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# Study on fungicides' use in viticulture: present and future scenarios to control powdery and downy mildew

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## 1 Introduction:

In 2021 the European Commission has established the so-called European Green Deal (COM/2019/640), pointing out the new "Farm2Fork" strategy, aiming to keep a high production in terms of quantity and quality, being sustainable and stable in future years. The European Union has set up specific goals for the pesticide use in agriculture, especially with the aim to reduce by 50% the use of chemical pesticides, and particularly the most dangerous for human health and environment by 2030. In the last years the European Union already limited some pesticides, some of them have been revoked, some others are going to be revoked in the next years or limited in their use (Dir. 2009/128/EC; Dir. 2019/782/EC; Reg. 2009/1107/EC; Reg. 2011/540/EC).

This study analyzed the fungicides' use in viticulture in Veneto (Italy) to control powdery and downy mildews, evaluating how the choice of active ingredients changed during two different periods in the last years, considering the Mode of Action (MoA) and defining future scenarios to control diseases in vineyard, considering all the available solutions to reach an adequate production, and at the same time avoiding the insurgence of new resistance to fungicides and hypothesizing possible further restrictions to actual available fungicides.

Powdery and downy mildews represent two of the most severe diseases of grapevine that can cause severe yield losses. Powdery mildew is caused by *Erysiphe necator*, a polycyclic pathogen, that can cause primary infections in spring when ascospores are released from chasmotecia, the overwintering structure of the fungus, and reach leaf tissues where they can germinate and cause primary infections. Later, fungal colony can form new conidia, that can cause secondary infections during the entire growing season (Gadoury *et al.,* 1990; Thind *et al.,* 2004; Caffi *et al.,* 2010; Jailloux *et al.,* 2011). Normally powdery mildew is controlled applying fungicides during the season, and the availability of models, that can predict the pathogen development and its possibility to cause infections, are fundamental tools to optimize and rationalize fungicides applications, knowing that disease development is function of weather parameters (Thind *et al.,* 2004; Caffi *et al.,* 2010; Sozzani *et al.* 2010; Bertocchi *et al.,* 2010). Downy mildew is caused by *Plasmopora viticola*, a polycyclic pathogen, that cause primary infections when the overwintering oospores reach grapevine leaves, germinate, form sporangia, that will release zoospores which in turn can cause disease development. Later the mycelium can sporulate producing new spores for the secondary infections (Brook, 1992; Burruano, 2000; Thind *et al.,* 2004). Downy mildew appearance, as powdery mildew before, is strictly linked to the environmental conditions of vineyard, and as before, different models have been created to rationalize fungicides application during the growing season (Brook, 1992; Madden *et al.,* 2000; Caffi *et al.,* 2010).

The most used fungicides worldwide are copper to control downy mildew and sulphur to control powdery mildew. Copper is a heavy metal, that can be accumulated in the soil determining negative effects on the environment; for this reason, the actual limit to copper is 4 kg/ha per year (a maximum of 27 kg/ha in 7 years) (Mirlean *et al.,* 2005; Fernández-Calviño *et al.,* 2008; Beni *et al.,* 2009; Kovačič *et al.*, 2013)

## 2 Methods:

In this study two three-years-periods were considered (the first between 2015 and 2017, and the second between 2018 and 2020), underlining the fungicides used, grouped according to their MoA, chemical group, and risk of resistance development. Then, a future scenario to 2023 was created considering the possible future strategies to control both diseases, taking in account possible restrictions or withdrawal of fungicides now still in use. For pesticides listed in "substances candidate to substitution" a reduction of 20% in their use was supposed, and a reduction of 10% for the substances classified as high risk to induce the development of new resistances in pathogen population. Based on those two assumptions, future calendar for diseases control were elaborated aiming to substitute products with a high risk of resistance with fungicides less risky. The analysis used data provided by 179 farmers across Veneto region through the decision support system (DSS) vite.net®, developed by Horta. Data were made anonymous, and then elaborated according to different key information as #year, #disease, #active_substance, #MoA, #dose, #treated_area, #period_of_treatment etc. Data were divided for powdery and downy mildews to evaluate the number of treatments applied in each season in the two periods considered. Fungicides were classified according to their FRAC code showing the risk class. The study has the objective to show how the fungicides choice changed in the two periods, underlining if the riskiest ones have been substituted with product less risky and elaborate a future diseases control scenario more sustainable, with less risky products.

