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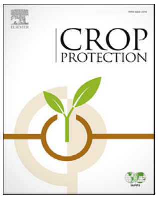

Sensitivity of cold-climate wine grape cultivars to copper, sulfur, and difenoconazole fungicides

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ABSTRACT

The development of wine grape cultivars that can withstand temperatures as low as −40 °C, hereafter referred to as cold-climate cultivars, has been critical to the establishment and growth of the wine industry in the northern USA. While some grape cultivars are susceptible to leaf injury following application of copper, sulfur, and difenoconazole fungicides, the sensitivity of most cold-climate cultivars to these fungicides is not known. In field trials conducted over four years at two locations in Wisconsin, USA, we found that most of the 15 cold-climate cultivars evaluated were not highly sensitive to copper, sulfur, or difenoconazole, although there were important exceptions. Sensitivity was expressed in relative terms, with comparisons made among the cultivars tested, and more weight given when injury was observed after a small number of applications. Regarding copper: Brianna was highly sensitive, showing injury in seven of 11 trials, sometimes after three or fewer applications; Léon Millot, and Maréchal Foch were moderately sensitive, each showing injury in three of six trials; and Frontenac, Frontenac gris, La Crescent, Marquette, and St. Croix were slightly sensitive, each showing injury in one or two trials. Regarding sulfur: Brianna, Léon Millot, and Maréchal Foch were highly sensitive, each showing injury in three trials, sometimes after three or fewer applications; and La Crescent and St. Croix were slightly sensitive, each showing injury in one trial. With the exception of Noiret, which showed injury in one trial, none of the cultivars was sensitive to difenoconazole. It should be possible for growers to integrate these fungicides into disease management programs that will control important diseases of wine grape and delay the emergence of pathogens resistant to major classes of synthetic fungicides.

1. Introduction

The Upper Midwest and Northeast regions of the USA are home to more than 300 wine grape vineyards, 80% of which have been established since 2002 (Tuck and Gartner, 2013). The wine grape and locally-sourced wine industries in those regions are valued at more than $400 million annually (Tuck and Gartner, 2014). The development of cultivars that can withstand temperatures as low as −40 °C, hereafter referred to as cold-climate cultivars, has been critical to the continued growth and sustainability of the wine grape industry in the northern USA. In many cold-climate cultivars, the genes for cold hardiness originated with *Vitis riparia* and other grape species native to North America, and were introgressed into a background of *V. vinifera*, the conventional wine grape cultivated in more moderate climates. Although many of the hybrid cultivars are reportedly more resistant than *V. vinifera* to some major grape diseases (Bordelon et al., 2016; Weigle and Carroll, 2016), the moist, humid climate of the Upper Midwest and Northeast regions of the USA is conducive to fungal diseases, some of which can lead to 100% crop loss if left unchecked, or reduce wine quality if present even at low levels. Because of this combined high risk and low tolerance for disease, growers typically spray fungicides six to 10 times per year.

Wine grape disease management programs currently rely on fungicides that have one or more significant drawbacks. For example, the sterol demethylation inhibitor (DMI) and strobilurin fungicides are highly effective in controlling a wide range of diseases, but their specific modes of action have led to the emergence of fungicide-resistant grape pathogens (Délye et al., 1997; Chen et al., 2007; Miles et al., 2012; Colcol and Baudoin, 2016). Mancozeb is classified as a B2, or "probable" carcinogen and has a 66-day pre-harvest interval that restricts its use after grape berry set. By contrast, copper and sulfur fungicides remain effective despite

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decades of use in vineyards, and their use in the USA is permitted up to the day of harvest. In grape production, copper and sulfur are highly effective for controlling downy mildew and powdery mildew, respectively, although both fungicides have limited activity toward other diseases (Bordelon et al., 2016; Weigle and Carroll, 2016). Nevertheless, an integrated spray program of copper, sulfur, and synthetic fungicides would likely be effective in controlling all the major fungal diseases and forestall resistance to DMI and strobilurin fungicides. Further, some forms of copper and sulfur also are among the most effective fungicides permitted for use in organic vineyards (Weigle and Carroll, 2016). Unfortunately, the foliage of some grape cultivars is sensitive to injury from copper and/or sulfur, with native American and interspecific hybrids at greatest risk (Wilcox and Wong, 2015; Bordelon et al., 2016; Weigle and Carroll, 2016). Likewise, possible phytotoxicity on *V. labrusca* hybrid grape cultivars from the DMI fungicide difenoconazole has prompted the manufacturer to post a warning on labels for products containing difenoconazole. Information on the sensitivity of cold-climate cultivars to copper, sulfur, and difenoconazole is limited because many of the cultivars have only recently been widely planted, and the sensitivity of these cultivars to these fungicides has never been studied in randomized, replicated trials. Until this gap in knowledge is filled, growers of cold-climate cultivars will be hesitant to integrate copper, sulfur, and difenoconazole into spray programs.

The objective of the present study was to assess the sensitivity of several cold-climate wine grape cultivars to copper, sulfur, and difenoconazole fungicides under field conditions. Implications of the results for disease management are discussed.

