Scientific Papers. Series B, Horticulture. Vol. LXVIII, No. 1, 2024
Print ISSN 2285-5653, CD-ROM ISSN 2285-5661, Online ISSN 2286-1580, ISSN-L 2285-5653

# BIOLOGICAL ASPECTS AND MANAGEMENT APPROACHES OF THE GRAPEVINE PEST, *PULVINARIA VITIS*, IN THE CLIMATE CHANGE CONTEXT

**Ioana Sorina GIURCA, Liliana Lucia TOMOIAGĂ, Maria Doinița MUNTEAN, Maria COMȘA, Alexandra Doina SÎRBU, Horia Silviu RĂCOARE, Veronica Sanda CHEDEA**

Research Station for Viticulture and Enology Blaj (SCDVV Blaj),
2 Gheorghe Barițiu Street, Blaj, Romania

Corresponding author emails: comsa_m@yahoo.com, tirnovean.ioana@gmail.com

***Abstract***

*The aim of this study arises from the emergence of new outbreaks producing damage in vineyards from Transylvania and also from the limited amount of updated literature on Pulvinaria vitis, in Romania. The present paper provides an overview of the biology and control of Pulvinaria vitis in the climate change context, because further research is needed, especially on specific regions where it was identified, in order to understand the full range of impacts and to elaborate effective management strategies. In the last few years, wine growers reported the presence of a sticky black residue on the grapevines and a cottony grape scale, which seems to produce economic losses. Pulvinaria vitis has the ability to cause damage by feeding on phloem sap and excreting honeydew on which sooty mold develops, reducing the plant's capability of respiration, transpiration, and photosynthesis. Additionally, it has been identified as a vector for several grapevine-infecting viruses. Recent climate change appears to be influencing the distribution and life cycle of Pulvinaria vitis and also making the plants more susceptible to pest damage.*

***Key words**: climate change, vineyard pest, management strategies, Pulvinaria vitis*

## INTRODUCTION

At the global level, the last two years were characterized by high rates of inflation, disruptions in supply chains and an energy crisis induced by the Ukraine conflict. In this context, many markets experienced substantial increases in wine prices which lead to a slight decline in global consumption volumes. The current value of international wine exports, though, is at an all-time high (State of the world vine and wine sector in 2022. April 2023. OIV. Retrieved from https://www.oiv.int/sites/default/files/documents/OIV_State_of_the_world_Vine_and_Wine_sector_in_2022_2.pdf), therefore the importance of viticulture is increasing.

FAO and OIV latest statistics regarding the current status of grapevine cultivated areas and grapes production in Romania are presented in Figure 1. According to the FAO's statistics, in 2022, Romania harvested an area of 159.740 ha (representing 2.6% of the global harvested area) and produced 804.800 tons of grapes (Food and Agriculture Organization of the United Nations. Crops and livestock products. Data retrieved from www.fao.org/faostat/en/#data/QCL). The EU holds 46.20% of the total grape harvested area in the world, and Romania ranks 5th out of the 25 EU member states. OIV supports the FAO`s statistics and ranks Romania on the 10th place out of the 98 states of the world (Country Statistics. International Organisation of Vine and Wine. Romania, 2022 data. Retrieved from https://www.oiv.int/what-we-do/country-report?oiv). Also, OIV statistics highlight a 0.6% decrease of the harvested area in Romania in 2022 compared to 2021. In fact, significant decreases in the harvested areas are noted for the last 2 decades all over the world. Even so, the production of grapes has the tendency to remain at the same levels (World Statistics. International Organisation of Vine and Wine. World, 2022 data. Retrieved from https://www.oiv.int/what-we-do/country-report?oiv). This implies that along time, better vineyard management strategies were used and this domain is always under ongoing adjustments and improvements.

