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Review

Pest management under climate change: The importance of understanding tritrophic relations

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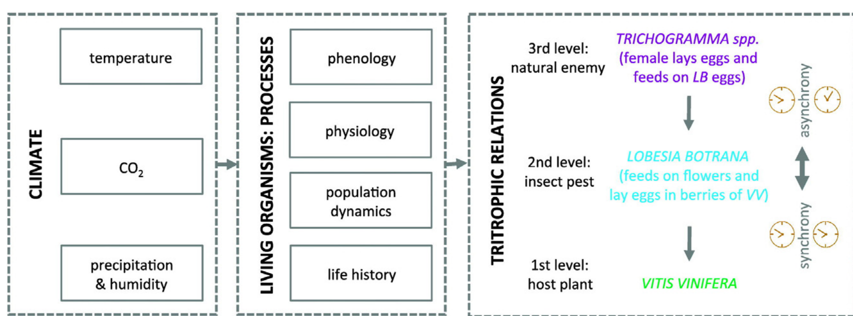
HIGHLIGHTS

- Climate change might affect trophic interactions in timing and distribution.
- Warmer conditions will enhance shifts in plant and insect phenologies.
- Voltinism might increase in warmer regions previously unsuitable.
- Southern regions could become too warm in the future for optimal IPM.
- Warming conditions may change the latitudinal distribution of insect pests.

GRAPHICAL ABSTRACT



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ABSTRACT

Plants and insects depend on climatic factors (temperature, solar radiation, precipitations, relative humidity and CO_2) for their development. Current knowledge suggests that climate change can alter plants and insects development and affect their interactions. Shifts in tritrophic relations are of particular concern for Integrated Pest Management (IPM), because responses at the highest trophic level (natural enemies) are highly sensitive to warmer temperature. It is expected that natural enemies could benefit from better conditions for their development in northern latitudes and IPM could be facilitated by a longer period of overlap. This may not be the case in southern latitudes, where climate could become too warm. Adapting IPM to future climatic conditions requires therefore understanding of changes that occur at the various levels and their linkages. The aim of this review is to assess the current state of knowledge and highlights the gaps in the existing literature concerning how climate change can affect tritrophic relations. Because of the economic importance of wine production, the interactions between grapevine, *Vitis vinifera* (1st), *Lobesia botrana* (2nd) and *Trichogramma* spp., (3rd), an egg parasitoid of *Lobesia botrana*, are considered as a case study for addressing specific issues. In addition, we discuss models that could be applied in order quantify alterations in the synchrony or asynchrony patterns but also the shifts in the timing and spatial distribution of hosts, pests and their natural enemies.

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Contents

1. Introduction

Plants and insects are dependent on heat and sunlight accumulation for their development. Plant phenology (the sequence of developmental stages) is directly influenced by weather and climate (temperature, photoperiod, CO_2, relative humidity, precipitation) (Bale et al., 2002; Bregaglio et al., 2013; Caffarra and Donnelly, 2011; García de Cortázar-Atauri et al., 2010). Insect pests are as well influenced directly (climatic factors) and indirectly (length of the growing season, habitat structure, food quality, overwintering, oviposition) in their development (Moreau et al., 2008; Reineke and Thiery, 2016). Previous studies have shown that changes in climatic conditions over the last three decades have already influenced interactions between plants and insects pests. Concerning future climate change, even stronger impacts on population dynamics, adaptation, limits of development and phenological stages are expected (Caffarra et al., 2012).

The Intergovernmental Panel on Climate Change (IPCC) reports that levels of CO_2 around 280 ppm prior to the industrial period have today exceeded 400 ppm and could attain up to 550 ppm in 2050, depending on emission scenario (Solomon et al., 2007). In line with this, climate models project a further increase in mean temperature for the future. They further indicate shifts in precipitation patterns and higher frequencies of extreme weather events, even if such changes are harder to predict (Edenhofer et al., 2015). As discussed in Rogeli et al. (2016), the 2015 Paris climate agreement (COP-21) aims at limiting emissions to hold global warming below 2 °C (based on the IPCC AR5 Scenario Database). In a more pessimistic scenario, an increase of 4 °C to 6 °C become probable if Paris targets are not reached.

For agriculture, the evaluation of the impacts of a changing climate on plant growth plays a key role in view of the necessity to adapt crop management (Bregaglio et al., 2013). Gregory et al. (2009) point out that integration of pests into such assessment is necessary to develop effective measures of adaptation to future climatic conditions. Higher temperatures are expected to affect not only plants and insects phenology and physiology individually, but also biological interactions between these two trophic levels (Kalinkat et al., 2015). Initially defined by Solomon (1949), the concept of "trophic interactions" refers to the predation risk for the prey. This concept can be extend to include a third level, where natural enemies act as predator of insect pest (Price, 1980). Tritrophic relations are particularly important in the context of sustainable agriculture because they are at the heart of Integrated Pest Management (IPM) (Wajnberg et al., 2016). In fact, IPM aims at using natural predators as biological control agents against insect pests.

The overarching goal of this study is to review current knowledge on how climate change can affect agricultural crops, pests and their natural enemies. Concepts and ideas are developed here referring to pests and pest management in viticulture, more specifically to the three levels of interactions where *Vitis vinifera* acts as host plant (1st level), *Lobesia botrana* as the herbivore (2nd level) feeding on *V. vinifera*, and *Trichogramma* spp., an egg parasitoid of *L. botrana*, as natural enemy (3rd level).

First, this review aims at emphasizing that under climatic change, and at different latitudes, tritrophic relations might evolve in synchrony or asynchrony according to bioclimatic regions. Secondly, considering the important range shifts that have already occurred for a number of taxa with respect to latitude and altitude in the recent past (Chen et al., 2011). It is expected that warming climate might alter tritrophic relations leading to stable, expansion or to extinction of some species, but the knowledge on their timing and distribution in the future is still unclear. This literature review aims at obtaining an overview of validated facts, models, historical and observed data in the objective to model and understand whether the expected range shifts might evolve under global warming conditions.

1.1. Climatic variables and phenology

1.1.1. Grapevine and climate

V. vinifera (*grapevine*), as a perennial plant, can provide valuable information on past climatic variations (observed phenology) allowing predictions to be made concerning future development under changing climatic conditions (Lacombe et al., 2013). In this context, climate is considered as a long-term forcing factor, while weather comprises short-term meteorological variations that are linked to local or regional specificities such as altitude, exposure to sunlight and slope orientation and modulated by the seasonality of grapevine growth (Rusch et al., 2015). All these factors will influence the accumulation of Degree Days (DD) and induce changes in the phenology and physiology (roots system, foliage and aerial system) of *V. vinifera*.

Phenology is the study of development stages of plants as a result of heat (forcing) and cold (chilling) accumulation during growing and dormancy periods. In many wine-growing European regions, the trends recorded in the last decade reveals changes in growing season