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Kaolin clay for sustainable olive growing: Biophysical protection and environmental compatibility

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Abstract

Olive cultivation faces increasing challenges from environmental stressors such as extreme heat, water scarcity, and pest infestations, especially the olive fruit fly (Bactrocera oleae). Kaolin clay, a naturally occurring aluminum silicate mineral, has gained prominence as an eco-friendly solution in sustainable agriculture. This review explores the diverse functions of kaolin particle film applications in olive production, emphasizing its physical barrier properties against pests, its role in mitigating physiological stress, and its compatibility with organic farming systems. Kaolin reduces oviposition and feeding behaviors in B. oleae, limits pest mobility, and demonstrates synergistic effects when combined with biopesticides and pheromone traps. Moreover, kaolin enhances olive oil quality by preserving phenolic compounds, enhancing oxidative stability, and positively influencing aroma profiles. The review also examines kaolin's impact on beneficial insects, plant anatomy, and transpiration regulation, highlighting its potential in climate-resilient agriculture. Regional effectiveness and optimal application strategies under varying climatic conditions are discussed, alongside economic evaluations and future recommendations for integrated pest management. Overall, kaolin emerges as a strategic input for sustainable olive growing, offering multifaceted benefits in ecological protection, crop quality, and adaptation to climate change.

Keywords: Kaolin Clay; Olive Fly; Sustainable Agriculture; Integrated Pest Management; Organic Olive Farming; Climate Adaptation; Olive Oil Quality; Biopesticides; Particle Film Technology

1. Introduction

The olive tree (*Olea europaea*) possesses a certain degree of resilience to environmental stress conditions; however, it can still be adversely affected by various stressors, particularly extreme temperatures, water scarcity, and pest attacks (Fernández et al., 2020).

A common method employed to protect against these adverse effects is the application of kaolin coatings. The thin reflective film formed by kaolin on the leaf surface protects the plant from excessive heat thanks to its reflectivity, while also providing indirect biotic protection by reducing the contact of harmful insects with the plant (Glenn et al., 2019).

Kaolin, chemically composed of aluminum silicate ($Al_2Si_2O_5(OH)_4$), is a naturally occurring, fine-grained, white clay mineral with a wide range of applications. It is extensively used in various industries, including ceramics, paper manufacturing, cosmetics, and agriculture (Murray, 2007). Different types of kaolin have been developed to suit various application fields.

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1.1. Types of Kaolin

Table 1 Types of Kaolin

Type of Kaolin	Description	Reference
Natural Kaolin	A minimally processed, raw form of kaolin.	Grim, 1968
Washed Kaolin	Refined through physical and chemical treatments to remove impurities.	Singer & Sonja, 1971
Calcined Kaolin	Thermally processed at high temperatures to alter its crystal structure.	Patterson & Murray, 1983
Activated Kaolin	Modified surface properties for specific applications.	Christidis & Scott, 1999
Metakaolin	Heated to 600–800°C to become amorphous in structure.	Ambikadevi & Lalithambika, 2000

As shown above, different types of kaolin used in olive cultivation are classified based on their processing methods and application characteristics.

2. Biological and Ecophysiological Effects of Kaolin Clay on the Olive Fruit Fly (*Bactrocera oleae*)

The olive fruit fly (Bactrocera oleae) is one of the most widespread and damaging insect pests affecting olive trees (Olea europaea L.) worldwide (Saour & Makee, 2004). Traditionally, chemical pesticides have been used against this pest. Nevertheless, due to the environmental impacts and potential health risks associated with these chemicals, efforts to develop more environmentally friendly and sustainable control methods have intensified. One of the prominent alternatives is kaolin, a non-toxic agent that targets the biological and ecophysiological processes of the pest, thereby reducing its damage.

Kaolin applications act as an effective biophysical barrier (Dehbi et al., 2021). The thin reflective film formed on the fruit surface deters female flies from laying eggs and feeding, while also limiting their mobility, thus influencing population dynamics. Recent studies have demonstrated that kaolin is an effective strategy in managing olive fruit fly populations (Rameau et al., 2020; Nardi et al., 2019).

Unlike chemical pesticides, kaolin does not pose a risk of resistance development. This is because kaolin does not function as a toxic agent but as a physical barrier (Mazor & Erez, 2004). Research has shown that kaolin significantly affects the oviposition behavior, larval development stages, adult mobility, and overall population structure of the olive fruit fly.

2.1. Physical Effects of Kaolin on the Olive Fruit Fly

Kaolin creates a white film on the fruit surface, making it more difficult for olive fruit flies to recognize the fruit as a host. This visual camouflage effect leads to a reduced preference for the treated fruit. In the study by Rameau et al. (2020), damage to kaolin-treated olives was reported to decrease by 40–60%.

2.2. Effects on Oviposition Behavior

Kaolin applications disrupt the biological cycle of the pest by preventing egg laying. Research by Puterka et al. (2005) indicated that the kaolin film applied to leaves acts as a structural barrier that significantly restricts the oviposition behavior of certain species. Nardi et al. (2019) reported that pest populations in kaolin-treated olive orchards were reduced by more than 50% compared to control groups. Similarly, Pasqualini et al. (2003) observed that kaolin applications in pear cultivation in Italy significantly reduced the egg-laying capacity of *Cacopsylla pyri* females.

