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SHORT COMMUNICATION

Controlling *Scaphoideus titanus* with kaolin? Summary of four years of field trials in Switzerland

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ABSTRACT

Flavescence dorée is a quarantine phytoplasma-borne disease transmitted primarily by the leafhopper *Scaphoideus titanus*. When *S. titanus* and Flavescence dorée are present in the same vineyard, the vector has to be controlled mandatory with insecticides to limit the transmission of the disease to healthy grapevines. Natural pyrethrins are currently the only registered insecticide to control this vector in Swiss commercial vineyards. To find alternative products against this insect, we tested the effectiveness of kaolin, a white inert aluminosilicate mineral, in 11 independent field trials over four consecutive years from 2018 to 2021. Using kaolin at rates between 20 and 40 kg/ha applied two to three times at the beginning of hatching resulted in an average reduction in leafhopper densities of 36.8 %, with efficacy values ranging from 0 to 88.9 % for the 18 different interventions. Overall, the efficacy of the different kaolin dosages and application strategies did not equal those commonly recorded for natural pyrethrins, which showed a mean efficacy of 74.8 % in the six independent field trials and single reduction values ranging from 41.3 to 97.4 %. Given these highly variable efficacy levels of kaolin, we conclude that the use of kaolin to control *S. titanus* does not provide an efficient alternative to natural pyrethrins in compulsory control areas of Flavescence dorée in Swiss vineyards.

KEYWORDS: *Vitis vinifera*, Cicadellidae, grapevine yellows, elm yellows group (16SrV), transmission, IPM, alternative control

INTRODUCTION

European vineyards are infested by two grapevine yellows, Bois noir and Flavescence dorée (FD) (Caudwell, 1990). Both are phytoplasma-borne diseases transmitted by insect vectors, and the two induce identic visual symptoms. First, the leaves curl downwards and become yellowish in white and reddish in red cultivars; second, the inflorescences and berries shrivel; and third, the rubbery shoots fail to lignify (Caudwell, 1957). Since the optic symptoms of Bois noir and FD are identical, they can only be unmistakably distinguished by molecular analyses (Oliveira *et al.*, 2019). Bois noir is caused by "*Candidatus* Phytoplasma solani" (16SrXII), a taxon infecting a wide range of herbaceous and woody plant species (Quaglino *et al.*, 2013), and its most common vector is *Hyalesthes obsoletus* Signoret (Hemiptera: Cixiidae), a polyphagous cixiid living and feeding preferentially on stinging nettle (*Urtica dioica* L.) and field bindweed (*Convolvulus arvensis* L.) (Kessler *et al.*, 2011). Noteworthy, both the phytoplasma strains related to FD, which belong to the elm yellows group (16SrV) (Angelini *et al.*, 2003; Debonneville *et al.*, 2022), as well as its main vector *Scaphoideus titanus* Ball (Hemiptera: Cicadellidae) live on a more restricted range of host plants (Chuche and Thiéry, 2014). Furthermore, FD is classified as a European quarantine disease and is consequently officially regulated in Europe (EFSA *et al.*, 2020) as well as Switzerland (OSaVé, 2018). When *S. titanus* and the disease are simultaneously present in the same vineyard, the vector has to be controlled, mandatory with insecticides, to limit the transmission of the disease to healthy grapevines (EFSA Panel on Plant Health *et al.*, 2016).

The leafhopper *S. titanus* was introduced from North America to Europe and is developing in the latter nearly exclusively on the species of the genus *Vitis* (Chuche and Thiéry, 2014). Its first observation in Europe dated from 1958 and was located in the vineyards of southwestern France (Bonfils and Schvester, 1960). In Switzerland, *S. titanus* was first observed in the late 1960s in Ticino, and it is now present in various regions of Western Switzerland (Baggiolini *et al*., 1968; Clerc *et al*., 1997; Schaub and Linder, 2007; Linder *et al*., 2019). Alike, FD was first detected in Ticino in the early 2000s, and the Ticino, as well as the Misox Valley in Grisons, are now considered fully colonised by the disease and its vector (Schaerer *et al*., 2007). As a consequence, mandatory vector control measures have been applied there for nearly two decades (Jermini *et al*., 2007; Jermini *et al*., 2014). Recently, the presence of FD has also been confirmed in the Swiss cantons of Vaud, Valais and Geneva, with the subsequent implementation of mandatory control measures (Schaerer *et al.,* 2017; Office cantonal de la viticulture Valais (OCV), 2017; Office cantonal de l'agriculture et de la nature Genève (OCAN), 2019; Schaerer *et al*., 2019).

