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ARAŞTIRMA MAKALESİ **RESEARCH ARTICLE**

Effectiveness of Some Biological and Chemical Fungicides to Control Powdery Mildew in Zucchini

Kabakgillerde Küllemeyi Kontrol Altına Almak İçin Bazı Biyolojik ve Kimyasal Fungisitlerin Etkinliği

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Abstract

Powdery mildew is one of the most devastating diseases affecting zucchini (*Cucurbita pepo* L.), leading to substantial economic losses by reducing plant vigor, yield, and fruit quality in open-field cultivation. The primary causal agents are *Erysiphe cichoracearum* and *Podosphaera xanthii (syn. Sphaerotheca fuliginea*) common pathogens of cucurbit crops. Traditional management has relied heavily on chemical fungicides, however, their continuous use has led to the development of resistance, environmental pollution and health concerns regarding pesticide residues. Therefore, the search of safe and sustainable alternatives has become a priority for integrated disease management. The objective of the current research was to determine the efficacy of three chemical fungicides (Baymert, Heros, and Pancho) and two biological control agents (*Trichoderma* sp. and *Penicillium* sp.) to decrease infections of powdery mildew and to enhance the yield of zucchini under field conditions in Jisr al-Shughur, Syria, during the 2024 season. *E. cichoracearum* and *P. xanthii* were artificially inoculated into plants and disease severity was evaluated 3, 7 and 12 days after treatment. Findings indicated that powdery mildew had a quick initial control with the use of chemical fungicides. Three days later, Heros recorded a control efficiency of 56.2%, after spraying. However, they were not effective over time, especially in the case of Pancho, which had reduced to only 18.1% control by day 12. Conversely, biological control agents proved to act later but to have lasting effects. *Trichoderma* sp. recorded the highest control efficiency among the biological treatments at 55.4% after 12 days and produced the highest vegetative yield, reaching 116.8 g/plant after 15 days, compared with 29.5 g/plant in the untreated control. The second-best performer in terms of vegetative yield (89.6 g/plant) was Heros, and *Penicillium* sp. gave moderate but consistent control. Such results are in line with the fact that chemical fungicides are only capable of short-term suppression, but they do not persist effectively in the field. Biological control agents, specifically *Trichoderma* sp, are a better long-term solution, with long-term disease control and increased growth of plants and yield advantages. The research highlights the importance of the inclusion of biological control as an idea in sustainable powdery mildew management measures in zucchini production in reducing the usage of synthetic fungicides and in making agricultural systems safer and cleaner.

