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Effects of the Mating Disruption Strategy on In-Season Damage and Overwintering Population of Cydia pomonella (L.) in Karaman Province

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Abstract

This study evaluated the potential of mating disruption (MD) using Isomate C Plus pheromone dispensers for suppressing codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), in commercial apple orchards under the ecological conditions of Karaman Province, Türkiye, during the 2018 and 2019 growing seasons. The study compared an MD-treated orchard, where 1000 Isomate C Plus dispensers ha^{-1} were deployed, with a conventionally managed orchard. Codling moth population activity was monitored using pheromone traps, while fruit damage was assessed during the growing season and at harvest. Overwintering larval density was determined after harvest using corrugated cardboard band traps. Three generations of C. pomonella were observed, with the highest adult activity occurring from late July to early August. At harvest, fruit damage in the MD-treated orchard was 0.70% in 2018 and 0.35% in 2019, compared with 5.70% and 4.25%, respectively, in the conventionally managed orchard. Based on Abbott's formula, the estimated reduction in fruit damage was 90.7% and 94.8% in 2018 and 2019, respectively. Overwintering larval densities were 0.95 and 0.31 larvae tree^{-1} in the MD orchard and 6.40 and 4.10 larvae tree^{-1} in the conventionally managed orchard in 2018 and 2019, respectively. These observations indicate substantial suppression of fruit damage and overwintering population density under the MD treatment. However, because female mating status was not directly assessed and the study design did not include independent replicated experimental plots, the results should be interpreted as evidence of population suppression rather than direct confirmation of mating disruption efficacy. Further studies incorporating adequately replicated experimental units and direct assessment of female mating status are required to validate the mechanism and efficacy of MD under different orchard conditions. Overall, Isomate C Plus showed considerable potential as a component of integrated pest management programs for C. pomonella in the study region. These findings indicate that the application of Isomate C Plus significantly suppressed both in-season fruit damage and baseline population levels, demonstrating that mating disruption constitutes a reliable and sustainable component of integrated pest management (IPM) programs under the ecological conditions of Karaman.

Introduction

Apple (*Malus domestica* Borkh.) is one of the most economically important temperate fruit crops worldwide and represents a major component of pome fruit production in many countries, including Türkiye (Ay et al., 2007; Ulaşlı & Can, 2024). However, sustainable apple production is challenged by several insect pests, among which the codling moth, *Cydia pomonella* (L.) (Lepidoptera: Tortricidae), is considered one of the most economically important pests of apple and other pome fruits worldwide (Balaško et al., 2020; Pajač et al., 2011; Ulaşlı & Can, 2024). The species has a cosmopolitan distribution and is established in most major apple-growing regions. Larvae penetrate developing fruits and feed towards the seed cavity, causing direct yield losses and rendering damaged fruits unsuitable for commercial marketing. Under favorable conditions and in the absence of effective control measures, crop losses may reach 60–100% (Kutinkova et al., 2009; Yeşilırmak & Ay, 2023).

Management of *C. pomonella* has traditionally relied heavily on insecticides. However, the high reproductive capacity and multiple generations of the species, together with repeated insecticide applications, have contributed to the development of resistance to several insecticide groups, including organophosphates, pyrethroids, and other commonly used compounds (Balaško et al., 2020; Pajač et al., 2011). In addition to resistance development, intensive pesticide use raises concerns regarding pesticide residues, environmental contamination, human health, and adverse effects on beneficial and non-target organisms. These challenges

have increased the importance of Integrated Pest Management (IPM) approaches that combine effective pest suppression with reduced reliance on conventional insecticides (Ferracini et al., 2021; Whitfield & Fountain, 2024).

Mating disruption (MD) is an important component of IPM programs for the management of *C. pomonella*. The technique is based on the continuous release of synthetic female sex pheromone, primarily codlemone [(E, E)-8,10-dodecadien-1-ol], into the orchard environment. Increasing the pheromone concentration in the orchard atmosphere interferes with the ability of males to locate females by disrupting or masking the natural pheromone plume and thereby reducing the probability of successful mating (Kehat et al., 1995; Preti et al., 2021; Whitfield & Fountain, 2024). Reduced mating success can subsequently decrease the number of fertile eggs and developing larvae, ultimately contributing to lower fruit infestation. Unlike broad-spectrum insecticides, MD is highly target-specific and has relatively limited direct effects on natural enemies and other non-target organisms, making it a valuable tool for environmentally compatible pest management (Ferracini et al., 2021; Perrin et al., 2024).

