

Original article (Orijinal araştırma)

Mating disruption method to control vine mealybug, *Planococcus ficus* (Signoret, 1875) (Hemiptera: Coccoomorpha: Pseudococcidae) in Manisa (Türkiye) vineyards¹

Manisa (Türkiye) bağ alanlarında asma unlubiti *Planococcus ficus* (Signoret, 1875) (Hemiptera: Coccoomorpha: Pseudococcidae)'un çiftleşmeyi engelleme metodu ile kontrolü

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Abstract

Planococcus ficus (Signoret, 1875) (Hemiptera: Coccoomorpha: Pseudococcidae) is considered as an important pest of vineyards in Türkiye. Control methods for *P. ficus* worldwide are often based on using insecticides. However, due to the cryptic lifestyle of *P. ficus*, reasons such as its presence under the bark, its body being covered with a waxy layer, and the inappropriate timing of insecticide use often cause insecticides to fail to perform as expected. Therefore, using alternative pest control methods can be more effective in *P. ficus* management. Mating disruption (MD) is a commercially available and environmentally sustainable control method for *P. ficus*. This study was conducted in the Aegean Region, which covers a total of 30% of Türkiye's grape production areas. Field trials were conducted in Manisa, over 3 years by monitoring the mealybug population in table grape vineyards managed with MD and in a control (Non-MD) plot. In this study, pheromone-based mating disruption was applied in an open-field design using a sprayable microencapsulated pheromone (Check-Mate VMB- F) at 12.4-74.4 g of active ingredients per ha through the season. Trap catches and bunch damage in the MD plot were far lower than in the Non-MD plot. In 2019, 2020, and 2021, crop damage rates were 12.3%, 3%, and 2.3% in the MD plot, respectively, while they were 56%, 37%, and 41% in the Non-MD plot. The results of the 3-year study have shown that MD can be used safely in integrated pest management to control vine mealybug in the vineyards of the Aegean region.

Keywords: Biotechnical method, monitor trap, semiochemicals, sustainable agriculture, vineyard pests

Öz

Asma unlubiti *Planococcus ficus* (Signoret, 1875) (Hemiptera: Coccoomorpha: Pseudococcidae) Türkiye bağ alanlarında önemli zararlı bir türdür. Zararıyla mücadelede genellikle pestisitler kullanılmaktadır. Ancak *P. ficus*'un gizli korunaklı alanlarda yaşamını sürdürmesi, kabuk altı dokuda bulunması, vücudunun mumsu tabaka ile kaplı olması ve insektisitlerin doğru zamanda uygulanmamasına bağlı olarak mücadelede istenilen sonuçlar alınamamaktadır. Bu sebeple alternatif mücadele metotları *P. ficus*'a karşı mücadelede daha etkili olabilmektedir. Çiftleşme engelleme (ÇE), *P. ficus* için ticari olarak mevcut ve çevre dostu bir kontrol yöntemidir. Bu çalışma Türkiye'deki bağ alanlarının yaklaşık %30'una sahip olan Ege Bölgesi'nde yürütülmüştür. Denemeler çiftleşmeyi engelleme parseli ve kontrol olmak üzere 3 yıl boyunca Manisa ili bağlarında yürütülmüştür. Çalışmada püskürtülebilir mikroenkapsül çiftleşmeyi engelleme feromonu (Check-Mate VMB- F) geniş alan deneme deseni kullanılarak, her yıl 12.4-74.4 g aktif içerik/ha olacak şekilde uygulanmıştır. Çiftleşmeyi engelleme parselinde, eşeyssel çekici tuzaklarda kaydedilen birey sayısı ve salkımlardaki zarar oranı kontrole göre oldukça düşük kaydedilmiştir. 2019, 2020 ve 2021 yıllarında salkımlardaki zarar oranı çiftleşmeyi engelleme parselinde sırasıyla %12, 3, %3 ve %2,3 olarak kaydedilirken, kontrol parselinde sırasıyla %56, %37 ve %41 olmuştur. *Planococcus ficus*'a karşı yapılan 3 yıllık çalışmanın sonucu, çiftleşmeyi engelleme metodunun Ege Bölgesi bağ alanlarında *P. ficus* mücadelesinde güvenle kullanılabileceğini göstermiştir.

Anahtar sözcükler: Biyoteknik metot, izleme tuzakları, semiokimyasallar, sürdürülebilir tarım, bağ zararlıları

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Introduction

Türkiye is one of the most suitable regions for viticulture in the world. Table, raisin and wine grapes, produced from approximately 417.000 hectares of area, with a total production of 4.200.000 tons of crops, are consumed as domestic market and export products. On the other hand, it is among the leading countries in terms of viticulture with a production of approximately 4 million tons from a total area of 4.2 thousand hectares every year. The Aegean Region is the most important area, constituting 30% of the vineyard area in Türkiye (TUIK, 2025). Manisa and İzmir provinces are among the important provinces where viticulture is carried out in that region. In Türkiye, approximately 50% of the grapes produced are consumed as table grapes, 38% as raisins and 12% as wine for the domestic market and export (Ministry of Agriculture and Forestry, 2025).

The Sultani seedless grape variety (*Vitis vinifera* L.) (Vitales: Vitaceae) ranks first in grape production for export in Türkiye. In Türkiye, 95% of grape exports are made up of the Sultani seedless variety, which is exported as raisins. Türkiye, which ranks first in the world raisin exports (32.5%), sends a significant portion of its exports to European countries (Ministry of Agriculture and Forestry, 2025).

