Journal of Animal & Plant Sciences, 32(4): 2022, Page: 1018-1027
ISSN (print): 1018-7081; ISSN (online): 2309-8694
http://doi.org/10.36899/JAPS.2022.4.0505

EFFECTS OF ECO-FRIENDLY TREATMENT PROGRAMS ON POWDERY MILDEW (*ERYSIPHE CORYLACEARUM* BRAUN & TAKAM) IN HAZELNUT

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ABSTRACT

The efficacies of tebuconazole plus azoxystrobin/*Reynoutria* spp. extract, sulfur (S)/*Reynoutria* spp. extract, *Reynoutria* spp. Extract/S, KH_2PO_4 plus S, Na_2SiO_3 (moduli m2 and m3) plus S, and $NaHCO_3$ against powdery mildew caused by *Erysiphe corylacearum* were investigated on the hazelnut cultivars Kara and Sarı. The study was carried out during the 2019 vegetation season in a hazelnut orchard in the Akçakoca district of Düzce, Turkey. The experiment was established in a randomized complete block design with three replications, and twelve plants in two plantings (ocaks) were used for each parcel. The data on different parameters were analyzed using Minitab® Statistical Software Release 19, and the mean values were compared by the Tukey multiple range test ($P \leq 0.05$). The alternation treatment program of tebuconazole plus azoxystrobin/*Reynoutria* spp. extract exhibited the highest efficacy (93.6%) against disease on the leaves of the Kara cultivar, followed by the other treatment programs with efficacies between 91.8% and 79.6%. On the leaves of the Sarı cultivar, the alternation treatment program tebuconazole plus azoxystrobin/*Reynoutria* spp. extract, with 96.2%, and the mixing treatment program KH_2PO_4 plus S, with 94.9%, showed the highest effectiveness, followed by the application programs Na_2SiO_3 (m3) plus S, Na_2SiO_3 (m2) plus S, and S/*Reynoutria* spp. extract, with efficacies of 92.5%, 92.2%, and 91.3%, respectively. Na_2SiO_3 (m3) plus S (100%), S/*Reynoutria* spp. extract (94.6%), and Na_2SiO_3 (m2) plus S (93.9%) were most effective against powdery mildew on the fruit clusters of the Kara cultivar, and Na_2SiO_3 (m2) plus S (98.7%), KH_2PO_4 plus S (97.8%), and Na_2SiO_3 (m3) plus S (94.9%) had the highest efficacies on the fruit clusters of the Sarı cultivar, followed by tebuconazole plus azoxystrobin/*Reynoutria* spp. extract and KH_2PO_4 plus S on the Kara cultivar, and tebuconazole plus azoxystrobin/*Reynoutria* spp. extract and S/*Reynoutria* spp. extract on the Sarı cultivar. *Reynoutria* spp. extract/S showed moderate efficacies between 65.0% and 79.6% against powdery mildew on the leaves and fruit clusters. While $NaHCO_3$ had moderate or high efficacies on the leaves of both cultivars (80.4% on the Kara cultivar and 57.9% on the Sarı cultivar), its effects were the lowest than those of other all treatment programs on the fruit clusters. The treatment programs had no phytotoxic effects on the leaves or fruit clusters of either hazelnut cultivar. The present study has demonstrated that all spraying programs except $NaHCO_3$ could be used effectively as eco-friendly spraying programs against powdery mildew in hazelnut.

Keywords: Hazelnut, powdery mildew, *Erysiphe corylacearum*, eco-friendly treatment programs

Published first online January 06. 2022 Published final July 30. 2022

INTRODUCTION

Turkey has favorable climatic conditions for hazelnut growing, and about 400,000 farm families in 39 provinces are involved in hazelnut agriculture, particularly in the eastern and western parts of the Black Sea Region (Erdoğan, 2018). In addition to inadequate cultural practices, such as a lack of pruning in accordance with good technique, leaving an excessive number of main plants (15–20) per ocak insufficient weed control, and failure to do analysis-based fertilization, adverse weather conditions affect hazelnut yield and quality in some years.

Furthermore, diseases such as powdery mildew (*Erysiphe corylacearum*, *Phyllactinia guttata*), gray rot (*Botrytis cinerea*), root rots (*Dematophora necatrix*, *Armillaria mellea*), hazelnut bacterial blight (*Xanthomonas arboricola* pv. *corylina*), and apple mosaic virus (ApMV) cause further reductions in hazelnut yield and quality (Kara, 2012; Sezer and Dolar, 2012; Sezer *et al*., 2017). Recently, *E. corylacearum* and *P. guttata* have caused powdery mildew epidemics in the Black Sea Region that led to considerable quality and yield losses in hazelnut production (Altınyay, 1979; Altın, 2017; Sezer *et al*., 2017). A survey of hazelnut diseases in the Black Sea Region between 1988 and 1990 demonstrated that the disease severity of *P. guttata* (syn. *P. suffulta*) was very high (81.7% in 1989) in hazelnut-growing areas (Yürüt *et al*., 1994). In Düzce, where this study was conducted, it was reported that the prevalence and disease severity of hazelnut powdery mildew were 100% and 35.01%, respectively (Altın, 2017).