## 3 Results

During the two three-years periods the average number of treatments applied in the vineyard did not change significantly, ranging from 12 to 14 treatments per season (Fig. 1). In the first period, the number of interventions varied a lot, also among single years, between 6 and 17 times (in 2015) and between 7 and 25 (2016). In the second period, the variability was reduced with a range of 11-17 treatments in 2018. Thus,

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even if the average number of treatments did not change in the two periods, the variability was reduced in the second one.

Then, the study considered separately the number of interventions to control powdery and downy mildew, evaluating the number of fungicides used, grouped according to their MoA and their risk of resistance based on FRAC classification.

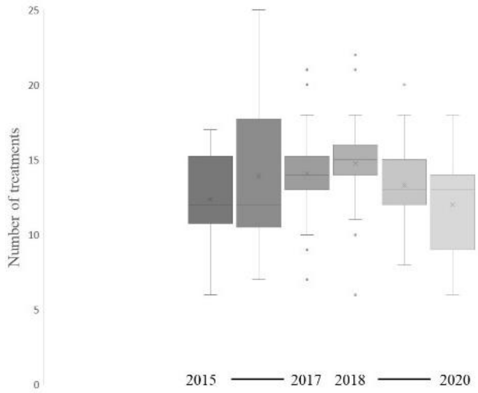


Figure 1: Variability in the number of treatments (sprayer entering into the vineyard) applied between 2015 and 2020 in Veneto (Italy).

*Powdery mildew*

Some fungicides used in last years to control powdery mildew, such as thiophanate methyl and quinoxyfen, have been revoked, respectively in 2021 and in 2019. The average number of treatments applied during a season did not change between the two periods, but the average dose applied in each intervention was reduced in the second period. Considering the chemicals applied, an increase in the use of inorganic fungicides was evident (sulphur is the most used) on the total while the use of others, such as IBS group, was reduced. Among IBS, Tebuconazole and Difeconazole are included, and they are considered candidates to substitution. In the second period considered (2018-2020) a general reduction was found for products classified as low- and medium-risk, substituted with high-risk products (Fig. 2). Moreover, in the last period farmers started to apply biocontrol agents and botanicals, classified by FRAC as unknown risk compounds. The results underlined the possibility to control disease, keeping the same number of treatments but reducing the dose applied of each product during the season and getting satisfying results.

Using data collected a future scenario for powdery mildew control was elaborated, considering the limitation and the possible further restriction for products candidate to substitution. To date, sulphur is not a candidate to substitution and no limitations are present, however, we hypothesized a reduction of 25% because of the new alternative methods available. Thus, we assumed to cover an average of 13 treatments during the season (in other words maintaining the same average of the analyzed period) combining different fungicides as follow: seven sulphur applications, combined with site specific fungicides, then three treatments with SBI class I and the last three with other available products as Spiroxamine, Meptyldinocap. During the season the use of these fungicides should be alternated and mixed with products with different mode of actions, as IBE, QoI etc. However, one of the biggest limits found for powdery mildew control is a lack in contact, broad-spectrum, and low risky products, that are normally mixed with site specific fungicides. Nevertheless, for powdery mildew a wide range of resistance inducers (e.g. *Cerevisane*), biocontrol agents (e.g. *Ampelomyces quisqualis*) and botanicals (e.g. essential oil) are available, and they can be used to increase variability of MoA applied. Especially botanicals can be applied in the last part of the season to avoid problem of fungicides residue on grapes at harvest.

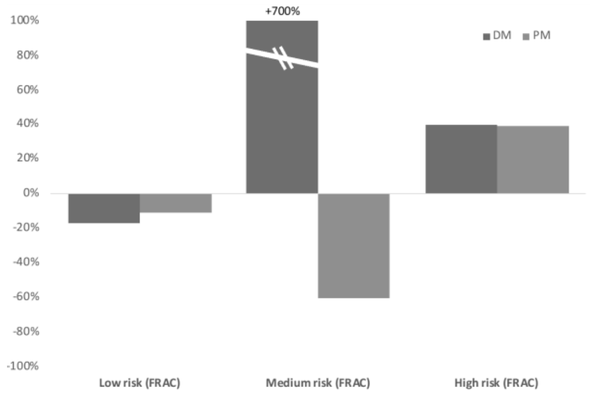


Figure 2: Percentage variation of risks classes (low, medium, and high), according to FRAC, of active ingredients used to control downy and powdery mildews between in 2018-2020 comparted to 2015-2017.