The effectiveness of MD, however, is not uniform across all orchard systems. Its performance can be influenced by initial pest density, orchard size and configuration, degree of isolation, pheromone release characteristics, landscape structure, and the temporal and spatial distribution of the pest population. Consequently, evaluation of MD under local agroecological conditions is essential for determining its practical effectiveness and for integrating the technique into regional IPM programs (Candan & Aslan, 2022; Kutalmış & Ögür, 2025; Knight et al., 2025). In addition, assessment of MD efficacy should not rely solely on pheromone trap captures or fruit damage; complementary biological indicators, including female mating status and the presence of spermatophores, can provide more direct evidence of disruption of successful mating. Such parameters have been emphasized in previous studies as important tools for evaluating the biological effectiveness of pheromone-based mating disruption (Trematerra et al., 2013).

Although MD has been extensively investigated internationally, further field validation is needed under the specific climatic and production conditions of different apple-growing regions. In particular, information regarding the effects of pheromone-based MD on both seasonal fruit damage and the subsequent overwintering population of *C. pomonella* remains important for developing effective regional management programs. Therefore, the present study aimed to evaluate the effects of the Isomate C Plus pheromone dispenser on *C. pomonella* population dynamics, in-season fruit damage, and overwintering larval population under the ecological conditions of Karaman Province, Türkiye. The study was designed to provide region-specific information on the practical contribution of MD to the sustainable management of this economically important pest and to support its integration into IPM programs.

Materials and Methods

Study Area and Experimental Orchards

The study was conducted during the 2018 and 2019 growing seasons in the central district of Karaman Province, Türkiye. The experimental orchard was established in 2005 and covered approximately 4 ha. It consisted of ‘Golden Delicious’ and ‘Granny Smith’ apple cultivars grafted onto MM106 rootstock. The control orchard was located in the same production area and covered approximately 3 ha, with the same cultivar–

rootstock combinations. The experimental orchard contained 5,000 trees (3,200 ‘Golden Delicious’ and 1,800 ‘Granny Smith’), whereas the control orchard contained 3,750 trees (2,500 ‘Golden Delicious’ and 1,250 ‘Granny Smith’) (Table 1). Both orchards were approximately 15 years old.

The experimental orchard was relatively isolated from other fruit orchards and was mainly surrounded by field crops, particularly maize. This condition reduced the likelihood of immigration of mated females from neighboring orchards, which is considered an important factor affecting the performance of mating disruption (MD). In contrast, the control orchard was managed according to conventional grower practices. During each growing season, 17–22 insecticide applications were made, including 13 applications specifically targeting *Cydia pomonella*.

Table 1
Structural and compositional characteristics of the experimental and control orchards

Orchard	Area (ha)	Age (years)	Number of Trees
Golden Delicious K	3	15	2500
Granny Smith K			1250
Golden Delicious F	4	15	3200
Granny Smith F			1800

Mating Disruption Treatment

Mating disruption was implemented in the experimental orchard using Isomate C Plus pheromone dispensers. Following the detection of the first adult emergence, 1,000 dispensers ha^{-1} were uniformly distributed throughout the orchard at approximately 1.5–2.0 m above ground level and within the upper third of the tree canopy. Each dispenser contained approximately 190–205 mg of (E, E)-8,10-dodecadien-1-ol, the principal sex pheromone component of *C. pomonella*.

The MD treatment was maintained throughout the growing season. The technique was intended to reduce successful mating by disrupting male orientation toward females through saturation of the orchard atmosphere with synthetic sex pheromone. Selective insecticides compatible with Integrated Pest Management principles were used only when necessary to manage pests other than *C. pomonella*.

Climatic Data and Its Influence on the Study

Long-term climatic data (monthly averages) for Karaman province are presented in Table 2. These data are critical for interpreting adult flight curves, generation number, and overall population dynamics of codling moth from an ecological perspective (Balaško et al., 2020; Ulaşlı & Can, 2024).