Keywords: *Trichoderma, Penicillium*, Fungicides, Powdery mildew, Zucchini

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Öz

Külleme, açık alan yetiştiriciliğinde bitki gelişimini, verimi ve meyve kalitesini düşürerek önemli ekonomik kayıplara yol açan, kabakta (*Cucurbita pepo* L.) en tahrip edici hastalıklardan biridir. Başlıca etmenler, kabakgil ürünlerinin yaygın patojenleri olan *Erysiphe cichoracearum* ve *Podosphaera xanthii*'dir (*syn. Sphaerotheca fuliginea*). Geleneksel mücadele çoğunlukla kimyasal fungisitlere dayanmaktadır; ancak bunların sürekli kullanımı direnç gelişmesine, çevre kirliliğine ve pestisit kalıntılarına ilişkin sağlık sorunlarına yol açmıştır. Bu nedenle, güvenli ve sürdürülebilir alternatiflerin aranması entegre hastalık yönetimi için bir öncelik haline gelmiştir. Bu araştırmanın amacı, Suriye'nin Cisr eş-Şuğur bölgesinde 2024 sezonunda tarla koşulları altında, üç kimyasal fungisitin (Baymert, Heros ve Pancho) ve iki biyolojik mücadele etmeninin (*Trichoderma* sp. ve *Penicillium* sp.) külleme enfeksiyonlarını azaltma ve kabak verimini artırma üzerindeki etkisini belirlemektir. *E. cichoracearum* ve *P. xanthii* bitkilere yapay olarak inoküle edilmiş ve hastalık şiddeti uygulamadan 3, 7 ve 12 gün sonra değerlendirilmiştir. Bulgular, küllemenin kimyasal fungisitlerin kullanımıyla hızlı bir başlangıç kontrolüne sahip olduğunu göstermiştir. Püskürtmeden üç gün sonra Heros, %56,2'lik bir kontrol etkinliği kaydetmiştir. Ancak kimyasallar zamanla etkilerini kaybetmiştir; özellikle Pancho'nun kontrol etkinliği 12. güne gelindiğinde %18,1'e düşmüştür. Aksine, biyolojik mücadele etmenlerinin daha geç etki gösterdiği ancak kalıcı etkilere sahip olduğu kanıtlanmıştır. *Trichoderma* sp., 12 gün sonra biyolojik uygulamalar arasında %55,4 ile en yüksek kontrol etkinliğini kaydetmiş ve 15 gün sonra, kontrol grubundaki 29,5 g/bitki değerine kıyasla 116,8 g/bitki ile en yüksek vejetatif verimi üretmiştir. Vejetatif verim açısından en iyi performans gösteren ikinci uygulama Heros (89,6 g/bitki) olmuş, *Penicillium* sp. ise orta düzeyde ancak istikrarlı bir kontrol sağlamıştır. Bu sonuçlar, kimyasal fungisitlerin yalnızca kısa süreli baskılama yeteneğine sahip olduğu, ancak tarlada etkili bir şekilde kalıcılık göstermediği gerçeğiyle örtüşmektedir. Biyolojik mücadele etmenleri, özellikle de *Trichoderma* sp., uzun süreli hastalık kontrolü, artan bitki büyümesi ve verim avantajları ile daha iyi bir uzun vadeli çözümdür. Araştırma, sentetik fungisitlerin kullanımını azaltmak ve tarımsal sistemleri daha güvenli ve temiz hale getirmek için kabak üretiminde sürdürülebilir külleme yönetim tedbirlerine biyolojik mücadelenin dahil edilmesinin önemini vurgulamaktadır.

Anahtar Kelimeler: *Trichoderma, Penicillium*, Fungisitler, Külleme hastalığı, Kabak

1. Introduction

Zucchini or courgetti (*Cucurbita pepo* L.) is a summer vegetable. It is a plant with yellow or green fruits, and its shape is generally similar to a cucumber. Zucchini is typically consumed as fresh vegetables, meaning it is usually served as a main dish or appetizer. In Syria, zucchini cultivation covered approximately 4,999 hectares during the 2023 growing season, producing 76,017 tons with an average yield of 15,207 kg/Ha, FAOSTAT (2023). However, zucchini production is constrained by numerous insect pests and plant diseases, among which powdery mildew is one of the most widespread and destructive diseases affecting cucurbit crops, particularly zucchini (Jiang and Xiao, 2024). Crops are exposed to many biotic and environmental stresses that negatively affect their productivity. Fungal diseases are among the most significant biotic stresses, with powdery mildew (Rudolph et al., 2024) being one of the most important due to its global distribution (Alsalmo et al., 2025). Powdery mildew affects many plant hosts, including cucumber (*Cucumis sativus* L.), zucchini (*Cucurbita pepo* L.), pumpkin (*Cucurbita maxima* Duch.), cantaloupe (*Cucumis melo* var. musk), watermelon (*Citrullus vulgaris* L.), gherkin (*Cucumis melo* L.), and pineapple (*Ananas comosus* L.) (Lebeda et al., 2024).

Powdery mildew (*Ouidium* sp.) is a fungal disease caused by two types of fungi: *Podosphaera xanthii* (*Podosphaera fuliginea* (Schltdl.) U. Braun and S. Takam.) and *Erysiphe cichoracearum*, (*Golovinomyces cichoracearum* D.C. Heluta) Wang et al, (2024), with *E. cichoracearum* being the most common. Powdery mildew can lead to a significant reduction in yield, and in severe infections, it can cause plant death if the responsible fungus is not controlled (Margaret, 2013). The first symptoms appear on the leaves as round, white, powdery spots that begin to expand on older leaves, eventually covering all the leaves (*Figure 1*). These spots lead to rapid leaf loss, reducing the growth rate and consequently decreasing the yield, As the severity of the disease increases and the duration of plant infection lengthens, these losses become more pronounced (Mossler and Nesheim, 2001). On flowers and fruits, small spots appear in the form of white, powdery clusters on the fruits. Additionally, flower infection causes abortion and dropping of newly formed flowers and fruits (Rudolph et al., 2024).

