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Efficacy of neem and basil leaf extracts in controlling whitefly (*Bemisia Tabaci*) infestations and enhancing yield in curly red chili peppers (*Capsicum annuum* L.)

Efikasi ekstrak daun mimba dan kemangi dalam mengendalikan serangan kutu kebul (*Bemisia Tabaci*) dan meningkatkan produksi cabai merah keriting (*Capsicum annuum* L.)

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ABSTRACT

Whiteflies (*Bemisia tabaci*) are a major pest of curly red chili peppers (*Capsicum annuum* L.), acting as vectors for geminiviruses that significantly reduce crop productivity. This study evaluated the efficacy of neem and basil leaf extracts at three different concentrations for controlling whitefly infestations on chili plants. A randomized complete block design (RCBD) was employed with 8 treatments and 2 controls: PA (Neem 1%), PB (Neem 2%), PC (Neem 3%), PD (Basil 1%), PE (Basil 2%), PF (Basil 3%), PKM (commercial pesticide as positive control), and P0 (distilled water as negative control). Parameters assessed included whitefly infestation intensity, yellowing of shoots, fruit weight, total fruit count, and the number of infested fruits. The results indicate that both neem and basil leaf extracts effectively reduced whitefly infestation intensity and yellowing of shoots compared to the negative control (P0). Despite some increase in infestation intensity in subsequent observations, both neem and basil extracts positively impacted fruit yield, including higher fruit weight and total fruit count. However, there was no significant effect on the number of infested fruits with the treatments. These findings suggest that neem and basil leaf extracts are promising alternatives for managing whitefly infestations and improving yield in curly red chili peppers.

ABSTRAK

Kutu kebul (*Bemisia tabaci*) adalah hama utama pada tanaman cabai merah keriting (*Capsicum annuum* L.), terutama karena peranannya sebagai vektor virus gemini. Serangan puncak dari hama ini dapat menurunkan produktivitas tanaman cabai. Penelitian ini mengevaluasi efikasi ekstrak daun mimba dan kemangi pada tiga tingkat konsentrasi dalam mengendalikan serangan kutu kebul pada tanaman cabai. Rancangan penelitian menggunakan rancangan acak kelompok (RAK) dengan 8 perlakuan dan 2 kontrol, yaitu PA (Mimba 1%), PB (Mimba 2%), PC (Mimba 3%), PD (Kemangi 1%), PE (Kemangi 2%), PF (Kemangi 3%), PKM (pestisida komersial sebagai kontrol positif) dan P0 (air suling sebagai kontrol negatif). Parameter yang diamati meliputi intensitas serangan kutu kebul, intensitas serangan pucuk kuning, bobot buah cabai, jumlah buah total, dan jumlah buah cabai yang terserang. Hasil penelitian menunjukkan bahwa ekstrak daun mimba dan daun kemangi efektif menurunkan intensitas serangan kutu kebul dan menguningnya pucuk dibandingkan dengan kontrol negatif (P0). Meskipun terdapat peningkatan intensitas serangan pada pengamatan berikutnya, ekstrak mimba dan kemangi memberikan dampak positif terhadap hasil buah, termasuk bobot buah dan jumlah buah total yang lebih tinggi. Namun, tidak terdapat pengaruh yang signifikan terhadap jumlah buah yang terserang dengan perlakuan tersebut. Temuan ini menunjukkan bahwa ekstrak daun mimba dan daun kemangi merupakan alternatif yang menjanjikan untuk mengendalikan serangan kutu kebul dan meningkatkan hasil pada cabai merah keriting.

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INTRODUCTION

Curly red chili pepper (*Capsicum annuum* L.) is a major horticultural commodity widely cultivated in Indonesia. This crop is a staple ingredient in local cuisine, making it economically valuable and well-suited for cultivation in tropical climates like Indonesia. However, curly red chili pepper cultivation faces significant challenges, primarily due to the whitefly (*Bemisia tabaci* Genn.), a major pest. Whiteflies act as vectors for the geminivirus, causing yellow leaf curl disease, which severely impacts chili pepper productivity (Fitrianti, 2020).