In recent years, farmers have used registered synthetic fungicides to control powdery mildew in hazelnut, but the desired success in disease control could not be achieved. The success of the disease control was reduced because the farmers failed to place enough importance on cultural practices such as weed control, pruning, leaving an appropriate number of the plants in each ocak (5–6 main plants). The main reason for the lack of success in the fight against powdery mildew in hazelnuts, however, is that an effective spraying program has not been developed to date. Consequently, the farmers tend to use excessive and inappropriate fungicides against powdery mildew in hazelnuts during epidemic years, which can cause problems such as the development of fungicide resistance in the pathogen, deterioration of ecological balance, and suppression of microbial biodiversity. Therefore, in recent years, there have been several studies on the efficacy on hazelnut diseases of environmentally friendly compounds, such as biological agents, plant extracts and oils, sodium and potassium salts, and silicates, in addition to synthetic fungicides (Altın and Gülcü, 2018; Sezer, 2018; Türkkan *et al*., 2018; Sezer *et al*., 2019).

Fungicides, biological agents, and some alternative substances have been tested individually against powdery mildew in those studies, but combinations such as alternations or mixtures of them have never been studied. Moreover, cultural practices (fertilization, pruning, planting methods, weed control, or the number of the main plants per planting) were not addressed in those studies. The use of fungicides without adequate cultural practices in hazelnut orchard is insufficient to control powdery mildew disease. As a result of that, the results of the scientific studies on the control of powdery mildew on hazelnut do not provide the desired results under farm conditions. The results of the present study have provided options for more effective and more eco-friendly fungicide programs consisting of combinations or mixtures of silicates, sodium and potassium salts, plant extracts, sulfur, and fungicides, together with cultural practices, to control powdery mildew.

MATERIALS AND METHODS

Fungal Inoculum: *Erysiphe corylacearum*, which has caused powdery mildew infections in previous years in the trial orchard, was the fungal material of the study.

Plant Material: The study was performed during the 2019 growing season in a forty-year-old hazelnut orchard comprising 500 plantings per hectare at 4.5 x 4.5 m intervals in the Akçakoca district of Düzce Province in Turkey. The plant material of the experiment included the Kara and Sarı (syn. Mincane) hazelnut cultivars, which produce the most common commercial Turkish hazelnut (*Corylus avellana* L.) in the region. Sarı hazelnut received Geographical Indication registration as "Akçakoca Sarı Fındığı" in 2019.

Cultural Practices in the Trial Orchard: In Turkey, hazelnuts traditionally have been grown in clumps or planting groups called "ocak", consisting of multiple plants in a circle about 1.2 m in diameter, and each plant is modified as a leader (Erdoğan, 2018). In autumn, the number of main plants in each planting is reduced from 14–18 to six, which is an ideal number.

After winter pruning, which is performed in November for better aeration and exposure to sunlight, a spray application of a Bordeaux mixture (1.5%) against fungal and bacterial infections is done. The hazelnut gardens receive soil fertilization of 26% ammonium nitrate (700 g per ocak) in March and May, foliar fertilization of amino acid plus trace elements in May, and potassium plus trace elements in June.

Test Chemicals: The effectiveness of spraying programs created with chemical fungicides and eco-friendly substances and a plant extract against powdery mildew in hazelnut were investigated. Some characteristics of the eco-friendly substances and chemical fungicides used in the treatment programs are given in Table 1.

Table 1. Characteristics of eco-friendly substances and chemical fungicides.

Commercial name	*Active ingredients*	*Rate of active ingredients (%)*	*Form[3]*	*Dosage (%)*	*Usage dosage with the atomizer (%)*	*Manufacturing firm*
Regalia	*Reynoutria spp. Extract*	*224.6 g*	*SC*	*0.1*	*0.32*	*Sygenta*
Azimut 320 SC	*Tebuconazole + Azoxystrobin*	*200 g/L + 120 g/L*	*SC*	*125 ml/da*	*400 g/da*	*Adama*
Heliosoufre	*Mic. Sulfur (S)[4]*	*700 g/L*	*SC*	*0.3*	*0.96*	*Boyut Dış Ticaret LTD.*
Potassium di-hydrogen phosphate	*KH_2PO_4*	*99.5*	*SC*	*1.5*	*4.8*	*Carlo Erba*
Water glass m2[1]	*$Na_2O + SiO_2$*	*28.5–31 + 67.0–70.5*	*SC*	*1.0*	*3.2*	*Tunçtaş A.Ş.*
Water glass m3[2]	*$Na_2O + SiO_2$*	*21.5–25 + 72.0–76.5*	*SC*	*1.0*	*3.2*	*Tunçtaş A.Ş.*
Baking powder	*$NaCO_3$*	*99–100.5*	*WP*	*1.5*	*4.8*	*Carlo Erba*

