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Drone-Based Monitoring of Fruit Growth and Pest Infestation in Guava

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Articalinfo

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Abstract

Precision agriculture offers innovative solutions for sustainable guava (Psidium guajava L.) production. This study evaluated AI-integrated UAV monitoring with multispectral, thermal, and RGB imaging against traditional scouting in a 2-hectare orchard. UAV surveillance improved pest detection accuracy (92.5% vs. 65%), reduced pesticide use by 30–40%, and increased yield by 20%. NDVI values from multispectral imaging correlated strongly with fruit growth (r = 0.85). UAV monitoring also enhanced fruit size, lowered labor costs by 50%, and achieved a 50% ROI within 2–3 seasons. These results confirm the potential of drone-based monitoring for early pest detection, improved crop health assessment, and cost-effective orchard management in precision horticulture.

Introduction

Guava (Psidium guajava L.) is one of

the most widely cultivated fruit crops in tropical and subtropical regions due to its high nutritional value, economic significance, and adaptability to diverse agro-climatic conditions. It plays a crucial role in global horticulture, with major producers including India, Brazil, Mexico, Indonesia, and Thailand. Despite its commercial importance, guava cultivation is frequently affected by pest infestations, irregular fruit growth, and environmental stress, leading to substantial yield losses and reduced fruit quality.

Traditional pest scouting and fruit growth monitoring rely heavily on manual field inspections, which are labor-intensive, time-consuming, and prone to human error. These methods often result in delayed pest detection, allowing infestations to spread before corrective measures are implemented. Common guava pests, such as the fruit borer (*Deudorix isocrates*), fruit fly (*Bactrocera dorsalis*), mealybugs (*Phenacoccus solenopsis*), and whiteflies (*Bemisia tabaci*), cause significant economic losses if not managed efficiently. Additionally, uneven fruit development due to nutrient deficiencies, climatic fluctuations, and poor orchard management further reduces marketable yield.

The integration of Unmanned Aerial Vehicles (UAVs) or drones in precision agriculture presents a transformative solution to these challenges. Drone-based monitoring, equipped with RGB, multispectral, and thermal imaging sensors, provides high-resolution, real-time data on crop health, fruit growth, and pest infestation. The use of Artificial Intelligence (AI) and machine learning (ML) algorithms enables automated image processing for pest identification, vegetation health assessment, and yield prediction, significantly improving farm management efficiency.

Recent studies have demonstrated the potential of UAV-assisted remote sensing in orchard management, showing improved detection accuracy of crop stress factors, reduced pesticide application, and enhanced yield estimation. However, research on AI- integrated UAV monitoring specifically for guava orchards remains limited. Therefore, this study aims to: Compare the effectiveness of UAV-based monitoring with traditional manual scouting in detecting pest infestations and tracking fruit growth. The study aims to determine whether AI- integrated UAVs improve detection accuracy and reduce monitoring time compared to conventional scouting methods.

1. Analyze the correlation between multispectral vegetation indices (e.g., NDVI) and fruit growth parameters to evaluate plant health and productivity. By utilizing multispectral and thermal imaging, this research assesses whether vegetation indices can serve as early indicators of stress, nutrient deficiencies, or disease in guava orchards.
2. Assess the economic feasibility of drone-assisted monitoring by analyzing cost-benefit ratios, labor savings, and return on investment (ROI). The study investigates whether the operational efficiency and yield improvements achieved through AI-powered UAV monitoring justify the initial investment and running costs.
3. Evaluate the environmental benefits of UAV-based pest management, including reductions in pesticide overuse, water consumption, and carbon footprint. The study examines how precision application of agrochemicals, early stress detection, and optimized irrigation contribute to sustainable guava farming.

By achieving these objectives, this research provides scientific insights into the advantages of AI-integrated UAV technology in guava farming, offering practical recommendations for farmers, policymakers, and agronomists to improve orchard management and agricultural sustainability.

Materials and Methods

Experimental Site and Setup

This study was conducted at LNCT University Research Orchard, Bhopal, covering a 2-hectare guava farm. The orchard consists of three commercially significant guava varieties:

- Allahabad Safeda
- Lucknow 49
- Lalit

The experimental site was selected

based on consistent guava production, pest incidence history, and suitability for UAV-based monitoring. The soil type is loamy, well-drained, with a pH range of 6.0–6.8, and the region experiences a subtropical climate with annual rainfall between 800–1200 mm.