The fungi responsible for powdery mildew belong to the phylum *Ascomycota*, class *Leotiomycetes*, order *Erysiphales*, and family *Erysiphaceae*. The principal genera associated with cucurbit powdery mildew include *Erysiphe*, *Podosphaera* (formerly *Sphaerotheca*), *Leveillula*, and *Phyllactinia* (Wijayawardene et al., 2022). Powdery mildew affecting members of the Cucurbitaceae family is considered one of the most economically important diseases, causing substantial yield losses worldwide (Hacquard et al., 2013; Margaret, 2013; Rivera-Romero et al., 2024). Braun (1995) reported several species infecting cucurbits in Europe, including representatives of *Erysiphe*, *Podosphaera*, and *Leveillula*. In Jordan, *Erysiphe cichoracearum* has been documented on various cucurbit crops.

It was also found that occurred in both its conidial and sexual forms on zucchini, while it was found only in its conidial form on other cucurbits (El-Ammari and Khan, 1987). indicated that powdery mildew on cucurbits in Sweden is caused by the species *E. polyphaga*. In Germany, cucumber plants were found to be infected with both *E. cichoracearum* and *P. xanthii*. High humidity levels of 94–100% are ideal conditions for *P. xanthii* to dominate over *E. cichoracearum* (Janke et al., 1977). Previous studies in Syria reported *E. cichoracearum* on several cucurbit species in Latakia Governorate, Jisr al-Shughur, and other coastal regions. A subsequent survey also identified both *E .cichoracearum* and *P. xanthii* on various cucurbit crops, confirming their widespread occurrence in the Syrian coastal region. The results indicated that cucurbit plants were infected with the fungal species *E. cichoracearum* and *P. xanthii*, and the germination rate of the conidial spores of *P. xanthii* was higher than that of *E. cichoracearum*. As a result, *P. xanthii* dominated over *E. cichoracearum*. In the past decade, The use of fungicides is one of the most important tools in combating powdery mildew (McGrath, 1991), And therefore, in increasing production (Keinath et al., 2004). However, these fungicides may cause some harmful effects (McGrath, 2001). Therefore, we must continue to seek safer and more environmentally friendly alternatives (Almourrh et al., 2025).

One new approach that should be emphasized to reduce pesticide use, especially fungicides, is the use of seaweeds due to their beneficial properties, whether in enhancing the plant's ability to absorb nutrients or their effectiveness against various pests, insects, and diseases (Mishra et al., 2020). The commercial formulation of *Bacillus subtilis* (KTBS) are good sources of biologically active compounds, especially against fungi that cause plant diseases (Sawant et al., 2011). Thus, they are a valuable source of compounds used in combating plant

diseases. Seaweeds, particularly green, brown, and red algae and due to the safety of seaweeds, their low environmental impact, and their applicability, seaweed extracts have now become a good alternative to fungicides in controlling plant pathogens (Brimmer and Boland, 2003; Galal et al., 2011; Hamed et al., 2018). Consequently, a significant number of studies have demonstrated the role of seaweed and their extracts in protecting plants from fungal pathogens (Paulert et al., 2010; Abdel-Kader and El-Mougy, 2013; Ahmed et al., 2016).

The control of powdery mildew in cucurbits relies on the use of fungicides. However, there has been a problem in achieving good and effective control due to the development of fungal strains resistant to the fungicides currently in use. Additionally, chemical control pollutes the environment and increases the accumulation of toxic compounds in the food chain. Therefore, there is a growing need to search for safe alternatives for controlling plant diseases, such as cultivating resistant varieties or using compounds to induce resistance. Many of these compounds have been successfully used in the control of various plant diseases (Ibrahim et al., 2003).

