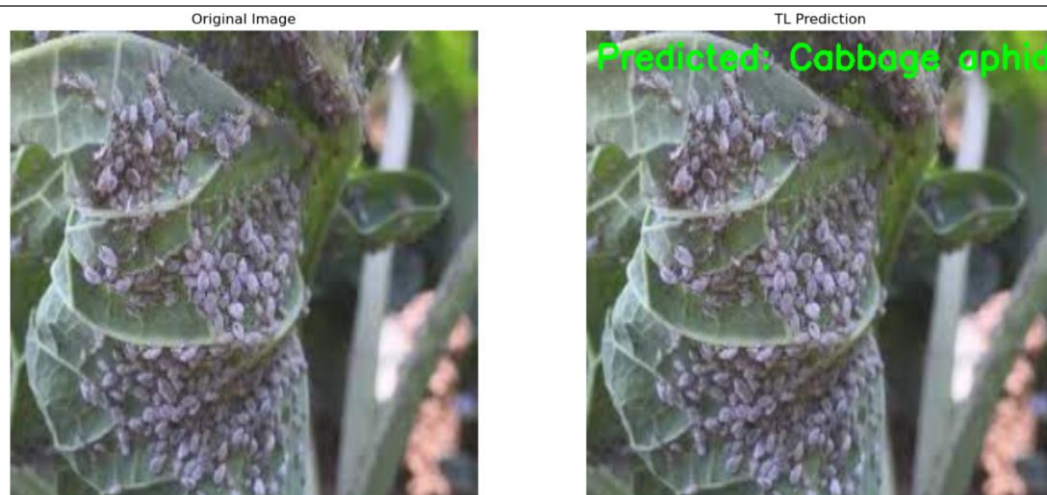
(a)



(b)



(c)



(d)

Fig. 5: Predictions on single test Image. (a) bacterial soft rot, (b) Alternaria Leaf Spot, (c) cauliflower mosaic, (d) Cabbage aphid colony.

Fig. 5 demonstrates the Leaf Guard AI system performing inference on a single cauliflower leaf image. The input image is pre-processed to standardize size, normalize pixel values, and enhance relevant leaf features.

Fig. 5 (a) Bacterial Soft Rot – The input leaf exhibits tissue softening and discoloration patterns. The IRNCNN model correctly identifies the characteristic water-soaked lesions and classifies the leaf with high confidence.

Fig. 5 (b) Alternaria Leaf Spot – The leaf shows small, dark circular spots with yellow halos. The model extracts fine-grained textural features to accurately detect the infection.

Fig. 5 (c) Cauliflower Mosaic – Symptoms include mosaic-like discoloration across the leaf surface. The hierarchical feature extraction captures both the irregular vein patterns and color variations, enabling precise classification.

Fig. 5 (d) Cabbage Aphid Colony – The leaf surface displays visible insect clusters. The model detects the aggregated aphid patterns and distinguishes this pest-related disease from fungal and bacterial infections.

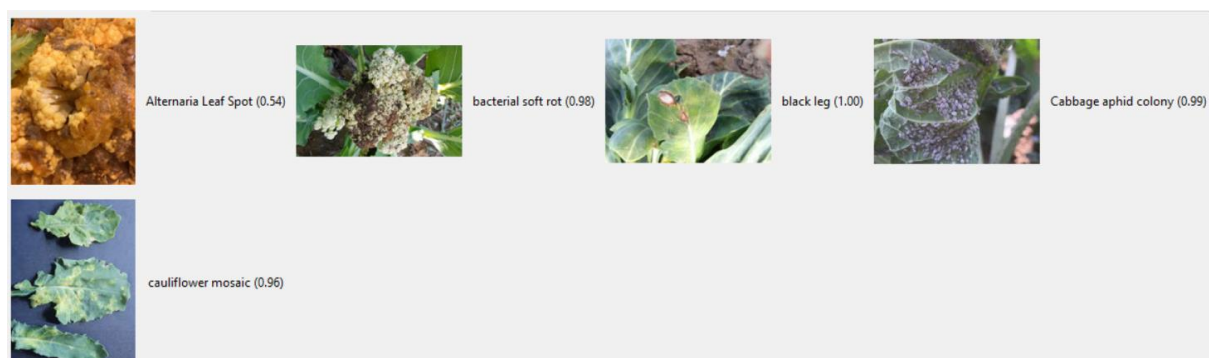


Fig. 6: Batch Predictions on Test Images

Fig. 6 showcases the system performing batch processing on multiple leaf images simultaneously. The model processes each image through the preprocessing and feature extraction pipeline, followed by disease classification for all samples in a single execution. The results are displayed in a tabular or

visual format showing predicted classes and confidence levels for each leaf. Batch predictions reduce processing time for large datasets, enabling farmers and researchers to monitor multiple plants quickly, ensuring timely detection of infections across a field.