[1] m2: Modulus 2 contains 2-molecule SiO_2; [2] m3: Modulus 3 contains 3-molecule SiO_2; [3]Form: Formulation; [4]Mic.: Micronized sulfur

To provide a homogeneous spread of sodium bicarbonate ($NaHCO_3$) onto the leaf and fruit cluster surfaces of the plant with an environmentally friendly chemical substance, soft soap (KOH and vegetable oil) was added to water at a dosage of 0.12% (Yıldırım *et al*., 2002).

Sulfur and *Reynoutria* spp. extract are not registered in Turkey against diseases of hazelnut, but they are registered against powdery mildew diseases in tomatoes and grapes and in some *Cucurbitaceae* and *Solanaceae* plants. A chemical fungicide (Azimut 320 SC) that includes the active ingredients tebuconazole and azoxystrobin is registered against powdery mildew in hazelnuts.

The sprayings were made with a knapsack atomizer, the brand and specifications of which are given below, and the application doses were calculated with the following formula:

$$D = \frac{v\,d}{V} \qquad (1)$$

D is dosage in atomizer (%); d is dosage in ordinary atomizer (%); v is medicated water volume in ordinary atomizer (80 L/da); V is medicated water volume in atomizer (25 L/da).

Spraying Programs: The trials were conducted on two different hazelnut cultivars, Kara and Sarı. The treatment programs with test chemicals were initiated on April 22, 2019, during the BBCH11 period (Orlandi *et al*., 2019), when the first true leaves appeared (the abbreviation BBCH derives from Biologische Bundesanstalt, Bundessortenamt and CHemical industry). The second and third spraying procedures were performed on May 09, 2019 and May 26, 2019, respectively.

The spraying programs with test chemicals are given in Table 2. Programs numbered 1, 2, and 6 were alternate spraying programs, whereas programs numbered 3, 4, and 5 were mixed spraying programs comprising two different chemical compounds. *Reynoutria* spp. extract was included as an alternative to sulfur in the systemic fungicide-sulfur alternation program, which is frequently used in the control of powdery mildew diseases (Program 1). The alternation programs of sulfur and *Reynoutria* spp. extract (Program 2) and *Reynoutria* spp. extract and sulfur (Program 6) were tested for the first time in this study. Programs 4, 5, and 7 had been tested previously against powdery mildew in grapes (Yıldırım *et al*., 2002; Yıldırım and Dardeniz, 2010). However, unlike in previous studies, two moduli of sodium silicate (Na_2SiO_3) with different Na_2O and SiO_2 contents were used (Tables 1, 2). Each treatment was applied to the plantings at the rate of 250 L of medicated water per hectare (0.5 L/planting) by a Stihl SR420 Mist Blower knapsack atomizer with a 2.60 kW (3.50 hp) motor power and a 13 L volume tank.

Table 2. Spraying programs on hazelnut orchards in 2019.

Program no	*First Spray[1]*	*Second spray[2]*	*Third spray[3]*
1	*Tebuconazole + Azoxystrobin*	*Reynoutria spp. extract*	*Tebuconazole + Azoxystrobin*
2	*S*	*Reynoutria spp. extract*	*S*
3	*KH_2PO_4 + S*	*KH_2PO_4 + S*	*KH_2PO_4 + S*
4	*Na_2SiO_3 (m2) + S*	*Na_2SiO_3 (m2) + S*	*Na_2SiO_3 (m2) + S*
5	*Na_2SiO_3 (m3) + S*	*Na_2SiO_3 (m3) + S*	*Na_2SiO_3 (m3) + S*
6	*Reynoutria spp. extract*	*S*	*Reynoutria spp. extract*
7	*$NaHCO_3$*	*$NaHCO_3$*	*$NaHCO_3$*
8	*Control (pesticide-free)*	*Control (pesticide-free)*	*Control (pesticide-free)*

[1]date of application April 22, 2019; [2]date of application May 09, 2019; [3]date of application May 26, 2019.

The experiment was established as a randomized complete block design with three replications, and twelve plants (two ocaks) were used for each variant. The disease evaluations on leaves and fruit clusters were made 30 days after the final application. The disease severity (DS) evaluation on the leaves was performed on 20 leaves per ocak (40 leaves in total in each parcel). The two lowest leaves of the main plants in four directions of each ocak were excluded.