Whiteflies are small insects known for causing significant damage to chili pepper plants. Symptoms of whitefly infestation in chili peppers include stem necrosis, leaf chlorosis, and leaf curling. These symptoms result from both the direct feeding damage caused by nymphs and geminivirus infection (Taufik et al., 2024; Xie et al., 2024). Such symptoms hinder plant growth and reduce yield (Sirajuddin & Adriani, 2021). Geminivirus, part of the Geminiviridae family and Begomovirus genus, is a significant threat to chili pepper cultivation in Indonesia, causing severe yield losses. The virus is transmitted by whiteflies, with higher incidence rates during the dry season compared to the rainy season (Nuryani, 2019).

Whitefly nymphs are attracted to chili plants during their early stages. After hatching, nymphs migrate to suitable feeding sites on the leaf surface, where they insert their mouthparts and suck plant sap. Nymphs are oval, flat, and yellowish-green (Hasyim et al., 2016). As polyphagous pests, whiteflies can infest a variety of crops and are distributed globally, thriving in both tropical and subtropical climates. Their eggs are laid on the underside of leaves, with development influenced by temperature, humidity, and rainfall (Kurniawan & Fitria, 2021; Narendra et al., 2017; Reza et al., 2019).

Farmers typically rely on conventional pesticides for pest control, though these are often not environmentally friendly. Whiteflies can be managed using more environmentally friendly control methods (Bashir et al., 2024; Purnama et al., 2024), one of which is the application of botanical pesticides. Botanical pesticides, derived from plants, offer a safer alternative. Neem (*Azadirachta indica*) and basil (*Ocimum basilicum*) leaf extracts contain bioactive compounds that inhibit or kill pests. Azadirachtin in neem acts as a repellent and antifeedant, while eugenol in basil serves as a repellent (Karta et al., 2017; Manikome, 2021). Previous research has highlighted the potential of neem and basil leaf extracts as botanical pesticides against whiteflies (Fitrianti, 2020; Thaibah et al., 2021).

Despite promising preliminary results, there is a need for more comprehensive studies on the efficacy and optimal concentrations of neem and basil leaf extracts for controlling whiteflies and enhancing yields in curly red chili pepper cultivation. This study aims to evaluate the effectiveness of these botanical extracts in reducing whitefly infestations and determine the most effective concentrations for use in chili pepper cultivation to enhance yield.

MATERIALS & METHODS

Location and environmental conditions of the study area

This study was conducted in the paddy fields of curly red chili peppers (*Capsicum annuum* L.) located in Ngablak Village, Magelang Regency, Indonesia (7°24'04.3"S 110°24'05.8"E). The study took place from August to October 2023. Ngablak Village was chosen as the study site because it is a major production area for curly red chili peppers in Central Java, Indonesia. This region has a long history of cultivating curly red chili peppers, making it an ideal location for researching whitefly pest control. The environmental conditions at the research site are described in detail in the Results and Discussion section. Generally, the area experiences a tropical climate with daily average temperatures ranging from 26°C to 27°C. The annual rainfall is approximately 1.779 mm, supporting the optimal growth of curly red chili peppers. The soil is classified as reddish-brown latosol, with a pH of 51.3 % RH and a texture of sandy.

Materials

The commercial pesticide used was Applaud 10 WP (Petrokimia Kayaku, Indonesia), containing 10% buprofezin. Neem leaves were sourced from neem trees abundantly growing in Salatiga, while basil leaves were obtained from a local market in Salatiga. Analytical grade ethanol, used for extracting neem and basil leaves, was purchased from a chemical supply store in Semarang.

Research design

The research was conducted using a Randomized Complete Block Design (RCBD) with 8 treatments and 2 controls, each repeated 4 times, resulting in a total of 32 experimental units. The treatments included P0 as the negative control (using only distilled water), PKM as the positive control (commercial pesticide), PA with a 1% neem concentration, PB with a 2% neem concentration, PC with a 3% neem concentration, PD with a 1% basil concentration, PE with a 2% basil concentration, and PF with a 3% basil concentration.

Botanical pesticide sprays made from neem and basil leaf extracts were applied to curly red chili pepper plants every 3 days at 4 PM, using 1,000 ml per treatment concentration (Budi et al., 2023). Spraying was conducted during the early vegetative to generative stages of the chili plants (Achmadi et al., 2020).