As in all cultivated plants, there are pests that affect yield and quality in viticulture. Vine mealybug, *Planococcus ficus* (Signoret, 1875) (Hemiptera: Coccoomorpha: Pseudococcidae), has become an increasing problem in vineyards of the Aegean Region vineyards in recent years. *Planococcus ficus* is one of the most important pests in vineyards. It is also a problem in Italy, Tunisia, Spain, South Africa and the USA (Walton et al., 2006, Mansour et al., 2017a; Daane et al., 2018). Mealybugs are tiny, hidden life cycle, piercing-sucking scales that feed on phloem. Mealybugs affect crop quality and yield by excreting honeydew, which covers the leaves, canes and bunches. Heavy infestations of bunches generate unmarketable table grapes and lower the quality of wine and raisin grapes. Additionally, *P. ficus* was known transmitting grapevine virus A, *Vitivirus alfavitis*, and grapevine virus B, *Vitivirus betavitis* (Tymovirales: Betaflexiviridae) (Tanne et al., 1989; Engelbrecht & Casdorf, 1990; Minafra & Haididi, 1994), and Grapevine Leafroll Associated Virus III (GLRaV-III), *Ampelovirus trivitis* (Martellivirales: Closteroviridae) (Mahfoudhi & Dhouibi, 2009). Vine mealybug affects grape areas directly and indirectly. The main damage caused by the pest occurs through feeding and the toxins it releases into the plant during feeding. As a result of this damage, a color change occurs in leaves and fruits. Because of pest damage, reduction in shoot and fruit growth rate, leaf defoliation, and decreased plant vigor may occur, which may lead to plant death in severe cases (Kosztarab, 1996; Franco et al., 2009). Indirect damage occurs as a result of honeydew excretion and development of sooty mold, as well as transmission of virus diseases, which may reduce photosynthesis area and plant vigor. Honeydew often attracts ants, which may block the activity of natural enemies and make possible the spread of mealybugs in the crop (Franco et al., 2009; Quesada et al., 2018). Their tiny size and hidden behavior make them difficult to detect. Insecticide applications are generally not effective against mealybugs because the pest may feed on all parts of the vine. Moreover, its cryptic life cycle and the hydrophobic wax layer of the pest protect it from pesticide applications. Pest control with synthetic insecticides is not effective enough, and it also has negative effects on the environment and non-target organisms. Also, mealybugs can develop pesticide resistance with repeated use. In recent years, residue problems may have arisen in exported Sultani seedless grapes due to intensive and calendar-based pesticide use.

All over the world, efforts are being made to minimize pesticide use to support residue-free production and reduce the negative impacts of pesticides on human health and the environment. Therefore, the development of effective and sustainable integrated pest management tools to control pest populations is a key challenge. For these reasons, it is necessary to put forward a new control method that can be applied in traditional or organic production, such as pheromone-based methods. The sex pheromone of *P. ficus* was first obtained in 2001 (Hinkens et al., 2001). The commercial production and application of this product for pest control began in 2006 and continued with the increase in commercial production in the following years (Walton, 2006).

The European Green Deal, launched by the European Commission in December 2019, is a major policy package addressing climate change. The European Green Deal focuses on sustainable agriculture and biodiversity conservation policies to minimize or mitigate the impact of climate change on Europe by 2050. The use of chemical pesticides in agriculture may contribute to soil, water and air pollution, biodiversity loss and can harm non-target plants, insects, birds, mammals and amphibians. Therefore, the goal is to reduce current pesticide use by 50% by 2030. To achieve the ambition of reducing insecticide use, biotechnical agricultural research plays a major role (Fetting, 2020).

As outlined above, reducing pesticide usage has become a goal shared by several European countries and a major issue in public policies due to the negative impacts of insecticides on the environment and human health. Mating disruption (MD) is an important control strategy that has been increasingly used as it is harmless to non-target organisms and without resistance problems. Pheromone-based MD is one of the most preferred methods by producers worldwide. Currently, MD is applied to 750,000 hectares of area against various pests (Franco et al., 2021). Most of these pests belong to the order of Lepidoptera and one or two of these are in the order of Hemiptera. One of the hemipteran species is the vine mealybug *P. ficus* that has a commercial formulation of MD. It is applied on an average of 130.000 hectares worldwide, including vineyards in South Africa, the USA, Spain, Italy and other European countries (Franco et al., 2021).

MD is a species-specific and environmentally pest control method. MD relies on the release of a synthetic sex pheromone to interfere with mate finding and reproduction of the target organism (Carde & Minks, 1995). Biparental scales are suitable targets for MD because females have limited movement ability, and adult males are short lived, so they have a limited time for mating. MD for mealybugs can be applied in small areas, and it can be appropriate with biological control in Integrated Pest Management (IPM) programs. On the other hand, MD is effective in small areas (>0.5 ha) for *P. ficus* (Sharon et al., 2016; Mansour et al., 2017b; Cocco et al., 2018; Franco et al., 2021). Male mealybugs are very reactive to sex pheromone, so a small amount of pheromone is sufficient for effective MD application, which makes the method economical for the producers. A lot of commercial products for *P. ficus* MD have been tried worldwide in vineyard areas, including the USA, North Africa, Tunisia, and Italy. The sprayable, microencapsulated formulation of the racemic sex pheromone, lavandulyl senecioate, was first tested in 2003 and 2004 by Walton et al. (2006), who showed that crop damage ratings were lower in MD plots than in control (Non-MD) areas. Also, Daane et al. (2020) obtained good results in the USA. Several studies have reported that microencapsulated (MEC) sex pheromone formulations reduced the pest densities of different moth species (Stelinski et al., 2007; Wins-Purdy, 2007). MECs are small droplets of pheromone enclosed within a polymer capsule, which controls the pheromone release rate. The capsules are small enough to be applied as suspensions using the same commercial equipment to spray insecticides. The effective field longevity of the materials generally ranges from days to weeks, depending on climatic conditions, capsule size and properties, and the chemical composition of the pheromone components.