Leaf infection was evaluated on the basis of a scale of 0–4 (TAGEM, 2016), wherein 0 = no colony on the leaf (n_0); 1 = 1–10% colonies per leaf (n_1); 2 = 11–30% colonies per leaf (n_2); 3 = 31–60% colonies per leaf (n_3); and 4 = more than 60% colonies per leaf (n_4).

Fruit cluster infection was evaluated on the basis of a scale of 0–1 (TAGEM, 2016) on 15 randomly selected fruit clusters from each planting group (30 fruit clusters in total from each plot), wherein 0 = no disease and 1 = disease presence.

The disease severity (%) was calculated by using the formula of Townsend and Heuberger (1943), and the efficacy of the treatment programs was evaluated by Abbott's formula (Abbott, 1925).

$$P = \sum[(n.v).100/x.N] \qquad (2)$$

P is disease severity; n is the number of leaves in scale value in each parcel; v is scale value; x is the highest scale value; and N is the total number of leaves.

$$\text{Efficacy (\%)} = (X - Y)/X \cdot 100 \qquad (3)$$

X is disease severity in the control and Y is the disease severity in the treatment.

Statistical Analysis: The resulting data were assessed with Minitab® Statistical Software Release 19. The mean values were compared by the Tukey multiple range test at $P \leq 0.05$.

RESULTS AND DISCUSSION

The efficacy of treatment programs applied as mixtures, alternations, or alone against powdery mildew caused by *E. corylacearum* in two hazelnut cultivars, Kara and Sarı, was investigated in this study.

Disease severity in interactions between the hazelnut cultivars, organs (leaves and fruit clusters), spraying programs, cultivars*organs (leaves or fruit clusters), cultivars*spraying programs, organs*spraying programs, and cultivars*organs*spraying programs were statistically different ($P \leq 0.05$). The Kara cultivar was statistically more susceptible to the disease than was the Sarı cultivar ($P \leq 0.05$). The fruit clusters of the Kara cultivar were more susceptible to powdery mildew than were those of the Sarı cultivar, while disease susceptibilities on the leaves were found to be similar in both cultivars ($P \leq 0.05$).

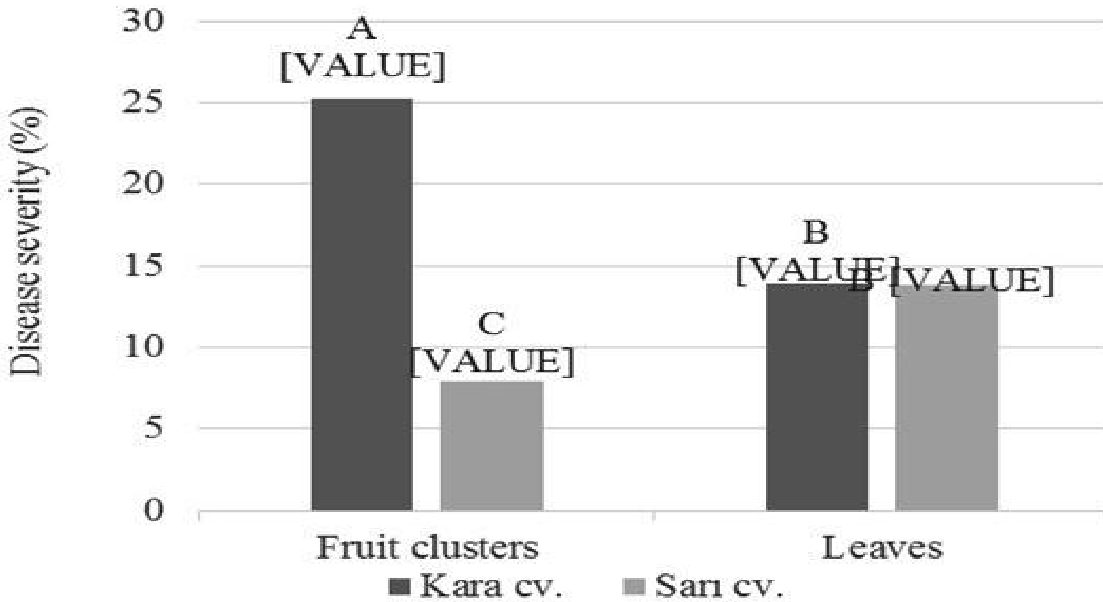

Figure 1. Disease severity in organs of hazelnut cultivars (P≤ 0.05)

In the control parcels, disease severities in the fruit clusters of the Sarı cultivar were observed to be lower than those in the Kara cultivar, but severities in the leaves were similar. Disease severity was 58.33% in leaves and 70% in fruit bunches in the Kara cultivar, while it was 55.42% and 25.26%, respectively, in the Sarı cultivar (Table 3). On the other hand, disease severity in the leaves and the fruit clusters of both hazelnut cultivars treated with the spraying program was found to be significantly lower than in the control ($P \leq 0.05$), with the exception of those treated with $NaHCO_3$ (Table 3). The disease severities in the fruit clusters of hazelnut cultivars Kara and Sarı in the parcels treated with $NaHCO_3$ were similar to those in the control parcels. The disease severity actually was higher on fruit clusters of the Kara cultivar in the $NaHCO_3$ (Program 1) treatment than in the control.