Elsisi (2019) found that the fungus *Trichoderma* sp. combats powdery mildew on zucchini in greenhouses. Similarly, Elsharkawy et al. (2014) reported that the fungus *Trichoderma harzianum* controls powdery mildew on cucumber in greenhouses, and Ünlü et al., (2023) used it as a biocontrol agent to manage powdery mildew on zucchini plants. In experiments utilizing antifungal and antibacterial agents, successful biological control of powdery mildew on cucumber and other vegetables was demonstrated by several researchers in greenhouses (Kiss et al., 2004; Hegazi and El-Kot, 2010; Moyer and Peres, 2008; Jiao et al,. 2020). In field trials, successful biological control using the fungus *Trichoderma* and the bacterium *Bacillus* was observed in reducing powdery mildew infection on various vegetable crops (Singh et al., 2000; Abd El-Moneim, 2001; El-Gamal, 2003; McGrath, 2001). Biological control methods are gaining popularity because of concerns about environmental safety, wildlife, and human health. Additionally, pests are developing resistance to conventional chemical pesticides (Al-Mourrh et al., 2024; Alsalmo et al., 2026). There is growing awareness regarding pesticide residues in vegetable crops, particularly zucchini, where fruits may be harvested shortly after pesticide application. Synthetic chemical pesticides can have adverse effects on soil microorganisms, non-target organisms, wildlife, and water resources. Although modern application technologies, such as electrostatic spraying systems (Amaya and Bayat, 2023; 2024), have been developed to improve spray efficiency and reduce excessive pesticide use and drift, concerns remain regarding residue accumulation and long-term environmental impacts. Therefore, reducing reliance on synthetic chemicals through the integration of environmentally friendly biocontrol agents may contribute to more sustainable crop protection strategies (Dalda Şekerci et al., 2024).

As a result, researchers have turned to finding safe and healthy methods to reduce pest density while minimizing the use of chemical pesticides. This has led to an increase in the search for natural pest control methods and a reduction in synthetic chemical inputs. Given the high field incidence of powdery mildew on zucchini and concerns regarding the effectiveness and safe use of chemical fungicides, particularly in crops harvested shortly after treatment, this study aimed to evaluate the efficacy of selected chemical fungicides and biological control agents for managing powdery mildew under field conditions.

2. Materials and Methods

2.1. Plant material and Field Cultivation

The zucchini (*Cucurbita pepo* L.) cultivar “Farah” (ANSA ZADEN, Netherlands) was used in this study. This cultivar is characterized by strong vegetative growth, high productivity, and resistance to several viral diseases. It is cultivated as a fall variety in September and as a spring variety in February. The fruits are pear-shaped, with an average length of 13–14 cm.

Plants were visually inspected for viral symptoms to ensure that no virus infections interfered with the evaluation of powdery mildew severity (Zelyüt et al., 2025). Seeds were sown in mid-April 2024 in an open field in Jisr al-Shughur, Syria (latitude 36.310301° and longitude 35.806411°). Plants were irrigated regularly and maintained under standard agronomic practices. Artificial inoculation was performed six weeks after planting.

2.2. Pathogen Collection and Identification

Powdery mildew pathogens were identified based on morphological characteristics observed under light microscopy, including mycelial location, conidial formation (single or in chains), presence of fibrosin bodies, conidial size and shape, and germ tube characteristics (*Figure 2*). Pathogen identification was carried out at the Plant Protection Laboratory, Faculty of Agriculture, University of Idlib, Syria.



Figure 1. Field symptoms of powdery mildew on zucchini leaves. Arrows indicate the characteristic white powdery lesions on the upper leaf surface

2.3. Preparation of the Powdery Mildew Pathogen Inoculum

Powdery mildew–infected zucchini leaves were collected from naturally infected plants in the Seijar area, Idlib Governorate. The causal agents were identified based on morphological characteristics observed under light microscopy, including mycelial growth pattern, conidial formation (single or in chains), presence or absence of fibrosin bodies, conidial shape and size, and germ tube characteristics. Identification was carried out according to the taxonomic descriptions provided by Braun (1995) and supported by Sletova (2022).

The fungal inoculum of *P. xanthii* (syn. *Sphaerotheca fuliginea*) and *E. cichoracearum* was obtained from freshly infected leaves. Conidia were gently brushed into 100 mL of sterile distilled water containing two drops of Tween-20. The suspension was filtered through sterile gauze to remove debris and adjusted to 5×10^5 conidia mL^{-1} using a hemocytometer.