This study was conducted to demonstrate the effects of sprayable synthetic sex pheromone on *P. ficus* population densities and crop damage for the first time in Türkiye. For this purpose, pest monitored using delta traps (Suterra 541-388-3688) baited with the vine mealybug sex pheromone (baited with a rubber septum lure loaded with 100 mg of the racemic pheromone) and pest damage was evaluated on bunches at the harvest time.

Materials and Methods

This study was conducted in a commercial vineyard area where the Sultani seedless cultivar was cultivated in Manisa province (Turgutlu) in 2019-2021.

Materials

The main materials used in this study were Sultani seedless cultivar, all biological stages of *P. ficus* (egg, nymph, adult), a sprayable microencapsulated pheromone formulation (Check-Mate VMB- F) (Table 1), delta traps, pheromone lures for monitoring (Scenturion® VMB lures by Suterra, 100µg lavandulyl senecioate), a garden sprayer, a microscope (Zeiss Discovery V8) and other supplementary materials. The field trials were conducted on commercially farmed large plots managed in Manisa (Türkiye), covering ~1.2 hectares.

Table 1. Information about the mating disruption pheromone was applied to control *Planococcus ficus*

| Active ingredient | Formulation | Commercial name | Manufacturer |
|------------------------------|--------------------|------------------|--------------|
| Lavandulyl senecioate %19.35 | Capsule Suspension | Check mate-VMB-F | SUTERRA Inc |

Grape cultivar

The vineyard where the trial was conducted comprises a 25-year-old Sultani seedless variety. The area has a drip irrigation, sandy soil, and the distance between rows is 3 meters and within rows is 1.75 meters. Non-MD plot was 0.05 hectares in size.

Sex pheromone

A microencapsulated (MEC) flowable pheromone was tested in an open field area for 3 years. The trials were conducted in a vineyard with medium-low population levels, which is a typical case for all biotechnical methods.

Methods

Study site, growing conditions and experimental design

Open-field trials focused on determining the effect of flowable pheromone formulation. The experiment was performed in accordance with standard sidelines established by the General Directorate of Agricultural Research and Policies suitable for the registration of MD products in Türkiye (Ministry of Agriculture and Forestry, 2025).

The MD plot was divided into 6 sub-plots, covering at least 0.18 hectares to ensure representative sampling across grapevines. Each subplot was composed of a minimum of 50 bunches, which were homogeneously distributed in the internal part of the plot, 20 m away from the borders. The MD plot was located 200 m away from the Non-MD plot.

Adult male *P. ficus* flights were monitored using delta traps (Suterra 541-388-3688) baited with the vine mealybug sex pheromone. Each trap was baited with a rubber septum lure loaded with 100 mg of the racemic pheromone (lavandulyl senecioate; Suterra LLC) and was hung on the vine canopy. Pheromone lures were changed monthly, while paper sticky delta traps were changed weekly. The aim of changing these traps in vineyards was to record the number of vine mealybug males weekly. Monitor traps were placed in MD and Non-MD plots at 1 trap per 1.2 hectares. In the laboratory, from April to August, all the male vine mealybugs gathered from each trap were counted weekly using a stereo microscope. The cumulative effect of MD MEC formulation on *P. ficus* males over time was evaluated by calculating the percentage of catch inhibition of males in monitor traps between MD and Non-MD plots in each check date using the following formula (Abbott, 1925):

$$\% \text{ Catch inhibition (reduction)} = [(N_{\text{Non-MD}} - N_{\text{MD}} / N_{\text{Non-MD}}) \times 100]$$

With: N_{MD} is the number of male vine mealybug trap catches in the MD plot; $N_{\text{Non-MD}}$ is the number of male vine mealybug trap catches in the Non-MD plot.

In the Non-MD plot, no insecticide application has been done against *P. ficus*. Other pesticide applications were conducted equally on all plots (including Non-MD). Tebuconazole and Azoxystrobin containing active ingredients have been used against vineyard diseases in the trial area. Climatic data regarding average daily temperature and relative humidity have been recorded by the electronic station used for Forecasting System by the Extension Service in Manisa.

Application times and rates

The application was repeated monthly. Accordingly, MD treatment was repeated every 28 days without interruption throughout the production season. However, MD treatment requires repetition if the leaf wetness lasts for a long time after more than a few hours of rain in the form of downpours during the season. Therefore, on June 11, 2019, assuming that the pheromone was washed off from the leaf surface, pheromone treatment was repeated on June 15, 2019, regardless of the date due to the rains prevailing in the region. The microencapsulated formulation was mixed with water and applied to the vines using a hydraulic garden sprayer at a rate of 12.5 g active ingredients (a.i.)/ha in all three years. No insecticides were programmed for the MD or Non-MD plots during the trial period. All years (2019-2021) Non-MD plots were never sprayed with any insecticide.

In 2019, the MD application was performed after the first adult was caught in the traps (9.05) at the rate of 12.4 a.i./ha. In total, 49,6 g a.i./ha through the season was applied in the MD plot. This flowable material was tested in four sprays: early season (09.05.2019), mid-season (07.06.2019), (15.07.2019) and late season (16.08.2019).