According to the literature, codling moth larvae begin pupation in spring when temperatures exceed 10°C (Pajač et al., 2011; Balaško et al., 2020). In Karaman, average maximum temperatures reach 12.8°C in March and 18.6°C in April, thereby exceeding the lower developmental threshold required for the pest to terminate diapause and resume biological activity (Balaško et al., 2020). Population density typically peaks between June and

August, when increasing maximum temperatures coincide with reduced precipitation (Pajač et al., 2011; Ulaşlı & Can, 2024). As shown in Table 2, maximum temperatures in July and August in Karaman reach 33.5°C and 33.2°C, respectively, while total monthly precipitation declines to approximately 5–6 mm and relative humidity decreases to 40–41%.

Such high-temperature and low-humidity conditions accelerate larval development and increase metabolic activity, thereby shortening generation time and facilitating rapid population growth during mid-summer (Perrin et al., 2024; Balaško et al., 2020).

Table 2
Long-term monthly climate averages for Karaman province, Türkiye

Month	Mini Temper (°C)	Max Temper (°C)	Total Precipitation (mm)	Relative Humidity (%)	Sunshine Duration (h)
January	-24.4	4.7	35	75	3.0
February	-28.0	7.5	30	70	4.2
March	-16.4	12.8	32	63	5.2
April	-8.3	18.6	35	58	6.4
May	-1.2	24.0	41	55	8.2
June	3.8	29.7	23	47	10.5
July	9.0	33.5	6	40	11.8
August	6.8	33.2	5	41	11.2
September	-1.0	28.4	9	45	9.5
October	-5.4	21.0	27	55	7.2
November	-21.2	12.2	30	68	5.1
December	-26.1	6.0	37	75	3.1

In contrast, the species overwinters in the fully developed larval stage within a thick silken cocoon, entering diapause in response to the harsh winter conditions of the region (Pajač et al., 2011; Balaško et al., 2020). In Karaman, minimum winter temperatures may decline to extremely low levels, reaching − 24.4°C in January and − 28.0°C in February, thereby necessitating the use of diapause as a survival strategy (Pajač et al., 2011). Furthermore, the decrease in maximum temperatures from 28.4°C in September to 21.0°C in October, together with the shortening of day length (photoperiod), constitutes key environmental cues triggering the transition to the overwintering stage (Lacey et al., 2008; Balaško et al., 2020).

Mating disruption application

Following the detection of the first adult emergence using pheromone traps, 1000 Isomate C Plus pheromone dispensers per hectare were uniformly installed in the experimental orchard at a height of 1.5–2.0 m, corresponding to the upper one-third of the tree canopy (Kutinkova, 2010). According to the literature, each

Isomate C Plus dispenser contains approximately 190–205 mg of the sex pheromone (E, E)-8,10-dodecadien-1-ol (Kutinkova, 2010; Stelinski et al., 2009). Placement in the upper canopy is critical, as mating activity and male flight of the codling moth predominantly occur in this zone (Kutinkova, 2010).

The fundamental principle of mating disruption (MD) is the saturation of the orchard atmosphere with synthetic pheromones, thereby interfering with male orientation and disrupting mate-finding communication (Kutinkova, 2010). This biotechnical approach impairs the ability of males to locate females, consequently reducing successful mating and minimizing the deposition of fertilized eggs (Joshi et al., 2008). In order to preserve ecological balance within the experimental orchard, only selective insecticides compatible with Integrated Pest Management (IPM) principles were applied against non-target pests (Perrin et al., 2024).

Control Orchard

In the control orchard, conventional chemical control was conducted according to standard grower practices (Kutinkova, 2010). This approach enabled a direct comparison between the biotechnical mating disruption strategy and intensive insecticide-based management under practical production conditions. Codling moth management worldwide continues to rely heavily on repeated insecticide applications, with approximately 70% of pesticide use in apple orchards directed against this pest (Pajač et al., 2011; Balaško et al., 2020). However, the species' multivoltine nature and high biological adaptability have contributed to the development of resistance to several insecticide classes, including organophosphates, pyrethroids, and insect growth regulators (IGRs) (Kutinkova, 2010; Pajač et al., 2011; Kehat et al., 1995).

Codling Moth Population Monitoring

Adult *C. pomonella* activity was monitored in both orchards using standard delta-type pheromone traps. Traps were inspected at regular intervals, and captured males were counted to characterize seasonal flight activity and population fluctuations.

Because high concentrations of synthetic pheromone in MD-treated orchards may interfere with the attractiveness of conventional monitoring lures, higher-dose lures were used for population monitoring in the treated orchard. Trap captures were evaluated comparatively between the MD-treated and conventionally managed orchards over the two growing seasons.

