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Modelling the impact of climate change on the interaction between grapevine and its pests and pathogens: European grapevine moth and powdery mildew

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ABSTRACT

Climate change may impact patterns of plant diseases and arthropod development in more complex ways than expected. In fact, whereas both crops and crop pathogens and pests are affected by climatic variables, they might be influenced by different combinations of driving factors, and they might respond to their change at different rates. In order to separate these effects, we need to improve our understanding of the host-pest/pathogen system, and consider their interaction. The aim of this study was to refine current assessments of climate change impacts on pest and disease pressure on grapevines by considering pest/pathogen–host interactions. This research (i) combined detailed phenological models of grapevine with phenological models of one of its key insect pests (European grapevine moth) and one of its key pathogens (powdery mildew), (ii) applied the models to climate change scenarios for a selected study area in the eastern Italian Alps, and (iii) considered potential changes in their interactions. These simulations suggest that in the warmer, more profitable viticultural areas of the study region increasing temperature might have a detrimental impact on crop yield due to increased asynchrony between the larvae-resistant growth stages of grapevine and larvae of the European grapevine moth. On the other hand, the increase in pest pressure due to the increased number of generations might not be as severe as expected on the basis of the pest model only, due to the advance in harvest dates limiting damages from late-season generations. Simulations for powdery mildew highlighted a decrease in simulated disease severity, especially in years with a later onset of the disease symptoms and in the climate scenario with higher temperature increases.

1. Introduction

Major shifts in temperature and changes in the seasonal pattern of rainfall distribution are currently affecting most of the world. Climatic projections suggest that these trends will continue in the coming decades, affecting both mean and extreme values of these variables (Easterling et al., 2007). In the latest report of the Intergovernmental Panel on Climate Change (IPCC), mean global temperature is estimated to increase between 1.8 and 4.0 °C (with a likely range of 1.1–6.4 °C), by the end of the present century, depending on the greenhouse gas emission scenario (Easterling et al., 2007). The combination of climate change, associated disturbances and other global change drivers is expected to exceed the resilience of many agro-ecosystems. As a consequence, climate change could substantially impact agriculture and food production (Olesen and Bindi, 2002; Fuhrer, 2003; Maracchi et al., 2005; Kang et al., 2009). The result of climatic change should not be always seen as a threat to farm productivity, especially where water is not a limiting factor. However, Olesen et al. (2011) pointed out that the perceived outcomes of climate change expected by European farmers remain mostly negative, and in particular, interviewed farmers disclosed the feeling that the risk from pests and diseases for grapevine will increase in the Alps (both north and south).

However, consequences of climate-driven changes are not easily predictable in complex agro-ecosystems, as the biology of pests and pathogens and that of their host plants are interdependent. For example, many pests/pathogens affect their host plant only during specific vulnerable periods of the plant life-cycle. This is the case of the pathogens that infect plants through their flowers, as the bacterium *Erwinia amylovora*, which can penetrate its hosts (e.g., apple and pear) during flowering (Thomson, 2000). Other pests might be able to attack their host throughout their growth season but cause higher damage during specific growth stages. For example, the larvae of European grapevine moth (*Lobesia botrana*) are less harmful during flowering (Gabel and Roehrich, 1995), but produce more damage in the post-veraison period, when they influence grey mould (*Botrytis cinerea)* infections (Moschos et al., 2004). Many plant species progressively increase their resistance to pests

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and pathogens as they age by developing "ontogenic" resistance, which may be active on the whole plant or in specific organs or tissues (Panter and Jones, 2002; Gadoury et al., 2003). For example, grape berries are reported to be susceptible to *Erysiphe necator* (the powdery mildew fungus) infections until soluble solids levels reach 8% (8°Brix), and the established fungal colonies are reported to sporulate until soluble solids levels reach 15% (15°Brix) (Delp, 1954; Chellemi and Marois, 1991).

Thus, in presence of pests, infestations will occur only under specific environmental conditions and only if the host plant is in a susceptible growth stage (Chakraborty et al., 2000). For pathogens, this interaction has been frequently represented by the "plant–disease triangle", which is made up by the three elements required for the infection to develop: a susceptible host, the presence of the pathogen, and a conducive environment (Chakraborty et al., 2000).

In addition to the above described "susceptibility windows", one should consider the duration of the productive cycle of each crop. In fact, while higher temperatures might favour the development of certain pests, they could also shorten the length of crop cycles, thus balancing out a potential increase in pest pressure. For example, higher temperatures might cause an increase in the number of generations of insect species that are able to produce several broods per year (multivoltine species). This would imply an increase in the number of reproductive events per year, leading to an increase in population, and increased levels of infestation (Yamamura and Yokozawa, 2002; Dukes et al., 2009). However, if the last generations emerge after a crop is harvested, they cannot impact crop yield, and pest population might decrease in size due to the absence of suitable food. Some pathogens are able to infect its hosts when the plants are in certain developmental stages. This means that in order to maximize their chance of infection, the life cycle of pathogen populations must be in synchrony with host development. Since climate change can influence the rate of both host and pathogen development, it could affect the development and impact of plant diseases. Some pathogen species may be able to maintain their synchrony with target host tissue, and others may become out of synchrony (Garrett et al., 2009).

