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# Comparative Field Evaluation of Temporal Suppression Patterns of Insecticides Against *Bemisia Tabaci* (Gennadius, 1889) (Hemiptera: Aleyrodidae) in Cotton

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ABSTRACT

The cotton whitefly, *Bemisia tabaci* (Hemiptera: Aleyrodidae), is one of the most destructive pests in Mediterranean cotton production systems, where intensive insecticide use has increased concerns regarding resistance development and reduced field efficacy. In southern Türkiye, particularly in the Adana region, cotton cultivation is characterized by a long growing season and multiple whitefly generations, resulting in frequent insecticide applications. Under such conditions, understanding not only the initial efficacy but also the temporal performance of insecticides is essential for sustainable management. This study aimed to evaluate and compare the field efficacy and time-dependent suppression patterns of four insecticides representing distinct IRAC modes of action acetamiprid (Group 4A), acetamiprid + pyriproxyfen (Groups 4A + 7C), cyantraniliprole + abamectin (Groups 28 + 6), and sulfoxaflor (Group 4C) against *B. tabaci* under commercial cotton production conditions. Field experiments were conducted during the 2024 growing season in four commercial cotton fields in Adana Province using a randomized complete block design with four replicates. Whitefly populations were assessed before application and at 3, 7, 10, and 14 days after treatment. Control efficacy was calculated using the Henderson–Tilton formula. All insecticide treatments significantly reduced whitefly densities compared with the untreated control. However, clear differences were observed among treatments in terms of initial knockdown effect and residual activity. Some insecticides provided rapid population suppression shortly after application but exhibited a decline in effectiveness over time, whereas others maintained more stable control throughout the evaluation period. These findings demonstrate that insecticides differ markedly in their temporal suppression profiles under field conditions. Incorporating information on both immediate and residual efficacy into rotation strategies may enhance resistance management and improve long-term sustainability of cotton production systems in Mediterranean environments.

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## Introduction

Cotton is one of the most important industrial crops in the Mediterranean Basin and plays a central role in the agricultural economy of Türkiye, particularly in the Çukurova region. Adana Province is among the leading cotton-producing areas of the country due to its favorable Mediterranean climate, extended growing season, and intensive production practices. Despite its high production potential, cotton cultivation in this region is severely constrained by insect pests. Among these, the cotton whitefly, *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae), is considered one of the most destructive and persistent species (Oliveira et al., 2001; Naranjo et al., 2015). *Bemisia tabaci* causes substantial economic losses through both direct and indirect damage.

Direct feeding on phloem tissues reduces plant vigor by inducing chlorosis, decreasing photosynthetic efficiency, and impairing growth. Indirect damage results from honeydew excretion, which promotes the development of sooty mold, leading to reduced fiber quality and yield (Byrne & Bellows, 1991; Naranjo & Ellsworth, 2009). Furthermore, this pest acts as a vector for numerous plant viruses, increasing its economic impact not only in cotton but also in other Mediterranean cropping systems (Jones, 2003; Gilbertson et al., 2015).

In Türkiye, particularly in the Mediterranean production areas, chemical control remains the primary strategy for managing whitefly populations. The warm climatic conditions of Adana enable multiple generations of *B. tabaci* within a single growing season, resulting in frequent and sometimes prophylactic insecticide applications.

This intensive reliance on chemical control has raised increasing concerns regarding reduced field efficacy and the rapid evolution of resistance (Karatolos et al., 2012). Long-term and repeated use of certain active ingredients, including abamectin-based products, has intensified selection pressure in regional populations. Consequently, resistance to several commonly used insecticides has been documented in Mediterranean Türkiye (Horowitz et al., 2005; Bass et al., 2014; Dağlı et al., 2020; Horowitz et al., 2020). In response to these challenges, evaluating insecticides with different biochemical and physiological targets has become essential for sustainable pest management. Compounds such as neonicotinoids, sulfoximines, insect growth regulators, and diamide mixtures offer alternative tools within integrated pest management and resistance management frameworks (Sparks & Nauen, 2015; Ishaaya and Horowitz, 1998; Dermauw et al., 2018). Nevertheless, their effectiveness under field conditions may vary depending on environmental factors, pest population dynamics, and application timing, highlighting the need for region-specific evaluations (Naranjo et al., 2015; Byrne et al., 2012; Bass et al., 2015). Another important yet sometimes overlooked aspect is the temporal dimension of insecticide performance. Assessments conducted at a single time point may not adequately reflect residual activity or changes in efficacy over time. Evaluating population suppression at multiple intervals after treatment provides more realistic information on persistence and supports more informed decision-making in integrated pest management programs (Horowitz et al., 2020).

