Gesunde Pflanzen
https://doi.org/10.1007/s10343-017-0411-y

ORIGINAL ARTICLE

Evaluation of Inhibitory Effect of Some Bicarbonate Salts and Fungicides Against Hazelnut Powdery Mildew

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Received: 26 September 2017 / Accepted: 15 November 2017

Abstract
Hazelnut (*Corylus avellana* L.) which is intensively grown in the Black Sea region is the most important agricultural product of Turkey. Hazelnut production and quality are negatively affected by several diseases and pests. Powdery mildew is nowadays one of the most common diseases in almost whole hazelnut producing areas. The disease is caused by two different species, *Phyllactinia guttata* (Wallr. et Lev.) Fr. and *Erysiphe corylacearum* U. Braun & S. Takam. For the last 4 years, *E. corylacearum*, a newly invasive fungus in Turkey, has been caused significant economic losses. In the present study, the efficacy of ammonium, potassium and sodium bicarbonates, and two fungicides were evaluated in field trials against powdery mildew on hazelnuts in Samsun in 2016. The application rates of compounds used in the experiment were as follows: ammonium, potassium and sodium bicarbonates (Sigma-Aldrich, Seelze, Germany) at 1.5, 3, 4.5 and 6% (w/v); Collis® SC (100 g/l Kresoxim methyl +200 g/l Boscalid, BASF, Spain) at 30 ml/100 l and Sulflow® 80 WG (Sulphur 800 g/l, Agrofarm, Turkey) at 400 g/100 l. Of the compounds tested, except for fungicides, sodium was found to be the most effective in controlling the powdery mildew on hazelnuts, followed by potassium and ammonium, respectively. Among those three, ammonium bicarbonate was ineffective against fruit infections of the disease. There was also no significant difference between inhibitory effects of 6% sodium bicarbonate, Collis and Sulflow against the disease ($P < 0.05$). In addition, bicarbonate salts was phytotoxic to hazelnut leaves at concentrations greater than 1.5%. The results indicate that sodium or potassium bicarbonate solutions seems to be a useful biocompatible fungicide for controlling the powdery mildew on hazelnuts.

Keywords Hazelnut · Erysiphe corylacearum · Bicarbonates · Fungicides · Alternative control

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Published online: 21 December 2017

Bewertung der hemmenden Wirkung einiger Carbonate und Fungizide gegen den Echten Mehltau der Haselnuss

Zusammenfassung

Die Haselnuss (*Corylus avellana* L.) wird in der Mittelmeerregion intensiv angebaut und ist das wichtigste landwirtschaftliche Produkt der Türkei. Die Produktion und Qualität der Haselnüsse können von verschiedenen Krankheiten und Schädlingen negativ beeinflusst werden. Echter Mehltau ist heute eine der häufigsten Krankheiten in fast allen Haselnuss-Anbaugebieten. Die Krankheit wird von zwei verschiedenen Arten ausgelöst, *Phyllactinia guttata* (Wallr. et Lev.) Fr. und *Erysiphe corylacearum* U. Braun & S. Takam. In den letzten vier Jahren hat ein neuer invasiver Pilz, *E. corylacearum*, in der Türkei zu bedeutenden wirtschaftlichen Verlusten geführt. In der vorliegenden Studie wurde 2016 in Samsun die Wirksamkeit von Ammonium-, Kalium- und Natriumbicarbonat sowie zweier Fungizide in Feldversuchen zur Behandlung von Echtem Mehltau bei Haselnüssen beurteilt. Die Ausbringungsraten der im Versuch verwendeten Verbindungen waren wie folgt: Ammonium-, Kalium- und Natriumbicarbonate (Sigma-Aldrich, Seelze, Deutschland) zu je 1,5 %, 3 %, 4,5 % und 6 % (w/v); Collis® SC (100 g/l Kresoxim-Methyl + 200 g/l Boscalid, BASF, Spanien) zu je 30 ml/100 l und Sulflow® 80 WG (Schwefel 800 g/l, Agrofarm, Türkei) zu 400 g/100 l. Abgesehen von den Fungiziden zeigte sich Natriumbicarbonat bei den getesteten Verbindungen als effektivste Bekämpfung des Echten Mehltaus bei Haselnüssen, danach Kalium- und Ammoniumbicarbonat in dieser Reihenfolge. Bei den Bicarbonaten war Ammoniumbicarbonat gegen Fruchtinfektionen der Krankheit wirkungslos. Es konnte auch kein signifikanter Unterschied zwischen der inhibitorischen Wirkung von 6 % Natriumbicarbonat, Collis und Sulflow gegen die Krankheit festgestellt werden ($P < 0{,}05$). Zusätzlich waren Bicarbonatsalze in einer Konzentration von mehr als 1,5 % phytotoxisch für das Haselnusslaub. Die Ergebnisse zeigen, dass Natrium- oder Kaliumbicarbonat-Lösungen als biokompatible Fungizide zur Bekämpfung von Echtem Mehltau an Haselnüssen eingesetzt werden können.