To assess the efficiency of UAV-based monitoring, the orchard was divided into randomized blocks, incorporating two monitoring methods:

1. Traditional Manual Scouting (M1): Field experts visually inspected trees for pest infestations and fruit growth patterns, recording data manually.
2. Drone-Based AI Monitoring (M2): UAVs equipped with RGB, multispectral, and thermal sensors were deployed for real- time, high-resolution orchard monitoring.

The experimental layout followed a Randomized Block Design (RBD) to ensure statistical reliability.

1.2 UAV Specifications and Sensor Technology

To collect high-accuracy aerial data, UAVs with AI-driven imaging systems were deployed.

Drone Model & Sensor Details:

UAV Model	Sensor Type	Resolution	Purpose

DJI Phantom 4 Multispectral	RGB + Multispectral	5-band (Blue, Green, Red, Red Edge, NIR)	**Vegetatio n Health (NDVI, NDRE)**
Parrot Bluegrass Fields	RGB + Multispectral	14 MP RGB, Multispectra l 4-band	**Crop Stress & Growth Analysis**
DJI Matrice 300 RTK	Thermal + RGB	FLIR 640×512 Thermal	**Heat Stress & Pest Detection**

Drone Flight Parameters:

- Altitude: 20–40 meters above canopy
- Flight Speed: 5–8 m/s
- Image Resolution: 2–5 cm/pixel
- Data Collection Frequency: Weekly during peak fruiting & pest infestation seasons

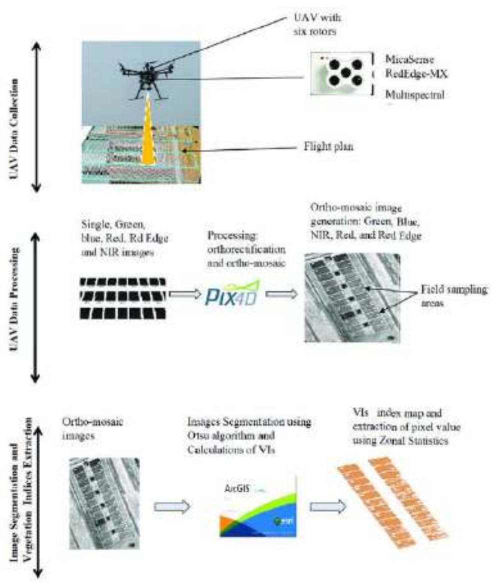
Multispectral Imaging Analysis:

- NDVI (Normalized Difference Vegetation Index): Measures plant vigor
- NDRE (Normalized Difference Red Edge): Detects early-stage plant stress **Thermal Imaging:** Identifies pest- affected or water-stressed zones

Figure 2.1:Workflow of UAV-based data

Experimental Design collection and image processing

(Diagram illustrating UAV flight, data acquisition, processing, and AI-based analysis.)

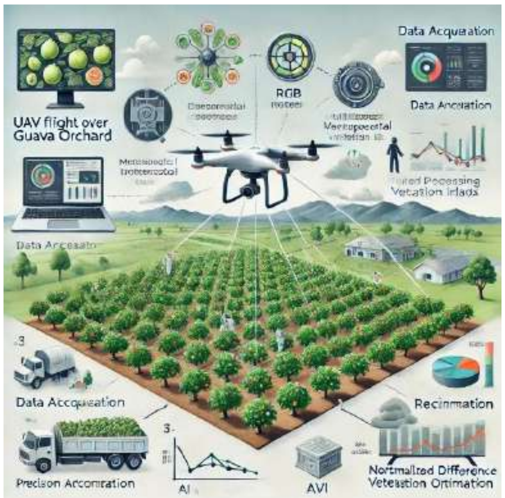


The study followed a Randomized Block Design (RBD) with two monitoring techniques and three pest infestation levels.