Assessment of Fruit Damage

Fruit damage caused by *C. pomonella* was assessed during the growing season and at harvest. Fruits were randomly selected and examined for characteristic larval feeding damage. Fruit infestation was expressed as the percentage of damaged fruits according to the following equation:

$$\text{Damage rate } (\%) = \left(\frac{\text{number of damaged fruit}}{\text{total number of examined fruit}} \right) *100$$

The same assessment procedure was applied to the MD-treated and control orchards in both experimental years.

Assessment of Overwintering Larvae

The overwintering population of *C. pomonella* was assessed after harvest by placing corrugated cardboard bands around tree trunks. On 20 September 2018 and 18 September 2019, bands 10 cm in width were installed approximately 30–40 cm above ground level on 50 randomly selected trees in each orchard. The bands were collected approximately 30 days later, on 20 October 2018 and 18 October 2019, respectively, and transported to the laboratory. Diapausing larvae present in the bands were counted and expressed as the number of larvae per tree.

Estimation of Treatment Efficacy

The apparent efficacy of the MD treatment against fruit damage was estimated using Abbott's correction:

$$\text{Efficacy } (\%) = \frac{\text{Damage rate in control} - \text{damage rate in MD Treatment}}{\text{damage rate in control}} * 100$$

The calculation was performed separately for each experimental year.

Statistical Analysis

The statistical analysis was performed separately for the principal response variables, including adult trap captures, fruit damage, and overwintering larval density. The two management conditions (MD-treated and conventional control) were compared within each experimental year.

Because the study was conducted using commercial-scale orchards rather than multiple independently replicated orchards assigned to each treatment, the orchard was considered the experimental unit for the management comparison. Individual trees and sampled fruits were treated as subsamples within the corresponding orchard rather than as independent experimental replicates. Accordingly, statistical comparisons were interpreted cautiously, particularly with respect to the generalization of treatment effects beyond the study orchards.

For descriptive and comparative analyses, means and measures of variability were calculated for the evaluated response variables. Where statistical comparisons were performed, significance was assessed at $P < 0.05$. Sampling dates were not considered independent biological replicates; rather, repeated observations over time were interpreted in relation to seasonal population dynamics.

The absence of independent orchard-level replication represents an important limitation of the present study and should be considered when interpreting the statistical significance and generalizability of the results.

Results and Discussion

Adult population dynamics

Pheromone-trap monitoring showed that *Cydia pomonella* adults were present in the Karaman apple-growing area from late April or early May until early October. In 2018, the first adults were recorded on 1 May, followed by a gradual increase in population density during May and subsequent population peaks during the summer

period. A pronounced population peak was observed on 23 July. A total of 610 adults were captured in the control orchard during the monitoring period. In 2019, adult emergence was detected earlier, on 28 April, and subsequent population peaks were observed toward the end of May and July, with 654 adults captured during the season. The observed flight pattern indicates that *C. pomonella* completed approximately three generations under the ecological conditions of Karaman.

The occurrence of three generations is consistent with previous reports showing that the number of annual generations of *C. pomonella* varies according to climatic conditions and geographical location (Balaško et al., 2020; Beers et al., 2000). Studies conducted in different regions of Türkiye have likewise reported three or more generations under favorable climatic conditions (Ulaşlı & Can, 2024). The pronounced population increase during July and August in the present study coincided with high summer temperatures, which may have favored larval development and shortened generation duration.

The early onset of adult activity in late April can be associated with the accumulation of temperatures above the developmental threshold required for the termination of diapause and subsequent development (Balaško et al., 2020; Pajač et al., 2011). The climatic conditions of Karaman, characterized by high summer temperatures and relatively low precipitation, therefore appear to provide suitable conditions for the completion of three generations.

It should be noted, however, that the present study was conducted using a single MD-treated orchard and a single conventionally managed orchard. Therefore, the observed differences in adult captures should be interpreted as descriptive evidence of population dynamics rather than as statistically replicated treatment effects. Further studies involving multiple independent orchards per treatment are required to statistically quantify the effect of MD on adult population density.

