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Kaolin in vineyards: Effects on the leafhopper *Erasmoneura vulnerata* and non-target species such as predatory mites and egg parasitoids

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ABSTRACT

Recently, *Erasmoneura vulnerata*, firstly reported in Italy, has emerged in other European viticulture areas, indicating a potential spread of its associated issues across Europe. The most effective control strategies against *E. vulnerata* are those based on chemical insecticides, which can negatively impact non-target species. Organic control strategies mostly rely on pyrethrum, but its effectiveness seems limited, given the outbreaks in organic managed vineyards in North-eastern Italy. The control of *E. vulnerata* in organic farms must therefore be improved. In this study large scale trials were planned in several organically managed vineyards located in North-eastern Italy. We evaluated kaolin's impact on *E. vulnerata* and the effect on beneficial arthropods, particularly Acari Phytoseiidae and the egg parasitoids Hymenoptera Mymaridae. A decline in the leafhopper nymph population was observed in three out of four vineyards, while adults in two out of four. Kaolin affected predatory mite populations, but not permanently, and did not affect mymarid parasitism rates.

1. Introduction

In the last decades, viticulture has received a significant boost in economic growth compared to other crops (Brostrom and Brostrom, 2009). At the same time, viticulture is facing new challenges due to: the continuous arrival of new alien invasive species, climate change and the demand for environmental-friendly management techniques. The European Commission recently unveiled its Farm to Fork strategy that imposes restrictions on pesticide use (European Commission, 2020). This has compelled winegrowers to implement agricultural practices that reduce environmental impact while maintaining profitability (Wery and Langeveld, 2010). In this framework, the search for alternatives to conventional insecticides is crucial, and the development of particle film technology based on kaolin is of particular interest.

Kaolin is a white, inert and non-toxic clay aluminosilicate applied as water formulation on cultivated plants to create a protective coating film (Sharma et al., 2015). The use of this technology in grapevine cultivation provides several advantages. Kaolin-based particle film is applied on leaves because of its reflectance proprieties to reduce sunburn and water stress (Boari et al., 2015; Brillante et al., 2016; Ferrari et al., 2017). Kaolin applications have also been proposed against various pests such as *Homalodisca coagulata* (Say) (Wood and McBride, 2001; Puterka et al., 2003; Barker et al., 2006; Tubajika et al., 2007); the grape phylloxera *Daktulosphaira vitifoliae* (Fitch) (Sleezer et al., 2011); grapevine leafhoppers such as *Zygina rhamni* Ferrari, *Hebata* (=*Empoasca*) *vitis* (Göthe) and *Scaphoideus titanus* Ball (Tacoli et al., 2017a, 2017b); the tortricid moth *Lobesia botrana* (Denis and Schiffermüller) (Pease et al., 2016; Tacoli et al., 2019); the spotted wing drosophila, *Drosophila suzukii* (Marsumura) (Linder et al., 2020; González-Núñez et al., 2021; Dam et al., 2022) and also the Mediterranean fruit fly *Ceratitis capitata* (Wiedemann) (D'Aquino et al., 2011; Campos-Rivela & Martínez-Ferrer, 2021). It has been observed that kaolin can reduce insect adhesion to the treated surfaces (Puterka et al., 2005; Salerno et al., 2020, 2021) and cause dehydration in small insects due to its hygroscopic nature, as observed by Bengochea et al. (2013). Moreover, kaolin application can act as a repellent barrier interfering with host-plant attractiveness, reducing insect feeding and oviposition (Glenn et al., 1999; Vincent et al., 2003; Barker et al., 2006; Lapointe et al., 2006; Valizadeh et al., 2013; Tacoli et al., 2017a, 2017b).

Here we tested the effect of kaolin-based applications for the management of the leafhopper *Erasmoneura vulnerata* (Fitch), an invasive pest of grapevine in Europe. This leafhopper, native to the Nearctic

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region, was recorded in North-eastern Italy in 2004, and for a decade has been considered a minor pest of grapevines (Duso et al., 2005, 2019). In 2016, the first *E. vulnerata* outbreaks were recorded in Italian vineyards (Duso et al., 2020a). These studies showed that *E. vulnerata* overwinters as adults in natural and artificial sites close to vineyards and completes three generations per year. This species is very competitive towards native leafhoppers and can reach significant densities in commercial vineyards. Organic vineyards are particularly exposed to *E. vulnerata* infestations, likely due to the moderate impact of naturally derived insecticides (Duso et al., 2020a; Tirello et al., 2021).

Recently, *E. vulnerata* has been reported in other European countries (Seljak, 2011; Chireceanu et al., 2020; Rizzoli et al., 2020; Šćiban and Kosovac, 2020), suggesting that current issues related to this species in Italy could involve other viticultural areas. Among strategies used to control *E. vulnerata*, those based on chemical insecticides gave promising results in small-scale trials (Tirello et al., 2021). In those trials, the efficacy of naturally derived insecticides was lower than that of conventional insecticides. Therefore, the control of *E. vulnerata* in organic farms must be improved. On the other hand, insecticide use should be reduced according to the objectives of EU policy. An increasing number of active ingredients widely used in vineyards have been banned in Europe due to toxicological and environmental issues; thus, alternatives to insecticides should be identified.

