

Research Report

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## Research on Insect Resistance Mechanisms in Loquat and Their Application in Pest Management

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**Abstract** Loquat (*Eriobotrya japonica*) is a valuable fruit crop with increasing global cultivation, but it faces significant challenges from pest infestations, which threaten yield and fruit quality. Enhancing insect resistance in loquat is crucial for sustainable crop protection. This study explores the mechanisms of insect resistance in loquat, focusing on plant structural defenses, phytochemical production, and genetic resistance mechanisms. Advances in molecular research, including the identification of resistance genes and breeding strategies, are also discussed. Integrated pest management (IPM) approaches that incorporate insect-resistant varieties are examined, with a case study demonstrating the effectiveness of these strategies in real-world loquat production. This study highlights the importance of developing insect-resistant loquat varieties as a sustainable solution to pest management challenges and outlines future directions for genetic enhancement and global application.

**Keywords** Loquat cultivation; Insect resistance; Pest management; Genetic resistance; Integrated pest management (IPM)

## 1 Introduction

Loquat (*Eriobotrya japonica* Lindl.) is a subtropical fruit tree native to southeastern China, widely cultivated for its sweet and tangy fruits. The cultivation of loquat has significant economic importance, particularly in regions such as China, Japan, and the Mediterranean, where it is a valuable fruit crop. The genetic diversity between wild and cultivated loquats has been a focal point of research, revealing insights into the domestication and breeding of improved varieties (Jing et al., 2022). The high-quality genome assembly of wild loquat has provided a comprehensive understanding of its genetic makeup, which is crucial for advancing breeding programs aimed at enhancing fruit quality and resistance to pests.

Insect pests pose a major threat to loquat cultivation, leading to substantial economic losses. The emergence of new pests, such as the bark beetle *Cryphalus eriobotryae*, has exacerbated the challenges faced by loquat growers. This beetle has been identified as a lethal pest in China, causing significant damage to loquat plantations and resulting in the death of numerous trees (Zheng et al., 2019). Effective pest management strategies are essential to mitigate these threats and ensure sustainable loquat production. Understanding the genetic and molecular mechanisms underlying insect resistance in loquat can provide valuable insights for developing resistant cultivars and implementing integrated pest management practices.

This study investigates the mechanisms of insect resistance in loquat and their application in pest management. By leveraging genomic, transcriptomic, and metabolomic data, this study identifies key genes and metabolic pathways involved in insect resistance; characterizes the genetic basis of resistance traits, understanding the role of specific genes in defense responses, and explores potential targets for breeding insect-resistant loquat varieties. Ultimately, this study aims to contribute to the development of effective pest management strategies that can enhance the resilience of loquat crops against insect pests, thereby supporting sustainable agricultural practices and improving fruit production.

## 2 Overview of Loquat Pests

### 2.1 Common pests affecting loquat

Loquat (*Eriobotrya japonica*) is susceptible to a variety of pests that can significantly impact its growth and yield. Among the most common pests are the Mediterranean fruit fly (*Ceratitis capitata*), the loquat fruit borer (*Cryptophlebia illepidata*), and various species of aphids and mites. These pests not only cause direct damage by feeding on the plant but also act as vectors for plant diseases, further exacerbating the problem (Bass and Jones, 2018; Horowitz et al., 2020).

### 2.2 Impact of pest infestation on yield and quality

Pest infestations in loquat can lead to substantial yield losses and a decline in fruit quality. For instance, the Mediterranean fruit fly lays eggs in the fruit, leading to larval development inside, which causes the fruit to rot and become unmarketable. Similarly, the loquat fruit borer tunnels into the fruit, causing internal damage that reduces both the aesthetic and nutritional value of the fruit. Aphids and mites, while smaller, can cause significant damage by sucking sap from the leaves and stems, leading to reduced photosynthetic capability and overall plant vigor. The cumulative effect of these pests can result in yield losses of up to 20% annually, which translates to significant economic losses for growers (Wang et al., 2022).

### 2.3 Traditional pest control methods

Traditional methods for controlling loquat pests have heavily relied on the use of synthetic insecticides. These chemical treatments have been effective in reducing pest populations and minimizing damage. However, the over-reliance on chemical pesticides has led to the development of resistance in many pest species. For example, pests such as the Mediterranean fruit fly and various aphid species have developed resistance to multiple classes of insecticides, including neonicotinoids and pyrethroids (Alhousari and Greger, 2018; Siddiqui et al., 2023). This resistance complicates pest management efforts and necessitates the development of integrated pest management (IPM) strategies that combine chemical, biological, and cultural control methods to sustainably manage pest populations (Gao et al., 2012; Zhu et al., 2016; Karaağaç, 2023).