Conventional management strategies rely first on the production and planting of phytoplasma-free propagation material, the rogueing of infected grapevines as well as the application of insecticides against the main vector *S. titanus* (Oliveira *et al*., 2019). The treatment of FD-infected vineyards with insecticides is mandatory in most European countries and remains the principal measure to control vector populations and consequently reduce disease pressure in commercial vineyards (EFSA Panel on Plant Health *et al.*, 2016). Since all nymphal instars are capable of passively acquiring FD phytoplasmas when they feed on infected plants, and as the incubation period takes about one month until

FIGURE 1. Grapevine treated with kaolin against the nymphal instars of *S. titanus*.

these individuals become infectious (Boudon-Padieu, 2000), insecticide applications generally target the nymphs of *S. titanus* and are applied up to three times a year in epidemically infected viticultural areas (Chuche and Thiéry, 2014). Chemical control is generally based on active ingredients from the classes of butenolides (e.g., flupyradifurone), keto-enols (e.g., spirotetramat), neonicotinoids (e.g., acetamiprid), natural pyrethrins and pyrethrinoids (e.g., cyhalothrin, cypermethrin, deltamethrin, esfenvalerate, etofenprox, tau-fluvalinate) (https://ephy.anses.fr, https://www.sian.it/, https://www.psm.admin.ch/, https://psmregister.baes.gv.at). In Switzerland, insecticide control was based until 2018 on two applications of buprofezin in Integrated Production or two to three applications of natural pyrethrins in organic vineyards. With the withdrawal of the authorisation for buprofezin, commercial products based on natural pyrethrins are currently the only insecticides authorised to control *S. titanus* in Swiss commercial vineyards. These products can be used in all production schemes, but their active ingredients pose risks to bees, aquatic organisms, natural enemies and a range of other species (Dubuis *et al*., 2023). Moreover, there is a considerable threat from the development of resistance in *S. titanus*. To overcome these general drawbacks of authorised insecticides, various alternatives have been tested

TABLE 1. Summary of efficacy trials against *S. titanus* in Western Switzerland from 2018 to 2021.

Year	Site	Variants	Kg or L/ha	*S. titanus* Mean / 100 leaves		% of reduction
				Control	Variants	
2018*	Gland[1]	kaolin	20 - 20	44.7	38.8	13.2
	Morges[2]	kaolin	20 - 20	23	11	52
			20 - 20 - 24	21.4	6.1	71.5
	Grône[3]	kaolin	24 -32	6.5	1	84.6
			20 - 24 - 32	11.4	8.9	21.9
2019**	Gland[1]	kaolin	40 - 20	13	8,1	37.7
			40 - 20 - 20	11.8	5.3	55.1
	Morges[2]	kaolin	40 - 20 - 20	7.2	0.8	88.9
		pyrethrins	1.2 - 1.6	7.2	1.4	80.6
	Grône[3]	kaolin	40 - 20	12.8	4.1	68
			40 - 20 - 20	10.9	4	63.3
2020**	Gland[1]	kaolin	40	31	58.5	0
			40 - 20	26.7	31.5	0
		pyrethrins	1.2 - 1.6	26.7	7.9	70.4
	Duillier[4]	kaolin	40	39.3	41.5	0
			40 - 20	22.2	22.8	0
		pyrethrins	1.2 - 1.6	22.2	5.1	77
	Morges[2]	kaolin	40	31	17.8	42.6
			40 - 20	18.4	6.4	65.2
		pyrethrins	1.2 - 1.6	18.4	10.8	41.3
2021**	Gland[1]	kaolin	40 - 20	33	45.8	0
		pyrethrins	1.2 - 1.6	33	6	81.8
	Duillier[4]	kaolin	40 - 20	9.5	15.5	0
		pyrethrins	1.2 - 1.6	9.5	0.25	97.4

*early hatching strategy **hatching peak strategy

[1]Gland (46°25′34′′ N 6°16′56′′ E, 410 m a.s.l.)

[2]Morges (46°31′12′′ N 6°26′03′′ E, 435 m a.s.l.)

[3]Grône (46°14′59′′ N 7°27′13′′ E, 540 m a.s.l.)