While it is clear that all these factors respond to climatic variables, they might be controlled by different combinations of driving factors, or respond to their change at different rates. In order to separate these effects, we need to better assess the dynamical interactions of the host-pest/pathogen system. Indeed, meaningful projections of climate change impacts on disease/infestation pressure can be obtained only by coupling host phenology with patterns of pest development and infestation (Grulke, 2011). At present, only a few modelling studies have considered these interactions for the projection of climate change impacts on agriculture (Baker et al., 2005; Calonnec et al., 2008; Ponti et al., 2009; Gutierrez et al., 2009). In fact, most research has concentrated on the effects of climate change on either the physiology/phenology of single crops (see, for example Webb et al., 2008; Hall and Jones, 2008; Eccel et al., 2009; Caffarra and Eccel, 2011) or pests alone (see, for example Porter et al., 1991; Woiwod et al., 1997; Bale et al., 2002; Salinari et al., 2006; Estay et al., 2009). Whereas the pressure of pest/pathogen on their host plant will probably also depend on factors other than the direct effect of temperature on their development, such as genetic adaptation, the simulation of the effects of climate change on their phenological interaction is nonetheless useful to highlight possible trends in future disease/infestation patterns.

The aim of this study was to refine current assessments of climate change impacts on pest/pathogen occurrence on grapevines by simulating pest/pathogen–host interactions. This research (i) combines detailed phenological models of grapevine with phenological models of one of its key pests (*Lobesia botrana*, Den. and Schiff., Lepidoptera: Tortricidae) and one of its key pathogens [*E. necator*, (Schw.) Burr.], (ii) apply the models to climate change scenarios for a selected study area (in the eastern Italian Alps (Fig. 1), and (iii) consider potential changes in the interactions in these two systems.

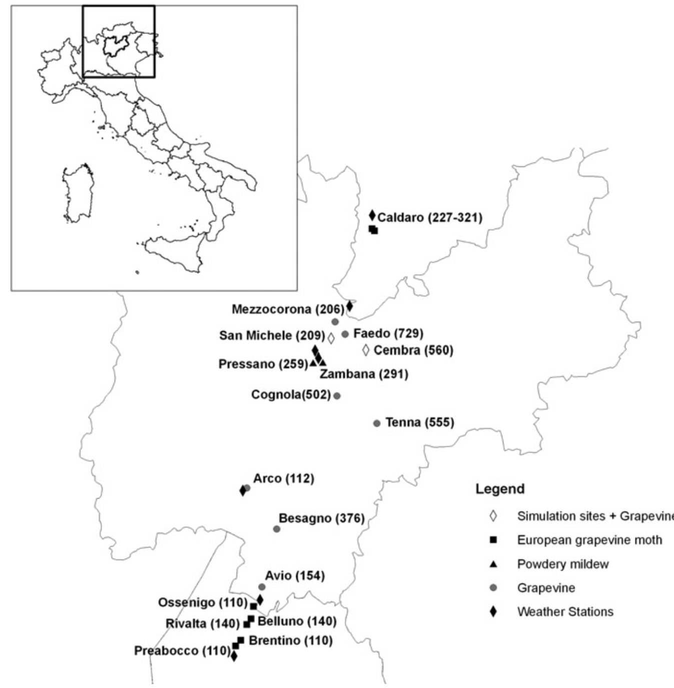

Fig. 1. Location of the meteorological stations used for the study, the simulation sites and the sites of provenance of the grapevine phenology, pest and pathogen observations used for model calibration and validation. The meteorological stations used to calibrate and validate the models for the sites of Cembra, San Michele, Besagno, Cognola, Faedo and Tenna were in close proximity (less than 1 km) to the phenology/pest and disease monitoring sites and are not represented in the map for clarity. Between parenthesis (): elevation above sea level of each site. Inset: The Trento province is highlighted in bold at the centre of the square encompassing the study area.

The European Grapevine moth (*Lobesia botrana)* is one of the most noxious vineyard-pests in the European and Mediterranean areas (Delbac et al., 2010). Its larvae feed on grapevine flowers and berries, with a facultative diapause and a variable number of generations per year, depending on temperature and photoperiod (Pavan et al., 2010). It is usually reported as being trivoltine in Mediterranean areas although, in the warmest years, a fourth partial generation has been reported (Torres-Vila et al., 2004). The first adults of *L. botrana* appear in the spring and are shortly followed by the first generation of larvae which feed on inflorescences and buds; in Northern Italy this occurs between May and June. Subsequent generations feed on berries and usually cause considerable damage (Moschos et al., 2004). However, the sensitivity of grapevines to infestation by this pest varies during the grape growing season (Gabel and Roehrich, 1995; Pavan et al., 2009). Gabel and Roehrich (1995) compared the damage produced by larvae infestation at different growth stages on different grapevine cultivars and observed for all stages a period in which fructiferous organs (flowers and berries) were unsuitable for infestation by freshly hatched larvae, i.e. flowering and fruit set. During this "resistant" phenological window, the level of damage caused by larvae was significantly lower compared to earlier and later growth stages.

Powdery mildew (*E. necator*) is one of the major diseases in grapevine (Gadoury et al., 2003; Bendek et al., 2007; Caffi et al., 2011). It affects green leaves and fruit and reduces the yield of grapes and the quality of must and wine (Gadoury et al., 2001; Campbell et al., 2006). This pathogen undergoes sexual and