In summary, while traditional pest control methods have been effective in the short term, the development of resistance and the environmental impact of chemical pesticides highlight the need for more sustainable and integrated approaches to pest management in loquat cultivation.

## 3 Mechanisms of Insect Resistance in Loquat

### 3.1 Plant structural defenses

Loquat plants, like many other plants, have evolved structural defenses to deter herbivorous insects. These defenses include physical barriers such as thickened cell walls, trichomes, and waxy cuticles that make it difficult for insects to feed on the plant tissues. Silicon accumulation in plant tissues can also enhance these physical barriers, making the plant less palatable or more difficult for insects to penetrate (Alhousari and Greger, 2018).

### 3.2 Chemical defenses: phytochemicals and secondary metabolites

Chemical defenses in loquat involve the production of phytochemicals and secondary metabolites that are toxic or repellent to insects. These compounds can be constitutively present or induced in response to insect attack. For instance, secondary metabolites such as alkaloids, terpenoids, and phenolics can disrupt the growth, development, and reproduction of herbivores (Rattan, 2010). Additionally, volatile organic compounds (VOCs) released by the plant can attract natural enemies of the herbivores, providing an indirect defense mechanism (War et al., 2012). The use of phytohormones like jasmonic acid (JA) can also enhance these chemical defenses, as seen in other plant species.

### 3.3 Genetic resistance mechanisms

Genetic resistance in loquat involves the presence of specific genes that confer resistance to insect pests. These genes can encode for proteins that are directly toxic to insects or that strengthen the plant's overall defense mechanisms. For example, resistance genes in other plants have been shown to produce proteins that interfere with the digestive processes of insects or that trigger cell death in the affected tissues, thereby limiting the spread

of the damage (Mishra et al., 2022). The identification and incorporation of such resistance genes into loquat cultivars could provide a sustainable approach to pest management.

### 3.4 Induced resistance responses

Induced resistance refers to the plant's ability to enhance its defensive capacity in response to initial insect attack. This can involve the activation of signaling pathways that lead to the production of defensive compounds or the strengthening of physical barriers. For instance, the application of chemical elicitors like methyl jasmonate (MeJA) can prime the plant's defense system, leading to a faster and stronger response upon subsequent attacks (Figure 1) (Mageroy et al., 2020). The interaction between herbivore-associated elicitors (HAEs) and pattern-recognition receptors (PRRs) in the plant can also trigger a cascade of defense responses, including the accumulation of reactive oxygen species (ROS) and the activation of mitogen-activated protein kinases (MAPKs) (Malook et al., 2022). These induced responses can be a crucial component of integrated pest management strategies, reducing the reliance on chemical insecticides.