[4]Duillier (46°24′24′′ N 6°13′59′′ E, 460 m a.s.l.)

(Constant and Lernould, 2014; Tacoli *et al.*, 2017a; Prazaru *et al.,* 2023). In field trials conducted in France and Italy, kaolin showed some potential to control *S. titanus*. This white inert aluminosilicate stone powder (Figure 1) impairs the feeding of *S. titanus* on the phloem of grapevine leaves and thereby reduces the pest's density over time. We were, therefore, interested in evaluating the efficacy of kaolin under Swiss conditions. Here we present a synthesis of our 11 independent field trials conducted in Western Switzerland between 2018 and 2021. Overall, we tested the efficacy of kaolin against *S. titanus* for four different dosages at three application moments in 18 different interventions over four consecutive years.

MATERIALS AND METHODS

Trials were set up in four commercial vineyards of the cultivar Chasselas, Merlot and Pinot noir located in the cantons of Vaud and Valais (Table 1). All four sites were well colonised by *S. titanus,* and kaolin was applied at dosages ranging from 20 to 40 kg/ha with 1 to 3 applications of Surround WP (95 % kaolin) deployed at a mean interval of 9 days (Table 1). In 2018, the treatments targeted the first two nymphal instar of *S. titanus* (="early hatching strategy"). From 2019 onwards, the strategy was adapted, and the first application targeted the peak of the hatching period, coinciding with the emergence of the first individuals of the third nymphal instar of *S. titanus* (="hatching peak strategy"). The surface of a treatment ranged from 180 to 1700 m^2, and the application volume was based on the theoretical spray volumes of 1000 to 1600 l/ha deployed either with backpack or turbo sprayers. A single field trial always consisted of 1 to 3 treated areas as well as an untreated plot of similar size that served as an untreated control. Treatments were assigned randomly to the different plots within a vineyard; however, none of the treatments was replicated in an individual field trial. Visual controls were conducted once before the first treatment and four to ten days after the last application. They comprised the visual inspection of 3 to 4 sets of 100 leaves per treatment. The densities of *S. titanus* in the kaolin treatments were compared to this in the untreated control. In 2019, 2020 and 2021, the efficacy of kaolin was also compared with the reference strategy of two applications of Parexan N EC (5 % natural pyrethrins, 20 % sesame oil) at a mean interval of 13 days. Except for mating disruption against the two grape moths *Lobesia botrana* and *Eupoecilia ambiguella*, no other insecticide was applied in the four vineyards where the field trials were conducted.

The efficacy of the treatments was expressed as the percentage of reduction in *S. titanus* density in comparison to the untreated control. In addition, the efficacy of kaolin was compared to one of natural pyrethrins by nonparametric Mann–Whitney U Tests. To understand the relationship between kaolin's efficacy and the density of *S. titanus,* the two variables were correlated in a simple linear regression.

RESULTS

In 2018, kaolin applied twice at various dosages showed an average efficacy of 49.9 % against *S. titanus*, similar to three applications of kaolin, which provided a mean reduction of 46.7 % (Table 1 and Figure 2). Overall, the early hatching strategy at rates of kaolin between 20 and 32 kg/ha applied two to three times resulted in an average reduction in leafhopper densities of 48.6 %, with individual values ranging from 13.2 to 84.6 % for the five different interventions.