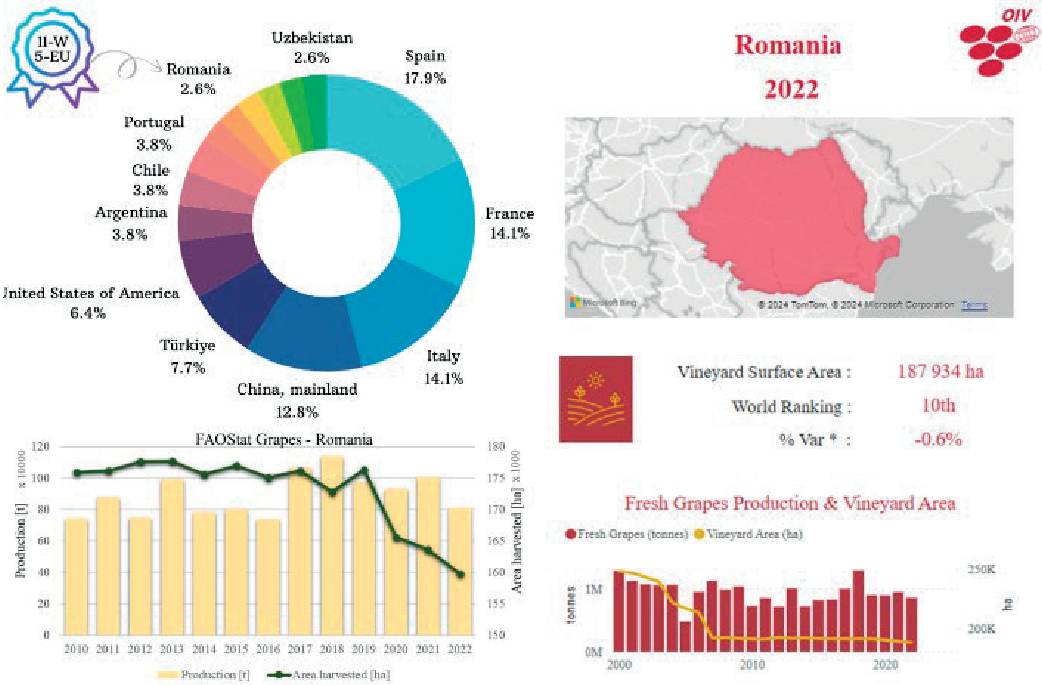


Figure 1. Statistics regarding the harvested areas and grape productions in Romania

Due to its fertile soils and advantageous climatic conditions, viticulture has thrived in Romania since ancient times (Chedea et al., 2021; Chiurciu et al., 2020; Muntean et al., 2022). Positioned in Eastern Europe, Romania spans from 43°37′ to 48°15′ N latitude and 20°15′ to 29°44′ E longitude. The country's climate is classified as temperate continental according to the updated Koppen-Geiger climate classification, supporting eight prominent viticultural regions (Irimia et al., 2018; Chedea et al., 2021; Muntean et al., 2022). In the last decade the cultivation of grapevines in Romania, deeply rooted in history and tradition, is transforming due to climate change. Even if this phenomenon is reshaping the viticultural landscape, Romanian viticulture has shown adaptability and resilience to changes in climate over time (Brașoveanu et al., 2020). Statista Research Department reports that approximately 1.2 thousand hectares of Romania's vineyards were under reconstruction and conversion in 2023 (Statista, 2023).

In a report from 2022, The Intergovernmental Panel on Climate Change states that the occurrence of hazards is on the rise due to climate change, which increases susceptibility and exposure and reduces the capacity of systems and individuals to cope. In addition to crop and agricultural production losses, the repercussions include the destruction of agricultural biodiversity balance and negative chain reactions that have far-reaching ramifications on a local, national, regional, and even global scale (Pörtner et al., 2022).

A significant aspect of the environmental impact on viticulture is the management of diseases and pests, which may cause pollution (Komárek et al., 2010) and adverse effects on human health (Ntzani et al., 2017). The biology and populations of pests are impacted by climate change; therefore, plant protection measures in vineyards may undergo modifications in response to the escalation of pest or diseases in the vineyards (Caffarra et al., 2012; Salinari et al., 2006). Also, the phenology of the vine, which is significantly impacted by global warming, increases plant vulnerability to pathogens, and vectors behaviour must all be considered in disease and pest management (Reineke & Thiéry, 2016). Adding to all of this the fact that the European Green Deal Agenda includes the reduction of insecticide use as a critical component for its ambitious goal of making the European Union climate neutral by 2050 (Tataridas et al., 2022), finding the appropriate management strategy could be quite a challenge in the next years.

Observations over the past thirty years regarding pests affecting grapevines have revealed an expansion in the habitat of grapevine mealybugs (Santos et al., 2020), which are part of superfamily Coccoidea, the same as *Pulvinaria vitis*. The Coccoidea forms a significant part of the vine insect complex. In 1997, Pellizzari reports that the soft scales that are identfied as vine pests are *Parthelonecanium persicae* (Fabricus)*, Neopulvinaria innumerabilis* (Rathvon)*, P. corni* (Bouchr)*, and Pulvinaria vitis* (Linnaeus) (Pellizzari G, 1997).

*Pulvinaria vitis* (Coccoidea superfamily, Coccidae family, *Pulvinaria* genus) also named the cottony grape scale is a scale insect, part of Coccidae family, which are sap-feeding insects. They target the fruit, roots, stems, leaves and buds of the plant. Usually abundant in warmer areas, many species represent important economic pests. The Coccoidea or scale-insects, including *Pulvinaria vitis* have been understudied in Romania and is quite likely that the economic importance of this group is underestimated (Fetykó et al., 2010). It has been estimated that scale insect-related agricultural losses and additional production expenses surpassed, at a global level, 1 billion $ annually (Kosztarab, 1977).

This review aims to explore the biological aspects and management approaches of the grapevine pest, *Pulvinaria vitis,* within the context of climate change, by synthesizing current knowledge and identifying future research needs.