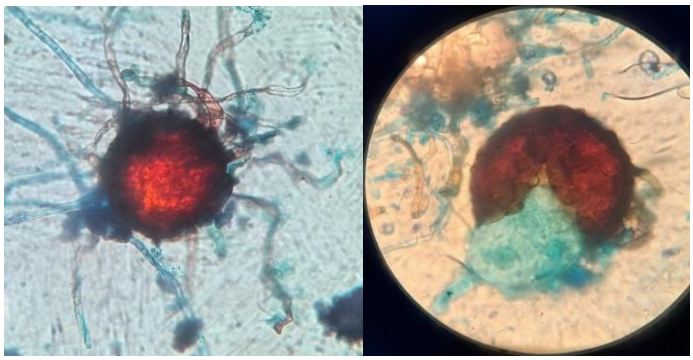


Figure 2. Microscopic observation of powdery mildew pathogen (Erysiphales) stained and magnified, showing conidiophore, conidia, and hyphal structures

2.4. Biological Control Agents and Chemical Fungicides Used

Trichoderma sp. and *Penicillium* sp. were used as biological control agents in commercial formulations. "Bio-Active" (Tasneem Company, China) containing *Trichoderma* sp. was applied at a rate of 1 L per 300 L of water. "Bio-Strong" (Tasneem Company, China) containing *Penicillium* sp. was applied at a rate of 1.5 kg per 1000 m^2 (equivalent to 15 kg per hectare), according to the manufacturer's recommendations. All treatments were applied under field conditions following standard agricultural practices.

2.5. Trichoderma sp. and Penicillium sp. Inoculum Preparation

Petri dishes containing Potato Dextrose Agar (PDA) medium were inoculated to obtain the fungal suspension used for spraying the cultivated plants in the field. The growing colony on a 9 cm Petri dish of the biological agent was dissolved in 100 ml of sterile distilled water, and the solution was then completed to 500 ml of water for spraying the plants. The spore concentration was adjusted to 5×10^6 spores/ml in the spraying solution using a hemocytometer slide. The following chemical fungicides were also used (Table 1).

Table 1: Chemical Fungicides Used in the Experiment

Serial Number	Trade Name	Active Ingredient and Concentration	Recommended Usage Rate by Manufacturer
1	**Pancho**	Cyflufenamid 34 g, Kg + Triflumizole 150 g, Kg	1 g, Liter
2	**Baymert**	Triadimenol 50 g, L	1 ml, Liter
3	**Heros**	Azoxystrobin 250 g, L	0.75 ml, Liter

2.6. Artificial Inoculation Procedure

The upper surfaces of all leaves were sprayed with the spore suspension using a hand sprayer, following the methods described by Reuveni et al. (2000) and Indermaur et al. (2024). After the industrial inoculation, the plants were kept under high relative humidity for 24 hours to facilitate the disease's occurrence and development. The control treatment was sprayed with water and maintained under similar conditions.

2.7. Disease Evaluation

The severity of the disease was calculated as the percentage of the area covered by the fungal colonies on five leaves from each plant, including older leaves, middle leaves, and upper leaves. The leaf area was measured, and the disease development was classified into five categories based on Morishita et al. (2003) using a scale from 0 to 4, as described by Reuveni et al. (2000),

using the following formula:

$$S(\%) = \frac{nxv}{Nx4} x\ 100 \qquad \text{(Eq. 1)}$$

Where: n = number of leaves infected in each category

v = numerical value for each infection (0-4), N = refers to the total number of leaves assessed

The scale is defined as follows:

- 0: No visible infection
- 1: 1–5% visible infection
- 2: 6–25%
- 3: 26–50%
- 4: More than 50% of the leaf area covered with fungal colonies.

The final disease evaluation was conducted 12 days after inoculation. The vegetative yield was recorded for each plant 15 days after treatment.The effectiveness of the fungicide in reducing the severity of powdery mildew was calculated using the formula:

$$Effectiveness\ of\ Fungicide = (Severity\ in\ Control - Severity\ in\ Treatment) / (Severity\ in\ Control \times 100) \qquad \text{(Eq. 2)}$$

2.8. Statistical Analysis

The experiment was designed using a completely randomized design with six replications for each treatment. Five plants in the field were used as replicates for each treatment per fungicide. Disease severity was evaluated 3,

7, and 12 days after industrial inoculation, and yield was assessed after each treatment (as volume per plant). Field experiments were conducted in the city of Jisr al-Shughur in 2024. The planting took place in April, the inoculation occurred in May, and the treatment was conducted on May 25, 2024. Disease severity and statistical analysis were conducted using the Genstat 12 statistical software, and means were compared using the least significant difference (LSD) test at a 5% significance level.