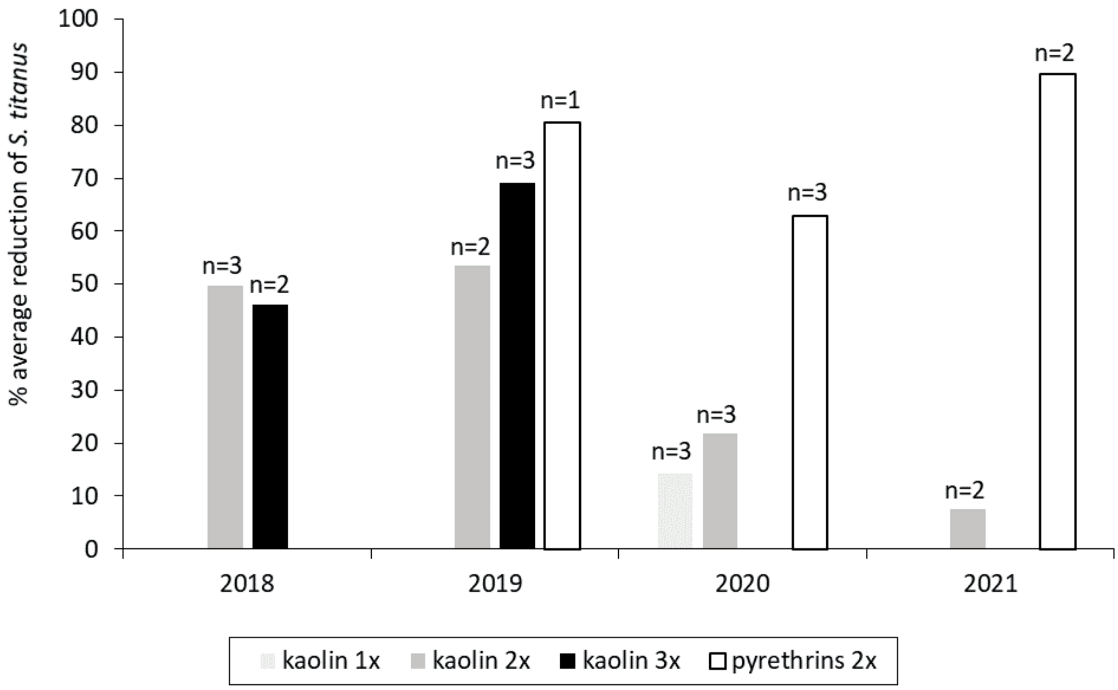

FIGURE 2. Average efficacy of kaolin and natural pyrethrins against *S. titanus* in field trials conducted in Western Switzerland from 2018 to 2021. n = number of different interventions.

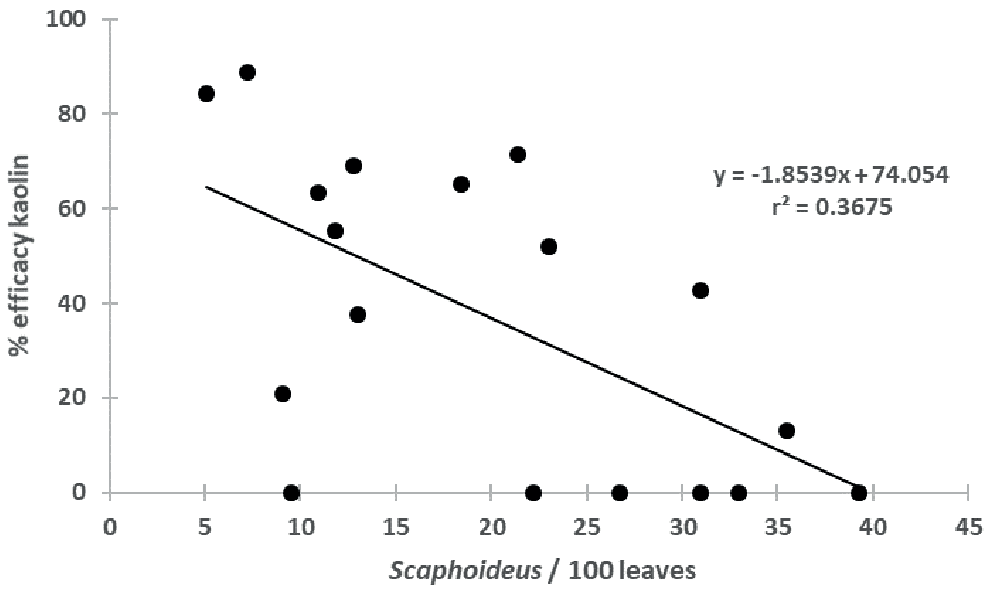

FIGURE 3. Average efficacy of kaolin against *S. titanus* in relation to its density over the 18 interventions conducted in Western Switzerland from 2018 to 2021.

From 2019 to 2021, the first application of kaolin was conducted at the peak of *S. titanus*' egg hatching. In 2019, kaolin applied twice resulted in an average reduction in *S. titanus* populations of 52.9 % (Table 1 and Figure 2). An additional application generally resulted in higher efficacy, with a mean population reduction of 69.1 %. On average, the calculated efficacy of the five interventions was 62.6 % and varied from 37.7 to 88.9 %. Yet, the calculated efficacy of two applications of pyrethrins in a single field trial at Morges was 80.6 %.