In 2020, the MD application was conducted after the first adult was caught in the traps (8.05). The pheromone was applied at the rate of 12.4 a.i./ha, with a total of 74,4 g a.i./ha through the season. This flowable material was tested in six sprays: early season (08.05.2020), (30.05.2020), (05.06.2020), (16.06.2020), mid-season (12.07.2020), and late season (09.08.2020).

In 2021, the MD application was carried out after the first adult was caught in the traps (5.05) at the rate of 12.4 a.i./ha. In total, 49,6 g a.i./ha through the season was applied in the MD plot. This flowable material was tested in four sprays: early season (05.05.2021), mid-season (30.05.2021), (28.06.2021) and late season (26.07.2021).

Data analysis

To evaluate the efficacy of the sex pheromone, the number of infested and non-infested bunches detected at pre-harvest in the MD and the Non-MD plots were compared using the Chi-square (χ^2) test. The Chi-square (χ^2) test was used to analyze observed count data (derived from a 2x2 contingency table (treatment x infestation status)) of infested and non infested bunches between MD and Non-MD plots. The level of significance level was set at $\alpha=0.05$. A total of 300 bunches were evaluated in the MD plot and 100 bunches were evaluated in the Non-MD plot.

Results

The results of this study, conducted under farmer managed field conditions (open-field test), vary depending on the year. The data obtained as a result of the study are shared below.

Mealybug male flight activity and pheromone trap catches

Adult male *P. ficus* flights were monitored starting from mid- April in 2019, 2020 and 2021. The first mealybug male flights were caught in the first week of May in the monitoring traps throughout all trial years (Table 2). After the first male adult was caught, the MEC pheromone was applied using a hydraulic garden sprayer. Zero trap captures (often referred to as trap shutdown effect) were recorded for consecutive weeks during the 2020 and 2021 experimental years (Table 2).

Table 2. Total numbers of males caught in mating disruption (MD) and non-mating disruption plot (Non-MD) at trials in 2019, 2020 and 2021

| 2019 | | | 2020 | | | 2021 | | | | | |
|--------------|-----------------------------------|---------------------------------------|--------------------------|------------|-----------------------------------|---------------------------------------|--------------------------|------------|-----------------------------------|---------------------------------------|--------------------------|
| Dates | Total nm. of males caught MD plot | Total nm. of males caught Non-MD plot | Average temperature (°C) | Dates | Total nm. of males caught MD plot | Total nm. of males caught Non-MD plot | Average temperature (°C) | Dates | Total nm. of males caught MD plot | Total nm. of males caught Non-MD plot | Average temperature (°C) |
| 08.05.2019 | 3 | 4 | 14,05 | 07.05.2020 | 20 | 4 | 15,05 | 04.05.2021 | 2 | 5 | 22,44 |
| 15.05.2019 | 4 | 12 | 23,59 | 14.05.2020 | 8 | 16 | 23,85 | 11.05.2021 | 1 | 16 | 18,87 |
| 22.05.2019 | 4 | 27 | 23,40 | 21.05.2020 | 3 | 22 | 26,20 | 18.05.2021 | 2 | 19 | 22,69 |
| 29.05.2019 | 4 | 38 | 25,77 | 28.05.2020 | 2 | 46 | 16,07 | 25.05.2021 | 2 | 26 | 25,22 |
| 05.06.2019 | 4 | 29 | 24,84 | 04.06.2020 | 4 | 32 | 19,66 | 01.06.2021 | 2 | 34 | 19,31 |
| 12.06.2019 | 7 | 28 | 23,36 | 11.06.2020 | 0 | 20 | 23,67 | 08.06.2021 | 0 | 15 | 24,83 |
| 19.06.2019 | 2 | 32 | 22,39 | 18.06.2020 | 0 | 35 | 22,46 | 15.06.2021 | 0 | 39 | 17,43 |
| 26.06.2019 | 5 | 19 | 27,86 | 25.06.2020 | 0 | 20 | 25,19 | 22.06.2021 | 2 | 31 | 26,19 |
| 03.07.2019 | 3 | 38 | 27,60 | 02.07.2020 | 0 | 32 | 27,26 | 29.06.2021 | 0 | 13 | 27,71 |
| 10.07.2019 | 5 | 35 | 27,77 | 09.07.2020 | 4 | 45 | 26,74 | 06.07.2021 | 4 | 15 | 25,79 |
| 17.07.2019 | 6 | 22 | 24,29 | 16.07.2020 | 0 | 22 | 23,85 | 13.07.2021 | 1 | 17 | 28,45 |
| 24.07.2019 | 4 | 32 | 25,84 | 23.07.2020 | 0 | 14 | 27,05 | 20.07.2021 | 1 | 45 | 28,06 |
| 31.07.2019 | 3 | 29 | 28,39 | 30.07.2020 | 0 | 29 | 28,64 | 27.07.2021 | 1 | 22 | 27,77 |
| 07.08.2019 | 4 | 32 | 25,31 | 06.08.2020 | 2 | 41 | 27,49 | 03.08.2021 | 0 | 26 | 30,47 |
| 14.08.2019 | 3 | 24 | 27,70 | 13.08.2020 | 1 | 27 | 27,79 | 10.08.2021 | 0 | 45 | 26,74 |
| 21.08.2019 | 3 | 20 | 25,57 | 20.08.2020 | 0 | 25 | 25,06 | 17.08.2021 | 1 | 45 | 25,50 |
| 28.08.2019 | 3 | 19 | 28,04 | 27.08.2020 | 0 | 24 | 27,52 | - | - | - | - |
| Total number | 70 | 440 | | | 44 | 454 | | | 19 | 413 | |

The total number of male vine mealybugs caught in traps in Non-MD plots was relatively high with 440, 454, 413 while it was recorded that the number in MD plots was 70, 44, 19 in 2019, 2020 and 2021, respectively. Generally, the highest season-long percentage of catch inhibition percentage was recorded as 95.39% in 2021. The percentages in 2019 and 2020 were lower, at 84.09% and 90.30, respectively (Table 3). Additionally, the weekly trap counts are presented in Figures 1, 2, and 3, respectively.