Disease severities were quite low on the leaves of the Kara cultivar that were treated with spraying Program 1 (tebuconazole plus azoxystrobin/*Reynoutria* spp. extract) and on the Sarı cultivar treated with Programs 1 and 3 (KH_2PO_4 + S), with 3.75%, 2.08%, and 2.75%, respectively (Table 3).

Disease severities on the leaves of the Kara cultivar treated with spraying Program 1 and of the Sarı cultivar, with spraying Programs 1 and 3 with 3.75%, 2.08%, and 2.75%, respectively, were quite low and were followed by the disease severities on leaves of the Kara cultivar treated with KH_2PO_4 plus S (5.62%) and Na_2SiO_3 (m3) plus S (4.79%) and of Sarı cultivar treated with S/*Reynoutria* spp. extract (4.79%) and Na_2SiO_3 (m3) plus S (4.37%). On the fruit clusters, however, similar disease severities ($P \leq 0.05$) were determined in the Kara cultivar treated with Programs 4 and 5, and in the Sarı cultivar treated with programs 1, 2, 3, 4, and 5 (Table 3).

There was no significant difference in the effectiveness of spraying programs against powdery mildew relative to hazelnut varieties ($P \leq 0.05$). For that reason, the effectiveness of spraying programs against powdery mildew was evaluated separately on the cultivars. The effectiveness of the programs against powdery mildew on the leaves and fruit clusters of the Kara hazelnut cultivar are presented in Table 4. The alternating program of tebuconazole plus azoxystrobin/*Reynoutria* spp. (Program 1) exhibited the highest effectiveness against powdery mildew on leaves of the Kara hazelnut cultivar, while other spraying programs displayed similarly high efficacies ($P \leq 0.05$).

Table 3. Disease severity on leaves and fruit clusters of the hazelnut cultivars.

Program No.	Application program	Kara cultivar				Sarı cultivar			
		On leaf (%) Disease severity[1]		On fruit cluster (%) Disease severity[1]		On leaf (%) Disease severity[1]		On fruit cluster (%) Disease severity[1]	
1	Tebuconazole + azoxystrobin /*Reynoutria* spp. extract	3.75	F	7.7	CDEF	2.08	F	1.84	F
2	S/*Reynoutria* spp. extract	6.87	CDEF	4.4	DEF	4.79	DEF	2.96	F
3	KH_2PO_4 + S	5.62	DEF	13.3	CDEF	2.71	F	0.36	F
4	Na_2SiO_3 (m2) + S	8.33	CDEF	3.3	F	4.17	EF	0.36	F
5	Na_2SiO_3 (m3) + S	4.79	DEF	0.0	F	4.37	DEF	1.48	F
6	*Reynoutria* spp. Extract/S	11.88	CDEF	23.3	CD	14.17	CDEF	8.14	CDEF
7	$NaHCO_3$	11.46	CDEF	80.0	A	22.92	CDE	23.32	CD
8	Control (pesticide-free)	58.33	B	70.0	AB	55.42	B	25.26	C

[1]Values are the mean of three replicates, and means that do not share a letter are significantly different, according to the Tukey Pairwise Comparisons test at $P \leq 0.05$.

Table 4. Effectiveness of the treatment programs against powdery mildew on Kara cultivar.

Program no	*Treatment programs*	*On the leaf (%)*		*On the fruit cluster (%)*	
		Efficacy[1]		*Efficacy[1]*	
1	*Tebuconazole + Azoxystrobin/Reynoutria spp. Extract*	*93.6*	*A*	*87.5*	*AB*
2	*S/Reynoutria spp. extract*	*88.3*	*AB*	*94.6*	*A*
3	*KH_2PO_4 + S*	*90.3*	*AB*	*76.6*	*AB*
4	*Na_2SiO_3 (m2) + S*	*85.7*	*AB*	*93.9*	*A*
5	*Na_2SiO_3 (m3) + S*	*91.8*	*AB*	*100*	*A*
6	*Reynoutria spp.* extract*/S*	*79.6*	*AB*	*65.5*	*B*
7	*$NaHCO_3$*	*80.4*	*AB*	*2.8*	*C*

[1]Values are the mean of three replicates, and means that do not share a letter are significantly different according to the Tukey Pairwise Comparisons test at $P \leq 0.05$.

