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Reduction of Sulphur Dose in the Control of Powdery Mildew of Grapevine through Silicate and *Equisetum arvense* Foliar Applications and Effect on Yield and Berry Quality

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Abstract: The protection of grapevine from the diseases is now particularly focused on the development of environmentally friendly strategies. Although sulphur is not in itself a toxic substance, a large use towards powdery mildew, in organic vineyards especially, may cause problems to environment, health and safety of viticultural workers and plant phytotoxicity. The activity on powdery mildew of sulphur applied at doses reduced up to 50% in tank mixtures with silicates and *Equisetum arvense* based products, never tested on grapevine, was assessed. Two-year trials were carried out applying the products every 7–9 days in the period of greatest risk for spring ascosporic infections, in two organic vineyards in the Abruzzo region, Italy. The effectiveness towards the disease of the mixtures was demonstrated, often to a greater extent than that of full-dose sulphur, normally used in the vineyards. Furthermore, in vines treated with the mixtures, increases in yield quantity and quality, such as higher contents of soluble solids and lower levels of total acidity, have been shown. Due to the strong efficacy demonstrated on the leaves, silicon-based products + sulphur mixtures can also be recommended in eradicative applications, aimed at reducing the inoculum of the disease. The great activity of the mixtures demonstrated in this study suggests confirmation through further investigations on different cultivars and vine-growing areas at different levels of infection, also testing the effectiveness of individual silicon products against the disease.

Keywords: *Erysiphe necator*; leaf applications; organic vineyard; silicon-based products; sustainable control measures

1. Introduction

Powdery mildew, one of the most important grapevine diseases, is caused by the ascomycete *Erysiphe necator* Schw. [syn. *Uncinula necator* (Schw.) Burr., anamorph *Oidium tuckeri* Berk.] [1]. The pathogen is an obligate parasite, particularly virulent in *Vitis vinifera*, so that several fungicide applications are required for the infection control [2].

The infection is mainly occurring and severe in hilly and foothill vineyards characterized by high temperature and windiness and moderate rainfall [3–5]. However, even in lower risk lowland vineyards the management of the disease cannot be underestimated especially when seasonal conditions, also affected by climate change, become favorable to infections [6]. Basically, the severity of the disease is low in rainy seasons, because the temperature is not a limiting factor, since the wide range of development of *E. necator*, ranging from 6 °C to 36 °C [1].

The infection occurrence and severity are also affected by the cultivar susceptibility to the disease or the grapevine phenological stage, the pathogen overwintering form and the amount of

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inoculum. The pathogen can overwinter as mycelium in the buds, which originated infected shoots, the flag shoots, with short internodes, leaves without sharp margins and covered by whitish fungal colonies [7]. Symptoms start from infected lateral buds and develop mainly after mild winters [8–10]. Further sources of inoculum are ascocarps, the chasmothecia, releasing ascospores able to generate infections. Chasmothecia are not present in all growing areas, as *E. necator* is a heterothallic ascomycete. Therefore, the sexual reproduction and ascocarp formation occur only between sexually compatible strains, which are not always present in the vineyard [11,12].

Both the overwintering forms, or even a bud contamination, involve an early control strategy starting immediately after bud-break. If the disease is caused by ascosporic infections, and at high disease pressure, the first fungicide application should be carried out before the infection occurrence, especially if the temperature exceeds 10 °C and upon a rainfall of at least 2.5 mm, that are conditions favorable to the release of ascospores [3,4,13]. If the disease pressure is low, the symptoms by ascosporic infections can be monitored and applications timely managed to stop the infections [14].

Agronomic practices aimed to limit plant vigor and green pruning to facilitate the canopy aeration are recommended. Excessive vegetative growth involves shades areas in which infection may take place [15]. In these conditions, the number and severity of infections increase, and the control of the disease is more difficult because of a non-optimizing fungicide distribution [16].

Preventive fungicide applications carried out from the 4–6 leaf stage (BBCH 15) to berry touch (BBCH 79) to control infections by ascospore or by overwintering mycelium are recommended under favorable conditions to the pathogen and in case of grapevine disease susceptibility [17,18]. A delay in applications can increase the risk of epidemic disease outbreaks due to secondary conidial infections, exacerbating the bunch damage [19].

From the beginning of veraison, foliar aging and bunch maturation reduce the plant susceptibility to the disease, so that fungicide applications can be stopped. Bunches are, in fact, particularly susceptible in the first two weeks, showing instead strong ontogenic resistance 3–4 weeks after full flowering [20–22].

The control of powdery mildew, historically based on sulfur applications, has improved by the introduction of new fungicides with preventive, curative and eradicant activity since the 1970s. This improvement allowed effective strategies in hindering the formation of haustoria, the infections at early stages, or the production of conidia on infected plants. However, unlike sulfur which acts on pathogen with different mechanisms, many of these fungicides have site-specific mode of action, leading to the development of pathogen resistant strains. Therefore, the use of these fungicides, such as ergosterol biosynthesis (EBIs) and quinone-outside (QoI) was subjected to limitations [23,24]. Furthermore, some of these products appear in the European Commission lists of "plant protection products candidates for substitution". In 2022, the European Commission presented a proposal for a "Regulation of the European Parliament and of The Council on the sustainable use of plant protection products" in which it states: "The Commission committed to take action to reduce by 50% the overall use and risk from chemical pesticides by 2030 and reduce by 50% the use of more hazardous pesticides by 2030" [25].

Although sulfur-based products are not included in the aforementioned EU lists of hazardous pesticide, the reduction of their use match with a more sustainable use of plant protection products. In fact, even sulfur can be a source of environmental pollution, due to the large quantities used in viticulture, in particular the organic one. The great increase in sulphate anions in soil and surface water negatively impacts with biological, chemical, and geological processes [26]. Sulfur demonstrated to be toxic to natural antagonists of *E. necator*, thus favoring secondary pests [27]. Applications carried out in warm and humid conditions cause phytotoxicity [28]. Furthermore, sulfur deposits on treated plants may cause irritations to those involved in vineyard productive system [29,30]. Finally, sulfur residues on the bunch are responsible for the formation of off-flavors, with a consequent decrease in the quality of the wine [31,32].

An improving of an environmentally friendly control strategy towards powdery mildew goes through the improving of biological and epidemiological knowledge of the pathogen [33]. In particular, the monitoring of the chasmothecia development, from late summer to the winter of the

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following year, is important to evaluate the inoculum in the vineyard, and the possible adoption of eradicative application strategy [18,34,35]. At high disease pressure, the control by spring applications can be increased by eradicative applications [36,37]. Further improvements in the disease control can be obtained from the use of mathematical models to predict time and severity of ascosporic infections, severity of conidial infections, risk of infection of the shoot buds (flag shoots) and dynamic of chasmothecia occurrence and maturation, aimed at both monitoring chasmothecia and carrying out appropriate eradicative applications [37–39]. Both spring and eradicative applications can be carried out with synthetic fungicides, or biological and natural resistance inducers products (PMI) to be preferred rather than synthetic ones [40].