2. Materials and methods

2.1. Field sites and treatments

Eleven field trials were conducted during 2012 through 2015 at West Madison Agricultural Research Station (WMARS) near Madison, WI, USA and Peninsular Agricultural Research Station (PARS) near Sturgeon Bay, WI, USA. At WMARS, trials were conducted in vineyards established in 2008 and 2012, designated WMARS-1 and WMARS-2, respectively. Similarly, at PARS, vineyards established in 2008 and 2012 were designated PARS-1 and PARS-2, respectively. Vineyards established in 2008 were planted with a vine spacing of 2.13 m within rows and 3.35 m between rows. Vineyards established in 2012 were planted with a vine spacing of 1.83 m within rows and 3.05 m between rows. Vines in all vineyards were trained to a vertical shoot positioning system. The soil types at WMARS were Griswold, Kegonsa, and Plano silt loams, and the soil type at PARS was Longrie Loam. Fertilizers were applied as needed based on annual foliar nutrient analysis to maintain good plant health. The vineyards were not irrigated during the course of this study. Cultivars tested, treatments applied, and numbers of applications varied among the trials (Table 1). The pedigrees, origins, and other traits of most of these cultivars are described by Smiley and Cochran (2016). Fungicides were mixed in a spray volume adjusted for canopy density at a concentration equivalent to the highest rate permitted on product labels in 378.5 L of water (equivalent to 100 gallons, a spray volume commonly used in vineyards). Water pH was 6.6–6.8 at WMARS and 6.8 to 7.2 at PARS. Fungicides were applied to vines with a hand-held pump sprayer (Solo 454, Solo USA, Newport News, VA, USA) at WMARS or a handgun sprayer at a pressure of 1.38 MPa (AA43 GunJet spray gun equipped with brass disc D2 nozzles [TeeJet Technologies, Glendale Heights, IL, USA] attached to a Rears Pak Tank RM30 [Rears Manufacturing Co. Coburg, OR, USA]) at PARS until runoff (i.e., foliage evenly wet and starting to drip). Treatments were applied in calm conditions to individual shoots or all shoots on an entire cordon on vines that were randomized by cultivar and replicated four (WMARS-1, PARS-1) or five (WMARS-2, PARS-2) times. For each replicate, fungicide-treated or control shoots or cordons were on separate vines to minimize spray drift among treatments and eliminate the possibility of systemic uptake of fungicide, particularly difenoconazole, influencing other treatments. In addition to the copper, sulfur, and difenoconazole treatments listed in Table 1, vines were sprayed with other commonly used pesticides for control of diseases and insect pests. Thus, the experimental copper, sulfur, and difenoconazole treatments were applied over a background of general maintenance fungicides. However, copper, sulfur, and difenoconzole always were applied alone and not mixed with other pesticides or adjuvants.

2.2. Data collection and analysis

Foliage was rated for injury one to seven times in the various trials (Table 1). In all trials except 2012 PARS-1, an untreated control shoot or cordon of each cultivar tested was inspected on each rating date to account for leaf spotting, speckling and/or discoloration unrelated to experimental treatments. Injury was rated by visual inspection of the entire unit treated (i.e., either an individual shoot or all shoots on a cordon) using the following scale: 1 = no visible injury; 2 = injury visible on < 25% of treated unit; 3 = injury visible on 26–50% of treated unit; 4 = injury visible on > 50 of treated unit and/or noticeable defoliation. Because the rating scale was subjective, a single rater collected data throughout the season for any given trial (Table 1). Also, the three raters (MS, PM, and VK) communicated during the course of this research with the goal of being consistent in rating the level of injury. The mean injury severity rating for each fungicide on each cultivar on each date in a trial was compared to the rating for that cultivar's untreated control. Data were analyzed by first converting rating values into a percentage using the midpoint of the corresponding range of percent injury. Thus, a rating of 1 corresponded to 0%; 2 corresponded to 12.5%; 3 corresponded to 37.5%; and 4 corresponded to 75%. For each trial, the resulting values were analyzed using SAS PROC MIXED (SAS Version 9.4, SAS Institute, Inc., Cary, NC). Each trial was viewed as a split plot experiment in blocks, where replicate was the block, cultivar was the whole plot treatment, fungicide was the subplot treatment, and date was treated as a subsubplot treatment. Accordingly, random effects were fit for the replicate by cultivar effect (whole plot error) and for the replicate by cultivar by fungicide effect (subplot error). The “residual” error fit by SAS corresponded to the subsubplot error. If there were significant ($P < 0.05$) effects of fungicide, or any interactions with fungicide, then for each date and cultivar the mean percent injury for each fungicide was compared to the mean percent injury on the corresponding untreated control using Fisher's Protected LSD ($P < 0.05$).

2.3. Environmental conditions

Because sulfur injury to grape leaves has previously been related to temperatures greater than 28–32 °C at the time of or immediately following application (Emmet et al., 2003; Wilcox and Wong, 2015), we recorded the maximum temperature within 24 h after fungicide application (Table 1). Because copper injury to grape leaves has previously been related to leaf wetness (Pertot et al., 2006a, 2006b; Wilcox and Wong, 2015), we recorded daily rainfall at WMARS and PARS in all years of the study. Daily high temperatures and rainfall were measured at WMARS with a Spectrum WatchDog 1000 Series Micro Station (Spectrum Technologies, Inc., Aurora, IL, USA) and at PARS with a CR 1000 Measurement and Control Datalogger (Campbell Scientific, Logan, UT, USA).