## BIOLOGY AND ECOLOGY

Scale insects are often small and easily overlooked therefore, they present considerable challenges regarding the taxonomy, especially due to their complex life histories and morphological variability. Sanders (1909) was among the first to point out the uncertainties and errors in identifying soft scales, by pointing out the influence of the host plant on the development of the pest. Phillips (1962) indicates a complex interaction between genetic factors and environmental conditions, especially the host plant, in determining the morphology of *Pulvinaria* species.

Recent taxonomic clarifications provided by (Tanaka & Kamitani, 2020), offer essential foundations for accurate pest identification and management, by enhancing taxonomic resolutions through the integration of molecular tools with traditional morphological approaches, facilitating precise monitoring and management of *Pulvinaria vitis*. Yet, they also underscore the necessity for continuous refinement of taxonomic frameworks and methodologies.

### Taxonomy and description

First described by Linnaeus in 1758, *Pulvinaria vitis* belongs to the phylum Arthropoda, which includes invertebrates with an exoskeleton, segmented body, and jointed appendages. In this phylum, *Pulvinaria vitis* is classified under the class Insecta. The order Hemiptera, to which it belongs, includes insects commonly known as true bugs, most of them being characterized by their piercing-sucking mouthparts. Just like aphids, whiteflies and jumping plant lice, they are members of the Sternorrhycha suborder (Gullan & Cook, 2007). Within this suborder, *Pulvinaria vitis* is further classified into the superfamily Coccoidea, family Coccidae, which includes more than 1200 known species. The Coccidae family is the third biggest in the Coccoidea superfamily (Ben-Dov, 1993) and the *Pulvinaria* genus, within this family, encompasses a group of scale insects, with *Pulvinaria vitis* being a specific species within this genus.

Scale insects are sap-sucking parasites, with different hosts plants almost all over the world. Scales are significant agricultural pests and can be distinguished from other insects by their protective waxy exudate, representing their characteristic appearance (Kozár et al., 2013). In the field of entomological taxonomy, the clarification of synonymies among species names is essential for the accurate identification and study of pests, regarding the case of *Pulvinaria vitis*, Newstead (1903) was the first to publish a synonymy consolidating *Pulvinaria betulae*, *Pulvinaria carpini*, and *Pulvinaria oxycanthae* under the name *Pulvinaria vitis*, thereby establishing priority for this nomenclature over others published simultaneously (Malumphy, 1991). This taxonomic decision has since directed the nomenclature usage across various regions, with *Pulvinaria vitis* being the preferred term in Western Europe, North America, North Africa, and New Zealand, while *Pulvinaria betulae* was predominantly used in Eastern Europe and Japan (Malumphy, 1991).

In 1909, J.G. Sanders highlighted widespread uncertainty and errors in the classification and identification of soft scales, attributing this confusion primarily to the fact that early entomologists underestimated the fact that the host plant can affect development, size, color and markings of mature females and also to the fact that it was believed that Coccidae insects are sedentary and could not live on different genera of host plants (Sanders, 1909). He disputed the distinct classification of *Pulvinaria innumerabilis* in the U.S., arguing no significant difference from *Pulvinaria vitis* based on a study that showed host plants affect development, size, coloration, and markings of mature females (Sanders, 1909). The publication of Steinweden from 1929, also provides a comprehensive analysis of various Coccidae family genera, including *Pulvinaria vitis.* He describes the morphological characteristics of adult females that differentiate them from other species (Steinweden, 1929).

J. H. H. Philips reported in 1962 four species of scale insects belonging to the genus *Pulvinaria*, identified in a study conducted in peach growing regions of southern Ontario: *Pulvinaria vitis* (Linnaeus)*, Pulvinaria innumerabilis* (Rathov)*, Pulvinaria acericola* (Walsh and Riky) and *Pulvinaria floccifera* (Westwood). Of these only *Pulvinaria vitis* and *Pulvinaria innumerabilis* were present in a number of economic importance. Also, he highlights the fact that the similarity of these two species, particularly in the presence of the ovisac, makes them prone to confusion (Phillips, 1962).

While the provided classification is accurate and valuable, there was still a need for future studies that should aim to incorporate genetic insights to further elucidate the taxonomy and evolutionary biology of *Pulvinaria vitis*. With the scales being small insects, frequently overlooked it is necessary to integrate the taxonomic information with current genetic and molecular studies to refine the understanding of *Pulvinaria vitis*'s position within the Coccidae family. Valuable works, such as those of Hodgson (1994) and Gullan and Martin (2003), highlighted the importance of integrating morphological taxonomy with molecular data to address the complexities of scale insect classification and phylogeny. This approach not only aids in clarifying taxonomic ambiguities but also enhances the comprehension of evolutionary relationships and adaptation mechanisms among scale insects (Gullan & Martin, 2009; Hodgson & Peronti, 2012).

The recent studies of Tanaka and Kamitani (2020) have shed some light on the detailed morphology of *Pulvinaria vitis*, by providing an extensive review of the morphological characteristics of four species of the *Pulvinaria* genus from the Ryukyu Islands, Japan (Tanaka & Kamitani, 2020).