Strategies based on the exploitation of biocontrol agents have also been explored. Inoculative releases of two predators, i.e., *Chrysoperla carnea* (Stephens) or *Orius majusculus* (Reuter) reduced *E. vulnerata* densities by about 30% in open field experiments (Prazaru et al., 2021). Promising results in controlling *E. vulnerata* have been obtained in small-scale trials using kaolin (Tirello et al., 2021). These results encouraged further evaluations of the possibility of developing control strategies based on kaolin. Here we tested the use of kaolin in real use scenario by performing large-scale trials in a number of vineyards located in North-eastern Italy. Moreover, in the light of incorporating kaolin applications in IPM programs in vineyards, the effect on beneficial arthropods, particularly natural enemies, should be considered (Duso et al., 2020b). Here we evaluated the side effects of kaolin on two groups of beneficials of importance for grapevine cultivation, predatory mites belonging to the Acari Phytoseiidae and the egg parasitoids Hymenoptera Mymaridae.

2. Materials and methods

2.1. Experimental design

The effects of kaolin on *E. vulnerata* populations were evaluated in four organic vineyards located in Verona and Treviso provinces (Veneto Region, North-eastern Italy) during three growing seasons (2019–2021). In 2019, trials were conducted in a hilly vineyard in Verona province (PO vineyard, Monteforte d'Alpone, cv. Garganega, pergola veronese training system, planting space 3.50 m × 0.80 m). In 2020, trials were conducted in two vineyards in the Verona province, one on the plain (SP vineyard, San Pietro in Cariano, cv. Corvina, doppia pergola veronese training system, planting space 3.20 m x 0.80 m), and the second in a hilly area (SU vineyard, Soave, cv. Garganega, Guyot training system, planting space 2.30 m × 0.9 m). An additional trial was conducted on the plain of Treviso province (GA vineyard, Ponte di Piave, cv. Glera, Bellussi training system, planting space 6 m × 4 m). The 2021 trials were performed in the GA vineyard only. In all vineyards, moderate to high populations of *E. vulnerata* had been reported in the season preceding the trials. In each vineyard, we tested different strategies of kaolin application (Surround WP by SERBIOS, dose 4 kg/100L) as reported in Table 1. In each trial, an untreated control was included for comparison. In 2019, kaolin was applied twice against the first and second generations of *E. vulnerata*. In 2020 and 2021 the timing of kaolin applications depended on leafhopper abundance over the growing seasons.

In all experiments a complete randomized block experimental design was used. Each treatment comprised four replicates of at least 2–3 rows (20–50 m). Sampling was conducted every 10–15 days throughout the growing season. A total of 40–80 leaves per treatment (10–20 leaves per replicate) were removed at each sampling date and transferred to the laboratory. There, leafhoppers and predatory mites were identified to genus or species level. Leafhoppers were identified using a dissecting microscope (Stemi 508, Carl Zeiss Microscopy GmbH, Jena, Germany), while predatory mites were identified at the compound microscope (Leica DM2000, Leica Microsystems, Wetzlar, Germany) using current keys. Leafhopper adults were monitored using yellow sticky traps (SUPER COLOR yellow, SERBIOS, 20 × 12 cm). In each vineyard, four traps per treatment (one trap per replicate) were placed after sprouting and renewed at each sampling date. In all trials, apart from GA vineyard in 2021, the emergence holes of leafhopper first instar nymphs and egg parasitoids (Hymenoptera Mymaridae) were recorded to calculate the parasitism rates (ratio between parasitoid emergence holes and total of observed emergence holes). Mymarid emergence holes are completely different in shape from those of leafhoppers. The mymarid ones are almost perfectly round, while those of leafhoppers are rhomboidal. Insecticide treatments with pyrethrins were conducted according to product label and the mandatory guidelines of the Veneto region for targeting *S. titanus*.

Table 1
Characteristics of trials carried out in the three growing seasons.

Year	Vineyard	Treatments	Application dates
2019	PO	Kaolin	June 24, July 1, July 24, July 31
		Control	–
2020	SP	Kaolin	June 23, July 1
		Control	–
	SU	Kaolin	May 16, June 16, August 8
		Control	–
	GA	Kaolin	June 12, June 22, August 1, August 8
		Control	–
2021	GA	Kaolin	May 20, May 27
		Control	–

2.2. Statistical analyses

The effects of kaolin on the abundance of *E. vulnerata* on leaves or traps were analyzed with a repeated measures linear mixed model with the MIXED procedure of SAS® (ver. 9.3; SAS Institute Inc., Cary, NC, USA). Similar procedures were applied to evaluate the side-effects of kaolin on predatory mites and the parasitism rate by Mymaridae. Data obtained in each field trial were analyzed separately. In this analysis, treatments (kaolin vs. control), date of sampling, and their interaction were considered sources of variation and tested with an F test ($\alpha = 0.05$). Comparisons between treatments on each date were performed using a *t*-test ($\alpha = 0.05$) on the least-square means. The degrees of freedom were estimated using the Kenward–Roger method, which can calculate non-integer values for error terms. Before the analysis, data were checked for model assumptions. The model was run on data transformed to log (n + 1), while the arcsine of the square root was applied to data on parasitism rate. Untransformed data are shown in the figures. The SLICE option of the LSMEANS statement was used to test treatment effect variation within observation periods.