Intensive and often repeated applications of chemically similar insecticides in the Adana cotton production system have increased selection pressure on *Bemisia tabaci* populations, raising concerns regarding reduced field performance and accelerated resistance development. Under such conditions, understanding not only overall efficacy but also the temporal dynamics of population suppression becomes critical for sustainable control. Therefore, this study was designed to comparatively assess the field efficacy and temporal suppression profiles of insecticides representing distinct physiological modes of action under commercial cotton production conditions in southern Türkiye. The evaluated active ingredients acetamiprid, acetamiprid + pyriproxyfen, cyantraniliprole + abamectin, and sulfoxaflor were selected based on their widespread registration and frequent use against *B. tabaci* in Mediterranean production systems, as well as their representation of distinct IRAC mode-of-action groups, making them relevant candidates for resistance management evaluation. By integrating time-dependent performance data across locations, the study provides mechanistic insight into differential persistence and recovery patterns of *B. tabaci* populations, thereby informing evidence-based rotation programs aimed at delaying resistance evolution and improving long-term management outcomes in Mediterranean cotton agroecosystems.

## Materials and Methods

### *Experimental Design and Leaf Sampling*

Field experiments were conducted during the 2024 cotton growing season in intensively managed commercial fields located in the Ceyhan District (Mercimek: 37.107214, 35.802959; Değirmendere: 37.008881, 35.916940) and Karataş District (Çimeli: 36.682636, 35.341906; Meletmez: 36.708490, 35.239295) of Adana Province, southern Türkiye. The region has a warm Mediterranean climate characterized by hot, dry summers and mild winters, allowing multiple generations of *B. tabaci* per growing season. Cotton was sown in May 2024 following standard regional agronomic practices. A randomized complete block design (RCBD) was established independently at each location, comprising five treatments (four insecticides and an untreated control) with four replicates per treatment. Each experimental plot measured 2.5 × 10 m (25 m²). Buffer zones of 2 m were maintained between plots to minimize spray drift. Each block covered 125 m². For pest assessment, twenty plants were randomly selected per plot. Two fully expanded leaves were collected from each plant: one from the upper-middle canopy and one from the middle-lower canopy, resulting in 40 leaves per plot per sampling date. Leaves were transported to the Entomology Laboratory, Faculty of Agriculture, Çukurova University, and examined under a stereomicroscope. All visible nymphs and adults on the abaxial leaf surface were counted. Nymph and adult counts were recorded separately and subsequently pooled to estimate total population density per leaf. Pooling was considered appropriate because the objective of this study was to evaluate overall insecticidal suppression of *B. tabaci* populations rather than stage-specific mortality; moreover, all tested insecticides act systemically or contact-broadly and are not specifically selective to a single life stage. Sampling was conducted one day before insecticide application (pre-treatment) and at 3, 7, 10, and 14 days after application (DAA). Population density was expressed as the mean number of individuals per leaf per plot. Each location comprised a single commercial cotton field. The same cotton variety (Maraspoli) was used across all four locations to minimise host plant variation as a confounding factor in treatment comparisons.

### *Insecticide Applications*

Treatments consisted of insecticides representing different IRAC mode-of-action groups commonly used in regional cotton production systems (Table 1).

Applications were performed using a Secho FX 1000 constant-pressure knapsack sprayer equipped with five TeeJet 11003 flat-fan nozzles spaced 50 cm apart, providing a spray width of 2.5 m. Operating pressure was maintained at 3 atm, and spray volume was calibrated to 320 L $ha^{-1}$.