In 2020, the observed efficacy of kaolin against *S. titanus* was low, with a calculated mean efficacy of 18.0 % and values spanning from 0 to 65.2 % for the 6 different interventions (Table 1 and Figure 2). Whereas kaolin showed zero reduction in populations after one or two applications in the field trials conducted in Gland and Duillier, an average reduction of 53.9 % was observed in Morges. Yet, two treatments with natural pyrethrins achieved an average vector reduction of 62.8 % in the three conducted field trials, with values ranging from 41.3 to 77 %.

In 2021, the two interventions with two applications of kaolin resulted in a mean efficacy of 0 %, while the average efficacy of natural pyrethrins reached 89.6 % against *S. titanus* and values ranging from 81.8 to 97.4 % (Table 1 and Figure 2).

Over the 4 years of field trials, the 18 different kaolin interventions against *S. titanus* were of an average efficacy of 36.8 % with values spanning from 0 to 88.9 %. This is about half the reduction of the 74.8 % efficacy for natural pyrethrins in the six independent interventions, with individual values ranging from 41.3 to 97.4 %. Overall, the efficacy of kaolin against *S. titanus* was significantly lower than the one of natural pyrethrins ($U = 18$, $P = 0.02$). However, complementary analyses revealed that the efficacy of kaolin decreased with increasing *S. titanus* density ($r = –0.60$, $P = 0.008$; Figure 3).

DISCUSSION

Out of our 18 interventions with kaolin, only three showed satisfactory results, with an efficacy level of over 70 % against *S. titanus*. This level corresponds to the one usually recorded with natural pyrethrins (Gusberti *et al*., 2008; Constant and Lernould, 2014; Prazaru *et al.,* 2023). However, these values were obtained at low to very low population densities of the leafhoppers (Figure 3). Yet, the French Commission for plant protection efficacy trials (CEB, 2001) recommends a minimal threshold of 25 *S. titanus* per 100 leaves. For the six interventions with vector densities over this threshold, the efficacy of kaolin remained below 43 %, with a mean efficacy of 9.3 % (Figure 3). Overall, the efficacy of kaolin against *S. titanus* was very variable and decreased significantly with increasing vector density.

Our results are in line with those received in other studies. Whereas Constant and Lernould (2014) measured efficacy levels between 0 and 83 % for four applications of kaolin at 50 kg/ha, Tacoli *et al*. (2017a) reported an insufficient efficacy of kaolin against *S. titanus* over their three field trials with three applications of 20 kg kaolin per hectare. Based on two conducted trials, Prazaru *et al*. (2023) concluded that among natural insecticides, pyrethrins show with 74% the best efficacy, while kaolin, with 54 % efficacy, might be used as a complementary active ingredient against *S. titanus* in organic vineyards. Inhibition of feeding, which is the main mode of action of kaolin on *S. titanus* nymphs (Tacoli *et al.,* 2017b), seems, therefore, to be considerably less effective than the direct intoxication and killing of individuals with traditional insecticides such as natural pyrethrins. There exists, thus, a general consent that modalities and conditions for the application of kaolin must be optimal to ensure good foliage coverage and to be able to perturb *S. titanus* nymphs. Regardless of our well-targeted applications of kaolin to the grapevine foliage, we observed a very important variance in its efficacy and failed in 15 of 18 interventions to achieve satisfactory control of 70 % efficacy. On the contrary, natural pyrethrins were more consistently successful, and efficacy exceeded the 70 % level in 5 out of 6 interventions. Overall, the extreme variability in the recorded efficacy of kaolin does not allow us to consider it as a valuable alternative to natural pyrethrins in the mandatory control areas of Swiss vineyards.

CONCLUSIONS

Vector control remains a key element of FD control. It still depends heavily on the application of traditional insecticides such as pyrethroids or neonicotinoids. With the exception of natural pyrethrins, products of natural origin that are compatible with organic production are not of satisfactory efficacy to be used and relied on in mandatory control areas. Nonetheless, there might be some niches for the use of kaolin. For example, it could help keep vector presence down in regions with low *S. titanus* population densities. In addition, kaolin might be a “low-risk” alternative in situations where the use of natural pyrethrins, which are highly toxic to water organisms, is prohibited, such as in buffer zones close to open watercourses (Directive 2009/128/EC of 21 October 2009). Overall, the research and development of alternative control methods remains an important challenge for European viticulture and must be actively pursued.

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