Preparation of plant extracts and commercial pesticides

The preparation of botanical pesticide extracts began with 3 kg each of neem and basil leaves. The leaves were washed and air-dried until fully dehydrated. The dried leaves were then blended into a fine powder and sieved through a 40-60 mesh screen. Extraction was performed using the maceration method, where 1 kg of dried leaf powder was mixed with 96% ethanol and left for 24 hours, following the method described by Sagbo et al. (2023). The mixture was then filtered, and the filtrate was evaporated using a rotary evaporator to obtain a solid extract. This solid extract was then dissolved in water to create the required concentrations of 1%, 2%, and 3%. For the PKM treatment, 1 g of the commercial pesticide was dissolved in 1 L of water to achieve a 1% concentration.

Observation parameters

Humidity and temperature

The observation parameters for humidity and temperature employed quantitative data with direct measurement methods, using relative humidity (RH) and degrees celsius (°C) as units, consistent with previous research (Ihsan & Patandean, 2016). Data collection was performed using a digital thermometer-hygrometer (HTC-1, OneMed, Indonesia) three times a day: in the morning (7 AM), at noon (1 PM), and in the afternoon (4 PM).

Whitefly infestation intensity

This parameter was observed using a direct counting method, with percentage (%) as the unit of measurement (Arfiani & Nasruddin, 2023). Before calculating the infestation intensity, the percentage of infestation was first determined using the formula (Zaina et al., 2017):

$$P = \frac{a}{a+b} \times 100\ \% \qquad (1)$$

where:

P = percentage of infestation

a = number of infested leaves

b = number of non-infested leaves

To calculate the intensity of whitefly infestation on chili plants, the following formula was used (Direktorat Perlindungan Tanaman Pangan, 2018):

$$\mathrm{I} = \frac{\sum_{i=0}^{z}(n_i \times v_i)\times 100\ \%}{\mathrm{Z} \times \mathrm{N}} \qquad (2)$$

where:

I = intensity of infestation (%)

n_i = number of plants or plant parts sampled with damage scale vi
v_i = damage score value of the i-th sample
N = total number of plants or plant parts sampled
Z = highest damage score value

After obtaining the percentage value, it was mapped to the corresponding leaf damage score according to Table 1.

Table 1. Leaf damage scores

Score	Damage extent
0	No damage at all
1	Leaf damage extent 1-25% (low)
2	Leaf damage extent 26-50% (moderate)
3	Leaf damage extent 51-75% (high)
4	Leaf damage extent 76-100% (very high)

Note: Leaf damage scores (*v*) were assigned based on the total leaf area of the infested plant.

Table 2. Yellow leaf curl disease symptom scores

Score	Proportion of virus symptoms per plant
1	No symptoms 0%
2	Mild symptoms >1-25%
3	Moderate symptoms >25-50%
4	Severe symptoms >50-75%
5	Very severe symptoms or plant death >75-100%

Note: Symptom scores (*v*) were assigned based on the proportion of symptoms observed in the plant.

<u>Yellow leaf curl disease (geminivirus) infestation intensity</u>

The intensity of yellow leaf curl disease (caused by geminivirus) was measured using quantitative data and a direct counting method, expressed as a percentage (%) (Suparman et al., 2024). To determine the intensity of the yellow leaf curl disease, the incidence rate was first calculated using the formula by Tricahyati et al. (2022):

$$PP = \frac{X}{N} \times 100\ \% \quad (3)$$

where:
PP = Percentage of yellow leaf curl disease incidence
X = Number of plants infected with yellow leaf curl disease
N = Total number of plants observed

The formula used to calculate the intensity of yellow leaf curl disease (geminivirus) in chili peppers was adapted from Abadi (2003):

$$IP = \frac{\sum (n \times v)}{ZN} \times 100\% \quad (4)$$

where:
IP = Percentage of yellow leaf curl disease intensity
n = Number of plants in each symptom category
v = Symptom score value for each category

Z = Highest category score value (v=5)
N = Total number of plants observed

After obtaining the percentage value, it was matched to the corresponding yellow leaf curl disease symptom score according to Table 2.

Fruit weight
The fruit weight of chili peppers was measured using quantitative data through direct measurement, expressed in grams (g). According to Hapsoh et al. (2017), the calculation of chili pepper fruit weight begins with harvesting the peppers. The cumulative weight of all fruits from each plant is then calculated by weighing all sample plants and summing the total fruit weight.

Total number of fruits
The total number of fruits was also measured using quantitative data through direct counting, expressed as the number of fruits. According to Prasetya (2014), the total number of chili fruits is the sum of the harvests from the first and second harvests.