Schlüsselwörter Haselnuss · Erysiphe corylacearum · Bicarbonate · Fungizide · Alternativer Pflanzenschutz

Introduction

Turkey is the biggest producer of hazelnuts in the world with a 77% of total production. Italy and USA follow Turkey with 13% and 5%, respectively (Köksal 2000). The hazelnut is mostly harvested for commercial purposes in the Black Sea region in Turkey in an area covering approximately 705,000 hectares (Köksal 2000; TUIK 2016). In regions where hazelnut are grown in the World, hazelnut production is negatively affected by many fungal pathogens. Among the most common fungal pathogens, *Armillaria mellea, Cytospora* sp., *Anisogramma anomola, Nectria* sp., *Phytophthora* sp., *Roselllinia necatrix, Phymatotrichopsis omnivora, Erysiphe corylacearum, Phylactinia guttata, Cryptosporiopsis tarraconensis, Pucciniastrum coryli, Gloeosporium coryli, Nematospora coryli, Monilia* spp., *Botrytis* spp., *Alternaria* spp., *Ramularia* sp. and *Pestolatiopsis* spp. have been associated with pathogenic degradation of phylloplane and rhizoplane of hazelnut plants (Snare 2006). *Armillaria mellea, Nectria galligena, Rosellinia necatrix, Phyllactinia guttata, Monilia coryli, Pestolatiopsis guepeni, Phomopsis* sp., *Fusarium* sp., *Epicoccum* sp., *Alternaria raphani* have been reported in Turkey (Bremer 1948; Yürüt and Erkal 1994; Toros and Hancıoğlu 1997; Karaca and Erper 2001; Erper et al. 2012). Recently, *Erysiphe corylacearum* has also been reported in Ordu, Giresun and Trabzon provinces in the Black Sea Region of Turkey where hazelnut is widely cultivated (Sezer et al. 2017). For the last 4 years, fungus is the most important disease in almost whole hazelnut producing areas and has been caused significant economic losses. Fungus causes infection in leaves, fruit clusters and shoots of hazelnuts. It first appears under hazelnut leaves as small, white areas. Later, mycelia cover all leaf surface and among them small, roundish, yellow to black chasmothecia form. Similar symptoms are also observed in fruit clusters. Infected leaves and fruit clusters loose their green color, become brown and prematurally drop. Some agronomic practices have been used to control powdery mildew, including the use of cultural treatments, for example removal of infected leaves from field and reduction of plant intensity in field; biological control including mycoparazitic fungi: *Ampelomyces quisqualis, Verticillium lecannii* and *Paecilomyces fumosoroseus* and chemical treatments including sulfur and some (sterol biosynthesis inhibitors) fungicides (Sundheim 1982; Pasini et al. 1997; Reuveni et al. 1998; Kavková et al. 2007). However, the extensive and prolonged use of the fungicides has resulted in the development of resistance in fungal diseases. The residual effects on the crop and environmental pollution are other problems associated with the use of the fungicides. In recently, the use of natural compounds, such as oils, salts, soluble silicon and plant extracts either alone or in combination with other control methods, appears to represent one of the best alternatives to

Table 1 Effect of treatment with bicarbonate salts and some fungicides on powdery mildew severity in hazelnut

Compounds	Concentrations (%, w/v)	Disease severity				Phytotoxicity
		Leaves		Fruit cluster		
Ammonium bicarbonate	1.5	2.93	ab[a]	2.33	ab	–[b]
	3.0	2.40	bcd	2.60	ab	+
	4.5	1.95	cd	2.00	ab	+
	6.0	2.48	bc	2.43	ab	+
Potassium bicarbonate	1.5	3.05	ab	2.67	ab	–
	3.0	2.18	bcd	1.67	abc	+
	4.5	1.53	d	1.67	abc	+
	6.0	1.83	cd	1.57	bc	+
Sodium bicarbonate	1.5	1.80	cd	2.00	ab	–
	3.0	0.95	e	2.50	ab	+
	4.5	0.90	e	1.38	bc	+
	6.0	0.45	f	1.00	bc	+
Collis	30 ml/100 l	0.40	f	0.71	c	–
Sulphur	400 ml/100 l	0.43	f	0.71	c	–
Control	–	3.68	a	3.57	a	–