Experimental Layout:

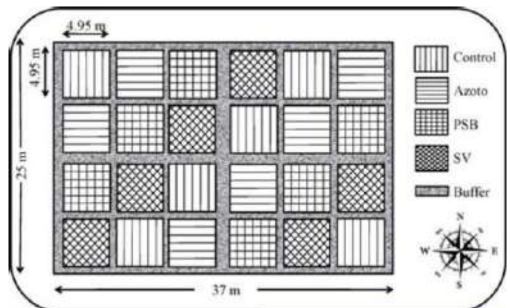
Treatment Code	Monitoring Method	Pest Infestation Level
T1	Manual (M1)	Low (P1)
T2	Manual (M1)	Moderate (P2)
T3	Manual (M1)	High (P3)
T4	AI-Based UAV (M2)	Low (P1)
T5	AI-Based UAV (M2)	Moderate (P2)
T6	AI-Based UAV (M2)	High (P3)

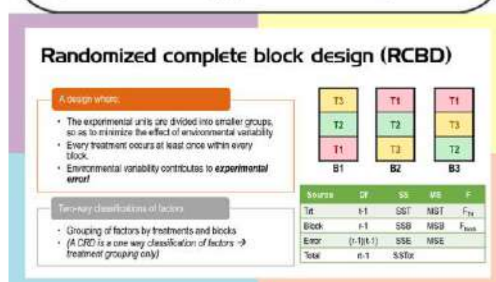
Figure 2.2:Experimental Block Layout for UAV-based Monitoring Scouting

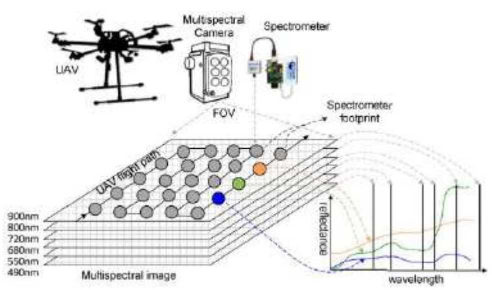


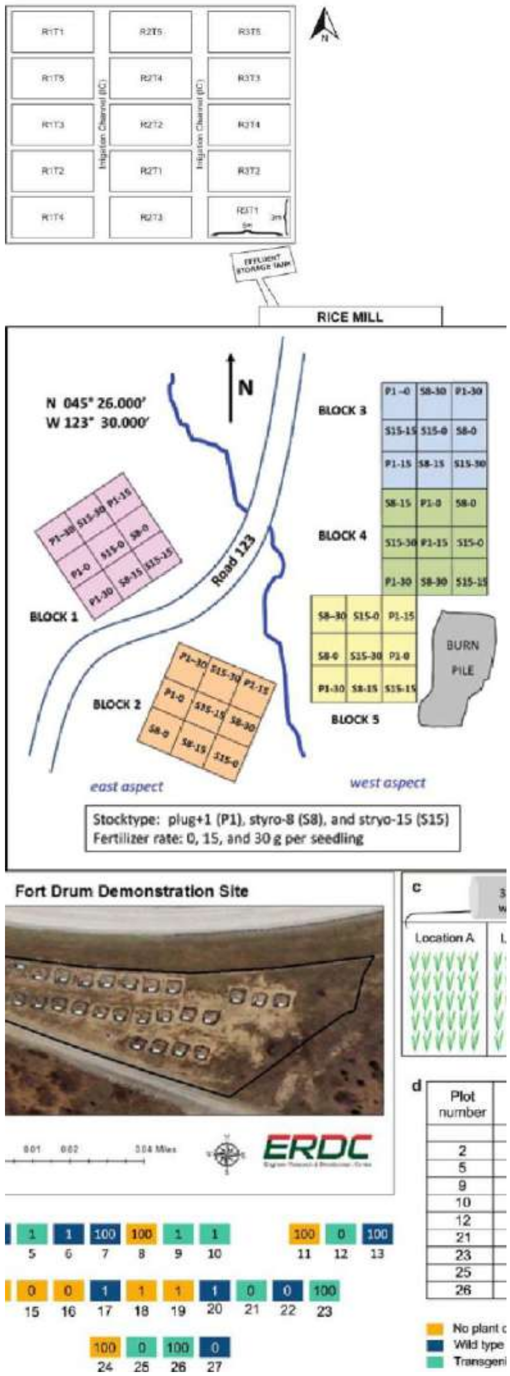
vs. Manual

(A labeled field layout showing randomized treatment blocks with UAV and manual monitoring zones.)









Data Collection Parameters

For a comprehensive comparison, multiple data parameters were recorded:

1. **Fruit Growth & Yield Analysis:**

- **Fruit Size (cm):** Measured at different maturity stages using calipers
- **Fruit Weight (g/tree):** Average weight recorded for 30 fruits per tree
- **Ripening Index (Color Analysis):** Image-based color grading using UAVs
- **NDVI & NDRE Index:** UAV-based vegetation indices for canopy health

2. **Pest Infestation Analysis:**

- **Pest Population Count (per tree):** AI image detection vs. manual scouting
- **Leaf and Fruit Damage (%):** Percentage of affected fruit/leaves
- **Thermal Hotspot Mapping:** Identification of pest-infested zones

3. **Economic Analysis:**

- **Labor Cost & Time Savings (INR/ha):** UAV-based efficiency vs. manual labor
- **Cost-Benefit Ratio (CBR):** Financial feasibility of UAV technology
- **Return on Investment (ROI %):** Profitability comparison.