3. Results

3.1. Effects of kaolin on *Erasmoneura vulnerata* nymphs and adults

3.1.1. PO vineyard (2019)

In this vineyard, kaolin was applied against the first (two applications) and the second (two applications) generations of *E. vulnerata*. *Erasmoneura vulnerata* nymph densities were lower in the treated plots compared to the control ones (F = 6.2; df = 1, 11.6; P = 0.029; Fig. 1). The effect of time was also significant (F = 3.25; df = 8, 44.5; P = 0.005) in contrast with the interaction treatment*time (F = 0.95; df = 8, 44.5; P = 0.484).

Erasmoneura vulnerata adults' captures were detected from the end of July onwards (Fig. 2). Their densities appeared to be higher in the control plots, but the effect of treatment and the interaction treatment*time were not significant (respectively: F = 0.68; df = 1, 4.30; P = 0.453; F = 1.83; df = 5, 11.13; P = 0.187; Fig. 2). The effect of time was significant (F = 4.29; df = 5, 11.3; P = 0.02).

3.1.2. SP vineyard (2020)

In this vineyard kaolin was applied twice against the first generation of *E. vulnerata.* The effect of treatment, time and their interaction were significant (respectively, F = 29.4; df = 1, 13.2; P < 0.0001; F = 3.83; df = 7, 38.2; P = 0.003; F = 2.68; df = 7, 38.2; P = 0.023) with nymph densities being lower in kaolin than in control plots, particularly during August (Fig. 3).

Concerning *E. vulnerata* adults, their presence was observed from the end of June. The effects of treatment and time were significant (respectively: F = 17,75; df = 1, 19; P < 0.001; F = 7.21; df = 7, 38.5; P < 0.0001) while their interaction was not significant (F = 0.9; df = 7, 38.5; P = 0.515). There were more adults in the control than in kaolin-treated plots (Fig. 4).

3.1.3. SU vineyard (2020)

Kaolin was applied three times, the first against *E. vulnerata* overwintered adults, the second against the first generation, and the third against the second generation. The effects of treatment, time and their interaction were significant (respectively: F = 127.69; df = 1, 60.5; P < 0.0001; F = 73.19; df = 8, 65.7; P < 0.0001; F = 117.31; df = 8, 65.7; P < 0.0001), with a higher number of *E. vulnerata* nymphs found in control compared to kaolin treated plots, particularly from August onwards (Fig. 5).

Erasmoneura vulnerata adult densities were significantly affected by kaolin application, especially in late summer (Fig. 6). In fact, the effect of treatment, time and their interaction were significant (respectively: F = 11.54; df = 1, 8.65; P = 0.008; F = 10.27; df = 8, 27.7; P < 0.0001; F = 4; df = 8, 27.7; P = 0.003).

3.1.4. GA vineyard (2020)

Kaolin was applied four times, against the first (two applications) and the second (two applications) generations of *E. vulnerata.* The effect of time was significant (F = 48.27; df = 10, 98.9; P < 0.0001), kaolin applications significantly reduced nymph densities (F = 62.78; df = 1,

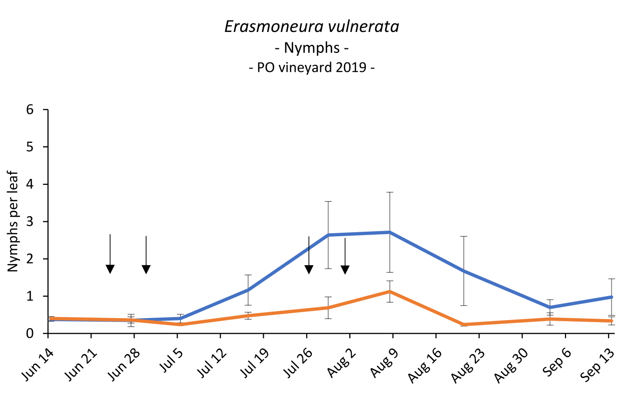

Fig. 1. Seasonal abundance of *E. vulnerata* nymphs (mean ± std. err.) in PO vineyard during 2019. Kaolin was applied four times (arrows indicate application dates).

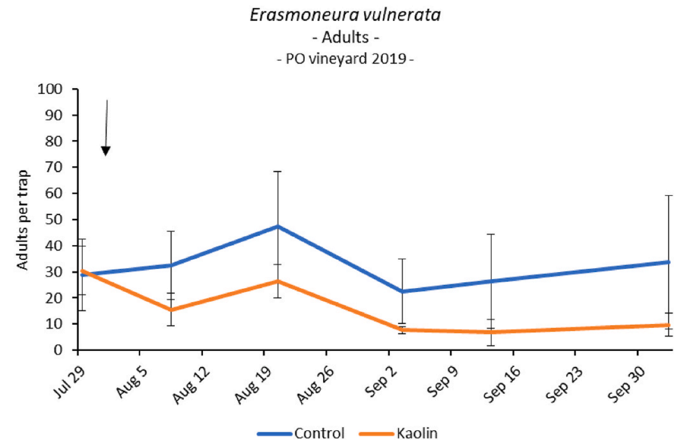

Fig. 2. Seasonal abundance of *E. vulnerata* adults (mean ± std. err.) in PO vineyard during 2019. Kaolin was applied four times but arrows indicate only the application made on July 31.