[a]Means in each column followed by the same letter are not significant different according to the Tukey HSD ($P < 0.05$)
[b]– = no phytotoxicity, + = phytotoxicity

synthetic fungicides for powdery mildews (Ziv and Zitter 1992; Reuveni et al. 1994; Pasini et al. 1997; Mcgrath and Shishkoff 1999; Yıldırım and Dardeniz 2010). Salts are generally recognized as safe (GRAS) by the United States Food and Drug Administration (FDA 2017). They have low mammalian toxicity, have been widely used in the food industry as preservatives, pH regulators and antimicrobial agents (Olivier et al. 1998), and their antifungal effects have been demonstrated on many pathogens. Bicarbonate and carbonate salts of ammonium, sodium and potassium have been shown to inhibit fungal pathogens of fruits, field crops, vegetables and ornamentals (DePasquale et al. 1990; Ziv and Zitter 1992; Punja and Gaye 1993; Palmer et al. 1997; Campanella et al. 2002; Yıldırım et al. 2002; Arslan et al. 2006, 2013; Ilhan et al. 2006; Jamar et al. 2007; Latifa et al. 2011).

The aim of this study was to evaluate the efficacy of bicarbonate salts of ammonium, potassium and sodium, and two fungicides in controlling *Erysiphe corylacearum*, the causal agent of powdery mildew in hazelnut.

Material and Methods

Chemicals

Bicarbonate salts of ammonium, potassium and sodium used in this study were purchased from Sigma-Aldrich (Sigma-Aldrich, Seelze, Germany), Collis ® SC (100 g/l Kresoxim methyl + 200 g/l Boscalid) and Sulflow® 80 WG (Sulphur 800 g/l) were purchased from BASF (Spain) and Agrofarm Turkish chemical Industry (Turkey), respectively.

Experiment

Experiment was conducted with the target to determine the efficacies of test chemicals in a spray programme against powdery mildew. The experiments were performed in a hazelnut garden in Çarşamba (Samsun, Turkey), where the powdery mildew disease appeared intensely, in 2016.

The treatment programmes including bicarbonate salts and two fungicides were applied at 15-day intervals from the stage of young fruits in the fruit clusters to 3 weeks until hazelnut harvest. Test chemicals were sprayed with a knapsack sprayer.

The disease evaluations on leaves and fruit cluster were made 15 days after the last application. Leaf and fuit cluster infections were evaluated based on the scale of 0–4, on 120 leaves for each replication; where: 0 = no colony on the leaf or fuit cluster; 1 = 1–10% colonies per leaf or fruit cluster; 2 = 11–30% colonies per leaf or fuit cluster; 3 = 31–60 colonies per leaf or fuit cluster; 4 = more than % 60 colonies per leaf or fuit cluster (TAGEM 2016).

The phytotoxic effects (nekrosis) of bicarbonate salts on the plant were determined in parallel experiments. Phytotoxic effects was recorded as present or none.

The experiments were established as randomized complete block design with four replications and six plants were used for each variant. The efficacies of the application programmes were evaluated using the Abbott formula.

Fig. 1 Appearance of hazelnuts after application of collis and sodium bicarbonate (above the control plants)

Statistical Analysis

The statistical analysis was performed using the statistical software IBM SPSS (version 22, Property of SPSS, Inc.; IBM Company). Results were separately subjected to one-way analysis of variance (ANOVA), and significant differences between means were determined by using the Tukey—*HSD* test ($P < 0.05$).