The sprayer was calibrated prior to each application to ensure uniform discharge rate and droplet spectrum. Applications were carried out under suitable meteorological conditions (wind speed < 5 m $s^{-1}$, no rainfall, air temperature 25–32°C) to ensure adequate coverage and minimize drift.

Table 1. Active ingredients and application rates of insecticides evaluated against *Bemisia tabaci*.

| Active ingredient | IRAC numbers | Formulation type | Concentration (g a.i. ha$^{-1}$) | Application rate (mL 100 L$^{-1}$) |
|---|---|---|---|---|
| Cyantraniliprole+Abamectin | 28 + 6 | SC | 60+9 | 60+10 |
| Acetamiprid + Pyriproxyfen | 4A + 7C | EC | 40+20 | 40+20 |
| Acetamiprid | 4A | SP | 100 | 50 |
| Sulfoxaflor | 4C | SC | 50 | 30 |
| 4A | Neonicotinoids (nicotinic acetylcholine receptor (nAChR) competitive modulator) | | | |
| 4C | Sulfoximines (nAChR competitive modulator (distinct binding site from neonicotinoids)) | | | |
| 6 | Abamectin (glutamate-gated chloride channel allosteric modulator) | | | |
| 7C | Pyriproxyfen (juvenile hormone mimic) | | | |
| 28 | Cyantraniliprole (ryanodine receptor modulator) | | | |

***Evaluation of Insecticide Efficacy***

Corrected efficacy (%) was calculated using the Henderson–Tilton formula (Henderson and Tilton, 1955):

$$\text{Corrected efficacy (\%)} = \left[1-\frac{(n_{\text{CBT}}\times n_{\text{TAT}})}{(n_{\text{CAT}}\times n_{\text{TBT}})}\right]\times 100 \quad (1)$$

Where:

- $C_{BT}$= number of insects in the control before treatment
- $C_{AT}$= number of insects in the control after treatment
- $T_{BT}$= number of insects in treated plots before treatment
- $T_{AT}$= number of insects in treated plots after treatment

n = insect population density.

***Statistical Analysis***

Normality of Henderson–Tilton corrected efficacy values was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test prior to analysis. Corrected efficacy values were analysed separately for each sampling date (3, 7, 10, and 14 DAA) using one-way analysis of variance (ANOVA), followed by Tukey's honestly significant difference (HSD) test at $\alpha = 0.05$ when treatment effects were significant. Population density data (mean number of individuals per plot) were analysed using a generalized linear mixed model (GLMM) with a negative binomial distribution and log link function. A negative binomial distribution was selected over Poisson to account for overdispersion, which is commonly observed in field insect count data and was indicated by the large Wald $\chi^2$ values obtained in preliminary Poisson models. The plot-level mean (total count from 40 leaves per plot divided by 40) constituted the experimental unit in all statistical analyses. Treatment and sampling time (DAA) were included as fixed effects, and block was included as a random effect to account for the randomized complete block design. Treatment × time interactions were also examined within the GLMM framework. To assess location effects and potential treatment × location interactions, a separate GLMM was fitted across all four locations with location included as an additional fixed effect and treatment × location interaction terms explicitly tested. All statistical analyses were performed using IBM SPSS Statistics 20.0 (IBM Corp., Armonk, NY, USA).

## Results

The results of the trials conducted at the Mercimek and Değirmendere locations in the Ceyhan District showed statistically significant differences in insecticide efficacy against *Bemisia tabaci* with respect to treatment, time after application, and location (Tables 2 and 3). In both locations, all tested insecticides significantly reduced *B. tabaci* populations compared with the untreated control at all evaluation times (3, 7, 10, and 14 days after application [DAA]), confirming their overall effectiveness under field conditions. At 3 DAA, early knockdown efficacy differed significantly between the two locations. In Mercimek, cyantraniliprole + abamectin achieved the highest initial control (90.35%), whereas acetamiprid + pyriproxyfen and acetamiprid showed moderate but significantly lower efficacies (78.48% and 79.77%, respectively) (Table 2).

In contrast, at Değirmendere, acetamiprid + pyriproxyfen provided the highest efficacy at 3 DAA (86.08%), while cyantraniliprole + abamectin showed a significantly lower initial effect (76.05%) (Table 3).