2.3. Inhibition of Feeding Behavior and Mobility

Kaolin alters host recognition by the pest, thereby reducing feeding activity. It also adheres to the insect's body surface, limiting physical movement (Dehbi et al., 2021). Research has demonstrated that kaolin particularly reduces the frequency and speed of movement in larval and nymph stages. Larvae moving on kaolin-coated surfaces were observed to cover shorter distances, pause frequently, and fail in host-seeking behaviors.

Similar findings were reported by Puterka et al. (2005) and Unruh et al. (2000), who noted significant movement restrictions in adult psyllids and early-stage larvae of *Cydia pomonella* after kaolin film application.

2.4. Effects on Population Dynamics and Ecophysiology

Over time, a significant decrease in pest populations has been observed in areas treated with kaolin. Pests tend to shift to alternative food sources, which helps suppress the olive fruit fly while reducing the need for chemical pesticides, thus contributing to ecosystem-based sustainability (Rameau et al., 2020).

Kaolin clay stands out as both an effective and environmentally friendly alternative for olive fruit fly management. Studies have demonstrated that kaolin disrupts the pest's biological cycle and significantly reduces population density. Nevertheless, the effectiveness of the application may vary depending on dosage, application frequency, and regional climatic conditions.

Therefore, future research should focus on the integration of kaolin with biological control methods and assess its long-term environmental impacts. This will allow a more holistic evaluation of kaolin-based applications within sustainable farming systems.

3. Alternative Integrated Management Approaches Against Olive Fruit Fly Using Kaolin and Biopesticide-Based Strategies

Kaolin clay and biopesticides are considered sustainable alternatives to chemical pesticides and are among the environmentally friendly strategies for pest management. While kaolin suppresses egg-laying and feeding behaviors of the olive fruit fly (*Bactrocera oleae*) through the formation of a physical film on the plant surface, biopesticides—such as entomopathogenic fungi and plant-derived natural insecticides—directly reduce pest populations (Hajjar et al., 2020; Moore et al., 2018).

Field studies conducted in Syria have demonstrated that olive trees treated with kaolin experienced significantly less damage from olive fruit flies compared to untreated control plots. Similarly, successful results have been obtained with kaolin applications in apple and mango orchards in South Africa, where Ceratitis species are major pests. Moreover, studies have documented the effectiveness of kaolin against various tephritid species, including B. oleae (Cytrynowicz et al., 1982; Stark & Vargas, 1992; Alyokhin et al., 2000).

Research on the olive fruit fly's color preferences revealed that the species is highly attracted to yellow and orange hues but shows minimal interest in white-colored surfaces (Katsoyannos, 1989; Katsoyannos & Kouloussis, 2001). Accordingly, the bright white appearance created by kaolin applications on olive trees is thought to have a repellent effect on the pest.

Current control strategies for tephritid species largely rely on synthetic insecticides. Nevertheless, comparative applications against B. oleae showed that while kaolin and dimethoate initially demonstrated similar levels of efficacy, pest populations remained lower on kaolin-treated trees, whereas pest resurgence was observed in dimethoate-treated areas (Kombargi et al., 1998; Maklakov et al., 2001). Moreover, no phytotoxic effects (e.g., leaf burn, drop, or bronzing) were observed on the foliage or fruit surfaces of trees treated with kaolin.

Saour & Makee (2004) reported that kaolin-coated olive trees were less recognizable to olive flies, and the altered physical structure of the surface exerted a deterrent effect on female insects. In another study conducted by Joubert et al. (2004), significant effects of kaolin film were demonstrated on both olive fruit fly and olive moth populations. Kaolin suspensions applied at concentrations of 5%, 3%, and 1.5% showed varying impacts on pest density. While the control group exhibited an average of 18.78 ± 0.34 pest infestations per tree, the 5% kaolin treatment reduced this number to 3.84 ± 0.28. Similarly, the 3% and 1.5% applications resulted in averages of 6.96 ± 0.42 and 10.1 ± 0.18, respectively.

Adult populations of olive moths were also affected, with counts of 2.02 ± 1.05 and 3.11 ± 1.54 in the 5% and 3% kaolin treatments, compared to 4.01 ± 3.12 in water-treated trees and 4.01 ± 3.63 in the control. For olive psyllid eggs, 5% and 3% kaolin treatments yielded 1.67 ± 0.94 and 1.77 ± 0.87, whereas the water-treated group had 3.46 ± 1.62, and the control recorded 4.37 ± 2.13.

Regarding olive moth nymph populations, the 5% and 3% kaolin applications resulted in 3.00 ± 1.43 and 4.46 ± 2.54 individuals, compared to 4.70 ± 0.98 in the water-treated group and 8.01 ± 3.54 in the control. These data support the effective integration of kaolin into pest management systems for the control of multiple olive pests.