Seasonal fruit damage and mating disruption performance

Fruit damage showed a clear difference in magnitude between the MD-treated and conventionally managed orchards throughout both study years (Table 3). In 2018, fruit damage in the MD orchard remained very low during the first part of the season, increasing from 0.00% on 1 June to 0.70% at harvest. In the control orchard, damage increased progressively from 1.00% to 5.70% at harvest. Thus, the difference between the two management regimes became increasingly pronounced as the season progressed.

A similar pattern was observed in 2019. Fruit damage in the MD orchard remained below 0.20% until mid-August and reached 0.35% at harvest. In contrast, damage in the control orchard increased progressively and reached 4.25% at harvest. Based on Abbott's formula, the calculated reduction in harvest damage was 87.7% in 2018 and 91.8% in 2019. When the seasonal mean values were considered, the calculated efficacy was 90.7% and 94.8%, respectively. These values indicate a substantial reduction in fruit damage associated with the MD treatment under the conditions of the experimental orchards. The underlying data and calculated reductions are presented in Table 3.

Table 3
Seasonal fruit damage caused by *Cydia pomonella* in the mating disruption and control orchards during 2018 and 2019

Year	Assessment date	Isomate C Plus (%)	Control (%)	Reduction (%)
2018	June 1	0.00	1.00	100.0
2018	June 15	0.01	1.80	99.4
2018	July 1	0.05	2.10	97.6
2018	July 15	0.09	2.50	96.4
2018	August 1	0.10	3.20	96.9
2018	August 15	0.50	3.60	86.1
2018	September 1	0.60	4.40	86.4
2018	September 15	0.70	5.60	87.5
2018	Harvest	0.70 ± 0.05	5.70 ± 0.42	87.7
2018	**Seasonal mean**	**0.31 ± 0.04**	**3.32 ± 0.38**	**90.7**
2019	June 1	0.00	0.92	100.0
2019	June 15	0.00	1.45	100.0
2019	July 1	0.012	1.88	99.4
2019	July 15	0.083	2.60	96.8
2019	August 1	0.10	3.30	97.0
2019	August 15	0.19	3.50	94.6
2019	September 1	0.30	4.00	92.5
2019	September 15	0.35	4.21	91.7
2019	Harvest	0.35 ± 0.03	4.25 ± 0.36	91.8
2019	**Seasonal mean**	**0.15 ± 0.02**	**2.90 ± 0.31**	**94.8**

The efficacy observed in Karaman is broadly comparable with results reported from other regions. For example, Kutinkova et al. (2009) reported low fruit damage levels in Bulgarian apple orchards treated with Isomate C Plus, whereas Płuciennik (2013) reported variable efficacy depending on orchard and environmental conditions. More recent research has likewise emphasized that MD performance is influenced by orchard size, isolation, pest density, dispenser deployment and surrounding sources of infestation.

The relatively high reduction observed in the present study may partly be related to the structural characteristics of the experimental area. The MD orchard covered approximately 4 ha and contained 5,000 trees, whereas the control orchard covered approximately 3 ha and contained 3,750 trees. Both orchards were approximately 15 years old and had similar cultivar–rootstock combinations. However, because only one orchard was assigned to

each treatment, the contribution of orchard-specific characteristics cannot be separated statistically from the treatment effect.

An additional limitation concerns the biological mechanism of mating disruption. The present study evaluated MD performance primarily through pheromone-trap catches, fruit damage and overwintering larval density. Female mating status was not directly assessed, for example through examination of spermatophore presence. Therefore, the present data demonstrate a strong association between MD implementation and reduced fruit damage but do not provide direct evidence of the proportion of females that remained unmated. Direct assessment of female mating status has been recommended as an important complementary measure for evaluating mating disruption efficacy (Knight et al., 2025).

Accordingly, the high reduction values obtained in the present study should be interpreted as field-level suppression of fruit damage and overwintering population density, rather than as direct measurements of mating success.

Overwintering larval population

Overwintering larval densities were substantially lower in the MD orchard than in the control orchard in both years (Table 4). In 2018, the mean number of overwintering larvae was 0.95 ± 0.12 larvae tree^{-1} in the MD orchard compared with 6.40 ± 0.55 larvae tree^{-1} in the control orchard, corresponding to an 85.1% reduction. In 2019, the corresponding values were 0.31 ± 0.08 and 4.10 ± 0.48 larvae tree^{-1}, respectively, representing a 92.4% reduction.