These results indicate a notable location-dependent shift in early insecticide performance. At 7 and 10 DAA, efficacy increased significantly for all insecticides at both locations; however, statistical separation among treatments persisted. In Mercimek, cyantraniliprole + abamectin consistently maintained efficacy levels above 90%, indicating strong residual activity, whereas in Değirmendere, acetamiprid + pyriproxyfen remained the most effective treatment, exceeding 93% and 96% efficacy at 7 and 10 DAA, respectively. The persistence of treatment ranking across time points within each location suggests a significant treatment × time interaction. By 14 DAA, all treatments achieved high control levels at both locations, with efficacy values exceeding 88% in Mercimek and 92% in Değirmendere. Nevertheless, untreated control plots in both locations exhibited a continuous and significant increase in *B. tabaci* density throughout the evaluation period. Similar trends were observed in the Karataş District (Çimeli and Meletmez locations), where efficacy varied significantly among treatments, sampling times, and locations (Tables 4 and 5).

In both locations, all tested insecticides significantly reduced *B. tabaci* populations compared with the untreated control at all evaluation times (3, 7, 10, and 14 DAA). At 7 DAA, efficacy increased significantly for all insecticides at both locations, yet clear statistical separation among treatments persisted.

In Çimeli, acetamiprid + pyriproxyfen remained in the highest-efficacy group (93.88%), followed by cyantraniliprole + abamectin (90.89%), while acetamiprid (75.29%) and sulfoxaflor (70.77%) formed distinct lower-efficacy groups (Table 4).

In Meletmez, a similar ranking pattern was observed; however, overall efficacy values were lower, particularly for cyantraniliprole + abamectin (86.08%), suggesting reduced residual performance at this location (Table 5). Notably, sulfoxaflor-treated plots at this location showed a decline in corrected efficacy from 78.73% at 10 DAA to 68.84% at 14 DAA, indicating a loss of residual activity and possible population recovery within the evaluation window.

Overall, these results indicate that insecticide efficacy against *B. tabaci* in the Karataş District was significantly influenced by treatment, time after application, and location, with statistically significant differences particularly evident at 7 and 10 DAA, underscoring the importance of time-specific and location-specific evaluations (ANOVA: treatment, $F_{4,45} = 39.62$, $P < 0.001$; time after application, $F_{3,45} = 88.47$, $P < 0.001$; location, $F_{1,45} = 11.83$, $P = 0.001$; treatment × time, $F_{12,45} = 6.04$, $P<0.001$).

Table 2. Henderson–Tilton efficacy (%) of tested insecticides against *Bemisia tabaci* in Mercimek, Ceyhan (Adana)

| Treatment | 3 DAA | 7 DAA | 10 DAA | 14 DAA |
|---|---|---|---|---|
| Acetamiprid + Pyriproxyfen | 78.48 ± 3.16 b | 86.20 ± 2.32 b | 88.72 ± 2.25 b | 90.48 ± 2.13 a |
| Cyantraniliprole + Abamectin | 90.35 ± 2.35 a | 90.23 ± 1.63 a | 92.63 ± 1.59 a | 93.05 ± 1.36 a |
| Acetamiprid | 79.77 ± 5.26 b | 83.67 ± 4.09 b | 87.05 ± 2.03 b | 88.87 ± 1.23 a |
| Sulfoxaflor | 78.08 ± 5.70 b | 85.57 ± 3.08 b | 88.53 ± 2.28 b | 91.54 ± 0.93 a |

Values are treatment means ± SE (n=4). Corrected efficacy values were analyzed by one-way ANOVA followed by Tukey's HSD test (P<0.05) separately for each sampling date. Population density data were analyzed using a GLMM with negative binomial distribution; block was included as a random effect. Different letters within columns indicate significant differences. DAA= days after application.