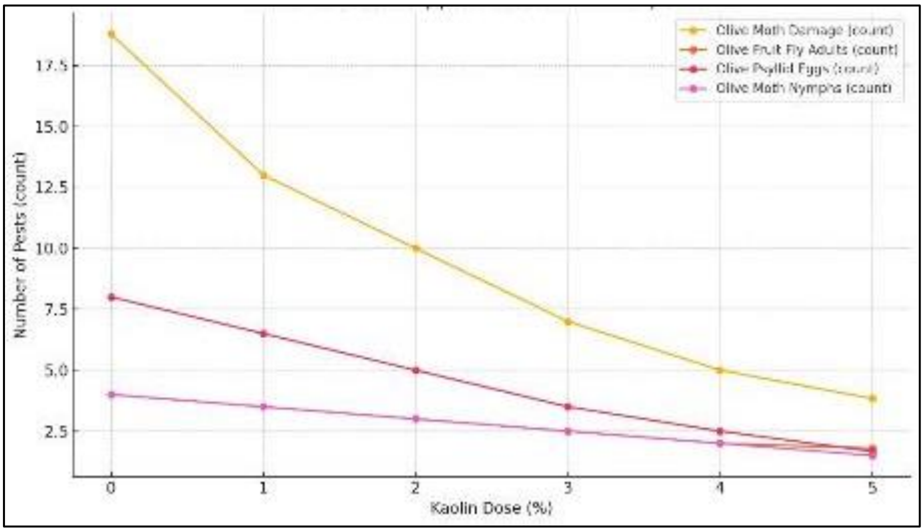

Figure 1 Effect of Kaolin Applications on Pest Population

The graph above illustrates the impact of different kaolin application doses on the population density of four pest groups (olive moth, olive fruit fly, psyllid eggs, and nymphs). Observations indicate that as the kaolin dose increases, the population of all pest types decreases significantly. The 5% kaolin dose results in the lowest population levels across all pests. This supports the conclusion that kaolin serves as an effective physical barrier in integrated pest management strategies.

4. Effects of Kaolin Applications on Beneficial Insects: The Case of Chrysopidae

There is a limited body of literature on the effects of kaolin film applications on beneficial insects. Nevertheless, in olive cultivation, individuals from the family Chrysopidae are known to be important biological control agents against Prays oleae (the olive moth). This natural enemy has the capacity to keep target pests below economic thresholds (Campos, 2001). Moreover, members of Chrysopidae have been found to prey on secondary pests such as Saissetia oleae (black scale) and Euphyllura olivina (olive psyllid).

In olive grove ecosystems, Chrysopidae species act as effective generalist predators that play a key role in the natural suppression of pest species such as the olive moth, black scale, and psyllids (Alrouechdi et al., 1981; McEwen et al., 2001). Therefore, it is essential to carefully evaluate the impact of pest management methods on these predatory species.

A study conducted by Medina et al. (2007) reported that kaolin application did not adversely affect populations of *Chrysoperla carnea*. On the contrary, an increase in the abundance of this predator was observed on olive branches treated with the Surround WP kaolin formulation. Similarly, research by Iannotta et al. (2007) found no significant reduction in Chrysopidae populations following kaolin application.

These findings suggest that kaolin film applications may be environmentally friendly not only for pest control but also in terms of their impact on natural enemies. Nevertheless, more ecological and behavioral studies are needed to fully understand species-specific effects on beneficial organisms.

5. Effects of Kaolin Applications on the Aroma and Chemical Composition of Olive Oil

Kaolin clay is widely used in olive cultivation as an environmentally friendly pest control strategy. Beyond its pest management benefits, kaolin applications have also been shown to influence the chemical composition of olive fruits and, consequently, the aroma profile of olive oil. Studies indicate that kaolin contributes to the preservation of phenolic compounds, thereby enhancing the antioxidant capacity of the oil (Gómez-Rico et al., 2007; Campestre et al., 2018).

5.1. Effects on Fruit Ripening, Phenolic Content, and Aroma Profile

Kaolin applications influence the fruit ripening process and support the stability of phenolic compounds. These compounds are key contributors to olive oil's pungency, bitterness, and antioxidant properties. The literature reports that kaolin-treated olives show an increase in phenolic content, which in turn enhances both the functional and sensory quality of the oil (Gómez-Rico et al., 2007).

The aroma profile of olive oil, composed of volatile compounds, is a critical factor in consumer preference. Kaolin coatings have been shown to affect lipolytic enzyme activities in the fruit skin, resulting in changes in volatile compound formation. This leads to more pronounced "green fruity" notes and improved sensory quality (Campestre et al., 2018).

5.2. Effects on Oxidative Stability and Shelf Life

Kaolin applications have been reported to positively influence the oxidative stability of olive oil, thereby extending its shelf life. This effect is attributed to the antioxidant roles of preserved phenolic compounds (Rizzo et al., 2019). Increased oleic acid content and a higher ratio of monounsaturated fatty acids also contribute to this improved stability.

5.3. Findings on Fatty Acid Composition and Physicochemical Properties

A field study conducted in Iran applied kaolin at different concentrations (0%, 3%, and 6%) to olive trees and analyzed the resulting oil's chemical properties. The findings revealed that kaolin treatments led to increased chlorophyll levels, while carotenoid contents, peroxide and iodine values, and UV absorbance coefficients decreased. Palmitic acid levels were highest in the untreated group (17%), while oleic acid content reached up to 65% in kaolin-treated groups. These results indicate that kaolin supports unsaturated fatty acid profiles, enhancing the oil's functional quality.