Regarding the scale insect fauna of Romania, Fetyko et al. (2010) stated that it is still poorly known, the first Romanian checklist of scale insects being compiled by Savescu in 1985 (Fetykó et al., 2010). The synthesis of Savescu (1983) validated the presence of *Pulvinaria vitis* in Romania among other two *Pulvinaria* species: *Pulvinaria floccifera* and *Pulvinaria regalis* (Paraschiv, 2023). Teodorescu I. (2018) reported that *Pulvinaria vitis* was also reported in Romania under the synonim *Pulvinaria betulae* (Munteanu, 2018).

**Morphology and life cycle**

There is a complex interaction between genetic factors and environmental conditions in shaping the morphology of *Pulvinaria* species (Phillips, 1962). The studies and observations made by Sanders (1909), Phillips (1962), and Steinweden (1929), collectively contribute to the understanding of host specificity, and morphological variations within the genus *Pulvinaria* and the broader family Coccidae. Steinweden (1929) experiment, which involved transplanting juvenile larvae of various *Pulvinaria* species between different host plants, revealed significant host-dependent variations in the development of these pest insects. The findings indicated that the host plant plays a crucial role in determining the size, pigmentation, and markings of mature females, suggesting a high degree of phenotypic plasticity within these species (Sanders, 1909). Phillips (1962) work further supports this by highlighting the minimal variation in specific body elements despite significant differences in overall body size among individuals from different hosts. They all highlight the importance of detailed morphological and ecological studies in understanding the taxonomy, evolution, and host specificity of scale insects (Sanders, 1909; Steinweden, 1929; Phillips, 1962).

J. P. Malumphy (1991) thesis is a valuable investigation work about *Pulvinaria vitis* complex in Europe. A more recent thorough analysis of *Pulvinaria* species from Japan, including *Pulvinaria vitis*, as a type species of the genus, was carried out by Tanaka (2020) and Tanaka & Kamitani (2020). In their study, they provide a detailed morphological description of the adult female of *Pulvinaria vitis*, comparing it with previous descriptions and other species within the genus. Their research provides important new insights into the morphological properties that differentiate *Pulvinaria vitis*, including body size, shape, dorsal and ventral surface structure. In order to distinguish *Pulvinaria vitis* from other species in the genus, a table of diagnostic morphological character sets and a key to the species of *Pulvinaria* are also included. They concluded that morphological descriptions of regional populations are important in order to understand the range of morphological variation in widespread species (Tanaka & Kamitani, 2020).

The life cycle and biological characteristics of soft scales, in general, is challenging due to the presence of great variations among species within the same genus (Kosztarab, 1996). The majority of the species under this group display cryptic characteristics and invasive behaviour (Malumphy, 1991; Paraschiv, 2023). In biparental species, males have a derived form of incomplete metamorphosis, which consists of two feeding nymphal instars followed by the nonfeeding prepupal (third-instar), pupal (fourth-instar), and adult (Camacho & Chong, 2015).

The soft scale insects are known for their distinct morphological features. Typically, the length of the scales does not surpass 5 mm and their sexual dimorphism is evident. The females are usually wingless and their reproduction is frequently parthenogenetic (Malumphy, 1991; Paraschiv, 2023).

According to (Jansen, 2000), the soft scale species of the genus *Pulvinaria* can be distinguished from other genera of the family Coccidae by the combination of specific characters. Immature females are almost twice as long than wide, the tibia and tarsus usually are freely articulating, also they produce a typical white cottony ovisac under the body (Jansen, 2000). The significant microscopic characters are represented by the three spiracular setae of which the median one is two or three times longer than the lateral two and different in shape (Jansen, 2000). Females of most *Pulvinaria* species are oval shaped, flat, wrinkly and the colour is from chestnut to greyish brown (Jansen, 2000).

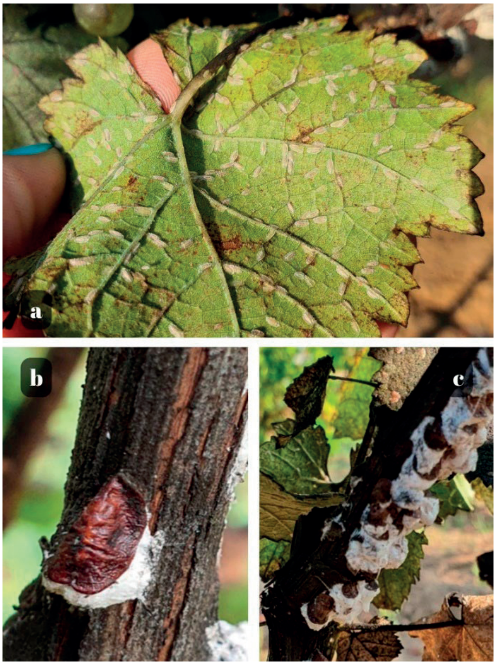


Figure 2. *Pulvinaria vitis* (L2) nymphs on grapevine leaf (a); *Pulvinaria vitis* adult female specimen on grapevine (b); *Pulvinaria vitis* infestation on grapevine (c)

The adult females of *Pulvinaria vitis* are 3-8 mm long, ovoid to circular, dark brown and flat, presenting 3-5 transversal striae. To the post reproductive female, the dorsum gets wrinkled and strongly sclerotized. The females of *Pulvinaria vitis* are known for their ability to produce a cottony ovisac that protects their eggs, a characteristic that is distinctive to the genus and critical for the protection of the next generation (Phillips, 1962).The ovisac is wide convex, cottony, white, and longer than the body of adult female (Kosztarab & Kozár, 1988; Masten Milek et al., 2009). Figure 2 presents morphological aspects of different life stages of *Pulvinaria vitis* on grapevine.