Table 3. Catch inhibition rates of males caught in monitor traps mating disruption (MD) and non-mating disruption plot (Non-MD) between 2019-2021

| Years | Non-MD | MD | Catch inhibition (%) |
|-------|--------|-----|----------------------|
| 2019 | 440 | 70 | 84.09 |
| 2020 | 454 | 44 | 90.30 |
| 2021 | 413 | 19 | 95.39 |
| TOTAL | 1307 | 133 | 89.82 |

In May 2019, the highest number of males was recorded on 29 May, with 38 males/trap in the Non-MD plot. On this date, the average temperature was 25.77°C and the average relative humidity was 38.65%. In June, the highest number of males was recorded 19 June, with 32 males/trap. On this date, the average temperature was 22.39°C and the average relative humidity was 88.83%. In July, the highest number of males was recorded on 3 July, with 38 males/trap. On this date, the average temperature was 27.60°C and the average relative humidity was 54.30%. In August, the highest number of males was recorded on 7 August, with 32 males/trap. On this date, the average temperature was 25.31°C and the average relative humidity was 53.01%.

The highest average temperature recorded was on 31.07.2019 (28.39°C) with 29 males/trap captured in the Non-MD plot. Other dates when the highest temperatures were recorded in 2019 in the Non-MD plot were found to be on 28.08.2019 (28.04°C, 19 males/trap); and 26.06.2019 (27.86°C, 19 males/trap) (Table 2).

When the average climate data were examined during the months of May-August 2019 in the experiment area, it was recorded that the average temperature was 24.57°C, the average relative humidity was 58.67%, and the average wind speed was 0.56 m/s. The average rainfall of the region between May and August was recorded as 0.59 mm, but it was observed that the number of males captured in monitoring traps was not affected by the rain (Tables 2 & 4).

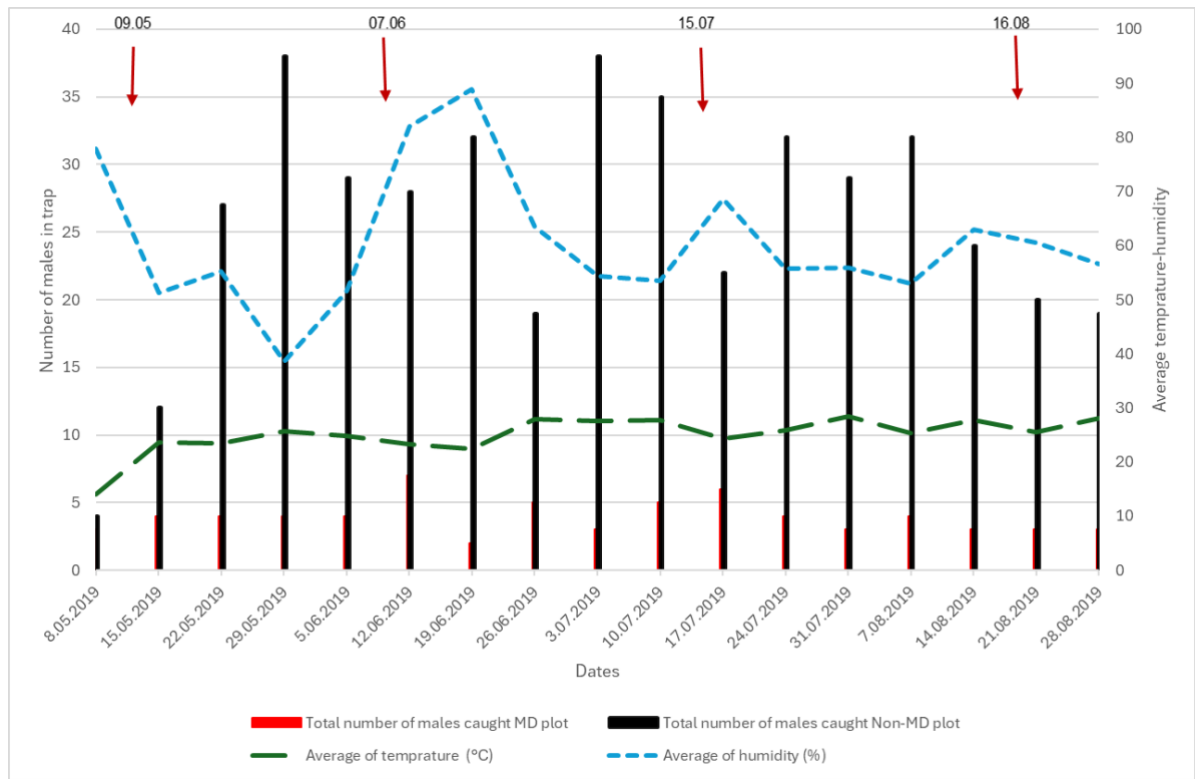


Figure 1. Weekly trap captured males at the vineyard for *Planococcus ficus* in trials in 2019 in Manisa (Red arrows indicate flowable pheromone treatment dates).