Resistant cultivars to powdery mildew have recently been introduced, but further work must be done for some characteristics that may limit their diffusion [41].

The evolution of eco-sustainable powdery mildew control strategies goes through the replacement of harmful with low impact plant protection products, as sweet orange oil and potassium bicarbonate, both active against *E. necator* in post-infection applications [42]. Biocontrol agents (BCA) such as *Ampelomyces quisqualis*, *Pythium oligandrum*, *Bacillus pumilus* and *Bacillus amyloliquefaciens* act before the infection occurrence, both by mycoparasitizing *E. necator* and by stimulating resistance mechanisms in the host-plant [36,43,44]. Although further studies are needed on the mechanism of activity of natural substances such as cerevisane, laminarin and the combination of oligo-galacturonides and chito-oligosaccharides, an induction of plant resistance towards powdery mildew infection could be hypothesized [45–48].

Silicon-based products should also be included as possible eco-friendly alternatives to synthetic pesticides. Exogenous applications of these products demonstrated their activity in many pathosystems. In various crops, applications of Si fertilizer to soil, as silicates, silicon dioxide sources, biogenic silica, and diatomaceous earth products, were effective in promoting the increase in plant growth and yield, reducing the impact of biotic and abiotic stresses as well [49–51]. The activity of silicon has been ascribed to the increase in the concentration of monosilicic acid in the soil, given the difficulty of the conversion of solid silicon minerals, the main source of silicon, into monosilicic acid, in a plant absorbable form [50–53].

Furthermore, many studies have been carried out using foliar applications with silicic acid compounds and with silicates, such as sodium silicate and potassium silicate, the latter in particular [54]. Applications of potassium silicate (K_2SiO_3) on cucumber, muskmelon, zucchini squash, strawberry, wheat, and grape reduced the powdery mildew infection rate, and only in a few cases had effects on plant growth and yield [55–58]. However, in some cases, on grapevine, potassium silicate applications failed to provide an adequate level of control under heavy disease pressure [59].

In numerous crops, foliar applications of silicic acid increased growth, yield and quality parameters [60–62]. These applications significantly reduced different fungal infections, including tomato powdery mildew, *Phytophthora infestans* on potato, and smallpox on papaya [60,63,64]. On rice grain husks, silicic acid applications showed effects on diseases and pests, enabling a 50% reduction in pesticide use [65].

The improving plant growth by silicon has been ascribed to a higher mechanical resistance of tissues [66,67]. In many pathosystems, this resistance has also associated to the inhibition of pathogen penetration, because of the strengthening of physical barriers such as cuticles and cell walls [68,69]. The physical barrier reinforcement would make more difficult both the mechanical penetration and the enzymatic degradation by pathogens [70–72].

The role of physical barrier reinforcement towards the infection occurrence has long been questioned because it would seem insufficient to prevent the pathogen penetration [73,74]. The reason of the debate is related to the accumulation of silicon at infection sites, as described in different pathosystems [75]. This accumulation would reduce the high rate of transpiration of the damaged cuticle, rather than preventing the pathogen infection. The accumulation of silicon observed in needle-punctured leaf holes, was indeed inhibited under saturated humidity [76]. Therefore, the role of cell wall reinforcement in the increased resistance of plants to pathogens is yet to be defined.

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Plant resistance to pathogens induced by silicon has been highlighted since the 1990s. Cucumber plants treated with silicon showed resistance to *Pythium* even under saturated humidity conditions, in which the accumulation of silicon in the infection sites was interrupted [77]. Further studies demonstrated that the induction of resistance to diseases by silicon in different pathosystems was associated with increased activity of defense-related enzymes and antimicrobial compounds such as chitinases, peroxidases and polyphenoloxydases, and increased production of phenolic compounds and specific flavonoid phytoalexins [78–85].

Furthermore, silicon induces plant defense responses also by the activation of salicylic acid, jasmonic acid, ethylene signaling pathways [86–89]. Finally, the mediated plant defence responses are also linked to molecular mechanisms such as to the regulation of genes and proteins related to plant defense response [90,91].

As described, positive results have been obtained with silicates and silicic acid in the disease control, vegetative growth and plant production of numerous crops. However, these compounds have not been much investigated on grapevine and among the few investigated compounds, potassium silicate did not show fully satisfactory results in the control of powdery mildew or improvement in vegetative growth and grape production [59].

Thus, the present study investigated the activity of silicon products, to our knowledge for the first time towards grapevine powdery mildew. The trials were carried out in vineyards at high risk for disease infections, where high amount of sulphur is frequently applied. Therefore, the main aim of the study was the reduction of sulphur in the control of powdery mildew, by applying reduced doses of sulphur in tank mixture with silicon-based products, evaluating the effects on plant growth and yield as well.

2. Materials and Methods

2.1. Vineyards

The study was carried out over a two-year period, in 2 organically managed vineyards both located in the Abruzzo region, Italy. Both vineyards are located in hilly areas with high infection risk by powdery mildew. Flag shoots have never been noticed in these vineyards, suggesting that *E. necator* overwinters as chasmothecia.

In 2022, trials were carried out in a 36-year-old vineyard of the cv. Trebbiano d'Abruzzo, 420A rootstock, Tendone training system, located in Ari, province of Chieti, Abruzzo region, Italy. The vineyard has a planting system of 2.6 × 2.6 m, productivity of 240 quintals/ha (mean value of the last 10 years) and clay-limestone soil.

In 2023, trials were carried out in a 4-year-old vineyard of the cv. Pecorino, 420A rootstock, double Guyot training system, located in Cellino Attanasio, province of Teramo, Abruzzo region, Italy. The vineyard has a planting system of 2.5 × 1.0 m, productivity of 54 quintals/ha assessed in 2023, the first year of full production, and a medium texture soil with prevalence of clay.

The harvest of Pecorino, an early cultivar, usually takes place in the first week of September, approximately 15–20 days earlier than the cv. Trebbiano d'Abruzzo.

The applications towards powdery mildew infections were carried out in Ari vineyard by a pneumatic sprayer with a volume of 400 L ha^{-1}, while an air blast sprayer with a volume of 750 L ha^{-1} was used in Cellino vineyard.

2.2. 2022 Leaf Applications

In 2022, the sulphur-based formulation (water dispersible microgranules) normally used in the vineyard was compared with the same formulation applied at a dose reduced by 40% and in tank mixture with silicate or *Equisetum arvense* based formulations (Tables 1 and 2).