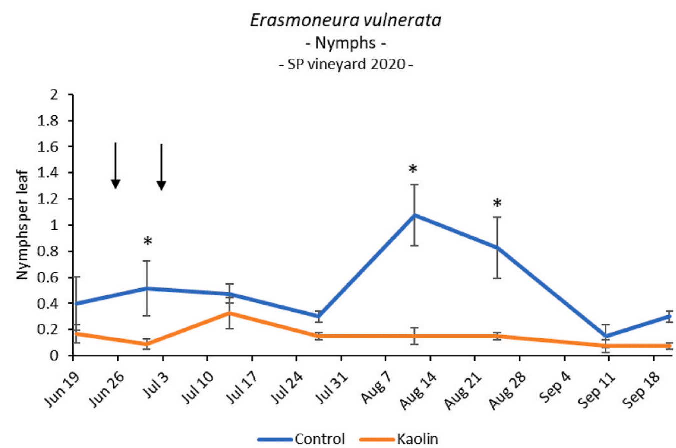

Fig. 3. Seasonal abundance of *E. vulnerata* nymphs (mean ± std. err.) in SP vineyard during 2020. Kaolin was applied twice (arrows indicate application dates). Asterisks indicate significant differences at the *t-test* (α = 0.05) on the least square mean for the same sampling dates.

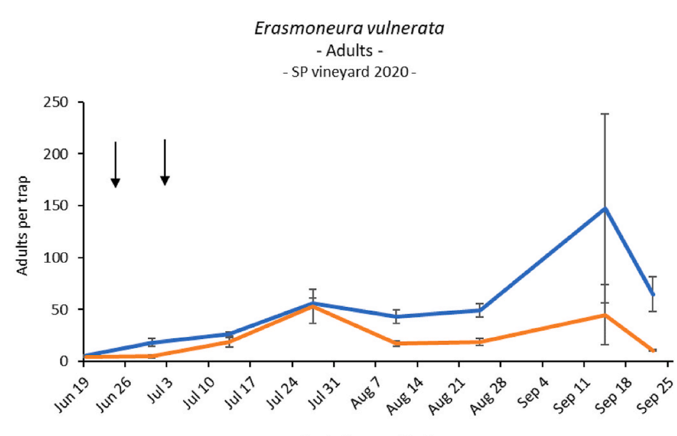

Fig. 4. Seasonal abundance of *E. vulnerata* adults (mean ± std. err.) in SP vineyard during 2020. Kaolin was applied twice (arrows indicate application dates).

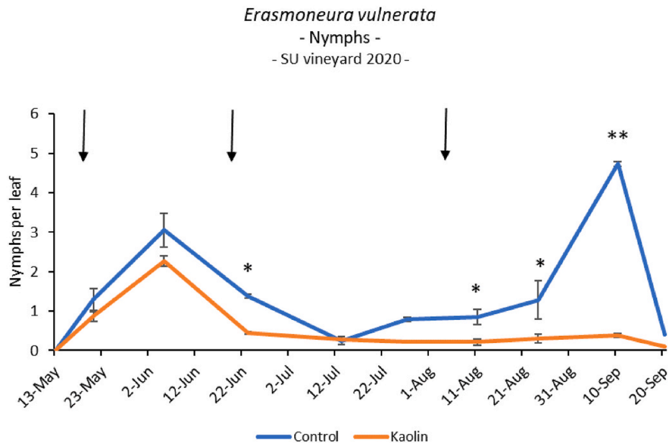

Fig. 5. Seasonal abundance of *E. vulnerata* nymphs (mean ± std. err.) in SU vineyard during 2020. Kaolin was applied three times (arrows indicate application dates). Asterisks indicate significant differences at the *t-test* (α = 0.05) on the least square mean for the same sampling dates.

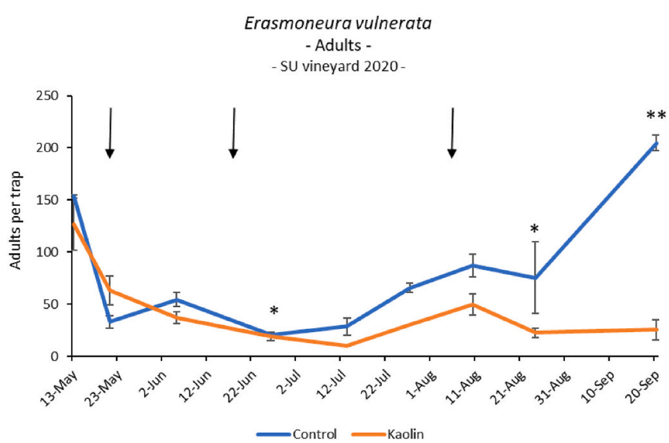

Fig. 6. Seasonal abundance of *E. vulnerata* adults (mean ± std. err.) in SU vineyard during 2020. Kaolin was applied three times (arrows indicate application dates). Asterisks indicate significant differences at the *t-test* (α = 0.05) on the least square mean for the same sampling dates.

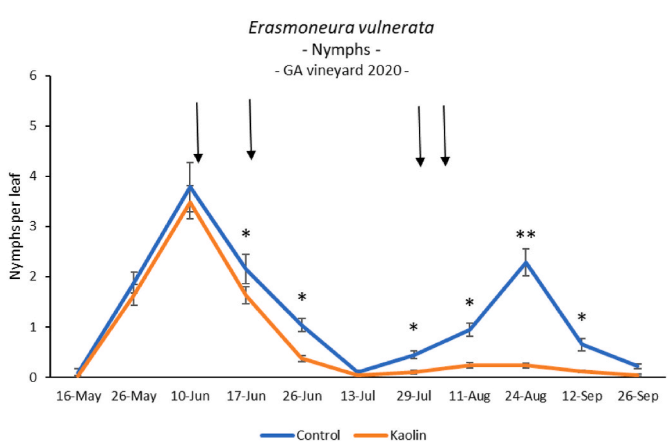

Fig. 7. Seasonal abundance of *E. vulnerata* nymphs (mean ± std. err.) in GA vineyard during 2020. Kaolin was applied four times (arrows indicate application dates). Asterisks indicate significant differences at the *t-test* (α = 0.05) on the least square mean for the same sampling dates.