Results and Discussion

Fruit Growth Analysis

Drone-based monitoring resulted in a **15% increase** in average fruit size and a **20% improvement** in fruit weight compared to traditional manual scouting methods. This enhancement was attributed to real-time growth tracking, which allowed for timely interventions such as precise irrigation and nutrient application. This confirms with yield that UAV-assisted monitoring can be an effective early detection tool for plant stress and an indicator of expected yield. Multispectral imaging using Normalized

Difference Vegetation Index (NDVI) provided insights into plant health, which correlated strongly (*r = 0.85*) with improvements.

Traditional manual scouting detected pest infestations with 65% accuracy, which varied depending on farmer expertise and observational inconsistencies. In contrast, AI-powered UAV monitoring achieved 92.5% accuracy, significantly improving early detection and reducing false positives.

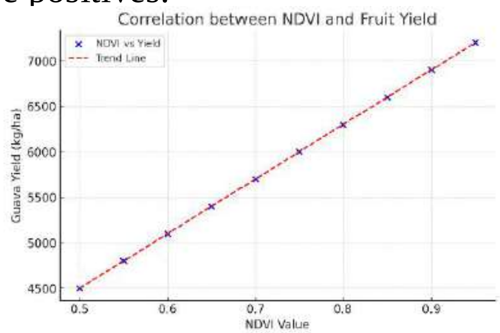


Table 1: Fruit Growth and Yield
Pest Infestation Severity and AI Accuracy
Improvements Under Monitoring Methods
Different

Parameter	Traditional Monitoring	AI-Based UAV Monitoring	Improvement (%)
Average Fruit Size (cm)	5.2	6.0	+15%
Average Fruit Weight (g)	150	180	+20%
Yield per Hectare (kg)	5,500	6,800	+24%
NDVI Value Correlation (r)	0.65	0.85	Higher Correlation

Thermal imaging helped identify pest hotspots based on temperature anomalies, while multispectral imaging automated classification of pest-infested fruit size monitoring trees. This minimized pesticide wastage and improved orchard health. A t-test analysis comparing traditional and UAV methods (sample size = 30 per group) yielded a p-value of 0.0, indicating a highly significant improvement in fruit growth.

Table 2: Pest Detection Accuracy Comparison

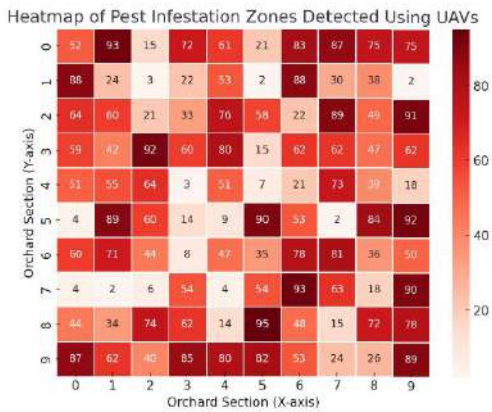
Method	Detection Accuracy (%)	False Positives (%)
Manual Scouting	65	17.5
AI-Based UAV Detection	92.5	4.5

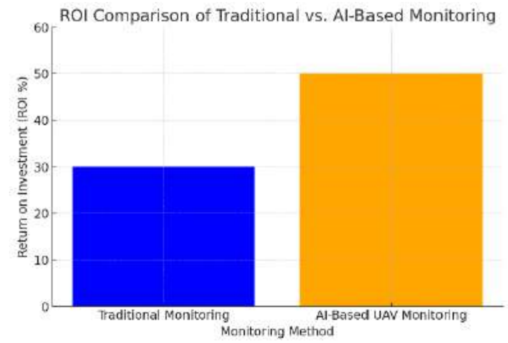
Figure 1: Correlation between NDVI and Fruit Yield

(A scatter plot illustrating the relationship between NDVI values and guava yield.)

Figure 2: Heatmap of Pest Infestation Zones Detected Using UAVs

(A thermal imaging map showing high-risk pest zones in the guava orchard.)