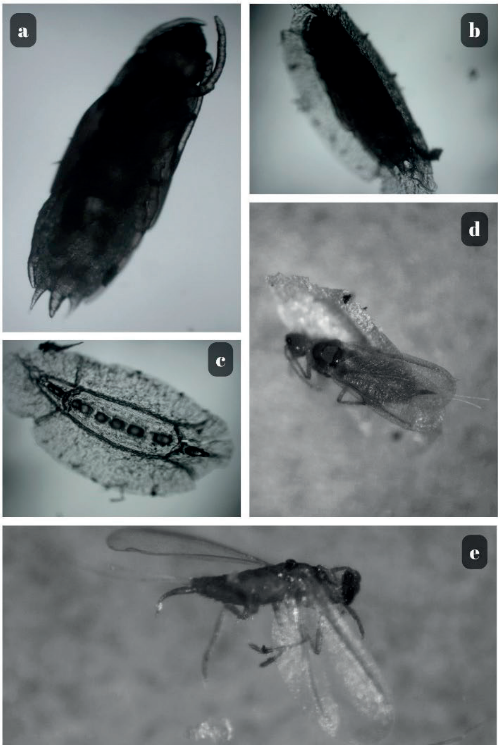


Figure 3. *Pulvinaria vitis* male specimen on different development stages (a, b, d, e); empty male test (c)

The adult males are pinkish and winged (Figure 3), smaller than the females, approximately 1.5 mm long (Gill, 1988; Hommay et al., 2021; Phillips, 1962; Tomoiagă Liliana, 2006). They do not feed as adults and they develop from unfertilized eggs, while females develop from fertilised eggs (Malumphy, 1991). They die after mating in the fall, while females overwinter and then produce white waxy egg masses from the end of April to early June. One adult female produces between 1000 and 5000 eggs, embedded within a cotton-like structure, called the ovisac, which grows beyond the shield and lifts it progressively (Phillips, 1962, 1963; Malumphy, 1991; Giuseppina Pellizzari, 1997; Hommay et al., 2021).

*Pulvinaria vitis* exhibits an univoltine life cycle, with one generation per year. The reproduction is both sexually and parthenogenetically and the mechanism that regulates the mode of reproduction is not completely understood (Phillips, 1963; M. Kosztarab & F. Kozár, 1988; Pellizzari, 1997; Camacho & Chong, 2015). Adults mate from September to October, then the insect overwinters as young females, protected under the bark of the shoots and completes its development in the following year (Phillips, 1963; Pellizzari, 1997; Camacho, 2015; Jansen, 2000; Hommay et al., 2021).

The eggs are orange to wine-red, 0.20-0.30 mm long, and hatch from late May to June (Tomoiagă, 2006; Hommay et al., 2021) when the temperature reached 14°C. An increase in temperature was found to be associated with an increase in the hatching rate. After the nymphs hatch, they disperse onto the leaves, petioles, or shoots (Phillips, 1963; Pellizzari G, 1997; Hommay et al., 2019). The nymphs, referred to as crawlers, represent the primary dispersal phase, facilitating the colonization of new host plants (Phillips, 1962; Malumphy, 1991). After emerging, the nymphs have phototactic and photokinetic attributes and their establishment to the host plant is influenced by several environmental factors like light intensity, humidity, and airflow (Phillips, 1963).

*Pulvinaria vitis* presents three nymphal stages with the first moult in July and the second in August (Pellizzari, 1997; Hommay et al., 2021). The first instar is initially just a bit bigger than the egg, around 0.5 mm, but grows rapidly to a length of maximum 1 mm. Initially having a deep orange hue, it transforms into a transparent orange-yellow as soon as it settles on the plant. The first moult takes place 12 to 18 days after hatching, the second after 28 to 36 days, and the third 56 to 93 days after hatching (Philips, 1963). The third instar is described to have maximum 3 mm in length and a yellow to greyish-brown color with reticulate dark brown patterns (Phillips, 1962; Steinweden, 1929; Pellizzari, 1997; Tomoiagă, 2006; Hommay et al., 2021).