The foliar applications were carried out in the period characterized by the greatest risk of infection, from 19 BBCH (9 leaves unfolded) to 79 BBCH (majority of berries touching) phenological growth stages. The first application on May 20th was correlated to the increase of temperature up to the optimum for *E. necator* development. Further 8 applications were carried out at 7–9-day intervals,

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except for the last application made 19 days after the previous one. Applications were made on: May 28, June 6, June 13, June 20, June 27, July 4, July 11, and July 31, according to the program reported in Table 2.

Table 1. Plant protection products used at Ari and Cellino vineyards in 2022–2023 growing seasons in the field trials towards powdery mildew.

Active Ingredients	Trade Name	Company	Formulation	Active Ingredient Concentration (%)
Sulphur	Tiovit Jet	Syngenta Group, Basel, Switzerland	water dispersible microgranules	80
Sulphur	ZolfoLiquido 40	SAIM srl, Napoli, Italy	liquid suspension	40
Calcium Silicate	Barrier SiCa	Cosmocel, San Nicolas de los Garza, N.L., Mexico	liquid suspension	21 CaO + 24 SiO_2
Silicon oxide + Iron	Optisyl	Manica S.p.A., Rovereto (TN), Italy	liquid suspension	16.5 SiO_2 + 2 Fe
Equisetum arvense L.	Equisetum arvense	Agrisystem, Lamezia Terme (CZ), Italy	liquid suspension	0,2

Table 2. Details of applications at Ari and Cellino vineyards in 2022 and 2023.

Treatment			
2022		2023	
Ari vineyard	Dose (Kg/L ha^{-1})	Cellino vineyard	Dose (Kg/L ha^{-1})
Sulphur 80%	5* – 8 **	Sulphur 40%	5
Calcium Silicate + Sulphur 80%	1.5 + 3* – 4.8**	Calcium Silicate + Sulphur 40%	1.5 + 2.5
(Silicon oxide + Iron) + Sulphur 80%	0.5 + 3* – 4.8**	/	/
Equisetum arvense L. + Sulphur 80%	3.0 + 3* – 4.8**	*Equisetum arvense L.* + Sulphur 40%	3.0 + 2.5
Untreated control	/	Untreated control	/

Sulphur 80% = Based sulphur formulation in water dispersible microgranules, at 80% of sulphur concentration. Sulphur 40% = Based sulphur liquid formulation as suspension, at 40% of sulphur concentration. * 5 Kg^{-1} = Sulphur dose in the farm treatment from 19 BBCH (9 leaves unfolded) to the beginning of BBCH 73 (berries groat-sized) growth stages. * 3 Kg^{-1} = Sulphur dose in the treatments in tank mixture with silicium based products from 19 BBCH (9 leaves unfolded) to the beginning of BBCH 73 (berries groat-sized) growth stages. ** 8 Kg^{-1} = Sulphur dose in the farm treatment from BBCH 73 (berries groat-sized) to BBCH 79 (maiority of berries touching) growth stages. ** 4.8 Kg^{-1} = Sulphur dose in the treatments in tank mix with siliciun based products from BBCH 73 (berries groat-sized) to BBCH 79 (maiority of berries touching) growth stages.

From the first application on May 20th to the fourth application on June 13th (corresponding to the beginning of the BBCH 73 growth stage, groat-sized berries), the dose of sulphur in the farm treatment was 5 Kg ha^{-1}. This dose increased to 8 kg ha^{-1} from the fifth application, increasing both the plant canopy and the risk of infections. The dose of sulphur of the treatments in tank mixture with silicon-based products was: 3.0 Kg ha^{-1} (from the first to the fourth application), 4.8 Kg ha^{-1} from the fifth application. The doses of the silicon-based products did not vary in all applications (Table 2).

2.3. 2023 Leaf Applications

The 2023 experimental plan was carried out in the Cellino vineyard as reported in Table 2. The sulphur-based product used in the farm treatments differed from the one used in 2022 in the Ari vineyard, for both the formulation (liquid suspension) and the concentration of active ingredient (Table 1). All farm treatment applications were carried out at 5 L ha^{-1} of sulphur. In tank mixture treatments, the dose of sulphur was reduced by 50%, while the dose of silicon-based products was the same used in the 2022. The first application was carried out on 16 June, in the BBCH 75 growth

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stage, berries pea-sized, because of the lack of favorable conditions for the disease in first part of the growing season. Further 6 applications were carried out up to the 79 BBCH (majority of berries touching) phenological growth stage. Applications were made on 23 June, 29 June, 5 July, 11 July, 19 July, and 28 July (Table 2).

2.4. Treatment Plots, Cultural Practices, and Weather Data Survey

In both vineyards, for each treatment, the applications were carried out in three separate plots, each consisting of a replicate. Each replicate consisted of 69 vines and 244 vines, in Ari and Cellino vineyard respectively. The plots were set up in the vineyard according to the randomized block design.

In the Ari vineyard, on 17 and 18 June 2022, at BBCH 73 growth stage, defoliation and secondary shoot removal were carried out, while in the Cellino vineyard, a defoliation was carried out on 3 June 2023, at BBCH 73.

In both vineyards, rainfall and temperatures were monitored from April to July, period of vine susceptibility to powdery mildew infections, during which leaf applications were carried out.

For each of the two growing seasons, rainfall and temperatures were collected by the 3bMeteo website (3BMETEO srl/Meteosolutions srl, https://www.3bmeteo.com/)

2.5. Disease Assessment

In both vineyards, assessments on leaves and bunches were carried out during the entire growing season to evaluate the development of the disease up to harvest. For each assessment, in each of the three plots of each treatment, 100 leaves and 100 bunches were observed recording both the disease incidence (percentage of affected leaves and bunches) and severity (percentage of affected surface on leaves and bunches). The assessment on leaves and bunches were carried out in the central area of the plot, avoiding the assessment in plants adjacent to the plot of another treatment.

In 2022, in the Ari vineyard, 5 assessments were carried out on 20 June (BBCH 73, berries groat-sized), 30 June (BBCH 75, berries pea-sized), 11 July (BBCH 77, berries beginning to touch), 3 August (BBCH 81, beginning of ripening) and 13 September (BBCH 89, berries ripe for harvest).

In 2023, in the Cellino vineyard, only two assessments were carried out on 13 July (BBCH 79, majority of berries touching) and August 18th, immediately before the harvest. This is because the short period in which infections occurred, and the low incidence of the disease recorded in the first part of the season. By farm choice related to the wine-making, the harvest in Cellino vineyard was brought forward by approximately 15 days than the full maturation.

