RAphids: Rapid phenotyping of plant resistance to aphids using smartphone imaging and deep learning

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Background

In plant breeding programs, **traditional assessment of plant-insect resistance using microscopes and hand lenses is labor-intensive, time-consuming, and prone to human error**. Accurate and digitalized phenotyping of plant-insect resistance is necessary, not only for faster screening, but also for extracting richer data and insights.

Objective

To develop a **low-cost mobile-based phenotyping method** that leverages smartphone imaging and deep learning to enable **rapid assessment of plant resistance to aphids**

Materials and Methods

Assay preparation

Five aphids (1-day old nymphs) were enclosed in individual clip cages. Each clip cage was attached to the leaves of plants of different genotypes and replicates (*Aphis gossypii* on pumpkin, *Aulacorthum solani* on pepper, and *Myzus persicae* on pepper and potato). After 9-12 days (depending on the crop), each leaf was cut and evaluated by experts through manual scoring under a microscope and by automatic scoring using RAphids.

Image data collection

The image of each leaf assay was taken using a smartphone attached to a phone holder, with white LED lighting support. A QR code label was attached to each leaf for sample tracking. The imaging setup is shown in Figure 1.

Each smartphone was installed with a mobile application called RAphids. RAphids is an interface used for acquiring images, managing trials, and managing samples. RAphids is connected to a remote server through an API for image analysis using a deep learning-based algorithm. Screenshots of RAphids is shown in Figure 2.

Three separate object detection models, based on YOLOv11, were trained for each aphid species. Each model was trained using tiled images, with two target classes: aphid nymph and aphid adult. The models were optimized based on tiling size and input size.

Figure 1. Imaging setup

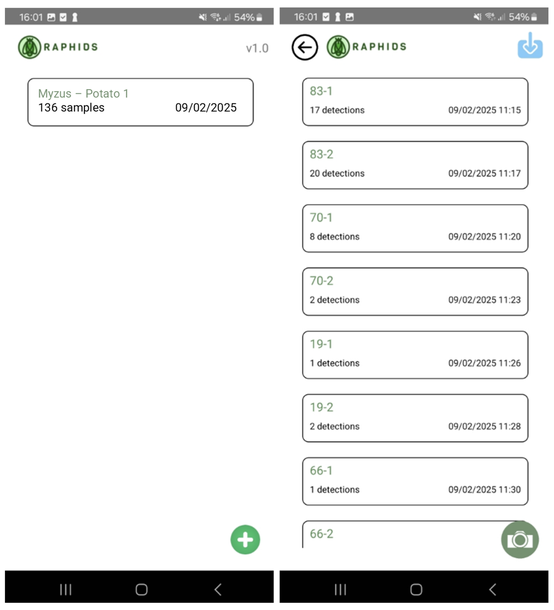


Figure 2. Screenshots of RAphids: (a) Trial management; (b) Sample management

Results

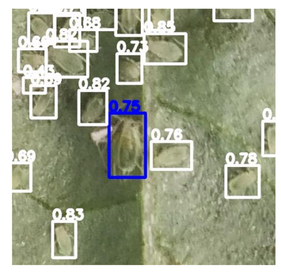
Comparison between manual vs. automatic aphid counts **shows high r^2 values, and no statistical differences**, as shown below:

Aphis gossypii

r^2_{nymph} = 0.92

r^2_{adult} = 0.67

r^2_{aphids} = 0.91



Myzus persicae

r^2_{nymph} = 0.97

r^2_{adult} = 0.54

r^2_{all} = 0.97

Aulacorthum solani

r^2_{nymph} = 0.95

r^2_{adult} = 0.87

r^2_{aphids} = 0.95

A sample image analysis output of RAphids is shown in Figure 3.

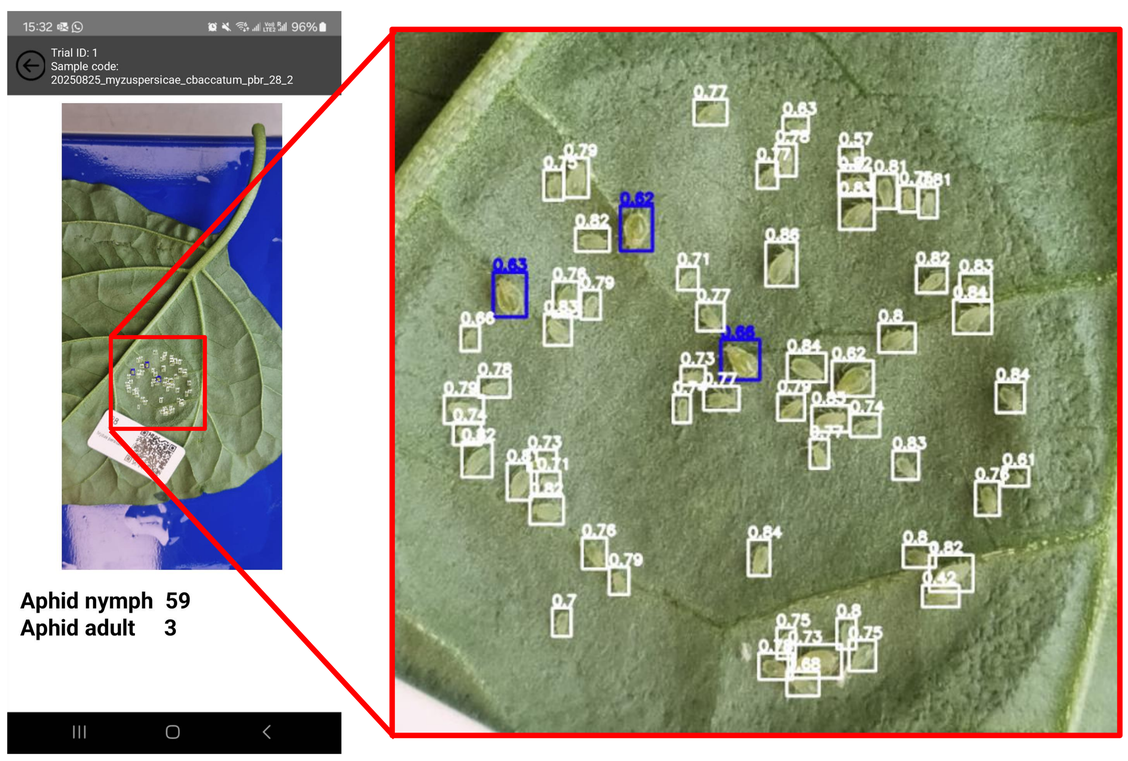


Figure 3. Sample image analysis result (*Myzus persicae* on pepper) using RAphids

Based on task time analysis, it takes an average of 7 seconds for RAphids to score one leaf, including image acquisition. Meanwhile, it takes about 1 minute to 2 minutes to manually score one leaf, depending on the number of aphids and leaf structure complexity. Therefore, there can be a maximum of 94% time reduction in scoring.

Conclusions

- A **low-cost solution** for accelerating plant-insect resistance scoring was developed
- RAphids acted as a **support tool** to reduce the effort in scoring plant-insect resistance under laboratory setups
- The **algorithm revealed high correlation** compared to expert manual count

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