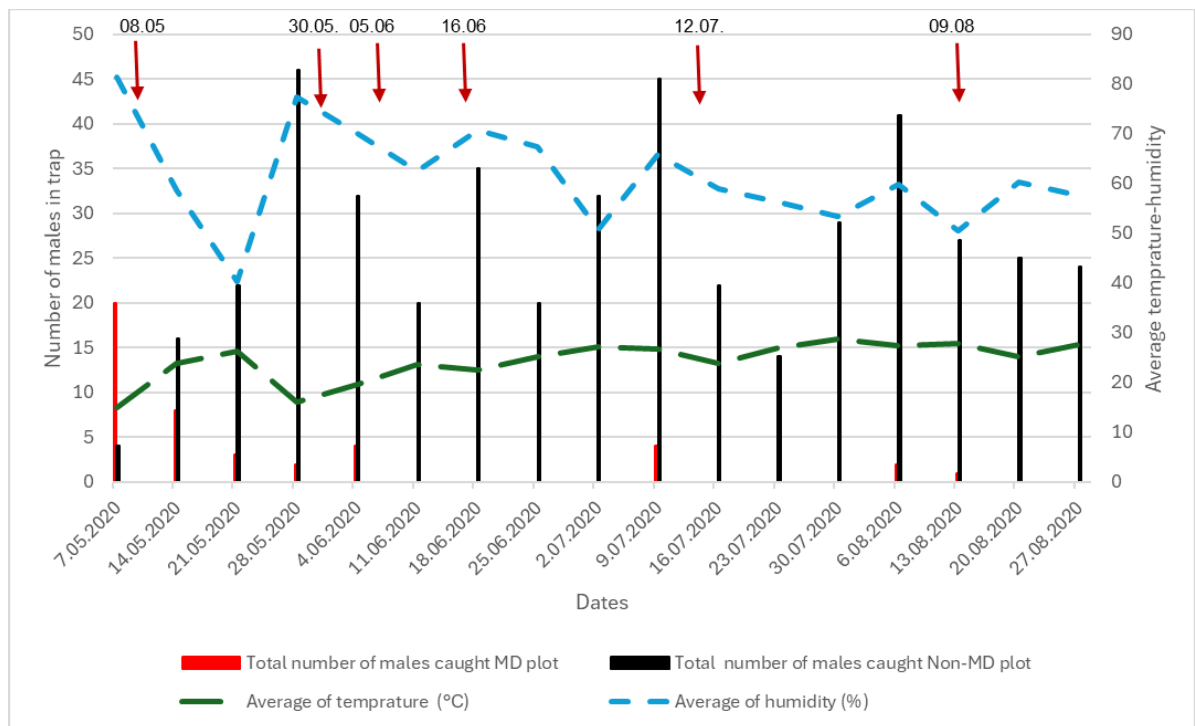


Figure 2. Weekly trap captured males at the vineyard for *Planococcus ficus* in trials 2020 in Manisa (Red arrows indicate flowable pheromone treatment dates).

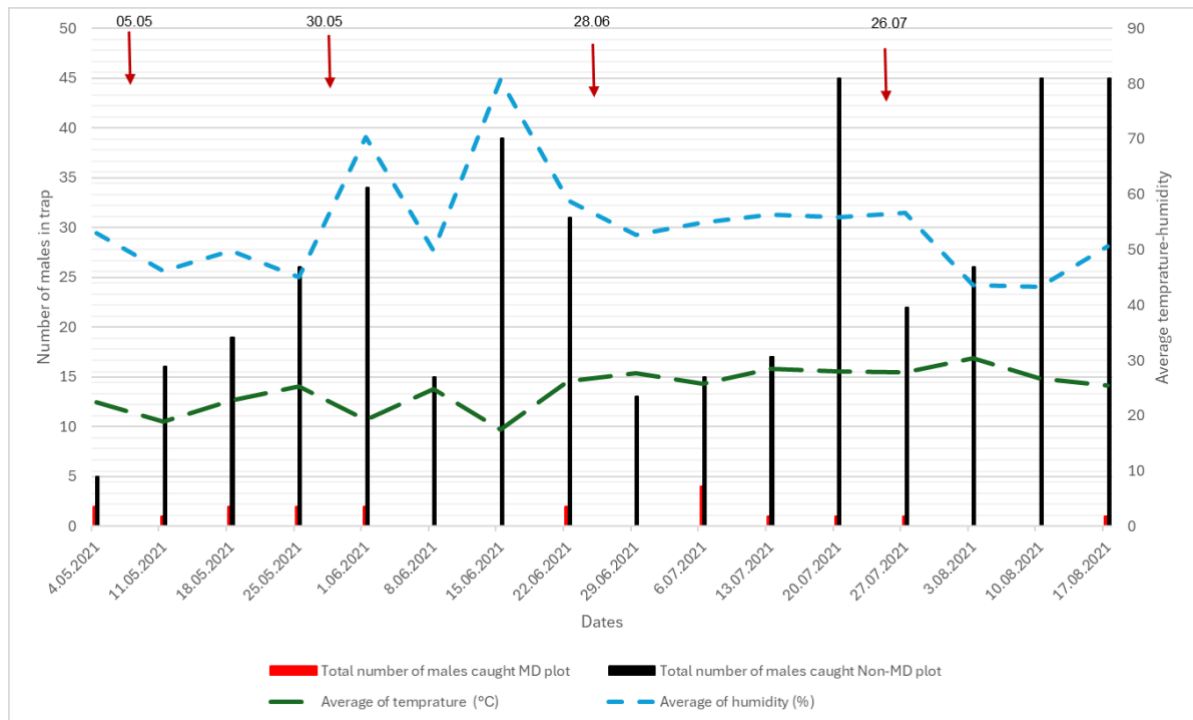


Figure 3. Weekly trap captured males at the vineyard for *Planococcus ficus* in trials 2021 in Manisa (Red arrows indicate flowable pheromone treatment dates).