5.4. Contributions to Oil Quality Alongside Olive Fly Control

A study conducted in the Eastern Calabria region of Italy compared the effectiveness of kaolin and rotenone applications against olive fruit fly. Results showed that pest damage was around 14% in kaolin-treated trees and 20% in rotenone-treated ones. Trees treated with kaolin exhibited higher levels of total phenols, oleic acid (C18:1), and K232 (a quality index), while levels of K270, carotenoids, and tocopherols were lower. No significant differences were found between treatments in terms of free acidity and peroxide values. These findings indicate that kaolin, especially in organic olive production systems, not only suppresses pests but also enhances oil quality.

Similar conclusions have been reported by researchers such as Mazor & Erez (2004) and Saour & Makee (2004), emphasizing the dual benefits of kaolin in pest control and product quality improvement.

When all findings are considered collectively, kaolin applications positively influence the biochemical composition of olive fruits and, consequently, the quality of olive oil. Kaolin contributes to the preservation of phenolic compounds, enrichment of volatile aroma compounds, and enhancement of oxidative stability—supporting both the functional and sensory value of olive oil. Therefore, kaolin should be considered not only as an integrated pest management tool but also as a strategic input for quality-oriented olive production.

6. Effectiveness of Kaolin Clay Against Various Agricultural Pests and Strategic Use Potentials

Kaolin clay is recognized as an environmentally friendly agent with broad-spectrum effects in pest management. Numerous studies in the literature have demonstrated its efficacy against a wide range of pest species in different crops. For example, it has shown effectiveness against *Diaphorina citri* in citrus (Hall et al., 2007; Puterka et al., 2005), *Cydia pomonella* (codling moth) in pear (Unruh et al., 2000), *Ceratitis capitata* (Mediterranean fruit fly) in apple (Mazor & Erez, 2004), *Thrips tabaci* in onion (Larentzaki et al., 2008), and *Myzus persicae* (green peach aphid) in peach (Karagounis et al., 2006).

Specifically in olive cultivation, kaolin applications have demonstrated successful outcomes against major pests such as the olive fruit fly (Bactrocera oleae) (Pascual et al., 2010; Saour & Makee, 2004) and black scale (Saissetia oleae). Similarly, its suppressive effect on early infestations of Cacopsylla pyricola in pear has been documented by various researchers (Glenn et al., 1999; Lapointe, 2000; Unruh et al., 2000; Knight et al., 2000; Showler, 2002; Liang & Liu, 2002; Cottrell et al., 2002; Arthur & Puterka, 2002; Sisterson et al., 2003; Vincent et al., 2003).

In the United States, kaolin is used in up to 30% of insecticide applications in pear production. This high usage rate reflects its strategic impact in reducing reliance on chemical pesticides.

A series of studies conducted in Syria between 2002 and 2003 compared the effectiveness of kaolin film to chemical insecticides (teflubenzuron, alpha-cypermethrin, thiacloprid) against the pistachio psyllid (*Agonoscena targionii*). These studies showed that trees treated with kaolin had lower numbers of adult and nymph individuals compared to control groups. Mid-season kaolin applications significantly suppressed pest populations, while teflubenzuron treatments during the same period were ineffective in controlling psyllid nymphs. These results suggest that kaolin film can provide effective control when pest density is high.

The color and texture alterations on kaolin-coated leaves affect host perception by adult insects and make egg-laying more difficult. Another study compared the effectiveness of kaolin and insecticides during early and mid-season infestations. It found that while teflubenzuron and thiacloprid had moderate success early in the season, only kaolin effectively suppressed high pest populations during peak periods.

Kaolin applications have not shown any phytotoxic effects on pistachio trees. On the contrary, two seasons of observation revealed that kaolin-treated trees demonstrated healthier and stronger growth compared to both untreated and insecticide-treated trees. These findings suggest that kaolin can be evaluated as an effective biophysical control tool against pistachio psyllid.

Additionally, a study on stored product pests involved applying kaolin to adult individuals of *Tribolium castaneum* and *Tribolium confusum*. When treated with a kaolin film at a concentration of 0.1 mg/cm^2, all *T. castaneum* individuals died within three days, whereas approximately 40% of *T. confusum* individuals survived after seven days. At higher concentrations, *T. castaneum* mortality occurred within two days, and complete mortality of *T. confusum* was achieved within five to six days. This study indicates that kaolin can also be an effective tool for managing pests in stored products.

7. Kaolin Application Rates, Economic Evaluation, and Future Role in the Context of Climate Change

7.1. Application Rates and Technical Methods

The effectiveness of kaolin applications varies depending on the dosage, environmental conditions, and the target pest (Table 2). Different concentrations are recommended for specific purposes such as olive fruit fly control or water stress management:

Table 2 Kaolin Application Rates and Purposes

Application Purpose	Kaolin Concentration	Application Timing / Frequency	Reference
Control of olive fruit fly	3–5% (30–50 g/L of water)	From fruit set onward; every 15–20 days	Saour & Makee, 2004
Reduction of transpiration (water stress)	4–6%	During high temperatures; every 2–3 weeks	Glenn et al., 2001

7.2. Economic Analysis of Kaolin Use

Kaolin is increasingly adopted in organic and sustainable production systems as an alternative to pesticides.