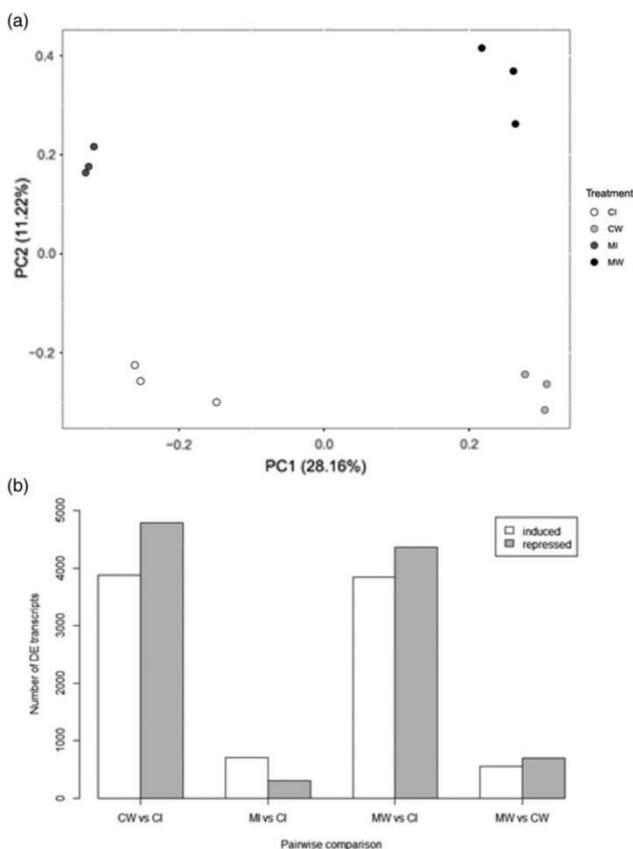


Figure 1 Transcriptome analysis of the bark of Norway spruce trees subjected to methyl jasmonate (MeJA) treatment and/or wounding 4 weeks later. (a) A principal component analysis (PCA) score plot showing the separation and grouping of treatments according to transfer-matrix method normalized transcript counts. Component 1 separates intact from wounded samples. Component 2 separates control from MeJA-treated samples. Abbreviations: CI, control and intact/unwounded; CW, control and wounded; MI, MeJA treated and intact; MW, MeJA-treated and wounded. (b) The number of significantly (false discovery rate-adjusted  $p$ -value  $< .01$ ) induced and repressed transcripts for the pairwise comparisons CI-CW, CI-MI, CI-MW and MW-CW (Adopted from Mageroy et al., 2020)

The principal component analysis (PCA) in panel (a) demonstrates distinct clustering of Norway spruce transcriptomes based on methyl jasmonate (MeJA) treatment and wounding. PC1 clearly separates intact from wounded samples, while PC2 further distinguishes control from MeJA-treated groups. The bar graph in panel (b) reveals that MeJA treatment and wounding both significantly alter gene expression, with notable differences between control intact (CI), control wounded (CW), MeJA intact (MI), and MeJA wounded (MW) groups. The most dramatic transcriptomic changes occur when both treatments (MeJA and wounding) are combined.

## 4 Advances in Genetic Research on Insect Resistance in Loquat

### 4.1 Identification of resistance genes

The identification of resistance genes is a critical step in developing insect-resistant loquat varieties. Recent studies have highlighted the importance of exploiting natural variation to identify genes responsible for insect resistance. By studying the molecular genetics and transcriptional background of this variation, researchers have been able to pinpoint specific resistance genes and processes that confer resistance to herbivorous insects (Broekgaarden et al., 2011). Additionally, advancements in genetic and genomic studies have facilitated the mapping and cloning of resistance genes, as seen in other crops like rice and soybeans, which can be applied to loquat research (Yan et al., 2023).

### 4.2 Molecular markers and breeding strategies

Molecular markers have become indispensable tools in breeding programs aimed at developing insect-resistant crops. Marker-assisted selection (MAS) allows for the precise identification and introgression of resistance genes into loquat varieties. Techniques such as quantitative trait loci (QTL) mapping, genotyping-by-sequencing, and genome-wide association studies have been employed to map resistance loci and develop gene-specific DNA markers (Kim et al., 2016; Kammar and Nitin, 2019). These markers are crucial for the efficient selection of resistant plants and the pyramiding of multiple resistance genes to achieve durable resistance (Sandhu and Kang, 2017).

### 4.3 Genetic engineering approaches for enhancing resistance

Genetic engineering offers powerful tools for enhancing insect resistance in loquat. Traditional breeding methods are often time-consuming and labor-intensive, whereas genetic engineering can introduce novel resistance genes from any source into loquat in a single generation. Techniques such as transgenic breeding, gene silencing, and gene editing (e.g., CRISPR/Cas) have shown promise in developing insect-resistant crops (Figure 2) (Tyagi et al., 2020; Luo et al., 2023; Huang, 2024). These approaches have been successfully applied in other crops to combat various pests and can be adapted for use in loquat to improve its resistance to insect pests (Mekonnen et al., 2017).