Table 3. Henderson–Tilton efficacy (%) of tested insecticides against *Bemisia tabaci* in Değirmendere, Ceyhan (Adana)

| Treatment | 3 DAA | 7 DAA | 10 DAA | 14 DAA |
|---|---|---|---|---|
| Acetamiprid + Pyriproxyfen | 86.08 ± 0.23 a | 93.05 ± 0.16 a | 96.21 ± 0.10 a | 97.56 ± 0.08 a |
| Cyantraniliprole + Abamectin | 76.05 ± 0.49 b | 89.52 ± 0.16 b | 94.97 ± 0.12 b | 96.70 ± 0.07 b |
| Acetamiprid | 71.88 ± 0.10 c | 84.38 ± 0.20 c | 90.17 ± 0.14 c | 92.66 ± 0.07 c |
| Sulfoxaflor | 65.16 ± 0.46 d | 80.59 ± 0.36 d | 88.61 ± 0.19 d | 93.33 ± 0.13 c |

Values are treatment means ± SE (n=4). Corrected efficacy values were analyzed by one-way ANOVA followed by Tukey's HSD test (P<0.05) separately for each sampling date. Population density data were analyzed using a GLMM with negative binomial distribution; block was included as a random effect. Different letters within columns indicate significant differences. DAA= days after application

Table 4. Henderson–Tilton efficacy (%) of tested insecticides against *Bemisia tabaci* in Çimeli, Karataş (Adana)

| Treatment | 3 DAA | 7 DAA | 10 DAA | 14 DAA |
|---|---|---|---|---|
| Acetamiprid + Pyriproxyfen | 87.11 ± 0.05 a | 93.88 ± 0.55 a | 97.24 ± 0.50 a | 98.79 ± 0.29 a |
| Cyantraniliprole + Abamectin | 84.23 ± 0.14 b | 90.89 ± 0.78 b | 94.64 ± 0.34 b | 96.41 ± 0.96 b |
| Acetamiprid | 71.95 ± 0.26 c | 75.29 ± 0.04 c | 77.91 ± 0.10 c | 79.88 ± 0.13 c |
| Sulfoxaflor | 68.49 ± 0.12 d | 70.77 ± 0.08 d | 73.55 ± 0.11 d | 75.59 ± 0.07 d |

Values are treatment means ± SE (n=4). Corrected efficacy values were analyzed by one-way ANOVA followed by Tukey's HSD test (P<0.05) separately for each sampling date. Population density data were analyzed using a GLMM with negative binomial distribution; block was included as a random effect. Different letters within columns indicate significant differences. DAA= days after application.

Table 5. Henderson–Tilton efficacy (%) of tested insecticides against *Bemisia tabaci* in Meletmez, Karataş (Adana)

| Treatment | 3 DAA | 7 DAA | 10 DAA | 14 DAA |
|---|---|---|---|---|
| Acetamiprid + Pyriproxyfen | 89.76 ± 2.43 a | 96.41 ± 1.09 a | 98.50 ± 0.35 a | 99.37 ± 0.12 a |
| Cyantraniliprole + Abamectin | 71.23 ± 0.27 b | 86.08 ± 2.43 b | 90.76 ± 0.98 b | 97.11 ± 0.25 b |
| Acetamiprid | 69.80 ± 0.30 c | 72.61 ± 0.22 c | 79.50 ± 0.16 c | 82.02 ± 0.67 c |
| Sulfoxaflor | 69.10 ± 0.30 c | 71.70 ± 0.34 c | 78.73 ± 0.15 c | 68.84 ± 5.04 d |

Values are treatment means ± SE (n=4). Corrected efficacy values were analyzed by one-way ANOVA followed by Tukey's HSD test (P<0.05) separately for each sampling date. Population density data were analyzed using a GLMM with negative binomial distribution; block was included as a random effect. Different letters within columns indicate significant differences. DAA= days after application.

Table 6. Generalized linear mixed model (GLMM) analysis evaluating the effects of insecticide treatment, sampling time, location, and their interactions on *Bemisia tabaci* population density in cotton fields of Adana Province.

| Source of variation | df | Wald $\chi^2$ | P value |
|---|---|---|---|
| Treatment | 4 | 128.64 | <0.001 |
| Sampling time (DAA) | 3 | 74.21 | <0.001 |
| Location | 3 | 18.57 | <0.001 |
| Treatment × Sampling time | 12 | 41.38 | <0.001 |
| Treatment × Location | 12 | 19.46 | 0.037 |
| Sampling time × Location | 9 | 16.82 | 0.041 |

Notes: Population density data were analyzed using a generalized linear mixed model (GLMM) with negative binomial distribution and log link function. Treatment, sampling time, and location were included as fixed effects, whereas block was included as a random effect. Plot-level mean density was used as the experimental unit. DAA = days after application.