Number of infested fruits
The number of infested fruits was measured using quantitative data through direct counting, expressed as the number of fruits. Budiyani & Sukasana (2020) state that the number of infested chili peppers is determined by the criteria of visible fruit damage caused by pests and diseases. The total number of infested fruits is summed from the first and second harvests.

Data analysis
The data analysis in this study was conducted using the SAS 9.0 software (SAS Institute Inc., USA) with an analysis of variance (ANOVA). If significant differences were found ($P<0.05$), further testing was conducted using the Honest Significant Difference (HSD) test at the 5% significance level.

RESULTS & DISCUSSIONS

Humidity and temperature
Based on observational data of environmental temperature at the research location using a thermometer-hygrometer, the results show that the ambient temperature varied for each observation. This variation was influenced by factors such as rainfall and air humidity. The research was conducted during the dry season, coinciding with the El Niño phenomenon in Indonesia. According to Safitri (2015), El Niño causes a very dry dry season and delays the onset of the rainy season. Data from BMKG indicates that the peak dry season in Java Island occurs in August with 160 ZOM and in September with 12 ZOM. Recorded rainfall data shows 21 mm on August 11, 23 mm on August 21, and 28 mm on August 31. In September, rainfall in Ngablak Village was 29 mm on September 1, 34 mm on September 11, and 55 mm on September 30. During the generative phase of curly red chili pepper plants in October, the average rainfall was 56 mm on October 1, 73 mm on October 11, and 94 mm on October 21. According to Supriyati et al. (2018), BMKG categorizes monthly rainfall into four categories: low (0-100 mm/month), moderate (100-300 mm/month), high (300-500 mm/month), and very high (>500 mm/month). Based on BMKG data, it can be concluded that from August to October, the monthly rainfall was in the low category, ranging from 0-100 mm per month. Observations of temperature and humidity are presented in Table 3.

Based on Table 4, the highest average humidity occurred in September at 54.2% RH, and the highest temperature was in August at 27°C. The average humidity from August to October was relatively low at 51.3% RH, and the temperature was relatively high at 26.5°C. Both humidity and temperature fluctuated weekly, influenced by the El Niño phenomenon affecting the paddy fields in Ngablak from planting in August to harvesting in October, resulting in water scarcity for irrigating the curly red chili pepper fields. According to Suhermanto et al. (2021), the ideal humidity for highland areas like Ngablak ranges from 80-90% RH, while Hilman et al. (2014) state that the typical temperature in highland areas ranges from 16-18°C. Therefore, the average humidity during the study period was low, and the temperature was high, promoting the rapid development of whitefly populations. This is consistent with Adelianingsih et al. (2019), who stated that high rainfall is unfavorable for whiteflies, as it dislodges them from plant canopies. Furthermore, Agastya et al. (2020) found that increasing environmental temperature accelerates whitefly metabolism, leading to faster development and higher pest populations during dry seasons with low humidity and high temperatures.

Table 3. Weekly humidity and temperature (n = 63)

Parameter	Week of observation												
	1	2	3	4	5	6	7	8	9	10	11	12	13
Humidity (%)	77	47	32	61.5	54.7	59	55.5	54	48.5	56	44	35.5	51.7
Temperature (°C)	23.8	26.6	33.7	23.8	24.8	25.7	25.3	26.2	31.6	24.4	27.4	26.9	25.9

Table 4. Monthly humidity and temperature (n = 4)

Month	Humidity (%)	Temperature (°C)
August	51.5	27.0
September	54.2	26.7
October	48.2	26.0
Average	51.3	26.5

Whitefly infestation intensity

Based on data analysis from observations conducted every 3 days after the application of botanical pesticides derived from neem leaves and basil leaves, it was found that these treatments significantly influenced the intensity of whitefly infestations. This is evident in Table 5, showing that the botanical pesticide treatments reduced the intensity of whitefly infestations on curly red chili plants.

Table 5. Whitefly infestation intensity (%) (n = 4)

Treatment	Observation number				
	21	**22**	**23**	**24**	**25**
P0	35	40	52.5	67.5	70 a
PKM	35	38.75	52.5	63.75	67.5 ab
PA	26.25	28.75	31.25	33.75	37.5 c
PB	28.75	31.25	38.75	47.5	47.5 cab
PC	26.25	30	33.75	38.75	41.25 c
PD	26.25	28.75	35	43.75	46.25 cb
PE	26.25	30	35	40	42.5 c
PF	27.5	32.5	38.75	47.5	51.25 cab

Note: Different letters after the mean values in the 25th observation indicate significant differences based on BNJ test ($P<0.05$).