However, the effectiveness of the programs on the disease in the fruit clusters of the Kara hazelnut cultivar was diverse (Table 4). S/*Reynoutria* spp. extract (Program 2), Na_2SiO_3 (m2) plus S (Program 4), S/*Reynoutria* spp. extract (Program 5), Na_2SiO_3 (m2) plus S (Program 4), and Na_2SiO_3 (m3) plus S (Program 5) had the highest and closest effectiveness to each other against powdery mildew on the fruit clusters. In particular, Program 5 was determined to completely inhibit *E. corylacearum* (Table 4). However, $NaHCO_3$, with 2.8%, exhibited the lowest efficacy against the disease, followed by *Reynoutria* spp. extract/S (65.5%).

The spraying programs were found to have efficacies against powdery mildew in the Sarı hazelnut cultivar that were similar to those in the Kara cultivar (Table 5).

In hazelnut cultivars, tebuconazole plus azoxystrobin/*Reynoutria* spp. extract (Program 1) and KH_2PO_4 plus S (Program 3) had the highest efficacies on the leaves, followed by Programs 2 (S/*Reynoutria* spp. extract), 4 (Na_2SiO_3 [m2] plus S), and 5 (Na_2SiO_3 [m3] plus S) (Table 5). In addition, KH_2PO_4 plus S (Program 3), Na_2SiO_3 (m2) plus S (Program 4), and Na_2SiO_3 (m3) plus S (Program 5) exhibited the highest efficacies against powdery mildew on the fruit clusters, followed by Programs 1, 2, and 6 ($P \leq 0.05$). On the other hand, *Reynoutria* spp. Extract/S had lower toxic effects on the leaves and fruit clusters than the others did. The effectiveness of $NaHCO_3$ (Program 7) against the disease was the lowest of all the programs (Table 5).

This study investigated the efficacies of the various spraying programs, including different combinations of eco-friendly chemicals and a biologic agent for the control of powdery mildew caused by *E. corylacearum* on hazelnut cultivars Kara and Sarı. They are potential alternatives to conventional programs that include a

chemical fungicide and sulfur and are used as the standard in the region.
In addition to alternation programs of chemical fungicides and sulfur, alternation programs of tebuconazole plus azoxystrobin/*Reynoutria* spp. extract, sulfur/*Reynoutria* spp. extract, and *Reynoutria* spp. extract/sulfur, the mixture application programs of KH_2PO_4 plus sulfur, Na_2SiO_3 (modulus 2 or modulus 3) plus sulfur, and $NaHCO_3$ alone were employed.

Table 5. Effectiveness of the treatment programs against powdery mildew on the Sarı cultivar.

Program no	*Treatment programs*	*On the leaf (%)*		*On the fruit cluster (%)*	
		Efficacy[1]		*Efficacy[1]*	
1	*Tebuconazole + Azoxystrobin/Reynoutria spp. Extract*	*96.2*	*A*	*92.9*	*AB*
2	*S/Reynoutria spp. extract*	*91.3*	*AB*	*89.0*	*AB*
3	*KH_2PO_4 + S*	*94.9*	*A*	*97.8*	*A*
4	*Na_2SiO_3 (m2) + S*	*92.2*	*AB*	*98.7*	*A*
5	*Na_2SiO_3 (m3) + S*	*92.5*	*AB*	*94.9*	*A*
6	*Reynoutria spp. extract/S*	*73.6*	*ABC*	*65.0*	*BC*
7	*$NaHCO_3$*	*57.9*	*C*	*9.9*	*D*

[1]Values are the mean of three replicates, and means that do not share a letter are significantly different according to the Tukey Pairwise Comparisons test at $P \leq 0.05$.

While the disease severity was found to be similar on the leaves of both cultivars, the fruit clusters of the Kara cultivar were more susceptible to *E. corylacearum* than were those of the Sarı cultivar (Figure 1). Although there have been some studies on the susceptibility of hazelnut cultivars to powdery mildew (Lucas *et al*., 2018), we have not found a study on the susceptibility of different organs of the plant. The differences in sensitivity of the clusters of hazelnut cultivars may be due to the morphological structures of the husks.

The treatment programs exhibited sufficiently high efficacy against powdery mildew caused by *E. corylacearum* in hazelnut cultivars, with the exception of $NaHCO_3$, which was used alone. However, in previous studies, chemical fungicides, biological agents, and alternative substances have been tested separately against powdery mildew in hazelnut on a single cultivar or on a cultivar not identified (Sezer, 2018; Türkkan *et al*., 2018; Sezer *et al*., 2019). Thus, the results of the previous studies were much different from those of our study.