55.3; P < 0.0001) and their effects were particularly significant during June and August (F = 4.93; df = 10, 98.9; P < 0.0001; Fig. 7).

Regarding adults, there was a significant variation during time (F = 11.41; df = 9, 62.3; P < 0.0001), but kaolin applications (F = 4.44; df = 1, 11.6; P = 0.058) and interaction treatment*time (F = 0.98; df = 9, 62.3; P = 0.464) were not associated with significant effects (Fig. 8).

3.1.5. GA vineyard (2021)

Kaolin was applied earlier than in previous trials, i.e., in the vineyard colonization phase by overwintered adults (Fig. 9). Kaolin applications significantly reduced *E. vulnerata* nymphs over the growing season (F = 80.79; df = 1, 12.4; P < 0.0001), with an effect that emerged in June and August in particular (time: F = 42.77; df = 8, 43.2; P < 0.0001; time*treatment: F = 7.58; df = 8, 43.2; P < 0.0001).

Kaolin applications did not affect *E. vulnerata* adult numbers (F = 0.6; df = 1, 19; P = 0.449). Only a significant variation during time was observed (F = 19.76; df = 6, 44.5; P < 0.0001), not the interaction treatment*time (F = 0.53; df = 6, 44.5; P = 0.781; Fig. 10).

3.2. Side-effects of kaolin on leafhopper parasitism

The occurrence of egg parasitoids belonging to the Hymenoptera Mymaridae (*Anagrus* spp.) was widely detected in vineyards in the 2019 and 2020 growing seasons (parasitism was not investigated in GA vineyard during 2021). The parasitism rate was calculated as the ratio between parasitoid emergence holes and the total of observed emergence holes (leafhopper nymphs + parasitoid adults). Kaolin applications did not affect the parasitism rate by *Anagrus* spp. (Fig. 11, Table 1S). The effect of time was significant in all vineyards because of the variation of parasitism throughout the season (Table 1S).

3.3. Side-effects of kaolin on predatory mites

3.3.1. PO vineyard (2019)

Predatory mites belonging to the species *Kampimodromus aberrans* (Oudemans) were commonly detected in this vineyard with significant variation over time (F = 6.25; df = 9, 59.2; P < 0.0001; Fig. 12). Predatory mite densities were not affected by kaolin applications (F = 0.01; df = 1, 59.2; P = 0.920) nor by the interaction treatment*time (F = 1.37; df = 9, 59.2; P = 0.225).

3.3.2. SP vineyard (2020)

SP vineyard was also colonized by *K. aberrans*. Kaolin applications did not affect predatory mite numbers (F = 2.65; df = 1, 50; P = 0.110) but the interaction time*treatment was significant (F = 3.36; df = 7, 50;

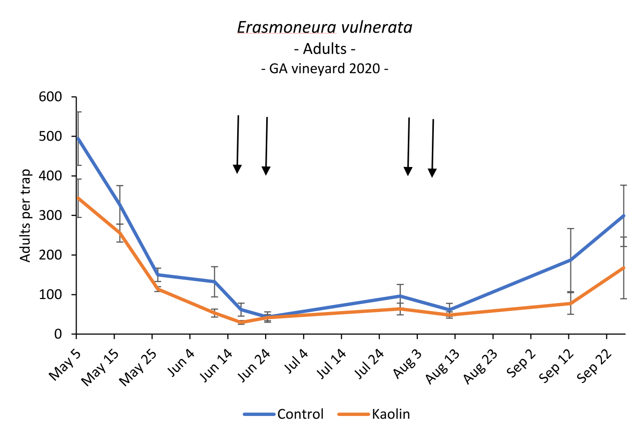

Fig. 8. Seasonal abundance of *E. vulnerata* adults (mean ± std. err.) in GA vineyard during 2020. Kaolin was applied four times (arrows indicate application dates).

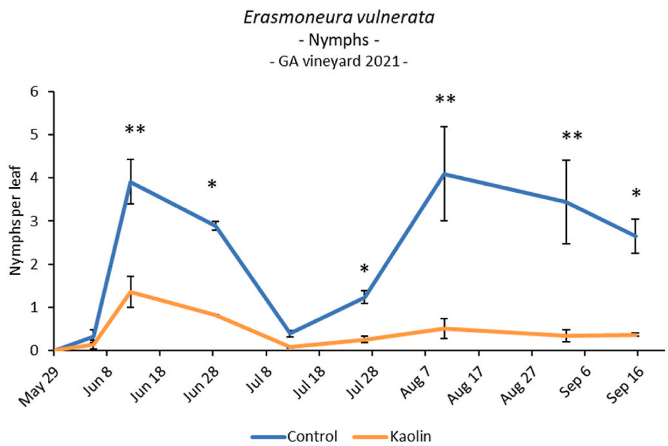

Fig. 9. Seasonal abundance of *E. vulnerata* nymphs (mean ± std. err.) in GA vineyard during 2021. Kaolin was applied twice against the overwintered adults of *E. vulnerata*. Asterisks indicate significant differences at the *t-test* (α = 0.05) on the least square mean for the same sampling dates.