In May 2020, the highest number of males was recorded on 28 May, with 46 males/trap in the Non-MD plot. On this date, the average temperature was 16,07°C and the average relative humidity was 77,42%. In June, the highest number of males was recorded on 18 June, with 35 males/trap. On this date, the average temperature was 22.46°C and the average relative humidity was 70.64%. In July, the highest number of males was recorded, on 9 July, with 45 males/trap. On this date, the average temperature was 26.74°C and the average relative humidity was 65.85%. In August, the highest number of males was recorded on 6 August, with 41 males/trap. On this date, the average temperature was 27.49°C and the average relative humidity was 59.79%.

The highest average temperature recorded was on 30.07.2020 (28.64°C), with 29 males/trap captured in the Non-MD plot. Other dates when the highest average temperatures were recorded in 2020 in the Non-MD plots were 13.08.2020 (27.79°C, 27 males/trap) and 27.08.2020 (27.52°C, 24 males /trap) (Table 2).

When the average climate data were examined during the months of May-August 2020 in the experiment area, it was recorded that the average temperature was 23.84°C, the average relative humidity was 60.05%, and the average wind speed was 0.56 m/s. The average rainfall of the region between May and August was recorded as 1.21 mm, but it was observed that the number of males captured in monitoring traps was not affected by the rain (Tables 2 & 4).

In May 2021, the highest number of males was recorded on 25 May, with 26 males/trap in the Non-MD plot. On this date, the average temperature was 25.22°C and the average relative humidity was 44.99%. In June, the highest number of males was recorded on 15 June, with 39 males/trap. On this date, the average temperature was 17.43°C and the average relative humidity was 80.70%. In July, the highest number of males was recorded on 20 July, with 45 males/trap. On this date, the average temperature was 28.06°C and the average relative humidity was 55.88%. In August, the highest number of males was recorded from 10 to 17 August, with 45 males/trap. On these dates, the average temperatures were respectively 26.74°C and 25.50°C and the average relative humidity was 43.35% and 50.55%, respectively.

The highest weekly average temperature recorded was on 03.08.2021 (30.47°C) with 26 males/trap captured in the Non-MD plot. Other dates when the highest average temperatures were recorded in 2021 in the Non-MD were 17 males/trap on 13.07.2021 (28.45°C) and 45 males/trap on 20.07.2021 (28.06°C) (Table 2).

When the average climate data were examined during the months of May-August 2021 in the experiment area, it was recorded that the average temperature was 24.16°C, the average relative humidity was 53.97%, and the average wind speed was 0.77 m/s. The average rainfall of the region between May and August was recorded as 0.99 mm, but it was observed that the number of males captured in the monitoring traps were not affected by the rain (Tables 2 & 4).

Table 4. Monthly average climate data for May and August in 2019-2022

| Months/ Years | Monthly average of temperature [°C] | | | Monthly average of relative humidity (%) | | | Total monthly rainfall (mm) | | | Monthly average of maximum wind speed (km/h) | | |
|------------------|-------------------------------------|-------|-------|--|-------|-------|-----------------------------|------|------|--|------|------|
| | 2019 | 2020 | 2021 | 2019 | 2020 | 2021 | 2019 | 2020 | 2021 | 2019 | 2020 | 2021 |
| May | 20,53 | 20,13 | 18,59 | 59,92 | 64,39 | 47,03 | 0,06 | 3,05 | 0,41 | 0,42 | 0,64 | 0,89 |
| June | 25,05 | 23,15 | 23,36 | 62,19 | 66,08 | 61,22 | 1,40 | 1,54 | 0,61 | 0,58 | 0,53 | 0,73 |
| July | 25,94 | 27,28 | 27,62 | 56,27 | 57,63 | 55,32 | 0,34 | 0,15 | 0,20 | 0,68 | 0,60 | 0,81 |
| August | 26,77 | 24,80 | 27,09 | 56,30 | 52,10 | 52,31 | 0,56 | 0,12 | 2,77 | 0,58 | 0,50 | 0,68 |
| Average | 24,57 | 23,84 | 24,16 | 58,67 | 60,05 | 53,97 | 0,59 | 1,21 | 0,99 | 0,56 | 0,56 | 0,77 |

Crop damage assessment

Harvest started in the last week of August for all three experimental years. Visual observations of vine mealybug presence on bunches were carried out in all three years shortly before the harvest in August. In the evaluation, 50 bunches were examined in each sub-plot of the MD plot (total 6 sub-plots; 300 bunches) whereas only 100 bunches were examined in the Non-MD plots. All live biological stages were counted on the bunches (Table 5). Crop damage rate was calculated as the number of infested bunches divided by the total number of bunches examined. Crop damage rates in the MD plot were 12.3%, 3% and 2.3%, in 2019-2021 respectively, while crop damage rates in the Non-MD plot were 56%, 37% and 41%.

Significant differences were detected between MD and Non-MD plots across all study years ($\chi^2=72.88$; $\chi^2=109.99$ and $\chi^2=131.76$, $df=1$, $p<0.001$). In 2019, infested bunches rates different significantly between the MD and Non-MD plots ($\chi^2=72.88$, $df=1$, $p<0.001$). In 2020, a similarly significant difference was observed ($\chi^2=109.99$, $df=1$, $p<0.001$). In 2021, the difference between treatments remained highly significant ($\chi^2=131.76$, $df=1$, $p<0.001$). As a result of the statistical analyses carried out in the study, it was noted that the MD decreased the number of infested bunches and increased the market value of the product compared to Non-MD. It is also another indicator of success in catch inhibition in the mealybug population in the monitoring traps.