The lower overwintering density recorded in 2019 compared with 2018 was accompanied by lower harvest damage in the same year. This temporal consistency suggests that sustained implementation of MD may contribute to a reduction in the population entering the following production season. Similar reductions in overwintering populations have been reported in apple orchards managed with mating disruption (Kutinkova et al., 2009; Płuciennik, 2013).

Nevertheless, the present study design does not allow a formal statistical attribution of these differences to the MD treatment because the orchard, rather than the individual tree, represents the experimental treatment unit. The 50 trees sampled within each orchard should therefore be considered subsamples within the respective orchard, rather than 50 independent treatment replicates. The originally reported *t*-test results should consequently not be interpreted as evidence of treatment-level statistical significance. The current data are more appropriately presented as descriptive estimates of the magnitude and consistency of population suppression.

Table 4
Overwintering larval density of *Cydia pomonella* in the mating disruption and control orchards

Year	Isomate C Plus (larvae tree^{-1})	Control (larvae tree^{-1})	Reduction (%)
2018	0.95 ± 0.12	6.40 ± 0.55	85.1
2019	0.31 ± 0.08	4.10 ± 0.48	92.4

Conclusion

The present study indicates that the use of Isomate C Plus pheromone dispensers was associated with substantial reductions in codling moth (*Cydia pomonella* (L.)) fruit damage and overwintering larval density under the ecological conditions of Karaman Province, Türkiye. In the mating disruption (MD) orchard, harvest fruit damage was 0.70% in 2018 and 0.35% in 2019, whereas the corresponding values in the conventionally managed orchard were 5.70% and 4.25%, respectively. Based on Abbott's formula, the estimated control efficacy was 90.7% in 2018 and 94.8% in 2019. These results suggest that MD can substantially reduce in-season fruit damage and maintain damage levels below the 1% threshold considered acceptable for commercial apple production.

The observed overwintering larval densities also showed a marked difference between the MD and conventionally managed orchards. Larval densities were 0.95 and 0.31 larvae per tree in the MD orchard in 2018 and 2019, respectively, compared with 6.40 and 4.10 larvae per tree in the control orchard. The lower larval density observed in the second year may indicate a potential cumulative suppressive effect of continued MD application. However, this interpretation should be considered cautiously because the experimental design and replication structure limit the extent to which year-to-year changes can be attributed exclusively to the MD treatment.

Pheromone-trap observations indicated the occurrence of three generations of *C. pomonella* under the climatic conditions of Karaman, with population activity reaching its highest level during late July and early August. Despite relatively high summer temperatures, the MD orchard maintained considerably lower fruit damage and overwintering larval densities than the conventionally managed orchard. These findings support the potential of pheromone-based management under the climatic conditions prevailing in the study area.

Nevertheless, the effectiveness of MD should not be inferred solely from pheromone-trap captures or reductions in fruit damage. In the present study, the mating status of females, including the presence or absence of spermatophores, was not directly assessed. Therefore, the observed reductions in fruit damage and larval density provide evidence of population suppression but do not constitute direct confirmation that mating disruption resulted from reduced female mating success. Future studies should incorporate direct assessment of female mating status together with adequately replicated experimental plots to provide stronger evidence of the mechanism and efficacy of MD.

The results further suggest that Isomate C Plus may serve as a useful component of integrated pest management programs for *C. pomonella*. Its potential to reduce reliance on insecticides, together with its target specificity and compatibility with other IPM practices, makes the technology relevant to sustainable apple production. However, its performance may vary according to initial pest density, orchard size, isolation, surrounding host plants, dispenser distribution, and environmental conditions.

Overall, the findings indicate that Isomate C Plus has considerable potential for reducing codling moth damage under the conditions studied in Karaman Province. Further multi-year studies using independent and adequately replicated experimental units, together with direct measurements of female mating status and standardized population monitoring, are recommended to confirm the efficacy and underlying mechanism of mating disruption under different orchard and climatic conditions.

Declarations

Conflict of Interest

The author declares that there is no conflict of interest.

Ethics Approval

Not applicable.

Clinical Trial Number

Not applicable.

Consent to Publish

Not applicable.

Consent to Participate

Not applicable.

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Author Contribution

S.E.D. conceived and designed the study, conducted the field experiments, collected and analyzed the data, and wrote the main manuscript text. S.E.D. prepared all tables and figures and reviewed and approved the final version of the manuscript.

Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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