A correlation between the life cycle of *Pulvinaria vitis* and the annual life cycle of grapevine is essential in the process of establishing and implementing Integrated Pest Management strategies. In this sense, Figure 4 presents the life cycle of *Pulvinaria vitis* - adapted after Jansen (2000) in correlation with the annual life cycle of grapevine, as described by Venios et al. (2020) Both studies are from the Northern emisphere (from Europe).

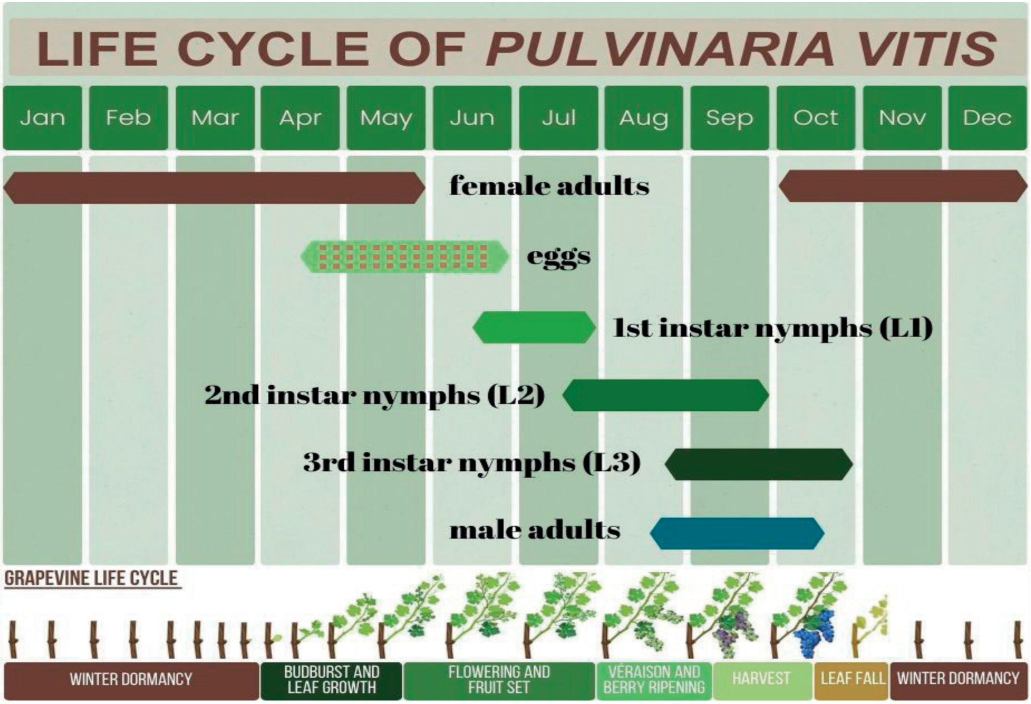


Figure 4. *Pulvinaria vitis* life cycle (adapted after Jansen, 2000) in correlation with the grapevine annual life cycle (described by Venios et al., 2020)

Some important distinctive microscopic characters in differentiating *Pulvinaria vitis* from other Pulvinarias are noted by Milek (2009). This refers to the marginal setae, the long-paired setae from meridian region, the ventral tubular ducts and the dorsal submarginal duct tubercules (Masten Milek et al., 2009).

The biology and ecology of *Pulvinaria vitis* is of great complexity. Future research areas should address the species' adaptability to the recent climate changes, host range expansion, and its interactions with other species within the ecosystem. Even tough significant progress has been made, particularly in the areas of genetic and molecular studies, the continued exploration of *Pulvinaria vitis* remains critical for developing effective management strategies and understanding its ecological impact.

**Host range and records**

Information on the geographical distribution of scale insect species can act as a reliable indicator of biodiversity across different ecosystems, including natural, agricultural, and urban environments. Such data may also be an indicator on the impacts of climate change over time (Kosztarab & Kozár, 1988).

Originating from the Palaearctic region, *Pulvinaria vitis* has expanded its presence to the Nearctic, Neotropical regions, and New Zealand, showcasing its adaptability and polyphagous nature (Gill, 1988). This scale insect targets a variety of woody plants and has been recognized as a pest affecting especially *Vitis vinifera*, but also other species (Malumphy & John, 2012; García Morales et al., 2016).

In the literature there are some authors documenting its presence on different host species and outbreaks on various parts of the world. J.H.H. Phillips (1962) reported that in Ontario, *Pulvinaria vitis* had a significant economic impact primarily on peach trees (*Prunus persica*). He also noted that laboratory studies showed his ability to infest willow

(*Salix*), poplar (*Populus*), gooseberry (*Ribes grossularia*), fox grape (*Vitis labruscana* Bailey), and hawthorn (*Crataegus* spp.) (Phillips, 1962)