Table 5. Number of infested and non-infested bunches recorded in trails during 2019-2021 and results of chi square tests (Evaluation based on 300 bunches from the MD plot and 100 bunches from the Non-MD plot) 2019 ($\chi^2=72.88$, $df=1$, $p<0.001$), 2020 ($\chi^2=109.99$, $df=1$, $p<0.001$), 2021 ($\chi^2=131.76$, $df=1$, $p<0.001$)

| Years | Trials | Infested bunches (Number) | Non-infested bunches (Number) | χ^2 | p -value |
|-------|-----------------------|---------------------------|-------------------------------|----------|------------|
| 2019 | Mating disruption | 37 | 263 | 72.88 | 0.001 |
| | Non-Mating disruption | 56 | 44 | | |
| 2020 | Mating disruption | 9 | 291 | 109.99 | 0.001 |
| | Non-Mating disruption | 37 | 63 | | |
| 2021 | Mating disruption | 7 | 293 | 131.76 | 0.001 |
| | Non-Mating disruption | 41 | 59 | | |

Discussion

Although previous studies on MD were not very numerous, they are promising when evaluated in terms of their results. A number of studies have reported sprayable pheromone formulations lower pest densities of -various moth and mealybug species (Walton et al., 2006; Stelinski et al., 2007; Wins-Purdy, 2007; Daane et al., 2021). Previous studies on *P. ficus* in areas where MD is applied area have shown that the number of males in monitor traps, crop damage and population density was clearly decreased (Millar et al., 2002; Walton et al., 2004; Bahder et al., 2013). Also, studies have shown that MD generally gives better results in pests with low-medium population density (Walton, 2006; Witzgall et al., 2010; Sharon et al., 2016; Daane et al., 2020). Biotechnical methods usually give better results when they are used at low pest density; at high densities, they are combined with other control tools.

In this study, catch inhibition was recorded 84.09%, 90.30% and 95.36%, respectively, in the monitor traps in the MD plot in 2019-2021, compared to the Non-MD plot. In previous studies, MEC formulations was effective in decreasing pest density, the percentage of ovipositing females, female fecundity and crop damage (Walton et al., 2006). The MD formulation used in the study was tested in the USA where it suppressed the pest when applied at a rate of 12.5 g a.i./ha in vineyards, with 5 applications throughout the season (Haviland, 2017). Mansour et al. (2017b) demonstrated the effect of the MD on *P. ficus* in Tunisian vineyard areas, and as a result of the study conducted in three different vineyard areas, they recorded a decrease in the number of males in traps by 94.29%, 75.58% and 86.63%. Cocco et al. (2018) tested MD for three years and reported that catch inhibition for *P. ficus* in traps were recorded as 74.6%, 85.3% and 96%, respectively.

Walton et al. (2006) demonstrated that in grape areas, after two years of MD, bunch damage was recorded as 4% and 3.1%, respectively, while in the Non-MD, it was recorded as 11.8% and 9.11%, respectively. Crop damage rates in the MD plot were 12.3%, 3% and 2.3% while crop damage rates in the Non-MD plot were 56%, 37% and 41% respectively in 2019-2021. Sharon et al. (2016) reported that MD application obtained good results in a high-population vineyard as a stand-alone control tool in two consecutive years. Similarly to our study, Hogg et al. (2021) found that male *P. ficus* captures in monitoring traps were correlated with mealybug population levels and crop damage. Daane et al. (2021) reported that effective results can be obtained with three applications of the MEC formulation during the season. Also, they stated that three spraying applications give better results than two for crop damage and trap caught inhibition.

Since early 2000's, MD programs for *P. ficus* have obtained commercial success in the USA, Europe, the Middle East, and Africa (Cocco et al., 2014, 2018; Sharon et al., 2016; Mansour et al., 2017b; Daane et al., 2020). MEC formulation of MD is sustainable control method for *P. ficus*. It is known that MD studies on *P. ficus* have been conducted for the last 20 years and are only now beginning to become widespread. The method, which is applied in an area of 130,000 hectares worldwide, is expanding its experimental area size each year. More data will be obtained in the coming years, especially with the increase in the number of applications and permanence of the flowable form in field conditions. Check-Mate VMB-F is a type of pheromone, a sprayable microencapsulated formulation that has several advantages compared to other types of dispensers. That sprayable formulation provides complete coverage and is suitable for mixing with other pesticides. Producers have flexibility in the quantity of pheromone used per hectare and can adjust the number of applications to pest density and harvest time. However, a disadvantage is that field longevity is often maximum a month, requiring repeated applications for season.

The consecutive insecticide applications are not effective in the next year's pest density. In contrast, the MD significantly reduces the vine mealybug populations when applied in consecutive years. MD's cumulative effect is a proven fact. Recently, biotechnical methods have been widely used and supported within the integrated pest management programmes. MD is the most widely used biotechnical method in the world. The most important advantages of MD are that it is very selective for species, affecting only the target organism and having no negative effects on humans, the environment, biological control agents and non-target organisms.

According to the data obtained from this study, MD is an effective control method for *P. ficus*. Its effectiveness as a pest control tool is demonstrated by reductions in crop damage and trap catches. Furthermore, it promises to suppress pests, often detected just before harvest, without leaving residues. Although the trials carried out around the world continue, especially the need for specialized knowledge and cost are the limiting factors of biotechnical methods. With the increase in the number of studies and variety of products, MD is expected to become more widespread and the preferred choice of producers.

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