*Downy mildew*

In the two periods (2015-17 and 2018-20) a trend in reducing the use of low-risk products was found considering downy mildew control, in favor of products with medium and high risk of inducing resistances (Fig. 2). This variation was due to the removal from the market of Mancozeb and Propinam, both revoked, and due to a limitation in copper maximum dose applicable, that was reduced from 6 kg/ha per season to 4 kg/ha by the European Union Commission. These chemicals were considered low risky products for resistances development. For instance, the amount of copper in the first period (2015-17) was in average close to the legal limit, while in the second period (2018-20) copper amount was on average less than 4kg/ha per season, lower than the new introduced limit. Thus, the average dose of copper applied in each season per intervention was reduced. Even if the number of treatments did not change, it was possible to reduce the dose applied, keeping a good disease control. Other products such as Dithiocarbamates and Cynamoxil faced a reduction in their use between the two periods, while new molecules or new formulations showed an increase in the second period as Phthalimides, Phenylamides and Phosphonates. In the first period these products were used in low percentages, while in the second one reached a higher level on the total interventions provided.

As for powdery mildew before, a future scenario for downy mildew control was created. We assumed to cover an average of 13 treatments per season, combining different fungicides as follow: five should be done using contact products between Quinones, Phthalimides and Dithiocarbamates groups (low risky products) mixed with single site products, then other five treatments can be done using copper and three/four with benzamides, that can be combined with single site products, phosphites and phosphonates. For copper we hypnotized a further restriction of 20%, being candidate to substitution. As seen for powdery mildew, the indicated chemicals should be alternated and mixed with other active ingredients characterized by different MoA.

## 4 Discussion

This study evaluated trends in fungicides use in viticulture in the recent years to control two of the most important diseases of grapevine, powdery and downy mildew, comparing two three-years periods (2015-17 and 2018-20). The study collected real data, uploaded by users on vite.net® decision support system, in the period 2015-2020, covering more than 43.000 ha in Veneto.

Data were analyzed to evaluate how fungicide choice, number of treatments, and dose applied changed in the two periods. Fungicides were classified according to their risk of resistance insurgence in harmful organism population, according to FRAC classification (https://www.frac.info/). Then, based on data collected from farmers, future scenario for diseases control were elaborated, based on Integrated Production Regulations in force in 2021 for grapevine cultivation in Veneto region (https://www.regione.veneto.it/web/fitosanitario/difesa-integrata). The scenario was created hypothesizing the removal of active ingredients revoked in the disease control program, a reduction by 20% of active ingredients candidate to substitution, and a further reduction (-10%) of molecules considered by FRAC as high risky for resistance, and consequently the adoption of molecules with similar or lower risks of resistance according to FRAC.

The control of the two diseases was considered separately, and in the second period (2018-20) some products' use was already reduced compared to the first period. Contact products were the ones mainly reduced in the second period, often because of a lack of alternatives, for limitation (candidate to substitution) or revocation. For instance, copper, the most used broad-spectrum fungicides to control downy mildew (Gessler *et al.*, 2011; Tamm *et al.*, 2022), was reduced to level lower than the actual legal limit of 4 kg/ha per season, demonstrating the possibility to reduce the dose applied and reaching a good disease control (Kuflik *et al.*, 2009). Others, as Mancozeb, were almost abandoned. Generally, the number of treatments did not change among the two periods under study for both powdery and downy mildew, but in both cases a reduction in the average dose applied was possible.

Future scenarios were elaborated considering the same number of treatments of the two periods, trying to reduce the dose applied and selecting chemical products according to the FRAC classification. The most common future scenario for disease control was characterized by a reduction in low risky products, and a too high availability of fungicides with a single site of action and high risk of resistance.

## 5 Conclusions

The main issue for the next years will be the availability of single site products but a lack of broad-spectrum fungicides to be mixed or combined during treatments. This is normally the most used strategy to avoid the insurgence of new resistances (Gessler *et al.*, 2011; Massi *et al.*, 2021), recommended also by FRAC. Clearly future scenarios created are based on data collected during years in Veneto, but every year and every local conditions should be evaluated (Gisi *et al.*, 2008; Pertot *et al.*, 2017), before deciding which and how many treatments are necessary for each specific conditions, considering weather conditions, disease presence etc., helped by models, thresholds, and monitoring activity (Kuflik *et al.*, 2009; Gessler *et al.*, 2011; Pertot *et al.*, 2017).

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