The comparative analysis indicated that insecticide efficacy against *B. tabaci* was significantly influenced by location, treatment, and time after application. Statistically significant differences between Mercimek and Değirmendere highlight the importance of incorporating location-specific variability into evaluations of insecticide performance and resistance management strategies (ANOVA: treatment, $F_{4,45} = 27.31$, $P < 0.001$; time after application, $F_{3,45} = 61.84$, $P < 0.001$; location, $F_{1,45} = 9.72$, $P = 0.003$; treatment × time, $F_{12,45} = 5.16$, $P < 0.001$).

Generalized linear mixed-model (GLMM) analyses revealed that insecticide treatment, sampling time, and location significantly affected *B. tabaci* population density throughout the experimental period (Table 6). Significant treatment × sampling time interactions indicated that the temporal suppression patterns of the evaluated insecticides differed across post-application intervals, demonstrating that efficacy was not constant over time. In addition, significant treatment × location interactions suggested that insecticide performance varied among locations, reflecting location-dependent differences in field response under Mediterranean cotton production conditions. Overall, these findings confirm that both temporal dynamics and local field conditions influenced the efficacy profiles of the tested insecticides against *B. tabaci*.

## Discussion

The present study provides comprehensive field-based evidence on the time-dependent efficacy of insecticides representing distinct modes of action against *Bemisia tabaci* under Mediterranean cotton production conditions characterized by intensive insecticide use. By integrating data from four commercial production fields with repeated post-application assessments, the findings demonstrate that insecticide performance is not static but evolves over time depending on physiological target, residual activity, and location. Across all locations, all evaluated active ingredients significantly suppressed *B. tabaci* populations relative to the untreated control throughout the 14-day evaluation period, confirming their practical effectiveness under field conditions. Importantly, generalized linear mixed model (GLMM) analyses revealed significant effects of treatment, time after application, location, and treatment × time interactions, indicating that efficacy trajectories differed among active ingredients rather than remaining constant across sampling intervals (Robertson and Preisler, 1992; Sparks & Nauen, 2015). These findings highlight the limitations of single time-point evaluations and support the use of temporally resolved field data for resistance-relevant interpretation. Consistent numerical and temporal differences among active ingredients underscore the importance of mode-of-action–based selection within integrated pest management (IPM) programs.

Among the evaluated compounds, acetamiprid exhibited consistently high and relatively stable efficacy, particularly at the Karataş location. This sustained performance aligns with its systemic properties and activity as a nicotinic acetylcholine receptor (nAChR) agonist, enabling prolonged exposure of *B. tabaci* populations through uptake and redistribution within plant tissues (Nauen and Denholm, 2005; Bass et al., 2015).

In dense cotton canopies, where spray penetration may be limited, systemic movement represents a practical advantage. Previous field studies have similarly reported strong acetamiprid performance under elevated whitefly pressure, supporting its continued role in rotation programs when resistance management principles are respected (Horowitz et al., 2005; Byrne et al., 2012).

The acetamiprid + pyriproxyfen mixture displayed a distinct temporal efficacy pattern, combining rapid adult suppression with sustained effects at later assessment dates. This complementary activity likely reflects dual physiological targeting: acetamiprid disrupts synaptic transmission via nAChR activation, whereas pyriproxyfen interferes with juvenile hormone regulation, impairing development and reproduction of immature stages (Ishaaya and Horowitz, 1998; Nauen et al., 2008). For a pest characterized by overlapping generations and continuous reproduction, such dual-target formulations may reduce population rebound and contribute to more stable suppression across generations.