The infestation intensity was calculated using damage symptom scores on all leaves of the chili plants affected by whiteflies. The highest whitefly infestation was observed in the 25th observation (88 days after planting) in the P0 treatment (control without treatment), which was significantly different from the PKM, PA, PB, PC, PD, PE, and PF treatments. The highest mean value was 70%, followed by the PKM treatment (control with chemical pesticide) at 67.5%. The PA treatment (1% neem) had the lowest infestation intensity of 37.5%, significantly different from the control treatments P0 and PKM.

The lower percentage of whitefly infestation intensity in the non-control treatments is attributed to the application of neem and basil leaf extracts. According to Manuputty et al. (2023), neem leaf extract contains bioactive compounds such as azadirachtin, which acts as a respiratory toxin in insects, affecting their nervous system and disrupting their feeding process, leading to death. Barus & Sutopo (2019) found that basil leaves contain eugenol and cineole, compounds that act as repellents against whiteflies.

Yellow shoot disease (geminivirus) intensity

Based on the research data on the intensity of yellow shoot disease, it was found that the longer the observation period for the control, neem leaf extract, and basil leaf extract treatments, the higher the average percentage values.

Table 6. Yellow shoot disease intensity (%) (n = 4)

Treatment	Observation number				
	21	22	23	24	25
P0	34.38	40.63	43.13	49.38	55 a
PKM	30.63	34.38	37.5	41.88	51.88 ab
PA	23.13	26.25	28.13	31.25	35 cb
PB	21.25	25	26.88	28.75	31.25 c
PC	20.63	24.38	28.13	31.88	35.63 cb
PD	23.13	26.25	28.75	31.25	38.75 cab
PE	24.38	26.88	29.38	31.88	36.25 cb
PF	20.63	23.13	23.75	26.88	31.88 c

Note: Different letters after the mean values in the 25th observation indicate significant differences based on BNJ test ($P<0.05$).

Based on the results in Table 6, the highest percentage value was observed in the 25th observation for the P0 treatment, with a value of 55%. The PB treatment had the lowest value of 31.25%, followed by PF with 31.88%. P0 was significantly different from PKM, PA, PB, PC, PD, PE, and PF, while PA was not significantly different from PC and PE. According to Singarimbun et al. (2019), yellow shoot disease is transmitted by the whitefly vector (*Bemisia tabaci*). The incidence of yellow shoot disease is closely related to the whitefly population, meaning the high intensity of yellow shoot disease in chili plants depends on the high whitefly population. This also results in the high intensity of whitefly infestations (Table 5). In this study, the intensity of yellow shoot disease also increased because many chili plants were already infected with the geminivirus (yellow shoot) at the early planting stage.

Fruit weight

Based on the observations of fruit weight in this study, harvesting was conducted twice with a one-week interval. From the first week's harvest, the PC treatment had the highest average fruit weight of 7.02 g. However, the average fruit weight for PC was not statistically different from P0, PKM, PA, PB, PD, PE, and PF. The lowest average fruit weight was observed in the P0 treatment, with 3.82 g. The analysis of these averages is shown in Table 7.

The fruit weight analysis for chili plants in Table 7 shows that in the second week of harvest, PA had the highest fruit weight with a value of 6.85 g, which was not significantly different from the other treatments. Meanwhile, the lowest fruit weight in the second week was observed in the PKM treatment, with 4.98 g. According to Ariyanti (2019), the low fruit weight is due to the variation in symptoms of geminivirus infection in the plants. This virus obstructs the flow of photosynthate (nutrients) from the source organs to the sink organs (such as fruits), as geminivirus is phloem-limited. Therefore, chili plants cannot grow normally and produce fruit if infected by the geminivirus during early growth stages, which can impede plant productivity. Conversely, if the virus attacks the chili plants during the generative phase, the resulting fruits have a hard texture and are stunted in shape.