3. Results

Powdery mildew is considered one of the most serious diseases affecting zucchini plants, being destructive if not controlled. However, the contents and nutritional value of zucchini can become toxic when using synthetic chemical pesticides. Therefore, employing safe biocontrol agents that are naturally present in the environment can effectively reduce disease incidence, providing a promising alternative to chemical control methods. White powdery spots started to appear on the leaves, stems, and even on the fruits of zucchini plants, with an infection rate nearing 100% for all field plants. From the first day of spraying, after 8 hours, symptoms of leaf recovery began to appear, indicating improved plant vigor and new leaf production.

3.1. Effect of Foliar Application of Fungicides and Biocontrol Agents on Powdery Mildew Severity After 3 Days:

All fungicides showed positive results two days post-application. It was noted that chemical fungicides were more effective than biocontrol agents after just one day of spraying. After three days, disease severity and the effectiveness of the applied fungicides were assessed. The size of the sprayed leaves showed no significant impact, but the area covered by powdery mildew spots was affected (Table 2).

Table 2: Area of Powdery Mildew Spots on the Surfaces, Disease Severity, and Average Effectiveness of the Applied Fungicides After 3 Days of Spraying

Treatment	Spot Area (cm^2)	Severity	Control Efficiency%
Control	7	7.3	0
Baymert	4	5	31.5
Heros	3.1	3.2	56.2
Pancho	3.4	4.5	38.4
Trichoderma sp.	2.8	3.7	49.3
Penicillium sp.	2.1	3.8	47.9
$LSD_{(0.05)}$	0.67	0.85	

Three days after spraying, the chemical fungicide Heros recorded the highest control efficiency against powdery mildew 56.2%, with a disease severity of 3.2 (spot area of 3.1 cm^2). This was followed by the biocontrol agent *Trichoderma* sp., which achieved a control efficiency of 49.3% and a disease severity of 3.7 (spot area of 2.8 cm^2). Closely behind was the biocontrol agent *Penicillium* sp., which demonstrated a comparable control efficiency of 47.9%, with a disease severity of 3.8 (spot area of 2.1 cm^2).The chemical fungicide Pancho showed control efficiency of 38.4%, with disease severity of 4.5 (spot area of 3.4 cm^2). Last among the treatments, the chemical fungicide Baymert recorded the lowest control efficiency 31.5% with highest disease severity with 5.0 (spot area 40. cm^2). By comparison, the control treatment recorded the highest spot area 7.0 cm^2 and the highest disease severity 7.3.

3.2. Effect of Foliar Application of Fungicides and Biocontrol Agents on Powdery Mildew Severity After 7 Days

After chemical spraying, new leaves appeared on the plants, and the occurrence of stormy rains provided a After spraying, new leaves appeared on the plants, and the occurrence of stormy rains provided a cleansing effect on the infected leaves. Although all plants produced fresh, healthy leaves, the number and size of leaf spots varied significantly among treatments (Table 3). Among all evaluated options, the best treatments were *Trichoderma* sp . and Heros ,with disease severities of 1.7 (spot area of 1.8 cm^2) and 2.6 (spot area of 2.3 cm^2), and control efficiencies of 71.2% and 55.9%, respectively. These were followed by *Penicillium* sp .and Baymert ,which recorded severities of 3.2 (spot area of 3.1 cm^2) and 3.7 (spot area of 3.4 cm^2), with control efficiencies of 45.8%

and 37.3%, respectively. Pancho recorded the highest disease severity among the treated plants ,with a disease severity of 3.8 (spot area of 3.8 cm^2) and a control efficiency of 35.6%.