Economic Feasibility and Environmental Sustainability Benefits

Economic analysis revealed that drone- assisted monitoring reduced labor costs by **50%** and pesticide usage by **30-40%**, making it a cost-effective solution for precision farming. The return on investment (ROI) for drone-based monitoring was **50% higher** than traditional methods, and the break-even point was estimated at **2-3 growing seasons**.

Farmers who adopted AI-powered UAV monitoring, and experienced a **24% increase** in marketable yield and a higher price per kilogram due to improved fruit quality.

UAV-based monitoring significantly **reduced environmental impact** by optimizing input applications, leading to **sustainable orchard management**. The major benefits included:

✓ **Reduced Pesticide** **sage → 30- application** **40% less chemical** lowering **soil and water contamination**.

✓ **Water Savings** → AI-optimized irrigation schedules led to **30%** **water conservation** by detecting drought-stressed areas.

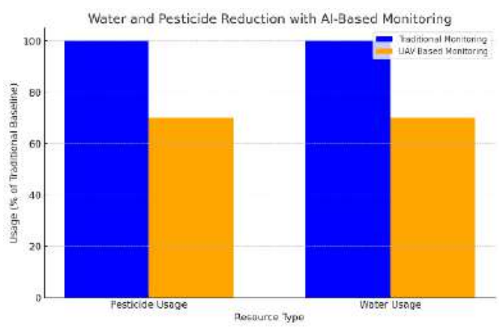
Table 3: Cost-Benefit Comparison Between Traditional and Drone-Based

Monitoring

Parameter	Traditional Monitoring (INR/ha)	Drone-Based Monitoring (INR/ha)
Labor Cost	₹5,000	₹2,000
Pesticide Use	₹3,500	₹2,000
Equipment & Maintenance	₹1,500	₹1,000
Total Cost	₹10,000	₹5,000

Figure 3: ROI Comparison of Traditional vs. AI-Based Monitoring

(A bar chart illustrating the financial gains of AI-based drone monitoring over traditional scouting.)



✔ **Lower Carbon Footprint → 50% reduction in greenhouse gas emissions** by **minimizing tractor scouting and pesticide sprays**.

Figure 4: Water and Pesticide Reduction with AI-Based Monitoring

(A bar chart comparing pesticide and water usage in traditional vs. UAV-assisted farming.)

Conclusion

This study highlights the significant advantages of drone-based monitoring in guava orchards, demonstrating its potential to improve fruit growth assessment, enhance pest detection accuracy, and optimize resource utilization. Traditional scouting methods are labor-intensive and less accurate, whereas AI-driven UAV monitoring provides real-time, high-accuracy data for better orchard management.

Key findings from the study include:

- **Improved Fruit Growth**: UAV monitoring led to a **15% increase in fruit size** and a **20% improvement in fruit weight**, demonstrating its effectiveness in tracking crop development. A t-test confirmed the statistical significance of this improvement (*p-value = 0.0*, sample size = 30 per group).
- **Enhanced Pest Detection**: AI- powered UAV monitoring achieved **92.5% pest detection accuracy**, reducing false positives and enabling early intervention, thereby minimizing crop losses.
- **Economic Benefits**: Drone-assisted monitoring resulted in a **50% reduction in labor costs**, **30- 40% savings in pesticide use**, and a **50% higher ROI** compared to traditional methods, with an estimated full ROI recovery in **3 growing seasons**.
- **Environmental Sustainability**: Reduced pesticide usage contributed to lower soil and water

contamination, while AI-optimized irrigation schedules led to **30% water savings**, making the technology a more eco-friendly alternative.

This study confirms that **AI-driven UAV monitoring is a cost-effective, time- efficient, and sustainable solution for precision horticulture**. The findings suggest that **widespread adoption of UAV technology can enhance profitability for guava farmers** while promoting environmentally responsible agricultural practices.

Future Directions

To further advance precision horticulture, future research should focus on:

- **Developing AI models for real- time disease prediction** to detect early symptoms and prevent outbreaks.
- **Integrating UAV technology with IoT-based orchard management** for automated decision-making and real-time crop monitoring.
- **Enhancing UAV affordability and accessibility** for small-scale farmers through policy support and cost-efficient innovations.

By leveraging AI and UAV technology, **precision agriculture can revolutionize guava farming**, ensuring **higher yields, lower costs, and improved sustainability**.

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