2.6. Yield Quantity and Qualitative Parameters of the Berries

At harvest, carried out on 18 September 2022 in the Ari vineyard and on 18 August 2023 in the Cellino vineyard, for each treatment, both the yield quantity and the quality parameters of the bunches were evaluated. In each plot of each treatment, 20 vines placed in the central area of the plot were considered. The 20 vines of each plot were separated from the 20 vines of the adjacent plot by four plant rows. In each treatment, the yield of the 20 vines of each plot, each consisting of a replicate, was weighed to evaluate the average yield per vine of each treatment.

At harvest, from 10 vines of each plot, 10 berries were collected from the wing, tip and central part of 3 bunches without disease symptoms. Three samples of 100 berries per treatment were obtained, each representing a replicate. The samples were analyzed to determine soluble solids (°Brix), pH and total acidity (g L−1). Furthermore, for each plot, the average weight of 30 berries and 30 seeds was determined.

The analyzes were carried out according to the methods of the Official Gazette of the European Communities. Commission Regulation (EEC) No. 2676/90 (Official Journal L 272, 3.10.1990).

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2.7. Statistical Analysis

For each year of trial and treatment: *i*) the incidence and severity of infections on leaves and bunches, *ii*) the yield, and the quality parameters of healthy grapes, were subjected to statistical analyzes using one-way analysis of variance (ANOVA). When significant differences were detected between the analyzed parameters, the separation of the means was carried out using Tukey's honest significant difference (*HSD*) test, for $p = 0.05$. Statistical analyzes were performed using XLSTAT 2016 (Addinsoft, Paris, France).

3. Results

3.1. Rainfall and Temperatures Recorded at Ari Vineyard in 2022

In 2022, in Ari vineyard, the average maximum temperature recorded in the first decade of April was 15.84 °C and increased to 18.5 °C in the third decade of April and in the first decade of May (Figure 1; Table S1). From the second decade of May the average maximum temperature increased considerably up to 26.47 °C, to stabilize at 28–29 °C, from the third May to the second decade of June. In the third decade of June the average maximum temperature still increased to 32.11 °C, with values of 30 °C in the first and second decade of July, and 32.23 °C in the third decade of July. (Figure 1; Table S1).

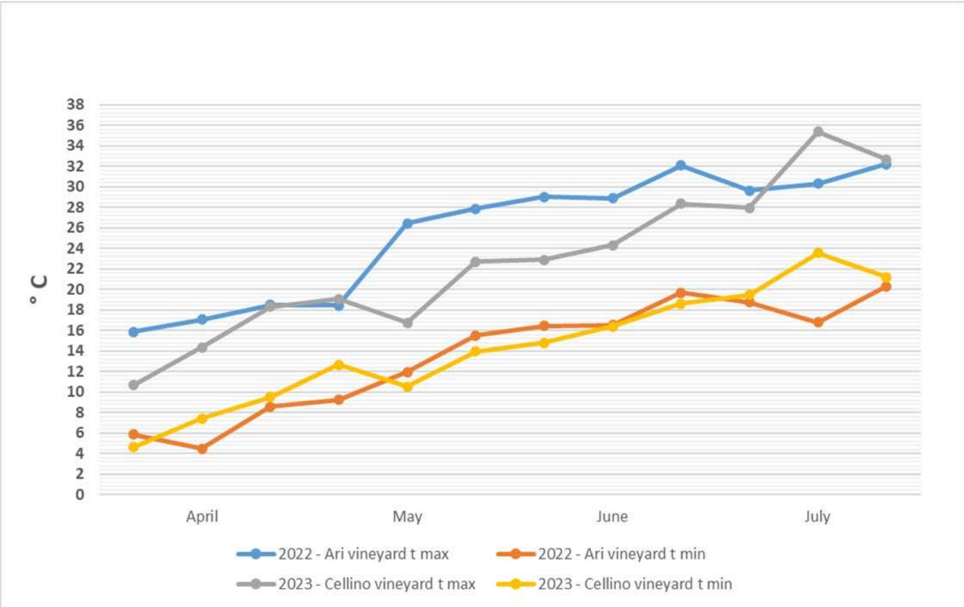

Figure 1. Maximum and minimum temperatures from April to July at Ari and Cellino vineyards in 2022 and 2023. Each point on the graph represents the average temperature for a decade.

As for the maximum temperature, the average minimum temperature increased from the first decade of April (5.87 °C) to 9.23 °C in the first decade of May (Figure 1; Table S1). The average minimum temperature reached 11.96 °C in the second decade of May, 15.49 °C in the third decade of May, and 16.5 °C in the first and second decade of June (Figure 1; Table S1). Further increases in the average minimum temperature were recorded in the third decade of June and July, with values of 19.60 °C and 20.32 °C, respectively. Slight decreasing of the average minimum temperature was observed in the first and second decade of July (Figure 1; Table S1).

In 2022, in Ari vineyard, the rainfalls from April to July were 155.5 mm. In particular, in April, May, June and July, 37 mm, 26.2 mm, 32.6 mm, and 59.7 mm of rain fell down along 7, 6, 4 and 10 days, respectively (Table S1).

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3.2. Rainfall and Temperatures Recorded at Cellino Vineyard in 2023

In 2023, in Cellino vineyard, the average maximum temperature in the first two decades of April and from the second decade of May to the third of June, was considerably lower than those detected in the same decades in 2022 in Ari vineyard (Figure 1; Table S2). This decrease was particularly remarkable from the second decade of May to the second decade of June, when, for each of the four decades, the average maximum temperature values were 16.73 °C, 22.69 °C, 22.91 °C and 24.31 °C, respectively. In July, the average maximum temperature values were comparable to those detected in 2022 in Ari vineyard, with the exception of the maximum value (35.37 °C) recorded in the second decade of July.

In Cellino vineyard, the trend of the minimum average temperature was similar to that of Ari vineyard, with the exception of higher values recorded in the first decade of April and May, and in the second decade of July (Figure 1; Table S2). As recorded for the maximum, the average minimum temperature registered from the second decade of May to the first decade of June, 10.54 °C, 13.95 °C, and 14.8 °C, for each of the three decades, respectively, was lower than that detected the previous year in the same decades in Ari Vineyard (Figure 1; Table S2). However, minor differences were observed between the two vineyards on the minimum compared to maximum average temperatures.

In 2023, in the Cellino vineyard, the rainfalls from April to July were 417.3 mm. In particular, in the months of April, May, June and July, 93.8 mm, 180.5 mm, 130.3 mm, and 12.7 mm of rain fell down along 17, 16, 12, and 4 days, respectively (Table S2).