Result and Discussion

According to the results obtained from leaf applications in, the most effective protection against *Erysiphe corylacearum,* the causal agent of hazelnut powdery mildew was achieved by the fungicides (Collis and sulphur), followed by sodium bicarbonate, potassium bicarbonate and ammonium bicarbonate, respectively (Table 1). With the exception of 1.5% applications of ammonium bicarbonate and potassium bicarbonate, all other leaf applications reduced development of the powdery mildew fungus on hazelnut leaves. Moreover, sodium bicarbonate was able to reduce the diseases severity of powdery mildew even at the lowest concentration used in the study. There was also no significant difference between inhibitory effects of 6% sodium bicarbonate and these two fungicides against the powdery mildew ($P < 0.05$) (Fig. 1). This is in line with Pasini et al. (1997), who reported that the efficacy of $NaHCO_3$ and KH_2PO_4 against *Sphaeroteca pannosa* var. *rosae* on roses was nearly similar to the efficacy of dodemorf. However, both ammonium bicarbonate and potassium bicarbonate could not able to produce a similar inhibitory effect even at the highest concentration used. Previous studies have also shown bicarbonate salts including sodium and potassium to have the effect of reducing the diseases severity of powdery mildew. Homma et al. (1981) found sodium bicarbonate to be inhibitory to powdery mildew on cucumber and green mould on citrus, and the addition of surfactants to improve the effectiveness of sodium bicarbonate against green mould on citrus. Horst et al. (1992) showed that rose powdery mildew (*Sphaeroteca pannosa*) and blackspot (*Diplocarpon rosae*) were significantly controlled by weekly sprays of 0.5% (w/v) aqueous solution of either sodium or potassium bicarbonate used alone or with 0.5% or 1.0% (v/v) Sunspray oils. Yıldırım et al. (2002) reported that $NaHCO_3/K_2SiO_3$ + sulphur spray program was found more effective (44.7%) against *Uncinula necator* (grapevine powdery mildew) on leaves than other spray programs (Na_2SiO_3 + sulphur, KH_2PO_4 + sulphur, KH_2PO_4/di-1-*p*-menthen, and penconazole/sulphur), during which the disease severity was especially higher. Moreover, they determined that $NaHCO_3$ and K_2SiO_3 were superior to penconazole and were as effective as sulphur in reducing the spore-bearing ability of the colonies in leaf infection. Jamar et al. (2007) determined that a single spray of 0.5 or 1% (w/v) aqueous solution of sodium or potassium bicarbonate applied on young apple seedlings significantly controlled *Venturia inaequalis* (apple scab) under controlled conditions in greenhouse experiments.

As observed in leaf applications, the fungicides were more effective than bicarbonate salts in controlling powdery mildew on fruit cluster of hazelnut. Sodium bicarbonate prevented fruit infections at a concentration of 4.5%, as did potassium bicarbonate at 6.0%. This finding is similar to that of Ilhan et al. (2006), who reported that 1% sodium bicarbonate significantly reduced disease incidence and severity on leaves and fruit of apple scab. Arslan et al. (2013) showed that 0.5 and 1% ammonium bicarbonate significantly and consistently reduced apple scab disease incidence and severity on apple (cv. Mutsu) leaves and fruit. Moreover, Palmer et al. (1997) determined that other bicarbonates salts, such as ammonium bicarbonate, were more effective than sodium or potassium bicarbonate salts in inhibiting the colony growth of *Botrytis cinerea* (Gray mold) *in vitro*. In the present study, in contrast, no significant difference was observed in its fungicidal activity despite the increased concentration of ammonium bicarbonate. A previous study (Punja and Grogan 1982) indicated that the interaction between salt and environment may have an important role. In addition, the pH of the solutions of salt is probably a very important role in the antimicrobial activity (Corral et al. 1988). This may be one of the reasons of inconsistency among present study and other.

In the present study, except for 1.5% of bicarbonate salts, necrosis in hazelnuts was observed at higher concentrations. These results are consistent with those of previous studies. In phytotoxicity studies using either powdery mildew (*Sphaerotheca fuliginea*)-infected or healthy cucurbit plants, Ziv and Zitter (1992) determined that ammonium, potassium and sodium bicarbonates caused beige necrotic spots on leaves at 2% and the higher concentrations (2.5 and 5%).

In conclusion, our results showed that the use of bicarbonate salts to control infections by *E. corylacearum*, the causal agent of powdery mildew on hazelnut, may be a valid alternative to the fungicides. Among the tested bicarbonate salts, sodium bicarbonate was the most effective salts in reducing the disease severity caused by powdery mildew. Among them, sodium and potassium bicarbonate can be used alone in organic growing or in rotation with each other and other safe treatments.

Conflict of interest M. Türkkan, İ. Erper, Ü. Eser and A. Baltacı declare that they have no competing interests.

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