In a study by Türkkan *et al*. (2018), kresoxim-methyl plus boscalid and sulfur exhibited the highest effectiveness against powdery mildew in hazelnut, followed by ammonium, potassium and sodium bicarbonates. Also, $NaHCO_3$, at the dosage of 1.5%, had the lowest efficacy against the disease on leaves and fruit clusters, 51.1% and 44%, respectively, and had a toxic effect on the leaves.

In our study, however, $NaHCO_3$, at a dose of 1.5%, had a similar effect (57.9%) against powdery mildew on the fruit clusters of the Kara cultivar, and, contrary to the previous study, had higher efficacy (80.4%) on the leaves. In addition, it exhibited a lower effect on the fruit clusters than that of the previous study (Tables 4, 5). Moreover, in our study, $NaHCO_3$, at the dosage of 1.5%, had no adverse effect on the leaves and fruit clusters of hazelnut cultivars Kara and Sarı. The different efficacies of $NaHCO_3$ in the two studies may be due to climatic conditions and/or cultivar differences.

In this study, while the $NaHCO_3$ application program had higher efficacy against powdery mildew on hazelnut leaves, the efficacy was too low in the fruit clusters. However, in a study conducted in two different vineyards, $NaHCO_3$, at the same dosage against powdery mildew caused by *Uncinula necator* (current name *Erysiphe necator*), exhibited lower effects on leaves, with 51.6% and 17.8% and higher effects, with 81.6% and 73.1%, efficacy on fruit clusters (Yıldırım *et al*., 2002).

The application programs of sulfur mixed with KH_2PO_4 and with Na_2SiO_3 (m2 and m3) exhibited over 90% efficacy against powdery mildew on leaves and fruit clusters of the hazelnut cultivars Kara and Sarı. The mixture treatments had similar or higher efficacies than did the alternation program of tebuconazole plus azoxystrobin/*Reynoutria* spp. extract, which is presented as an alternative to the conventional treatment program. This indicates that KH_2PO_4 or Na_2SiO_3 (m2 or m3) mixed with sulfur also could be used to control powdery mildew in hazelnut orchards.

Sulfur causes toxic effects on fungal cells by enzymatically converting to hydrogen sulfide (Tweedy, 1969), or first to SO_2 with heat, and then to sulfuric acid with water (Buchenauer, 1985).

The efficacy of silicates against powdery mildew diseases has been examined in many studies (Menzies *et al*., 1992; Bowen *et al*., 1992; Reynolds *et al*., 1996; Yıldırım *et al*., 2002; Buttaro *et al*., 2009; Yıldırım and Dardeniz, 2010; Prakash *et al*., 2011; Dallagnol *et al*., 2012). In this study, unlike in the earlier ones, two moduli of Na_2SiO_3 (m2 and m3), containing different ratios of SiO_3, were used, but no significant differences could be found between efficacies of application programs of sulfur mixed with the two silicates against powdery mildew, and they showed similar effectiveness against powdery mildew.

Studies to date have shown that soluble silica polarizes in plant cell walls, creating a natural physical barrier against pathogen penetrations (Kunoh and Ishikazi, 1976; Heath, 1981; Carver *et al*., 1987; Fawe *et al*., 2001). In addition, the continuous presence of silicon in dicotyledons is thought to induce a defense system (SAR) by causing the rapid emergence of phytoalexins in the plant (Daayf *et al*., 1997; Fawe *et al*., 2001).

KH_2PO_4, which has similar effects, penetrates the fungal cell, disturbs the balance of potassium, and causes the disintegration of conidial walls (Ziv and Zitter, 1992). In addition, KH_2PO_4 could induce systemic resistance against powdery mildew by forming crystallized insoluble compounds with Ca^{2+} inside the healthy plant cells (Gottstein and Kuc, 1989).

The data obtained from the study indicated that Na_2SiO_3 (m2 and especially m3), and KH_2PO_4 could be used successfully in a mixture with sulfur against *E. corylacearum* in hazelnut without an additional chemical fungicide, such as tebuconazole plus azoxystrobin.

In this study, *Reynoutria* spp. extract was substituted for sulfur or the chemical fungicide as an alternative to conventional treatment programs (a chemical fungicide plus sulfur) that are recommended for use against powdery mildew diseases in many plants. The alternation programs tebuconazole plus azoxystrobin/*Reynoutria* spp. extract and sulfur/*Reynoutria* spp. extract proved highly effective against the disease, and those alternation programs could be recommended for the control of powdery mildew caused by *E. corylacearum* on hazelnuts. Contrary to the results of this study, the effectiveness of *Reynoutria* spp. extract applied against *E. corylacearum* in hazelnut (Sezer, 2018) and the efficacies of *R. sachalinensis* extract applied against *Sphaerotheca pannosa* in rose (Pasini *et al*., 1997) and *Leveillula taurica* in tomato (Konstantinidou-Doltsinis *et al*., 2006) were reported to be low.