3.3. Incidence and Severity of the Disease at Ari Vineyard in 2022

3.3.1. Progression of the Disease in the Untreated Control Plants

In 2022, in Ari vineyard, the disease incidence and severity in the untreated control assessed on June 20 (BBCH 73, berries groat-sized), were 38.0% and 6.11% on leaves and 54.33% and 11.42% on bunches, respectively (Table 3). In the following assessments, the levels of incidence and severity in leaves and bunches, progressively increased until the last assessment of September 13, at harvest maturity. In the fourth assessment of August 3 (BBCH 81, beginning of ripening), incidence and severity were very high, 63.33% and 52.30% on leaves and 91.33% and 64.07% on bunches, respectively (Table 3). In the last assessment, at BBCH 89 growth stage, in the untreated control the disease was recorded on 93.0% of bunches, with a severity of 78.9%, while the incidence and severity on the leaves was 79.0% and 55.82% respectively (Table 3).

Table 3. Incidence and severity of powdery mildew on leaves and bunches of the different treatments and surveys at Ari vineyard in 2022.

Survey	Treatment	Leaves *Incidence* (%)	Leaves *Severity* (%)	Bunches *Incidence* (%)	Bunches *Severity* (%)
20/06/2022 BBCH 73	1—Sulphur *	1.67 b	0.11 b	27.67 b	4.35 b
	2—Calcium Silicate + Sulphur	0.00 b	0.00 b	12.00 c	0.39 d
	3—Silicon oxide + Iron + Sulphur	0.00 b	0.00 b	14.33 bc	0.61 d
	4—*Equisetum arvense L.* + Sulphur	0.00 b	0.00 b	22.33 bc	2.04 c
	5—Untreated control	38.00 a	6.11 a	54.33 a	11.42 a
30/06/2022 BBCH 75	1—Sulphur	9.67 b	0.56 b	30.00 b	7.35 b
	2—Calcium Silicate + Sulphur	0.00 b	0.00 b	15.33 c	1.86 c
	3—Silicon oxide + Iron + Sulphur	0.00 b	0.00 b	18.33 bc	6.05 b
	4—*Equisetum arvense L.* + Sulphur	0.00 b	0.00 b	23.67 bc	3.56 bc
	5—Untreated control	45.00 a	9.40 a	67.00 a	24.23 a
11/07/2022	1—Sulphur	16.00 b	2.37 b	34.00 b	6.48 b
	2—Calcium Silicate + Sulphur	0.00 c	0.00 c	20.33 c	3.80 b
	3—Silicon oxide + Iron + Sulphur	0.00 c	0.00 c	21.67 bc	5.33 b

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BBCH 77	4—*Equisetum arvense L.* + Sulphur	2.33 c	0.17 c	29.00 bc	5.56 b
	5—Untreated control	50.33 a	13.49 a	85.00 a	51.33 a
	1—Sulphur	23.33 b	11.95 b	37.67 b	9.39 b
	2—Calcium Silicate + Sulphur	0.00 d	0.00 d	23.33 c	6.13 b
03/08/2022	3—Silicon oxide + Iron + Sulphur	7.67 c	2.85 c	23.00 c	8.27 b
BBCH 81	4—*Equisetum arvense L.* + Sulphur	10.00 c	1.85 c	30.67 bc	7.32 b
	5—Untreated control	63.33 a	52.30 a	91.33 a	64.07 a
	1—Sulphur	32.67 b	15.15 b	40.33 b	12.77 b
	2—Calcium Silicate + Sulphur	14.33 d	1.40 d	27.33 d	8.15 c
13/09/2022	3—Silicon oxide + Iron + Sulphur	23.33 c	3.53 c	31.67 cd	9.88 bc
BBCH 89	4—*Equisetum arvense L.* + Sulphur	16.67 d	2.25 cd	35.33 bc	10.38 bc
	5—Untreated control	79.00 a	55.82 a	93.00 a	78.90 a

* Sulphur = Based sulphur formulation in water dispersible microgranules, at 80% of sulphur concentration, used in all treatments.

3.3.2. Incidence and Severity of the Disease on the Leaves of the Treatments

In the first three assessments, carried out on June 20, June 30 (BBCH 75, berries pea-sized) and July 11 (BBCH 77, berries beginning to touch), a significant decrease of disease incidence and severity on leaves in the treatment based on sulphur applications at full dose (the fungicide normally used in the vineyard towards powdery mildew), compared to the untreated control, was observed (Table 3). In the vines treated with silicates or *E. arvense* in tank mixture with reduced doses of sulphur, the leaves were generally did not show infections in the first three assessments, except for the *E. arvense* + sulphur treatment, but with percentages of incidence and severity of 2.33% and 0.17%, significantly lower compared both to those of the untreated control (50.33% e 13.49%) and of the sulphur at full dose (16.0% and 2.37%) (Table 3).

In the fourth assessment, carried out on 3 August, the leaf incidence and severity in the treatments based on silicon compounds in tank mixture with sulphur at reduced dose, were once again significantly lower compared both to those of the untreated control and of the sulphur at full dose. In particular, leaves treated with calcium silicate + sulphur did not show any disease symptoms (Table 3). In the last assessment, at the BBCH 89 growth stage, the leaf incidence and severity increased in vines treated with calcium silicate + sulphur and *E. arvense* + sulphur, with values of 14.33% and 1.4%, and 16.67% and 2.25%, respectively, with any statistically difference from each other (Table 3). These values were significantly lower than those of the untreated control (79.0% and 55.82%), the sulphur at full dose (32.67% and 15.15%), and the silicon oxide + iron + sulphur (23.33% and 3.53%). However, the percentages of incidence and severity of silicon oxide + iron + sulphur significantly differed both from those of the untreated control and of the sulphur at full dose (Table 3).

3.3.3. Incidence and Severity of the Disease on the Bunches of the Treatments

In the first three assessments (20 June, 30 June, and 11 July) the infections on the bunches progressed both in the untreated and treated plots, in which however the disease development was lower. From the first to the third assessment, the incidence of the disease on bunches showed the same statistical differences among treatments (Table 3). In particular, the lowest percentages of incidence were recorded in the calcium silicate + sulphur, which was statistically different in comparison with both the sulphur at full dose and the control. In the three assessments, the disease incidence assessed in the silicon oxide + iron + sulphur and *E. arvense* + sulphur was not statistically different either from those of the calcium silicate + sulphur or from sulphur at full dose (Table 3).