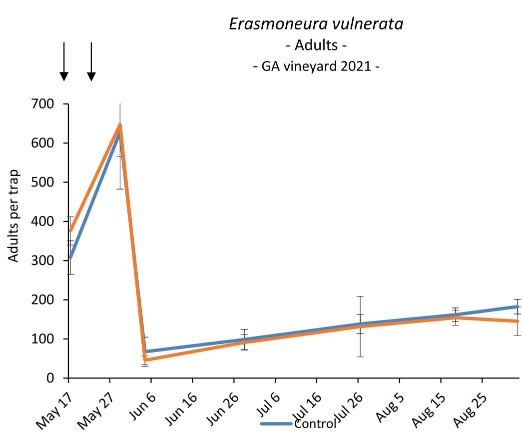

Fig. 10. Seasonal abundance of *E. vulnerata* adults (mean ± std. err.) in GA vineyard during 2021. Kaolin was applied twice (arrows indicate application dates).

P = 0.005): predatory mite densities appeared to be lower on kaolin treated plots for most sampling dates but the opposite situation emerged in late season (Fig. 13).

3.3.3. SU vineyard (2020)

SU vineyard was colonized by *K. aberrans*. Kaolin applications reduced predatory mite numbers (F = 11.92; df = 1, 21.4; P = 0.002), and their densities were lower as compared to the control, in particular from May to July (time: F = 30.18; df = 9, 58.2; P < 0.0001; time*-treatment: F = 2.81; df = 9, 58.2; P = 0.008; Fig. 14).

3.3.4. GA vineyard (2020)

Amblyseius andersoni (Chant) and *K. aberrans* colonized GA vineyard. The effects of treatment, time and their interaction were significant (respectively: F = 9.43; df = 1, 26; P = 0.005; F = 16.73; df = 10, 88.9; P < 0.0001; F = 2.71; df = 10, 88.9; P = 0.006). Kaolin applications reduced predatory mite densities, but this effect was clear from mid-summer onwards (Fig. 15).

3.3.5. GA vineyard (2021)

Kaolin applications did not affect predatory mite numbers. Only the effect of time was significant (F = 4.61; df = 8, 43.9; P = 0.0004), in contrast with the effects of treatment (F = 0.09; df = 1, 9.57; P = 0.770) and the interaction treatment*time (F = 0.95; df = 8, 43.9; P = 0.490) (Fig. 16).

4. Discussion

This study shows that kaolin treatments are useful for managing the leafhopper *E. vulnerata*. These results align with preliminary research on the same (Tirello et al., 2021), and other grapevine pests (Tacoli et al., 2017a; 2017b). In all the experiments, kaolin application significantly reduced *E. vulnerata* nymph densities on grapevine plants. In our trials, kaolin was applied two to four times starting from mid-May until the beginning of August. Reduction in nymph density was observed during the application period of kaolin but also for more than a month later. In this regard, SP and SU vineyards represent two interesting case-studies. In both vineyards, kaolin's effect emerged, particularly when nymph populations peaked in the control. Our results suggest that kaolin affects the nymphs directly and hampers oviposition by *E. vulnerata* adults. Previous studies on the effect of kaolin on leafhopper-infesting grapevines showed an increase in nymph mortality, and the primary mechanism was a reduction in their feeding activity (Tacoli et al., 2017a and b; Tirello et al., 2021) while an effect on oviposition has been observed on the glassy-winged sharpshooter *Homalodisca vitripennis* Germar (Puterka et al., 2003; Tubajika et al., 2007). The technology creates a long-lasting barrier (Sharma et al., 2015) and acts as a pest repellent (Sharma et al., 2015; Puterka et al., 2000, 2003), further inhibiting nymph activity. While reducing nymph populations, the effect on adult *E. vulnerata* was variable, with significant reductions in some experiments but generally lower captures in kaolin-treated plots. The adults' greater mobility and attraction to yellow sticky traps suggest further evaluation of kaolin's efficacy on adults in larger plots to mitigate edge effects, despite consistent nymph reduction across all trials.

The application of kaolin did not reduce parasitism rates in *E. vulnerata* eggs. Given that *E. vulnerata* constituted more than 95% of the total population (including both adults and nymphs) in the vineyards, it is assumed that the observed parasitism primarily affected this species. Consequently, kaolin usage did not interfere with the activity of Mymarid parasitoids on this leafhopper. Leafhopper eggs were constantly parasitized by *Anagrus* spp., with a parasitism level reaching a maximum of about 55% in the SP vineyard in August 2020 in kaolin-treated plots, highlighting the possible integration of particle film technology with biological control that can be based on conservative and augmentative strategies (Duso et al., 2020a; Prazaru et al., 2021; Zanettin et al., 2021).