Table 3 Economic Evaluation of Kaolin Clay

Evaluation Criterion	Explanation	Reference
Cost Factors	High initial cost; however, up to 40% reduction in pesticide use leads to long-term economic benefits.	Bové et al., 2019
Effects on Yield and Quality	Reduces sunburn damage, improves fruit quality, extends shelf life; adds value in the organic market.	Caleca et al., 2017
Adoption Rate	About 60% of producers are willing to use kaolin due to environmental and economic advantages; labor demand may be a limiting factor.	Saour & Makee, 2012

7.3. Climate Change and Olive Fruit Fly Dynamics

Climate change significantly influences the biology, geographical distribution, and population dynamics of pests such as the olive fruit fly (*Bactrocera oleae*). Rising temperatures accelerate pest life cycles and extend their active periods, increasing their damage potential (Ponti et al., 2014; Gutierrez et al., 2009).

Table 4 Effects of Kaolin Use in the Context of Climate Change and Olive Fruit Fly Biology

Topic	Explanation	Reference
Increased Population Density	A 2°C rise in temperature may increase fly populations by 30%; mild winters extend their period of activity.	Ponti et al., 2014; Daane & Johnson, 2010
Adaptive Role of Kaolin	Kaolin lowers leaf temperature by 4–5°C, reduces transpiration, and serves as both a protective and adaptive barrier.	Gómez-Rico et al., 2007
Sustainability Perspective	Suitable for organic farming, safe for humans and the environment, no resistance risk; expected to be used more under climate change.	Gutierrez et al., 2009

Although kaolin applications may initially require higher costs, they offer a sustainable solution by reducing pesticide dependency, minimizing environmental impacts, and improving olive fruit and oil quality (Table 4). To increase adoption among growers, the following strategies are recommended:

- Training programs
- Government incentive mechanisms
- Support for organic certification

Moreover, integrating kaolin with biopesticides can enhance effectiveness and reduce costs. In the future, comprehensive field trials should be conducted to assess kaolin efficacy under different climate scenarios.

8. The Role of Kaolin Clay in Integrated Pest Management Strategies for Organic Olive Cultivation

Organic farming systems are sustainable production approaches that prohibit the use of synthetic chemical inputs and aim to protect biodiversity. In olive cultivation, organic practices require the adoption of environmentally friendly and effective pest management strategies. In this context, kaolin stands out as a physical barrier agent compatible with organic production standards, particularly against pests like the olive fruit fly (Bactrocera oleae) (Saour & Makee, 2012; Caleca et al., 2017).

Kaolin applications can be effective on their own but can also enhance sustainability when integrated with other eco-friendly methods. Integration strategies involving biopesticides, pheromone traps, natural enemies, and cultural practices play a crucial role in suppressing pest populations.

8.1. Case Study from Southern Italy: A Multi-Application Approach

In a field study conducted in the Mirto-Crosia and Terranova da Sibari regions of Southern Italy, natural agents such as kaolin, copper, biopesticides (azadirachtin and rotenone), and propolis were applied and compared with water-treated control groups. The findings showed that kaolin had strong potential in suppressing pest populations. Copper and propolis were effective against both adults and nymphs, while rotenone's efficacy varied depending on location, and azadirachtin showed low efficacy in both regions.

8.2. Mechanisms of Action in Kaolin Integration

Kaolin clay is considered a multifunctional protective agent in organic olive cultivation (Table 5). Nevertheless, for maximum effectiveness, it is recommended that it be used as part of integrated pest management strategies rather than alone. The combination of kaolin with biopesticides, pheromone traps, beneficial insects, and cultural practices provides advantages in terms of both environmental and economic sustainability.

Table 5 Mechanisms of Action for Kaolin Integration

Method	**Description**	**Reference**
Kaolin + Biopesticide Combination	When combined with entomopathogenic fungi like *Beauveria bassiana* and *Metarhizium anisopliae*, kaolin exhibits a synergistic effect, significantly reducing pest populations.	Caleca et al., 2017
Kaolin + Pheromone Traps	Kaolin reduces pest attraction to fruit, thereby increasing catch rates in pheromone traps and enhancing their effectiveness.	Bengochea et al., 2020
Kaolin + Beneficial Insects & Cultural Practices	Effectiveness increases when used alongside natural enemies like *Psyttalia concolor*. Integrated use with early harvest, pruning, and tillage is recommended.	Haniotakis et al., 2011

Future studies should focus on the economic feasibility, environmental impacts, and quality outcomes of these combinations in order to facilitate the widespread adoption of such applications.

9. Anatomical and Histological Effects of Kaolin Applications on Olive Trees

Kaolin particle film not only plays a role in pest management in olive cultivation but also induces notable changes in the morphological and physiological structures of the plant. Nevertheless, literature focusing on the detailed examination of these structural changes remains limited. Preliminary studies have demonstrated that kaolin applications can regulate stomatal function, cause thickening in the fruit epidermis, and influence lignification in young stem tissues (Fernández et al., 2019; Rosati et al., 2017; Therios, 2009).

9.1. Alterations in Leaf Tissue

The deposition of kaolin particles on the leaf surface prolongs stomatal closure, thereby controlling transpiration. This effect helps conserve water and maintain physiological balance, especially under drought stress conditions. Research has shown that while kaolin does not alter stomatal density, it exerts a regulatory influence on gas exchange processes.