In the fourth assessment (August 3), both the calcium silicate + sulphur (23.33%) and silicon oxide + iron + sulphur (23.00%) treatments showed the lowest disease incidence, statistically different from those both of sulphur at full dose (37.67%) and of the control (91.33%). In this assessment, the incidence of the disease on the bunches in the *E. arvense* + sulphur (30.67%) differed only from the untreated control (Table 3). In the final assessment of 13 September, the lowest incidence was detected

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in the calcium silicate + sulphur (27.33%) and silicon oxide + iron + sulphur (31.67%), significantly different both compared to the sulphur at full dose (40.33%) and to the control (93.0%). However, the incidence in the calcium silicate + sulphur was also significantly different compared to that of the *E. arvense* + sulphur treatment (35.33%), which differed only from the untreated control (Table 3).

In the first assessment on 20 June, the disease severity on bunches in the calcium silicate + sulphur (0.39%) and silicon oxide + iron + sulphur (0.61%), was significantly lower than in the untreated control (11.42%), in the sulphur at full dose (4.35%), and in the *E. arvense* + sulphur (2.04%). The last two treatments significantly differed from each other and from the untreated control (Table 3). In the second assessment (June 30), the disease severity recorded in calcium silicate + sulphur (1.86%), statistically differed both from the untreated control (24.23%) and the sulphur at full dose (7.35%). The other treatments of silicon-based compounds showed different values of severity compared to the control, but not to those of the sulphur at full dose (Table 3). In the third assessment of 11 July and in the fourth assessment of 3 August, the same differences in disease severity among treatments recorded in the first two assessments were still noticeable, although not statistically. All treatments had very low percentages of disease severity, less than 6.5% and 10% in the third and fourth assessments respectively, compared to the untreated control, which showed a severity of 51.33% and 64.07%, respectively (Table 3). In the last assessment, at BBCH 89 growth stage, the percentages of disease severity on bunches showed again differences among treatments. The severity in the calcium silicate + sulphur (8.15%) differed significantly from that of sulphur at full dose (12.77%) and of the control (78.90%). The severity recorded in the silicon oxide + iron + sulphur (9.88%) and in the *E. arvense* + sulphur (10.38%) differed from that of the control, but not both from that of the calcium silicate + sulphur, and of sulphur at full dose (Table 3).

3.4. Incidence and Severity of the Disease at Cellino Vineyard in 2023

3.4.1. Progression of the Disease in the Untreated Control Plants

In the first assessment, carried out on 13 July (BBCH 75, berries pea-sized), the disease incidence and severity in bunches of the untreated control were 9.33% and 2.57%, respectively (Table 4). In the second and last assessment (August 18), at the beginning of the BBCH 89 growth stage, the incidence of disease on the bunch increased to 47.33%, while the severity was 13.87% (Table 4). In the untreated control, no leaf symptoms were detected throughout the entire growing season (Table 4).

Table 4. Incidence and severity of powdery mildew on leaves and bunches of the different treatments and surveys at Cellino vineyard in 2023.

Survey	Treatment	Leaves *Incidence* (%)	Leaves *Severity* (%)	Bunches *Incidence* (%)	Bunches *Severity* (%)
13/07/2023 BBCH 75	1—Sulphur *	/	/	4.33 b	1.20 b
	2—Calcium Silicate + Sulphur	/	/	0.33 c	0.05 c
	3—*Equisetum arvense L.* + Sulphur	/	/	1.67 c	0.13 c
	4—Untreated control	/	/	9.33 a	2.57 a
18/08/2023 BBCH 89	1—Sulphur	/	/	22.00 b	4.82 b
	2—Calcium Silicate + Sulphur	/	/	7.00 c	0.82 c
	3—*Equisetum arvense L.* + Sulphur	/	/	11.00 c	1.72 c
	4—Untreated control	/	/	47.33 a	13.87a

* Sulphur = Based sulphur liquid formulation as suspension, at 40% of sulphur concentration, used in all treatments.

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3.4.2. Incidence and Severity on the Leaves and Bunches of the Treatments

Foliar applications with silicon-based products were effective, as recorded in both assessments (Table 4). The incidence and severity of the disease on the bunches in the calcium silicate + sulphur were 0.33% and 0.05% in the first assessment and 7.0% and 0.82% in the assessment carried out at harvest maturity. In the silicon oxide + iron + sulphur, the disease incidence on bunches increased from 1.67% (first assessment) to 11.0% (second assessment), whereas the severity from 0.13% to 1.72%. In both assessments these values were significantly lower than those detected in the sulphur at full dose and in the untreated control. The sulphur at full dose had percentages of incidence and severity on bunches of 4.33% and 1.20% in the first assessment, and 22.0% and 4.82% in the second assessment, all significantly lower than those of the untreated control (Table 4).

No disease symptoms were ever detected on the leaves in any treatment during the entire season (Table 4).

3.5. Effect of the Leaf Applications on Yield Quantity and Qualitative Parameters of the Berries

3.5.1. Ari Vineyard

In the Ari vineyard, in 2022, vines treated with silicon-based products in tank mixture with sulphur achieved the greatest yield per plant, significantly higher than both those recorded in the untreated control (4.75 Kg vine^{-1}) and in the sulphur at full dose (14.40 Kg vine^{-1}) (Table 5). The yield collected from the 3 treatments consisting of silicon-based products did not differ statistically from each other, and were not dissimilar to the average yield per plant recorded in the last 10 years, about equal to 16.2 Kg vine^{-1} (Table 5). The amount of yield from the vines treated with the calcium silicate + sulphur was 17.45 Kg vine^{-1}. This yield was higher than that of the average of the last 10 years, of the silicon oxide + iron + sulphur, and of *E. arvense* + sulphur, both of which had values very close to the last-year average ones (Table 5).

The soluble solids recorded in the calcium silicate + sulphur (19.03 g L^{-1}) and in the *E. arvense* + sulphur (19.13 g L^{-1}) were significantly higher both than those of the untreated control (17.93 g L^{-1}) and of the sulphur at full dose (16.67 g L^{-1}). In such two treatments the total acidity levels were lower than those of the untreated control and the sulphur at full dose (Table 5).

The soluble solids found in the bunch of vines treated with silicon oxide + iron + sulphur (18.53 g L^{-1}) statistically differed from those of sulphur at full dose treatment, but not from those of the control. However, in silicon oxide + iron + sulphur and in the others two treatments consisting of silicon-based products, the pH and total acidity were significantly different compared to those of the other treatments (Table 5).

In the three treatments based on silicon-based products + sulphur, a trend of an increased seed and berry weight was detected. In the treatments based on calcium silicate + sulphur and *E. arvense* + sulphur, the average berry weight (2.6 g) was significantly higher than that of the untreated control and of the sulphur at full dose (2.4 g). In the silicon oxide + iron + sulphur the berry weight (2.5 g) did not differ from that of the other treatments (Table 5).