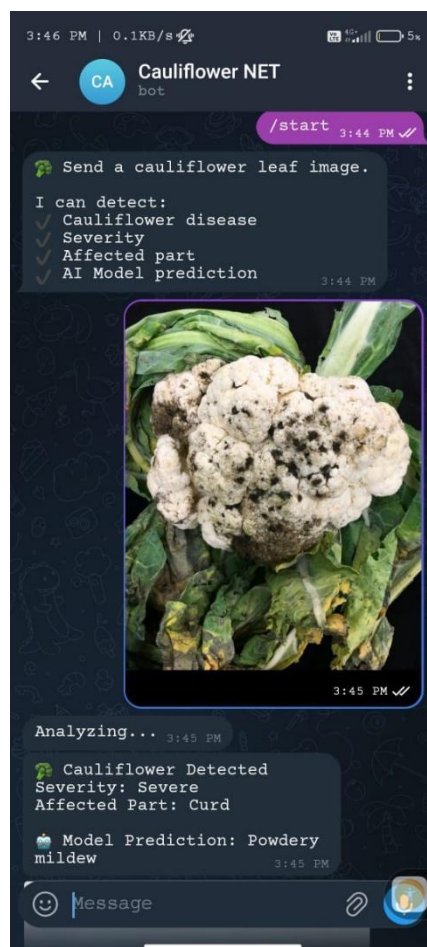


Fig. 7: Predictions with Telegram Bot

Fig. 7 illustrates the integration of the Leaf Guard AI system with a Telegram Bot interface. Users upload cauliflower leaf images directly from their mobile devices, and the IRNCNN model performs real-time disease detection. The system returns the predicted disease along with relevant diagnostic information, including confidence scores and suggested management actions. This mobile-accessible deployment demonstrates the system's practical applicability in field conditions, supporting farmers with immediate decision-making without requiring desktop access or expert intervention.

4.1 Comparative Analysis

Table 1 presents a comparison of four classifiers applied to cauliflower leaf disease detection. The LR model achieves high accuracy of 91.48% and demonstrates good overall performance, but struggles with subtle variations such as Powdery mildew and cauliflower mosaic. The DT model performs well on visually distinct classes but shows poor generalization for similar-looking diseases, resulting in an accuracy of 54.71%. The ANN model fails to learn discriminative features for multi-class classification, producing the lowest accuracy of 22.87% and misclassifying multiple disease types. In contrast, the proposed IRNCNN achieves perfect performance with 100% accuracy, precision, recall, and F1-score, effectively capturing both hierarchical and subtle features in leaf images. These results highlight the superiority of IRNCNN for automated, real-time disease identification in cauliflower crops, demonstrating robustness, high generalization, and suitability for practical deployment. The comparison

clearly shows that deep learning outperforms traditional ML classifiers in handling complex visual patterns of multiple foliar diseases.

Table. 1: Performance comparison of classification models

Classifier Model	Accuracy	Precision	Recall	F1-Score	Key Observation
LR model	0.9148	0.9271	0.9162	0.9175	Good baseline; struggles with subtle foliar variations like Powdery mildew and cauliflower mosaic.
DT model	0.5471	0.7834	0.5486	0.5840	Performs well on distinct classes but poor generalization on visually similar diseases.
ANN model	0.2287	0.2620	0.2187	0.1480	Fails to learn discriminative features for multi-class classification; largely misclassifies several diseases.
IRNCNN	1.0000	1.0000	1.0000	1.0000	Perfect classification; effectively captures hierarchical and subtle disease features.

5. CONCLUSION

The LeafGuardAI system successfully demonstrates an efficient, automated approach to identifying cauliflower foliar diseases using a combination of ML and DL techniques. Through systematic preprocessing, the system standardizes image quality and reduces noise, enabling models to learn meaningful disease patterns. LR, DT and ANN provide baseline classification performance, while the hybrid IRNCNN significantly enhances accuracy by extracting deeper spatial features from leaf images. The integration of multi-scale convolutions and residual connections contributed to faster convergence and better generalization compared to traditional architectures. Batch prediction and real-time inference further validate the model's practicality for field-level disease monitoring. The GUI built with Tkinter enhances usability, allowing even non-technical users to operate the system seamlessly. Performance evaluations, including accuracy, precision, recall, and confusion matrices, highlight the robustness of the proposed approach. By saving trained models and pre-processed datasets for future reuse, the system also minimizes computation time and improves overall efficiency. Thus, LeafGuardAI stands as a reliable and scalable solution for early detection of cauliflower diseases and can serve as a valuable decision-support tool for farmers and agricultural practitioners.

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