The impact of kaolin on predatory mites was also not dramatic. A significant reduction in beneficial mite populations was observed in only two out of five experiments. The reduction was about 40% in SU vineyard and about 27% in GA vineyard (2020) and seems to be associated with repeated kaolin applications. Indeed, in both the vineyards where kaolin affected predatory mites, its applications lasted until August. The moderately harmful effect of kaolin on predatory mites inhabiting grapevines is not new and was associated with reduced fecundity (Tacoli et al., 2017a). Kaolin was also associated with a reduction of spider mites (Knight et al., 2001; Lalancette et al., 2005; Arbabi et al., 2020), thus the reduction of prey may potentially impact predatory mites. It should be noted that in our experiments the presence of spider mites was never observed. However, in the case of generalist predatory mites (*sensu* McMurtry et al., 2013) that are the largely dominant species in European vineyards (Duso et al., 2012), these negative effects could be mitigated by habitat management practices that promote the availability of non-arboreal pollen (Pozzebon et al., 2014; Zanettin et al., 2021; Malagnini et al., 2022).

The use of kaolin in viticulture has positive effects on plant physiology, functioning as high temperature stress protectant and favoring the biosynthesis of anthocyanins, which are crucial for obtaining high-quality wines (Movahed et al., 2016; Frioni et al., 2019). Due to these advantages, the use of kaolin in viticulture is increasing.

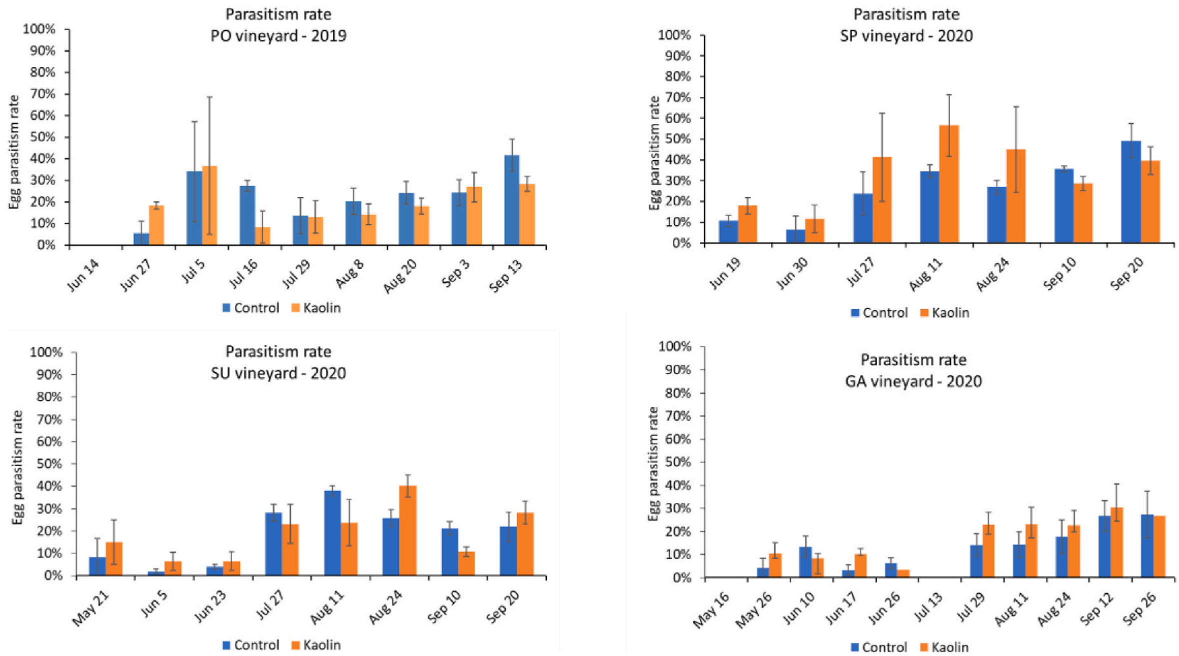

Fig. 11. Parasitism rate (mean ± std. err.) by *Anagrus* spp. observed in kaolin treated and untreated plots in vineyards under investigation. Asterisks indicate significant differences at the *t-test* (α = 0.05) on the least square mean for the same sampling dates.

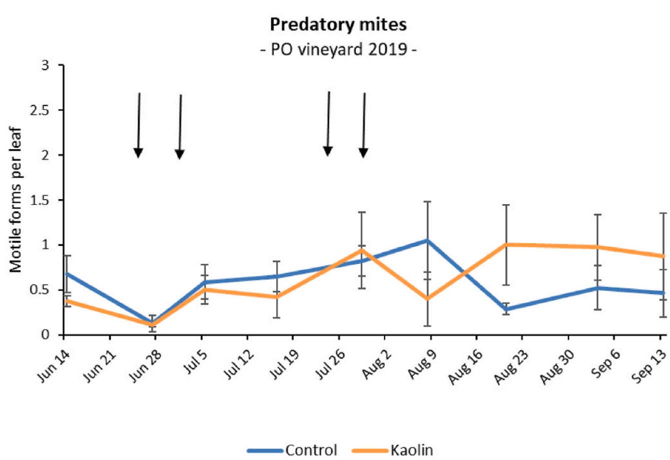

Fig. 12. Seasonal abundance of predatory mites (mean ± std. err.) observed in kaolin treated and untreated plots in PO vineyard during 2019.