Table 5. Mean yield and quality parameters of the berries from the vines of the different treatments at Ari vineyard in 2022.

Treatment	Yield * (Kg vine^{-1})	Soluble solids (° Brix)	pH	Total acidity (g L^{-1})	Grape seed weight (g)	Grape berry weight (g)
Sulphur **	14.40 b	16.67 c	3.29 b	7.10 a	0.4 a	2.4 b
Calcium Silicate + Sulphur	17.45 a	19.03 a	3.59 a	4.90 b	0.5 a	2.6 a
Silicon oxide + Iron + Sulphur	16.36 a	18.53 ab	3.53 a	5.17 b	0.5 a	2.5 ab
Equisetum arvense L. + Sulphur	15.79 a	19.13 a	3.55 a	5.27 b	0.5 a	2.6 a
Untreated control	4.75 c	17.93 b	3.35 b	6.30 a	0.4 a	2.4 b

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* The average yield per plant recorded in the vineyard in the last 10 years was equal to 16.20 Kg vine^{-1}. ** Sulphur = Based sulphur formulation in water dispersible microgranules, at 80% of sulphur concentration, used in all treatments.

3.5.2. Cellino Vineyard

In the Cellino vineyard, in 2023, the average yield per plant of the different treatments did not differ from each other, except for those of the untreated control (1.44 Kg vine^{-1}) (Table 6). The average yield per plant of the calcium silicate + sulphur (1.86 Kg vine^{-1}) and Equisetum arvense + sulphur (1.87 Kg vine^{-1}) was higher but not statistically than those of the sulphur at full dose (1.63 Kg vine^{-1}) (Table 6). Similarly, in the treatments consisting of silicon-based products + sulphur, a trend to higher soluble solids, pH, and berry weight, and to lower total acidity compared to those of the untreated control and sulphur at full dose treatments, were detected (Table 6).

Table 6. Mean yield and quality parameters of the berries from the vines of the different treatments at Cellino vineyard in 2023.

Treatment	Yield * (Kg vine^{-1})	Soluble solids (° Brix)	pH	Total acidity (g L^{-1})	Grape seed weight (g)	Grape berry weight (g)
Sulphur *	1.63 a	16.25 a	2.63 a	17.87 a	0.3 a	1.28 a
Calcium Silicate + Sulphur	1.86 a	17.45 a	2.67 a	16.10 a	0.3 a	1.33 a
Equisetum arvense L. + Sulphur	1.87 a	17.12 a	2.71 a	16.27 a	0.3 a	1.34 a
Untreated control	1.44 b	16.22 a	2.60 a	17.47 a	0.3 a	1.26 a

* Sulphur = Based sulphur liquid formulation as suspension, at 40% of sulphur concentration, used in all treatments.

4. Discussion

The development of control strategies against plant diseases careful to minimize unfavorable effects on human health and the environment, really took off since the early 1970s, after the widespread of new active synthetic fungicides [92]. Their large use soon highlighted several critical issues, consisting of a decreased activity of important classes of such fungicides due to the selection of resistant pathogen strains; the occurrence of new diseases and pests because of the elimination of antagonists by the side effects of fungicides application; the risk to the human health caused by mutagenic, teratogenic, and carcinogenic effects [92,93]. Increasingly safe, efficient, and respectful strategies have been developed for the protection of crops in integrated pest management (IPM) or biological control programs. In these last years, the ever-increasing focus on the sustainability of agricultural production led to significant actions of the European Commission, as resolutions for which hazardous substances were not only limited—as foreseen by IPM programs—but included in specific lists as candidate for substitution and banned [25].

The present work was therefore developed within a sustainable control strategy and aimed to both the activity assessment of different silicon-based products and the potential reduction of sulphur dose towards grapevine powdery mildew. Although sulphur cannot be considered as very dangerous product, it is, however, responsible for environmental damages when accumulated in excess in the soil, and for problems to the health of agricultural workers [26,29]. The reduction of sulphur in the control of powdery mildew was studied by verifying the activity of doses of sulphur reduced up to 50% and distributed in tank mixture with silicate or *E. arvense L.* based products.

The effectiveness trials were carried out in two growing seasons characterized by different climatic conditions with different conditions of disease pressure. In the Ari vineyard, in 2022, the growing season was particularly favorable to powdery mildew, with low rainfall and optimal temperatures for the pathogen throughout the period of higher susceptibility of the plant to infections [1]. In this condition, the infection on leaves and bunches of the untreated control, already very high in June, affected almost all of the plants at harvest, with severity of 80% on bunches and more than 50% on leaves.

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Despite this high disease pressure, from the first to the third survey, at BBCH 73 and BBCH 77 stage, the leaves in the three treatments with reduced doses of sulphur and silicon-based products, were just about without symptoms. The activity of the three mixtures was very high even in the fourth survey, at BBCH 81 stage, when the symptoms on the leaves were still absent in the calcium silicate + sulphur treatment, and at reduced incidence and severity in the other two treatments. Interestingly, in such treatments the symptoms on the leaves appeared with greater incidence and severity only in the survey at harvest, after the end of the applications at BBCH 81 stage.

However, leaf infections were significantly lower than both the untreated control and the sulphur at full dose (the farm strategy) treatments, highlighting the effectiveness of mixtures of sulphur and silicon-based products in reducing powdery mildew leaf symptoms. After veraison, the bunches showed a strong ontogenetic resistance to infections, whereas the leaves are still infectible, with some susceptibility decreasing to infections due to aging [1,94]. Studies reported the activity of *A. quisqualis* or sweet orange oil, carried out pre- and post-harvest, before leaf fall and/or at BBCH 01, beginning of bud swelling stage, applying mineral oils, sulfur, and sweet orange oil [36]. These applications can also be carried out with synthetic fungicides, which however can be avoided by using organic or natural products [34]. Eradicative applications aimed at better managing spring infections in the following season, by reducing the primary inoculum, the chasmothecia, and therefore delaying and slowing down the disease [34,37].

Our results confirmed the susceptibility of the leaves from veraison to harvest, clearly noticeable in the untreated control, and indicated a possible use of mixtures of sulphur and silicon-based products, not only against spring ascosporic infections, but also in the eradicative treatments, carried out before and after the harvest against chasmothecia. However, low inoculum levels do not require eradicative applications, whose implementation is dependent on the monitoring of chasmothecia in the leaf [37].

In the Ari vineyard, the applications of reduced doses of sulphur and silicon-based products strongly reduced infections on the bunch, compared to what observed in the untreated control. This activity was particularly notable in the calcium silicate + sulphur treatment, where the incidence and severity of the disease on the bunch at harvest were significantly lower than both those of the control and sulphur at full dose treatments. In the other two treatments consisting of silicon + sulphur based products, the disease incidence and severity on the bunches always tended to be lower, in some cases significantly, than those of the sulphur at full dose.