9.2. Effects on Fruit Epidermis

Kaolin applications result in thickening of the olive fruit epidermis and reinforcement of cell wall structures. This enhances resistance to physical impacts, pathogens, and water loss, ultimately contributing to improved fruit quality. Moreover, these epidermal changes also support the fruit ripening process.

9.3. Structural Changes in Stem Cortex

Although data on the impact of kaolin on stem tissues is limited, existing studies suggest that kaolin coatings may increase the density of cortical tissue in young shoots, thereby enhancing water transport and mechanical strength. Such changes in lignification processes are particularly important for maintaining stem integrity under hot and windy climatic conditions.

10. Effects of Kaolin Applications on Transpiration and the Role in Water Stress Management

Kaolin clay is emerging as an effective agricultural support material in reducing water loss through transpiration in plants. When applied to plant surfaces, kaolin forms a thin, reflective film that provides physical protection against environmental stressors. This property allows kaolin to offer physiological support to plants, particularly under hot and arid climatic conditions.

Reduction of Leaf Temperature: Kaolin reflects heat from the leaf surface, lowering leaf temperature and thereby limiting the rate of transpiration (Glenn et al., 2001).

Improved Photosynthetic Efficiency: Lower leaf temperatures and the scattering of sunlight enhance the plant's photosynthetic efficiency and net carbon gain (Rosati et al., 2006).

Increased Drought Resistance: Reduced water loss helps maintain plant water potential, enabling plants to remain more resilient under prolonged drought stress (Razaq & Hafeez, 2017).

Nakano and Uehara (1996) successfully applied kaolin film to protect plants from environmental stress factors and reported positive contributions to growth parameters. Similarly, Cantore et al. (2009) demonstrated that kaolin helps preserve optimal conditions for plant development.

Kaolin film also reduces photooxidative stress caused by solar radiation and protects leaf tissues by reflecting harmful UV rays. This reflective effect has been demonstrated to positively contribute to plant physiology in studies by Wand et al. (2006) and Saour & Makee (2003).

Moreover, Glenn & Puterka (2005) and Thomas et al. (2004) demonstrated that kaolin applications significantly reduce heat stress symptoms in plants and help maintain physiological balance.

Another key advantage of kaolin is its non-toxic nature, which poses no risk to human health or the environment. Therefore, unlike chemical pesticides, it does not trigger resistance development and leaves no harmful residues—making it particularly suitable for use in organic farming systems (Glenn & Puterka, 2005; EEC, 1991).

11. Regional Effectiveness of Kaolin Particle Film Technology Against Olive Fruit Fly

Kaolin clay has been adopted as an environmentally friendly alternative in the management of Bactrocera oleae and has been extensively studied in various agroecological regions. Nevertheless, its effectiveness has been demonstrated to vary depending on the climatic conditions of the region (Ramos et al., 2018; Caleca et al., 2019).

11.1. High Performance in Hot and Arid Climates

Applications in Spain and the Aegean region of Turkey have demonstrated that kaolin film can reduce olive fruit fly damage by 60–80%. In these areas, kaolin not only deters pest activity but also reflects sunlight, reducing water loss and supporting plant physiology under high heat stress.

11.2. Limitations Under Humid and Mild Conditions

Experiments conducted in more humid regions such as Italy and Greece have demonstrated that kaolin films tend to remain on the fruit surface for a shorter duration. This necessitates more frequent applications and leads to a reduction in the overall duration of efficacy.

11.3. Regional Application Frequency and Strategies

Comparative analyses indicate that the number of kaolin applications should be adjusted based on local climate conditions. While two applications may be sufficient in arid regions, 4–5 applications may be necessary to maintain effectiveness in more humid areas (Saour & Makee, 2012).

Given the impacts of climate change, it is important to improve kaolin formulations and develop application protocols adapted to different geographic conditions. Doing so will help establish sustainable and region-specific integrated pest management strategies.

12. Conclusion

Kaolin applications stand out as a strategic alternative for sustainable olive cultivation due to their environmentally friendly properties and multifunctional effects. Considering the short-term efficacy, development of resistant pest populations, and negative impacts of conventional chemical control methods on beneficial organisms, kaolin particle films offer a more lasting and low-risk solution in pest management.

Numerous studies on the control of the olive fruit fly (Bactrocera oleae) have clearly demonstrated the effectiveness of kaolin. Nevertheless, its performance depends on factors such as application frequency, dosage, and environmental conditions. While kaolin has shown high success rates in arid regions, its sustainable effectiveness in humid areas requires the development of improved formulations and optimization of application timing.

Kaolin not only acts against entomological pests but also enhances the plant's tolerance to water stress, supporting key physiological processes. Its effects—such as reducing leaf temperature, regulating transpiration, and maintaining fruit quality—highlight the compound's holistic benefits.

Moreover, in organic farming systems where the use of synthetic inputs is restricted, kaolin serves as a critical tool that promotes both economic and ecological sustainability. It is also gaining wider acceptance in conventional production systems for its ability to reduce chemical dependency and improve quality parameters.

Recommendations

- Kaolin applications should be adapted to different climate scenarios; new formulations with enhanced durability should be developed especially for humid regions.
- The integration of kaolin with biopesticides, pheromone traps, and beneficial insects in pest management should be supported, and synergistic effects should be explored.
- The long-term effects of kaolin on plant physiology should be further investigated through anatomical, histological, and biochemical studies.
- Extension activities, training programs, and demonstration plots should be established to increase growers' knowledge and implementation capacity.