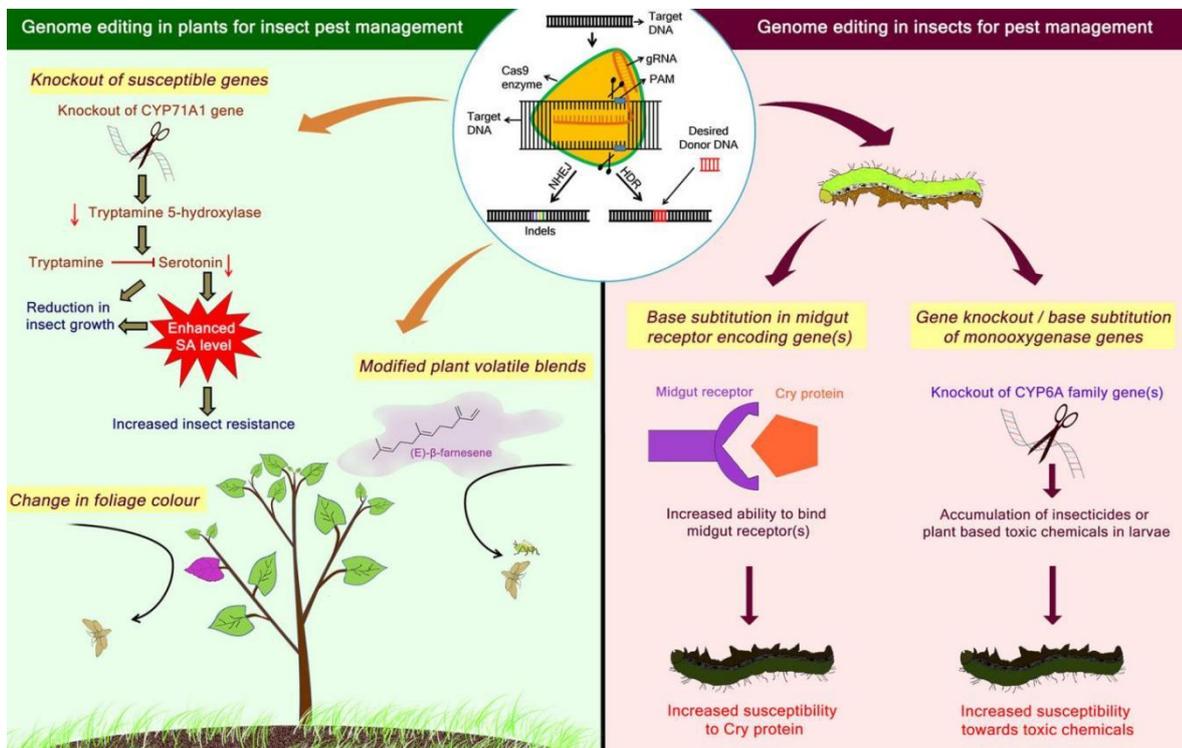


Figure 2 Strategies of CRISPR-based gene editing in plants and insects for pest management. Genome editing in plants for resistance against insect pests has been demonstrated by knocking down susceptible genes, modification of plant volatile blends, and changing foliage color. Editing in insects for susceptibility toward plants can be achieved by modification of Cry protein binding receptors and knockdown of detoxification enzymes (Adopted from Tyagi et al., 2020)

The study of Tyagi et al. (2020) outlines how CRISPR-based gene editing can be used in both plants and insects for pest management. In plants, resistance against insect pests can be enhanced by knocking out specific genes, altering plant volatile emissions, or changing leaf coloration. These modifications disrupt insect growth and increase plant resistance. In insects, susceptibility to plant defenses or insecticides can be increased by editing genes related to toxin detoxification or Cry protein binding receptors. This dual approach leverages genetic engineering in both organisms to manage pest populations and improve crop protection.

By integrating these advanced genetic research methods, the development of insect-resistant loquat varieties can be significantly accelerated, contributing to sustainable pest management and improved crop yields.

## **5 Application of Insect Resistance in Loquat Pest Management**

### **5.1 Integrated pest management (IPM) strategies**

Integrated Pest Management (IPM) is a holistic approach that combines multiple pest control techniques to manage pest populations at economically tolerable levels while minimizing the use of chemical pesticides. This strategy is particularly effective in reducing the risk of chemical and environmental contaminants and associated health issues (Hafeez et al., 2021; Siddiqui et al., 2023). IPM strategies for loquat pest management can include biological control, cultural practices, and the use of resistant plant varieties. The integration of these methods helps to delay the development of resistance in pest populations and optimizes the effectiveness of each control measure (Green et al., 2020).

### **5.2 Role of insect-resistant varieties in IPM**

Insect-resistant loquat varieties play a crucial role in IPM by providing a sustainable and environmentally friendly method of pest control. These varieties reduce the reliance on chemical pesticides, thereby lowering the risk of resistance development in pest populations (Zhu et al., 2016; Bass and Jones, 2018). The use of resistant varieties can be synergized with other IPM tactics such as biological control and cultural practices to enhance overall pest management efficacy. For instance, combining resistant varieties with biological control agents can create a more robust defense against pests, reducing the need for chemical interventions (Gurr and Kvedaras, 2010; Mouden et al., 2017).