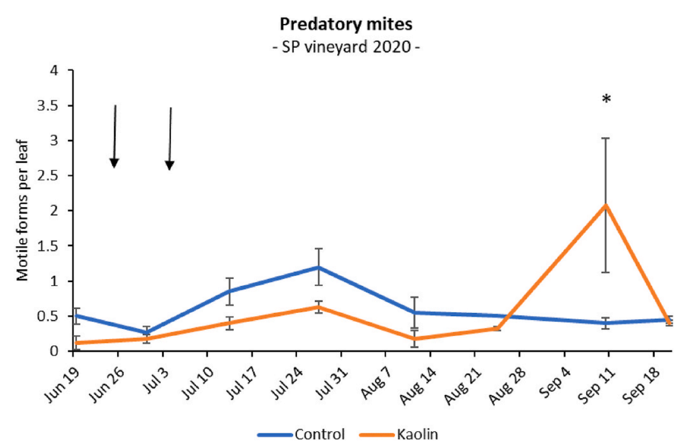

Fig. 13. Seasonal abundance of predatory mites (mean ± std. err.) observed in kaolin treated and untreated plots in SP vineyard during 2020. Asterisks indicate significant differences at the *t-test* (α = 0.05) on the least square mean for the same sampling dates.

5. Conclusion

In conclusion, the application of kaolin-based particle film technology represents a valid tool for the management of *E. vulnerata* that can be used in integrated pest management strategies. This technology is up-and-coming for organic agriculture, which was demonstrated to be more efficient than available tactics (Tirello et al., 2021). Moreover, kaolin application can have positive effects for the management of other grapevine pests and the improvement of physiological processes that enhance grapevine production. These aspects fulfill the requirement of EU targets to improve sustainability in agricultural production.

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CRediT authorship contribution statement

Stefan Cristian Prazaru: Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Paola Tirello:** Data curation, Formal analysis, Writing – original draft. **Filippo Rossetto:** Data curation, Writing – original draft. **Alberto Pozzebon:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Carlo Duso:** Conceptualization, Methodology, Project administration, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that there is no possible conflict of interest.

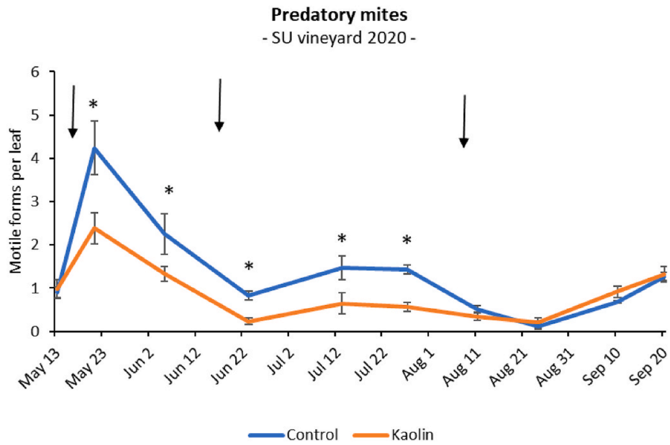

Fig. 14. Seasonal abundance of predatory mites (mean ± std. err.) observed in kaolin treated and untreated plots in SU vineyard during 2020. Asterisks indicate significant differences at the *t-test* (α = 0.05) on the least square mean for the same sampling dates.

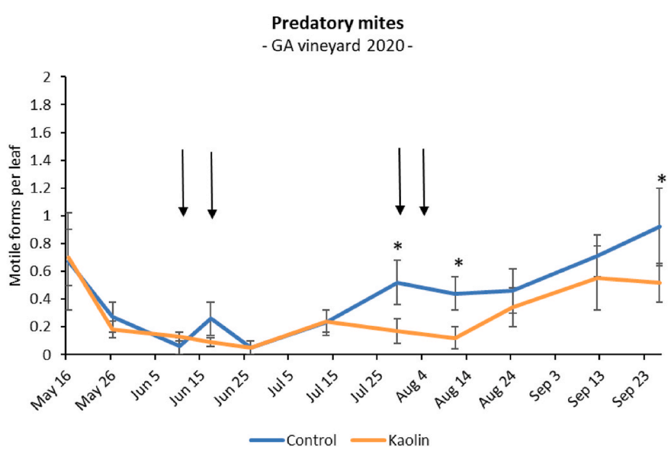

Fig. 15. Seasonal abundance of predatory mites (mean ± std. err.) observed in kaolin treated and untreated plots in GA vineyard during 2020. Asterisks indicate significant differences at the *t-test* (α = 0.05) on the least square mean for the same sampling dates.

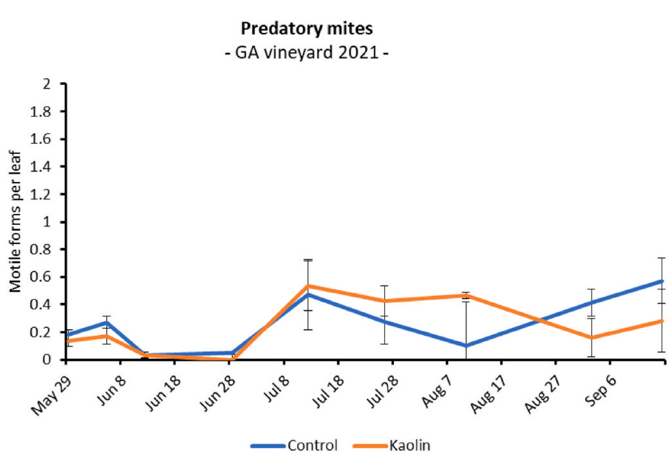

Fig. 16. Seasonal abundance of predatory mites (mean ± std. err.) observed in kaolin treated and untreated plots in GA vineyard during 2021.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.cropro.2024.106628.

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