Ben-Dov et al. (2008) reports host plants belonging to the following families: Aceraceae, Betulaceae, Celastraceae, Compositae, Corylaceae, Hippocastanaceae, Juglandaceae, Oleaceae, Rosaceae, Salicaceae, Tamaricaceae, Tiliaceae and Vitaceae (Ben-Dov et al., 2008). It was also recorded in Austria, Vienna by (Kosztarab & Kozár, 1988) on *Corylus* sp. (C. Malumphy & Kahrer, 2011). Acording to C. Malumphy & Kahrer (2011) *Pulvinaria vitis* was recorded feeding on plants belonging to at least 16 families, of which most common on Betulaceae, Grossulariaceae, Rosaceae, Salicaceae and Vitaceae (C. Malumphy & Kahrer, 2011). Also, *Pulvinaria vitis* has been reported as a major pest of *Vitis vinifera* in Croatia, where it was not considered to produce important economic loses until 2006 when a mass outbreak, showed that it can easily become of great economic importance (Masten Milek et al., 2008). The study of Masten Milek et al. (2007), including different grapevine varieties as host plants, found no significant difference in susceptibility between white and red grape varieties, although certain varieties displayed varying levels of sensitivity to infestation (Masten Milek et al., 2007). Additionally, the results of investigation showed that on the same soil type, intensity of infestation can highly variate, so it does not the depend on soil type (Masten Milek et al., 2008).

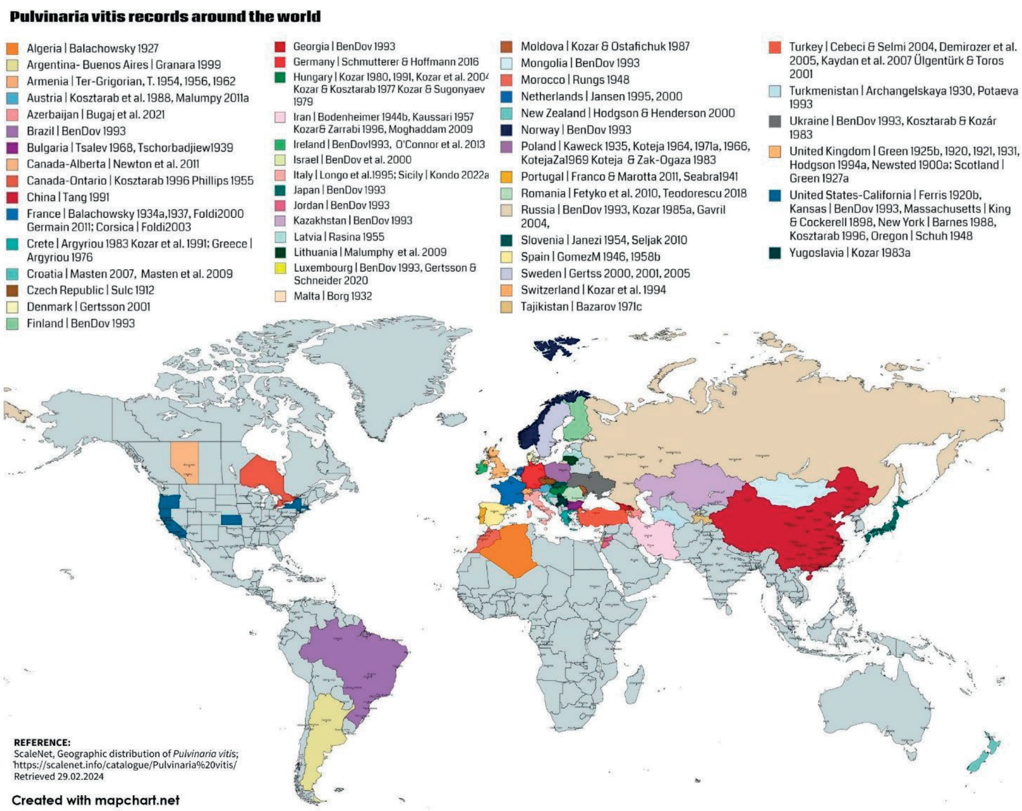

Figure 5. Records of *Pulvinaria vitis* around the world (according to Garcia Morales et al., 2016)

Figure 5 presents a geographic distribution of *Pulvinaria vitis* around the world, based on ScaleNet summarized reports of various authors (Garcia Morales et al., 2016).

The dispersal mechanisms of *Pulvinaria vitis*, particularly in its nymphal stages, are critical for understanding the spread of this pest within and between vineyards. Research has shown that nymphs, once past the crawler stage, can be transported by wind, from infested to uninfested plants (Phillips, 1963). This was evidenced in a controlled insectary setting where third instar nymphs were observed being carried across a six-foot open space, indicating the potential for wind-assisted dispersal in natural environments. Also, the ovisacs of *Pulvinaria vitis* are often found broken, with eggs exposed. These observations suggest that birds, while attempting to feed on the adult scales, may contribute to the spread of *Pulvinaria vitis* eggs by carrying them to other plants (Phillips, 1963). The combination of abiotic and biotic factors highlights the complexity of pest spread in vineyards and the need for comprehensive management strategies that consider multiple vectors of dispersal (Camacho & Chong, 2015).