Table 3: Spot Area on the Surfaces, Disease Severity, and Average Effectiveness of the Applied Fungicides After 7 Days of Spraying

Treatment	Spot Area (cm^2)	Severity	Control Efficiency
Control	6.3	5.9	0
Baymert	3.4	3.7	37.3
Heros	2.3	2.6	55.9
Pancho	3.8	3.8	35.6
Trichoderma sp.	1.8	1.7	71.2
Penicillium sp.	3.1	3.2	45.8
LSD (0.05)	1.03	0.84	

3.3. Effect of Foliar Application of Fungicides and Biocontrol Agents on Powdery Mildew Severity After 12 Days

All treatments showed varying levels of effectiveness against powdery mildew by reducing leaf spot area, with the exception of the chemical fungicide Pancho, whose efficacy significantly declined starting from the fourth day post-application. Disease severity parameters after 12 days are presented in Table 4. Pancho recorded the highest disease severity score of 6.8, with a control efficiency of only 18.1%, showing no statistically significant difference compared to the untreated control group. This decline may have been associated with environmental conditions, including rainfall and high relative humidity levels promoting new infection cycles. Among all tested treatments, the chemical fungicide Heros recorded the highest disease reduction, with a severity of 3.6 (spot area of 3.3 cm^2) and a control efficiency of 56.6%. This was closely followed by the biocontrol agent *Trichoderma* sp., which achieved a severity of 3.7 (spot area of 2.8 cm^2) and a control efficiency of 55.4%. The biocontrol agent *Penicillium* sp. followed, recording a severity of 4.2 (spot area of 5.1 cm^2) and a control efficiency of 49.4%. The chemical fungicide **Baymert** exhibited lower performance, with a severity of 5.7 (spot area of 6.4 cm^2) and a control efficiency of 31.3%.

Table 4: Spot Area on the Surfaces, Disease Severity, and Average Effectiveness of the Applied Fungicides After 12 Days of Spraying

Treatment	Spot Area (cm^2)	Severity	Control Efficiency
Control	9.6	8.3	0
Baymert	6.4	5.7	31.3
Heros	3.3	3.6	56.6
Pancho	5.8	6.8	18.1
Trichoderma sp.	2.8	3.7	55.4
Penicillium sp.	5.1	4.2	49.4
LSD (0.05)	**1.82**	**1.6**	

3.4. Effect of Foliar Application of Fungicides and Biocontrol Agents on Vegetative Yield After 15 Days of Spraying

The plants were in critical condition, leading the farmer to uproot part of the field. When sprayed, the plants were covered with powdery mildew (Figure 3). The number of leaf spots began to decrease two days after spraying, and the results were excellent, with plants showing renewed vegetative growth, producing flowers, and starting to yield again. Yield measurements were recorded after 12 and 15 days of spraying.

The vegetative yield of zucchini plants differed significantly across treatments at both 12 and 15 days after spraying. Plants treated with *Trichoderma* sp. showed the highest vegetative yield improvement, increasing from 77.0 g/plant at 12 days to 116.8 g/plant at 15 days, indicating both strong disease suppression and growth promotion. Heros followed as the second-best treatment, with yields of 54.3 and 89.6 g/plant at 12 and 15 days, respectively. *Penicillium* sp. also enhanced yield compared to the control, reaching 43.3 and 79.9 g/plant. In contrast, the untreated control plants maintained the lowest yields (33.3 and 29.5 g/plant), reflecting severe powdery mildew infection. The chemical fungicide Pancho showed limited improvement, while Baymert produced moderate yields. Overall, these results emphasize that biocontrol agents, particularly *Trichoderma*, not only reduce powdery mildew severity but also enhance plant vigor and productivity more effectively than chemical fungicides over time.