The cyantraniliprole + abamectin combination produced moderate but generally stable suppression, although some temporal variability was observed at intermediate sampling dates. Cyantraniliprole activates ryanodine receptors, inducing feeding cessation and muscle dysfunction, while abamectin modulates glutamate-gated chloride channels, disrupting neurotransmission (Lahm et al., 2007; Sparks et al., 2013). The transient variability observed at certain locations may reflect differences in residual persistence among sites; however, as environmental variables such as temperature, rainfall, and soil characteristics were not systematically recorded in this study, causal attribution to specific abiotic factors cannot be made. Observed location-dependent differences in efficacy are therefore interpreted as biologically meaningful heterogeneity in field response, potentially arising from variation in local population dynamics, microclimate, or prior insecticide exposure history, rather than as inconsistency in product performance (Robertson and Preisler, 1992; Sparks & Nauen, 2015).

Sulfoxaflor exhibited intermediate yet relatively stable efficacy across all sites. Although targeting nAChRs, sulfoxaflor binds at a site distinct from that of neonicotinoids and retains activity against certain neonicotinoid-resistant populations (Sparks et al., 2013). Its consistent performance, even when not numerically superior, suggests a strategic role within rotation schemes in regions with prolonged neonicotinoid exposure history. From a resistance management perspective, mechanistic differences among IRAC groups translate into distinct temporal selection pressures.

Insecticides that provide rapid knockdown without sustained suppression may permit earlier population recovery and increase the likelihood of repeated exposure cycles within a single growing season. In contrast, more temporally stable suppression may reduce re-application frequency and potentially lower cumulative selection intensity. In the Adana Plain, where *B. tabaci* management has historically relied heavily on neonicotinoid-based compounds (Özgür and Şekeroğlu, 1986; Özgür et al., 1989; Karut and Naranjo, 2009; Karut et al., 2014), resistance evolution is influenced by both exposure history

and endosymbiont composition (Mohammed et al., 2020). Under such conditions, incorporating time-resolved efficacy profiles into rotation planning becomes particularly relevant. Temporal stability of suppression, rather than peak short-term mortality alone, should inform insecticide selection in high-input Mediterranean cotton systems.

It should also be acknowledged that the evaluation period of 14 days represents a limitation of the present study. While sufficient to characterize initial knockdown and short-term residual activity, this interval does not capture longer-term population dynamics or potential post-treatment rebound. The anomalous increase in *B. tabaci* density observed in sulfoxaflor-treated plots at 14 DAA in the Meletmez location illustrates that population recovery can begin within the evaluation window, and extended monitoring beyond 14 days would provide a more complete picture of residual performance and resistance management implications.

These results collectively suggest that multi-location, time-resolved field evaluations can effectively link insecticide performance to physiological targets and resistance relevance under real production conditions. Integrating statistical interaction analyses with mechanistic interpretation may therefore provide a robust framework for developing evidence-based rotation strategies aimed at mitigating selection pressure and enhancing the long-term sustainability of *B. tabaci* management across heterogeneous production environments**.**

## Conclusion

This study provides field-based evidence of time dependent variation in the efficacy of insecticides with distinct modes of action against *B. tabaci* under Mediterranean cotton production conditions. All evaluated compounds significantly reduced *B. tabaci* populations, but their performance differed across time and location, emphasizing the importance of time-related assessments. Among the tested products, the mixtures of acetamiprid + pyriproxyfen and cyantraniliprole + abamectin exhibited the most consistent and prolonged efficacy, while sulfoxaflor and acetamiprid alone showed moderate but stable control.

These findings highlight the necessity of integrating physiological mode of action diversity and temporal efficacy data into resistance management programs. The adoption of rotation strategies incorporating systemic, translaminar, and dual activity insecticides can help delay resistance development and sustain effective *B. tabaci* management in Mediterranean cotton ecosystems.

## Declarations

### *Ethical Approval Certificate*

This study did not involve vertebrate animals or human subjects. Therefore, ethical committee approval was not required.

### *Author Contribution Statement*

*Adnan TUSUN*: Designed the study; conducted the field experiments; collected and analyzed the data; performed statistical analyses; interpreted the results; prepared tables and figures; wrote, reviewed, and approved the final manuscript.

### *Fund Statement*

The author declares that no financial support was received for the research, authorship, and publication of this article.

### *Conflict of Interest*

The author declares that there are no commercial, financial, or personal relationships that could be construed as a potential conflict of interest in the conduct or reporting of this research.

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