In conclusion, kaolin is not only a pest control agent in olive cultivation but also plays a strategic role in environmental protection, product quality, and grower health. Therefore, kaolin-based approaches should become central components of future integrated pest management and climate adaptation policies.

Compliance with Ethical Standards

Disclosure of Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] Ambikadevi, V. R., & Lalithambika, M. (2000). Effects of amorphization of kaolinite on its surface properties. *Clays and Clay Minerals*, *48*(2), 220–228.

[2] Alrouechdi, K., Nadel, H., & Campos, M. (1981). The importance of Chrysopidae in the biological control of olive pests. *Acta Oecologica*, *2*, 51–58.

[3] Arthur, F. H., & Puterka, G. J. (2002). Evaluation of kaolin particle films to control insects. *Journal of Economic Entomology*, *95*(3), 289–296.

[4] Alyokhin, A., Messing, R. H., & Duan, J. J. (2000). Visual and olfactory stimuli affecting host location in fruit flies. *Entomologia Experimentalis et Applicata*, *94*, 41–47.

[5] Bengochea, P., Caleca, V., & Rizzo, R. (2020). Synergistic use of kaolin and pheromone traps against olive fruit fly. *Journal of Applied Entomology*, *144*(7), 543–552.

[6] Bové, J. M., Dupuy, H., & Roussel, S. (2019). Economic feasibility of kaolin applications in olive groves. *Agricultural Economics Review*, *20*(1), 45–58.

[7] Caleca, V., Rizzo, R., & Caruso, T. (2017). Kaolin-based strategies for olive fly control: Economic and agronomic evaluations. *Journal of Pest Science*, *90*, 1231–1239.

[8] Campestre, C., Angelini, G., & Albi, T. (2018). Influence of kaolin particle films on the sensory properties and quality of virgin olive oil. *Journal of Food Quality*, *2018*, 1–7.

[9] Campos, M. (2001). Role of Chrysopidae in the natural control of olive pests. *Bulletin of Insectology*, *54*(1), 41–45.

[10] Christidis, G. E., & Scott, P. W. (1999). Origin of kaolin deposits and their uses. *Applied Clay Science*, *15*, 1–23.

[11] Cottrell, T. E., Horton, D. L., & Kring, T. J. (2002). Impact of particle films on natural enemies of insect pests. *HortTechnology*, *12*, 617–621.

[12] Cytrynowicz, M., Morgante, J. S., & De Souza, H. M. (1982). Visual response of South American fruit flies. *Environmental Entomology*, *11*, 778–781.

[13] Daane, K. M., & Johnson, M. W. (2010). Olive fruit fly biology in California. *California Agriculture*, *64*(1), 24–32.

[14] Dehbi, A., Arar, K., & Boularbah, A. (2021). Particle films and their impact on olive pests. *International Journal of Pest Management*, *67*, 101–110.

[15] EEC. (1991). Council Regulation (EEC) No 2092/91 of 24 June 1991 on organic production of agricultural products. *Official Journal of the European Communities*, *L 198*, 1–15.

[16] Fernández, J. E., Cuevas, M. V., & Rodríguez, M. (2019). Anatomical responses of olive trees to abiotic stress and particle film application. *Tree Physiology*, *39*(7), 1112–1124.

[17] Gómez-Rico, A., Salvador, M. D., & Fregapane, G. (2007). Effect of kaolin particle film on olive oil quality. *Journal of Agricultural and Food Chemistry*, *55*, 6170–6176.

[18] Glenn, D. M., & Puterka, G. J. (2005). Particle films: A new technology for agriculture. *HortReviews*, *31*, 1–44.

[19] Glenn, D. M., Erez, A., Puterka, G. J., & Gundrum, P. (2001). Effects of kaolin-based particle films on photosynthesis and yield in apple. *Journal of the American Society for Horticultural Science*, *126*(5), 611–617.

[20] Grim, R. E. (1968). *Clay mineralogy*. McGraw-Hill.

[21] Gutierrez, A. P., Ponti, L., & Cossu, Q. A. (2009). Effects of climate change on olive and olive fly. *Pest Management Science*, *65*, 1137–1146.

[22] Hajjar, R., Jaradat, A. A., & Mohtar, R. H. (2020). Biorational pest management in olives. *Agronomy*, *10*(4), 530.

[23] Hall, D. G., Lapointe, S. L., & Wenninger, E. J. (2007). Effect of particle film on citrus psyllid. *HortScience*, *42*(2), 296–300.

[24] Haniotakis, G., Michelakis, S., & Vreugdenhil, M. (2011). Biological and integrated control of Bactrocera oleae. *Integrated Pest Management Reviews*, *9*(3), 149–169.

[25] Iannotta, N., Belfiore, T., & Alibrandi, F. (2007). Population dynamics of Chrysopidae in olive groves treated with kaolin. *Bulletin of Insectology*, *60*, 81–88.

[26] Karagounis, C., Perdikis, D. C., & Fantinou, A. A. (2006). Evaluation of kaolin for pest control in peach orchards. *Crop Protection*, *25*, 915–922.

[27] Katsoyannos, B. I. (1989). Responses of olive fruit fly to visual stimuli. *Entomologia Hellenica*, *7*, 63–67.