### **5.3 Sustainable pest management practices**

Sustainable pest management practices aim to maintain pest populations at manageable levels while preserving the environment and human health. These practices include the use of biological control agents, such as natural predators and parasitoids, and the implementation of cultural techniques like crop rotation and habitat manipulation (El-Shafie, 2018). Additionally, the integration of microbial control methods and the exploitation of plant microbiomes can enhance plant defenses against pests, providing indirect pest control benefits (Francis et al., 2020). By adopting these sustainable practices, loquat growers can achieve long-term pest management solutions that are both effective and environmentally responsible (Alyokhin et al., 2015).

## **6 Case Study**

### **6.1 Description of the case study area**

The case study focuses on a loquat (*Eriobotrya japonica*) orchard located in a subtropical region known for its favorable climate for loquat cultivation. The area is characterized by mild winters and warm summers, providing an ideal environment for loquat growth. However, this climate also supports a variety of insect pests that pose significant challenges to loquat production.

### **6.2 Pest management challenges in loquat production**

Loquat production in the case study area faces several pest management challenges. The primary issue is the development of insecticide resistance among key pest species. Over-reliance on chemical insecticides has led to the emergence of resistant pest populations, making traditional pest control methods less effective (Karaağaç, 2023; Siddiqui et al., 2023). Additionally, the diverse pest species attacking loquat, including fruit borers and sap-sucking insects, complicate management efforts. The presence of these pests not only reduces fruit yield but also affects fruit quality, leading to economic losses for growers.

### 6.3 Implementation of insect resistance strategies

To address these challenges, an integrated pest management (IPM) approach was implemented in the loquat orchard. This strategy included the use of biological controls, such as introducing natural predators and parasitoids to reduce pest populations. Cultural practices, such as crop rotation and sanitation, were also employed to disrupt pest life cycles and reduce their habitat (Gao et al., 2012). Additionally, resistant loquat varieties were developed through selective breeding programs, focusing on enhancing the plant's natural defense mechanisms against pests (Douglas, 2018). The use of microbial insecticides and pheromone traps further complemented these efforts, providing targeted control without the adverse effects associated with chemical insecticides.

### 6.4 Outcomes and lessons learned

The implementation of these insect resistance strategies resulted in a significant reduction in pest populations and a corresponding increase in loquat yield and quality. The use of biological and cultural controls proved effective in managing pest resistance, while the development of resistant loquat varieties provided a sustainable long-term solution (López-Castillo et al., 2018). One of the key lessons learned was the importance of an integrated approach that combines multiple strategies to manage pest resistance effectively. Continuous monitoring and adaptation of pest management practices were also crucial in maintaining the effectiveness of the implemented strategies. This case study highlights the potential of integrated pest management in overcoming the challenges of insecticide resistance and ensuring sustainable loquat production.

## 7 Future Perspectives and Challenges

### 7.1 Opportunities for enhancing resistance in loquat

The development of insect-resistant loquat varieties presents a significant opportunity to enhance crop resilience and productivity. Advances in plant breeding and biotechnology offer promising avenues for achieving this goal. For instance, the use of genotyping by sequencing and high-throughput phenotyping can help identify and map resistance genes, expediting the development of resistant varieties (Smith, 2020). Additionally, understanding the common resistance mechanisms deployed by plants against sap-feeding insects can provide valuable insights for breeding loquat varieties with enhanced resistance (Leybourne and Aradottir, 2021). The integration of plant secondary metabolism and immunity, as well as microbiome science, can further optimize plant defenses against insect pests. These strategies not only promise to reduce crop losses but also contribute to sustainable agricultural practices.

### 7.2 Challenges in breeding and biotechnology

Despite the potential benefits, several challenges must be addressed to successfully breed insect-resistant loquat varieties. One major challenge is the limited progress in developing meaningful levels of pest resistance in certain crops, which underscores the need for more efficient breeding efforts. Additionally, the evolution of practical resistance by pests to genetically engineered crops, such as those producing *Bacillus thuringiensis* (Bt) toxins, highlights the need for sustainable resistance management strategies (Figure 3) (Tabashnik et al., 2023). The complexity of plant-insect interactions and the potential impact of climate change on resistant plants further complicate breeding efforts. Moreover, the integration of novel biotechnological approaches, such as metabolic engineering and microbiome manipulation, requires careful consideration of ecological and economic factors (Douglas, 2018).