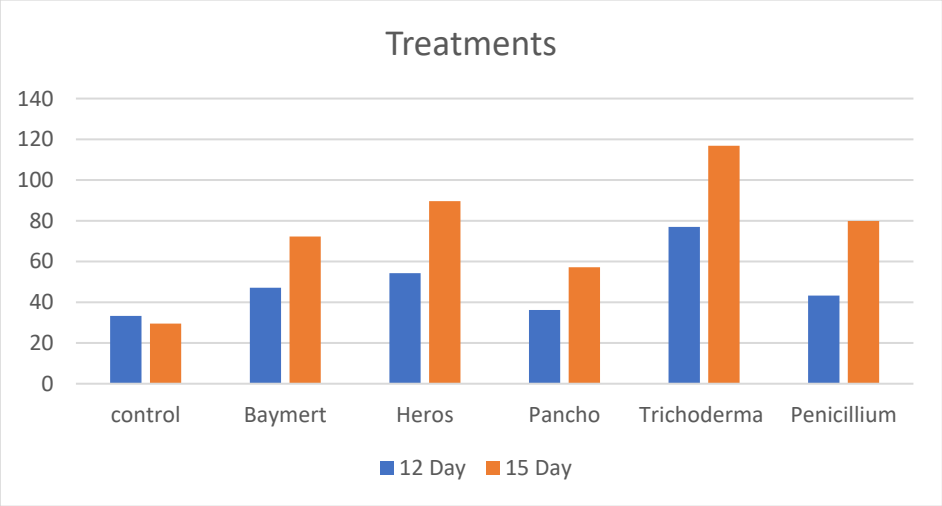


Figure 3: Vegetative yield of zucchini plants (g/plant) recorded 12 and 15 days after treatment with chemical fungicides and biocontrol agents. Trichoderma sp. treatment resulted in the highest yield improvement at both time intervals, followed by Heros, while untreated control plants showed the lowest yield due to severe powdery mildew infection

4. Discussion

The present study revealed clear differences between chemical fungicides and biological control agents in suppressing powdery mildew severity over time. At 3 days after treatment, chemical fungicides exhibited rapid disease reduction, which can be attributed to their immediate fungitoxic activity. However, differences among some treatments were not always statistically significant according to $LSD_{0.05}$ values, indicating that early suppression effects were sometimes comparable between chemical and biological agents (Wang et al., 2024).

At 12 days after treatment, more distinct differences emerged. *Trichoderma* sp. recorded significantly lower disease severity compared with Baymert and Pancho ($p \leq 0.05$), as supported by $LSD_{0.05}$ values. However, although Heros showed numerically lower severity than *Trichoderma* sp, the difference between these two treatments was not statistically significant ($p > 0.05$). This indicates that both *Trichoderma* and Heros provided comparable levels of disease control at the later evaluation stage. In contrast, Pancho showed a significant decline in efficacy, with disease severity not significantly different from the untreated control, suggesting reduced residual activity under field conditions (Hacquard et al., 2013).

The sustained performance of *Trichoderma* sp. may be explained by its multiple modes of action, including competition for nutrients and space, production of antifungal metabolites, mycoparasitism, and induction of systemic resistance in host plants (Alsalmo et al, 2025; El-Gamal, 2003). Unlike contact fungicides, which may degrade due to environmental factors such as rainfall and high humidity, biological agents can colonize plant surfaces and provide prolonged protection. These findings are consistent with previous reports highlighting the long-term protective role of *Trichoderma* species in cucurbit powdery mildew management (Ibrahim et al., 2003).

Yield data further confirmed the superiority of biological treatments. Plants treated with *Trichoderma* sp. produced significantly higher vegetative yield compared with the untreated control and Baymert ($p \leq 0.05$) Although Heros also improved yield substantially, its performance was statistically comparable to *Trichoderma* in some evaluation periods. The lowest yields were consistently recorded in untreated control plants, reflecting the severe impact of powdery mildew infection on plant productivity (Paulert et al., 2010; Al-Mourrh et al., 2024).

Overall, the results demonstrate that while chemical fungicides may provide rapid short-term suppression, biological control agents—particularly *Trichoderma* sp.—offer more stable and sustained disease management under field conditions. Integrating biological agents into powdery mildew management programs may therefore enhance long-term disease suppression while reducing dependence on synthetic fungicides (Almourrh et al., 2025).

5. Conclusion

Chemical fungicides are effective for rapid initial suppression of powdery mildew, but their efficacy declines over time. In contrast, biocontrol agents such as *Trichoderma* sp. and *Penicillium* sp. provide sustained disease control and contribute positively to plant vigor and yield. *Trichoderma*, in particular, showed superior performance beyond seven days and delivered the highest yield improvements. These findings highlight the potential of integrating biocontrol agents into powdery mildew management strategies, reducing reliance on chemical fungicides, and supporting safer, more sustainable zucchini production systems.

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Ethical Statement

There was no need to obtain permission from an ethics committee for this study.

Conflicts of Interest

We declare that there is no conflict of interest among the authors of this article

Authorship Contribution Statement

Conceptualization: Al-Mourrh, A.; Methodology: Al-Mourrh, A.; Investigation/Data Collection: Al-Mourrh, A., Formal Analysis and Statistics: Alsalmo, A.; Resources and Materials: Al-Mourrh, A., Writing – Original Draft: Alsalmo, A.; Writing – Review and Editing: Koç, G., Arpacı, B. B.

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