[28] Katsoyannos, B. I., & Kouloussis, N. A. (2001). Influence of fruit color on oviposition in Bactrocera oleae. *Bulletin of Entomological Research*, *91*, 257–263.

[29] Knight, A. L., & Light, D. M. (2000). Use of particle films to disrupt codling moth behavior. *Entomologia Experimentalis et Applicata*, *96*, 163–171.

[30] Kombargi, W. S., Issa, H., & Khouzami, N. (1998). Comparative efficacy of kaolin and dimethoate. *Journal of Applied Entomology*, *122*(1–2), 1–4.

[31] Larentzaki, E., Nault, B. A., & Shelton, A. M. (2008). Influence of particle film on onion thrips. *Crop Protection*, *27*, 1353–1358.

[32] Maklakov, A. A., & Kouloussis, N. A. (2001). Comparative studies of kaolin and insecticide applications. *Journal of Economic Entomology*, *94*, 1215–1221.

[33] Mazor, M., & Erez, A. (2004). Kaolin particle film: A physical barrier against Ceratitis capitata. *Crop Protection*, *23*, 555–562.

[34] McEwen, P., New, T. R., & Whittington, A. E. (2001). *Lacewings in the crop environment*. Cambridge University Press.

[35] Medina, P., Pliego-Alfaro, F., & Barceló, A. (2007). Effects of kaolin on Chrysoperla carnea. *Spanish Journal of Agricultural Research*, *5*, 1–8.

[36] Moore, S. D., Hattingh, V., & Johnson, J. (2018). Advances in olive fly biopesticides. *Biocontrol Science and Technology*, *28*, 1–13.

[37] Murray, H. H. (2007). Overview of the industrial clay minerals. *Applied Clay Science*, *38*, 210–233.

[38] Nardi, S., Marra, R., & Soppelsa, S. (2019). The impact of kaolin film on olive fruit fly. *Crop Protection*, *126*, 104919.

[39] Pasqualini, E., Civolani, S., & Boselli, M. (2003). Reduction of psyllid oviposition in pear trees treated with kaolin. *Bulletin of Insectology*, *56*, 79–83.

[40] Pascual, S., Cobos, G., & Seris, E. (2010). Management of olive pests with kaolin. *IOBC-WPRS Bulletin*, *54*, 185–192.

[41] Ponti, L., Gutierrez, A. P., & Cossu, Q. A. (2014). Insect pest population response to climate change. *Agricultural and Forest Entomology*, *16*, 1–11.

[42] Puterka, G. J., Glenn, D. M., & Sekutowski, D. G. (2005). Particle films for insect and disease management. *Annual Review of Entomology*, *50*, 399–423.

[43] Rameau, V., Hilaire, C., & Bérard, A. (2020). Impact of kaolin film on Bactrocera oleae behavior. *Agronomy for Sustainable Development*, *40*(1), 12.

[44] Ramos, P., Lopes, T., & Bento, A. (2018). Regional effectiveness of kaolin against olive fly. *Spanish Journal of Agricultural Research*, *16*(4), e1002.

[45] Razaq, M., & Hafeez, M. (2017). Role of kaolin in mitigating drought stress. *Agricultural Water Management*, *189*, 54–60.

[46] Rizzo, R., Caleca, V., & Lo Verde, G. (2019). Influence of kaolin on oil composition. *Journal of the Science of Food and Agriculture*, *99*, 1096–1103.

[47] Rosati, A., Paoletti, A., & Pannelli, G. (2006). Reflective particle films reduce leaf temperature. *Scientia Horticulturae*, *109*(2), 107–111.

[48] Rosati, A., & Palliotti, A. (2017). Anatomical modifications due to kaolin application. *Journal of Experimental Botany*, *68*, 535–546.

[49] Saour, G., & Makee, H. (2004). Impact of kaolin particle film on the behavior of olive fruit fly. *Crop Protection*, *23*, 733–737.

[50] Saour, G., & Makee, H. (2012). Effectiveness of kaolin and economic considerations. *Crop Protection*, *31*(2), 205–211.

[51] Showler, A. T. (2002). Visual cues in insect pest management. *Pest Management Science*, *58*, 877–885.

[52] Singer, R. F., & Sonja, B. W. (1971). Kaolin processing and applications. *Minerals Engineering*, *24*, 1–12.

[53] Stark, J. D., & Vargas, R. I. (1992). Comparison of alternative control methods for fruit flies. *Pesticide Science*, *36*, 195–202.

[54] Therios, I. N. (2009). *Olive production manual*. Science Publishers.

[55] Thomas, D. B., & Glenn, D. M. (2004). Evaluation of kaolin films on plant stress reduction. *HortTechnology*, *14*, 175–179.

[56] Unruh, T. R., Knight, A. L., & Glenn, D. M. (2000). Particle film effects on codling moth. *Journal of Economic Entomology*, *93*(3), 737–743.

[57] Vincent, C., Goettel, M. S., & Lazarovits, G. (2003). Biological control in sustainable agriculture. *Entomological Society of Canada Bulletin*, *35*, 121–127.

[58] Wand, S. J. E., Theron, K. I., Ackerman, J., & Marais, S. J. S. (2006). Kaolin particle film application reduces heat stress. *HortScience*, *41*, 1421–1425.