In previous studies, the low efficacy of *R. sachalinensis* extract against powdery mildew in various plants may be due to its use alone rather than in programs together with other alternative agents or fungicides (Sezer 2018; Passini *et al*., 1997; Konstantinidou-Doltsinis *et al*., 2006). Nonetheless, in parallel with our study, Konstantinidou-Doltsinis and Schmitt (1998) reported that the *R. sachalinensis* extract against powdery mildew in cucumbers had high efficacy when compared to fungicide applications, even under conditions of high disease severity.

The results obtained indicate that *Reynoutria* spp. extract could be used successfully in conventional treatment programs (systemic fungicide/sulfur) in place of either a systemic fungicide or sulfur against powdery mildew in hazelnut,

The different efficacy rates of *R. sachalinensis* extract against powdery mildew in different plants may also be associated with the technique and number of applications, disease pressure, and plant resistance (Konstantinidou-Doltsinis *et al*., 2006). Indeed, Daayf *et al*. (2000) determined that *R. sachalinensis* extract applied against powdery mildew (*S. fuliginea*, current name *Podosphaera fuliginea*) has been playing a significant role in disease resistance by generating increased phenolic glycones in especially resistant plants. They also exhibited that, in addition to the genetic characteristics of plants, *R. sachalinensis* extract applied against powdery mildew plays an important role in plant resistance (Daayf *et al*., 2000).

Reynoutria spp. extracts stimulate the release of phenolic compounds in the plants to which they are applied, thereby triggering the induction of resistance, as well as promoting the formation of papillae and H_2O_2. Additionally, they inhibit the formation of haustorium by powdery mildew agents, subsequently causing the collapse of the haustorium and inhibiting conidia germination (Daayf *et al*., 1997; Daayf *et al*., 2000; Moch *et al*., 2000).

As mentioned above, combinations of chemical fungicides and eco-friendly substances have not been tested in previous studies against powdery mildew in hazelnuts. Contrary to this study, they were tested separately, and sufficient effectiveness against the disease could not be achieved. In our study, alternating and mixing treatment programs against powdery mildew were applied three times at seventeen-day intervals and achieved high efficacies.

As a result, no difference was found between hazelnut varieties in terms of susceptibility to *E. corylacearum*, except in the $NaHCO_3$ spraying program and the control parcels. All spraying programs, except for the $NaHCO_3$ program, showed high effectiveness against powdery mildew in both hazelnut cultivars.

No spraying programs applied against powdery mildew on hazelnut caused phytotoxicity in the plants.

Conclusions: The results of this study reveal that successful measures against powdery mildew in hazelnut should combine both cultural treatments and spraying programs.

Nearly all the hazelnut orchards in the Black Sea Region have been established in the circular "ocak" planting system of about 1.2 m diameter and including 12–17 (and sometimes more) mother plants in each planting. To ensure high yield and quality and to control powdery mildew successfully in hazelnut orchards, the number of mother plants per planting must be reduced to the ideal number of 4–6. For that reason, the number of main plants was reduced to six for this study, and they were pruned to provide better aeration and sunlight and to facilitate spraying treatment of the orchards. In the early spring period, the infected leaves that could form the primary inoculum on the ground must be destroyed, and the sucker-shoots at the bases of the mother plants should be cut and removed. These cultural practices also must be supported by weed control.

In addition, the eco-friendly treatment programs were sprayed efficiently and homogeneously onto the green parts of the plants with an atomizer. The results support the use of an atomizer to spray against diseases in hazelnut orchards.

The present study indicated that the eco-friendly treatment programs S/*Reynoutria* spp. extract, KH_2PO_4 plus S, Na_2SiO_3 (m2) plus S, and Na_2SiO_3 (m3) plus S could be used successfully against powdery mildew on hazelnut in conventional agriculture, good agricultural practices, and ecological agriculture. In addition, the spray program tebuconazole plus azoxystrobin/*Reynoutria* spp. extract could be used in good agricultural practices and in conventional agriculture.

The alternation program of *Reynoutria* spp. extract/S (Program 6), which shows lower efficacy against the disease in both hazelnut cultivars when compared to other spraying programs, might be recommended for use in orchards with low disease pressure.

Acknowledgments: The author thanks Mr. Yücel Çelik, who allowed experimenting in his hazelnut orchard and provided the chemicals and the equipment for cultural processes and spraying in the garden. The author also wishes to thank his Lisans students, Mustafa Sönmez and Batuhan Şimşek, for helping during the experiment in the orchard. Even more, the author wishes to thank Prof. Dr. Habib Kocabıyık for performing the statistical analyses.

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