In 2023, in the Cellino vineyard, the epidemic course of the disease was strongly delayed and slowed down by the heavy rainfalls in May, and until mid-June, and by less favorable temperatures occurring in the period of greatest susceptibility of the plant to infections [1]. Therefore, in the untreated control, disease incidence and severity on the bunch, that were low at BBCH 73 stage, at harvest was less than 50% and 15% respectively, while the leaves of all treated plots were did not show any symptoms. At low disease pressure, the applications of the two mixtures of sulphur at reduced dose and silicon-based products were therefore very effective, to an even greater extent than what was noticed in conditions favorable to powdery mildew. Although not significantly, the activity of the calcium silicate + sulphur always proved to be generally better, as noticed in 2022. In any case, the activity of the two mixtures consisting of silicon + sulphur based products was always significantly higher than that found in the sulphur at full dose.

The satisfactory effectiveness of the silicon + sulphur based mixtures is probably due to the possible combined effects of the different mechanisms of action of the mixture components. The damage of fungal cells, the impairment of respiratory processes, the protein denaturation and the formation of toxic compound induced by sulphur could be further improved by the reinforcement of the cell wall and the induction of plant resistance through the action of silicon-based products [66,90,91]. The combination of the different mechanisms of action could therefore be the reason of the superior effectiveness of these mixtures in the control of powdery mildew, compared to what was found in the few studies carried out on vines with potassium silicate, which did not show satisfactory effects in the presence of high disease pressure [57,59]. However, the effectiveness of silicates and *E.*

arvense is in line with the results obtained on different crops with foliar applications of other silicates or silicic acid [54].

In the Ari vineyard, in the 2022 growing season, despite losses caused by the infection, the yield assessed in plants treated with silicon-based products, calcium silicate + sulphur in particular, was not lower than the average yield of the last ten years. The yield increasing, also observed in the higher grape berry weights, are in agreement with the results obtained with silicon-based products in different crops, including vines [54]. Foliar applications of potassium silicate on vines of the cv. Flame seedless were effective in promoting growth, as noted by higher total surface area and chlorophyll content, uptake of macro and microelements, and fruit yield [95].

However, similar applications carried out on the cv. Bacchus did not have the same effects on yield [59]. More consistent results on yield increases were noticed with foliar applications of silicic acid on Bangalore blue grapes, with higher bunch number and weight yield per vine, along with increases in growth parameters such as cane length, leaf area and total chlorophyll content [96]. Similar results with foliar applications of silicic acid were obtained in vines of cv. Thompson seedless, with greater berry length and diameter, and increases in bunch weight [97]. The increases in yield quantity due to these foliar applications was related to the effect of silicon both on growth processes and the increase in root growth, with an increased uptake of nutrients, and consequently of the yield [62,66,98].

In the sulphur at full dose treatment, the yield per plant was higher than the one of the control, which was very low because of the high incidence of the disease on bunches. Nevertheless, the yield of sulphur at full dose was lower than both the average yield of the last ten years and that of the treatments with silicon-based products. The low yield of the farm treatment (sulphur at full dose) was probably linked to symptoms of phytotoxicity observed on the leaves.

In the Ari vineyard, the content of soluble solids in healthy bunches of the three silicon + sulphur treatments was higher than that of healthy bunches of both the untreated control and the sulphur at full dose, and in particular in the calcium + sulphur and *E. arvense L.* + sulphur treatments. In these three treatments lower levels of total acidity were also recorded. Foliar applications of silicon-based products resulted in improvements in yield quality in different crops [54]. However, the silicon applications on vines provided contrasting results. Foliar applications of potassium silicate did not show effects on the yield quality, while applications of SiO_2 determined significant decreases in tartaric acid in two cultivars, and sugar increasing (just as trend) in one of the two cultivars [59,99,100]. On the contrary, other cultivars treated with SiO_2 did showed increases in anthocyanidin and proline contents only, hypothesizing that berry changes induced by silicon applications could depend on the cultivar [100]. The increasing of the main berry quality parameters due to foliar applications of silicic acid were also demonstrated in other studies [95–97].

In the present work, in 2023, in the Cellino vineyard, foliar applications of mixtures of sulphur and silicon-based products were effective against powdery mildew infections, but without any effect on the quantity and quality of yield. According to the results of Sut et al. (2022) [100], the cv. Pecorino might be less sensitive to the effects of silicon on yield and berry composition, compared to cv. Trebbiano d'Abruzzo, where these effects were evident in the 2022 season. Different factors may have been involved in the lack of effects on yield and berry composition in the cv. Pecorino vineyard, such as the 2023 seasonal course, which was not favorable for the plant physiological processes, particularly in the first part of the season characterized by continuous rainfall and low temperatures. Furthermore, it might not be excluded that young plants in the cv. Pecorino vineyard (4 years old), are less susceptible than adult plants to the effects of silicon on the quantity and quality of yield.

5. Conclusions

The results of the present study are in line with those obtained using silicon-based products in the control of diseases and in the increase of quality parameters of various crops in different pathosystems. The effectiveness towards powdery mildew of the mixtures consisting of sulphur at reduced-dose and silicon-based products, noticed in both years of trials, was higher than that of potassium silicate shown by other authors. The activity of these mixtures may depended on the

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combined mechanisms of actions of the different components. Therefore, further studies are needed to investigate the effectiveness of the silicon-based products without addition of sulphur, in growth stages at lower risk of infection, or applying the products in combination with reduced doses of sulphur in the stages at higher susceptibility to the disease, as carried out in the present study, to a better evaluation of synergistic effects. Furthermore, the strong activity of silicon-based products on leaves suggests their use also in eradicative treatments, carried out before and after harvest, in order to reduce the primary inoculum in the following season.

The positive effects on the quantity and quality parameters of the yield triggered by the applications of these products in 2022 in the Ari vineyard, were not observed in 2023 in the Cellino vineyard. The unfavorable seasonal outcome, the young age of the plants, a less susceptibility of the cultivar to silicon-based applications, might have been some of the factors involved in the lack of activity of such products. Further studies could therefore clarify the effects of applications on the yield quantity and quality, in different cultivars, age of plant and growing seasons. In conclusion, further studies will clarify how the silicon-based products can be usefully included in the powdery mildew control strategies, as alternative to synthetic fungicides.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Table S1: Rainfall and temperature in the 2022 growing season at Ari vineyard until the end of the period at high risk of powdery mildew infections; Table S2: Rainfall and temperature in the 2023 growing season at Cellino vineyard until the end of the period at high risk of powdery mildew infections.

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