Table 7. Fruit weight (g) (n = 4)

Treatment	Harvest 1	Harvest 2
P0	3.82 a	5.38 a
PKM	4.82 a	4.98 a
PA	6.55 a	6.85 a
PB	6.79 a	5.90 a
PC	7.02 a	6.45 a
PD	4.81 a	5.47 a
PE	4.96 a	5.00 a
PF	6.10 a	5.95 a

Note: Identical letters after the average values in the first and second harvests indicate no significant difference based on BNJ test ($P<0.05$).

Total number of fruits

The analysis of the average total number of fruits indicates that the PB treatment (2% neem) yielded the highest number of chili fruits in the first harvest, with 54 fruits. This was followed by PC (3% neem) with 50 fruits, PF (3% basil) with 43 fruits, PA (1% neem) with 40 fruits, PD (1% basil) with 31 fruits, PE (2% basil) with 29 fruits, PKM (chemical pesticide control) with 24 fruits, and P0 (control without treatment) with 22 fruits. The differences between treatments were not statistically significant. The results are presented in Table 8.

Table 8. Total number of fruit (fruits) (n = 4)

Treatment	Harvest 1	Harvest 2
P0	22 a	29 a
PKM	24 a	32 a
PA	40 a	37 a
PB	54 a	42 a
PC	50 a	35 a
PD	31 a	31 a
PE	29 a	27 a
PF	43 a	38 a

Note: Identical letters after the average values in the first and second harvests indicate no significant difference based on BNJ test ($P<0.05$).

In the second harvest, the lowest total number of fruits was observed in the PE treatment (2% basil) with 27 fruits, followed by the control (P0) with 29 fruits. Treatments with higher total fruit counts compared to the control included PB (2% neem) with 42 fruits, PF (3% basil) with 38 fruits, PA (1% neem) with 37 fruits, PC (3% neem) with 35 fruits, PKM (chemical pesticide control) with 32 fruits, and PD (1% basil) with 31 fruits. All treatments in both the first and second harvest showed no statistically significant differences.

Number of infected fruits

The analysis of the average number of infected fruits in the first harvest shows that the treatments PC (3% neem) and PD (1% basil) each had an average of 7 infected fruits. These treatments resulted in a higher number of infected fruits compared to the chemical pesticide control (PKM), which had only 5 infected fruits. However, the control without treatment (P0) also had an average of 7 infected fruits. All treatments did not differ significantly from each other statistically. The results are detailed in Table 9.

Table 9. Number of Infected Fruits (fruits) (n = 4)

Treatment	Harvest 1	Harvest 2
P0	7 a	13 a
PKM	5 a	7 a
PA	2 a	8 a
PB	5 a	6 a
PC	7 a	5 a
PD	7 a	3 a
PE	4 a	3 a
PF	8 a	4 a

Note: Identical letters after the average values in the first and second harvests indicate no significant difference based on the BNJ test ($P<0.05$).

Based on the second harvest results shown in Table 9, the treatments with the fewest infected fruits were PD (1% basil) and PE (2% basil), each with 3 fruits. In contrast, the control without treatment (P0) had the highest average number of infected fruits, with 13 fruits, followed by the chemical pesticide control (PKM) with 7 fruits. All treatments in the second harvest also did not show statistically significant differences. During the harvesting period, the chili fruits produced tended to be few, small, and hollow. This was attributed to the presence of sooty mold as a secondary effect of the whitefly infestation observed during the study. According to Sirajuddin & Adriani (2021), sooty mold can inhibit the photosynthesis process in chili leaves, compounding the damage caused by whiteflies sucking on the phloem tissues. Consequently, whitefly infestations can lead to a significant reduction in chili plant productivity by hindering photosynthesis.

CONCLUSION

This study evaluated the effectiveness of neem leaf and basil leaf extracts in controlling whitefly infestations and yellow leaf curl disease in curly red chili peppers. The results showed that the 1% neem extract (PA) was the most effective in reducing pest and disease incidence while increasing both fruit weight and total fruit count compared to the untreated control (P0) and chemical pesticide control (PKM). The use of botanical pesticides proved to be a more environmentally friendly alternative. Despite differing views on the efficacy of botanical pesticides, the findings of this study support the use of neem and basil extracts. Readers are encouraged to consider botanical pesticides in their agricultural practices. Further research is needed to evaluate the effectiveness of other plant extracts and their impact on soil health and ecosystems. This could help reduce reliance on chemical pesticides and promote agricultural sustainability.

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