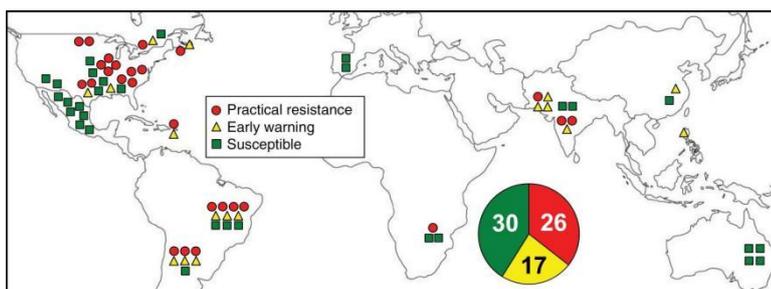


Figure 3 Global status of field-evolved pest resistance to Bt crops. Each symbol represents 1 of 73 cases indicating responses of one pest species in one country to one toxin in Bt corn, cotton, soy, and/or sugarcane (Adopted from Tabashnik et al., 2023)

The study of Tabashnik et al. (2023) provides a global overview of pest resistance to genetically engineered Bt crops. It highlights varying levels of resistance among pest species in different countries. Red dots indicate cases where pests have evolved practical resistance, whereas yellow triangles represent early warning signs of potential resistance development. Green squares show areas where pests remain susceptible to Bt crops. The accompanying pie chart summarizes the distribution of these cases, illustrating a significant global concern with evolving resistance patterns. This data underscores the importance of monitoring and adapting pest management strategies to sustain Bt crop efficacy.

### **7.3 Implications for global loquat production**

Enhancing insect resistance in loquat has significant implications for global production. By reducing reliance on chemical insecticides, resistant varieties can contribute to more sustainable and environmentally friendly pest management practices. This is particularly important in low-income regions where access to chemical controls is limited (López-Castillo et al., 2018). Furthermore, the development of insect-resistant loquat varieties can help mitigate the impact of pest-related yield losses, thereby improving food security and economic returns for farmers. However, the global adoption of these technologies will require coordinated efforts among researchers, policymakers, and agricultural stakeholders to address the challenges and ensure the long-term sustainability of resistant crops (Kamatham et al., 2021).

In conclusion, while there are substantial opportunities for enhancing insect resistance in loquat through advanced breeding and biotechnological approaches, several challenges must be overcome. Addressing these challenges will be crucial for realizing the full potential of resistant varieties and their positive impact on global loquat production.

## **8 Concluding Remarks**

The research on insect resistance mechanisms in loquat has revealed several critical insights that can be leveraged for effective pest management. Insecticide resistance in pests is a significant challenge, primarily driven by the overuse of synthetic chemicals, leading to the development of various resistance mechanisms. These mechanisms include behavioral, biochemical, physiological, genetic, and metabolic adaptations, with a notable emphasis on the overexpression of detoxifying enzymes such as cytochrome P450, glutathione-S-transferase, and esterases. Additionally, the role of microbial symbionts in conferring resistance has been highlighted, where gut bacteria can degrade insecticides, providing immediate resistance to the host insects.

The use of model organisms like *Drosophila melanogaster* has been instrumental in understanding these resistance mechanisms, particularly through genetic and biochemical analyses. Moreover, silicon-mediated resistance in plants has shown promise, with both physical barriers and biochemical pathways being upregulated to defend against insect pests. The exploitation of natural genetic variation in plants has also been identified as a valuable strategy for developing insect-resistant crop varieties.

Future research should focus on a multi-faceted approach to manage insect resistance in loquat effectively. There is a need for a deeper understanding of the molecular and genetic bases of resistance mechanisms, which can be achieved through advanced genome modification technologies like CRISPR/Cas9. This will help identify and characterize resistance genes and mutations in both model and non-model pest species. Additionally, exploring the role of microbial symbionts in resistance can open new avenues for biological control strategies, potentially reducing the reliance on chemical insecticides.

Integrated Pest Management (IPM) strategies should be prioritized, combining chemical, biological, and cultural control methods to minimize the risk of resistance development. The timing and dosage of insecticide applications should be optimized based on the understanding of pest biology and resistance mechanisms. Furthermore, the development of insect-resistant loquat varieties through the exploitation of natural genetic variation and the incorporation of silicon-mediated resistance traits should be pursued. Collaborative efforts between researchers, farmers, and policymakers will be essential to implement these strategies effectively and sustainably.

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## Conflict of Interest Disclosure

The authors affirm that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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