## DAMAGE

Insects can impact the growth and development of plants through direct consumption or indirectly by transmitting viruses and bacteria, or triggering alterations in plant biochemical processes (Zogli et al., 2020; Cooper et al., 2023). Insects equipped with piercing or sucking mouthparts extract nutrients from plants by consuming fluids, through either external digestion of cellular contents or by ingesting from the phloem or xylem (Cooper et al., 2023). This type of feeding can activate plant's immediate defensive mechanisms through the salicylic acid pathway, triggering various indirect defences, including alterations in plant hormone levels or attracting helpful insects by emitting volatile compounds, which could mitigate the impact of these pests (Erb, 2018; Cooper et al., 2023).

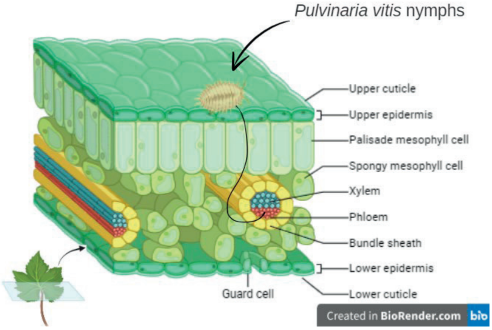


Figure 6. *Pulvinaria vitis* phloem-feeding on leaf

The phloem-feeding behaviour of soft scales, including *Pulvinaria vitis*, on grapevines constitutes a significant area of concern for viticulture, given the consequential impacts on the physiological and biochemical dynamics of the host plants (Hommay et al., 2021). *Pulvinaria vitis,* by its feeding mechanism, taps directly into the phloem sap, a rich source of sugars and other essential nutrients. The stylets are capable of penetrating deep into the plant tissues, reaching the phloem and sometimes even the xylem, which can cause significant damage to the cambium and overall health of the host plant (Phillips, 1963). The saliva of certain species includes proteinases and cellulases, enzymes that can disrupt cells and harm vascular and photosynthetic tissues close to the stylet's penetration point (Camacho & Chong, 2015). While the necrosis caused by single scale insects tends to be localized, extensive damage from severe infestations can result in the dieback of twigs and branches (Vranjic, 1997). This not only weakens the plant but also predisposes it to a spectrum of secondary infections and stress responses. Moreover, the feeding activity of *Pulvinaria vitis* is intricately linked to the transmission of grapevine leafroll-associated viruses. Almeida et al. (2013) emphasized the need for comprehensive research into the biology of leafroll transmission by soft scales, including *Pulvinaria vitis*, which has been identified in Europe as a vector for grapevine leafroll viruses. Their call for further investigation highlights the existing knowledge gap regarding the mechanisms of virus transmission by soft scales (Almeida et al., 2013). Complementing this, Hommay et al. (2021) provides compelling evidence of *Pulvinaria vitis* acting as a vector for Grapevine leafroll-associated viruses -1 and -3, as well as Grapevine virus A, to healthy vine cuttings. This study marks the first documented case of *Pulvinaria vitis* facilitating the grapevine-to-grapevine transmission of these viruses, establishing its significance in the epidemiology of grapevine viral diseases (Hommay et al., 2021).

The phenomenon of sooty mold development on grapevines, as a direct consequence of *Pulvinaria vitis* infestation, represents a significant pathological challenge within viticultural practices. Sooty mold fungi forms on the honeydew excreted during their phloem-feeding activities, forming a black coating on leaf surfaces, stems, and even fruit. Honeydew is comprised of a complex blend of phloem-derived sugars including sucrose, fructose, and glucose, alongside oligosaccharides like erlose and melezitose, which are synthesized by the phytophagous insects (Völkl et al., 1999; Wäckers, 2000). This fungal growth severely impedes the photosynthesis by obstructing light penetration to the leaf surface, thereby compromising the plant's energy acquisition processes. Furthermore, the presence of sooty mold on grape bunches significantly diminishes the aesthetic and market value of the fruit, leading to economic losse. Beyond the direct physical and economic damage, the establishment of sooty mold serves as an indicator of scale insect presence and abundance, suggesting an underlying pest management issue that requires immediate attention (Cooper et al., 2023).

Understanding the specific interactions between *Pulvinaria vitis* and host plants is crucial for developing targeted interventions. Strategies such as the use of resistant grapevine cultivars, the implementation of biological control agents, and the application of systemic insecticides could be optimized based on insights into the feeding behaviour of soft scales. Additionally, monitoring and managing the vector populations at critical points in the grapevine growth cycle could significantly reduce the incidence and spread of leafroll viruses, thereby minimizing the economic and agronomic impacts on viticulture.

## MANAGEMENT AND CONTROL

Implementing monitoring strategies is essential for the effective intervention and management of *Pulvinaria vitis* populations in the vineyards. When monitoring *Pulvinaria vitis*, attention should be directed towards identifying partially developed crawlers during pruning activities and locating mature females with their cottony ovisacs in late spring. The presence of honeydew on leaves and fruit in summer also serves as an indicator of infestation (Kabashima & Dreistadt, 2014). This honeydew not only attracts ants but also results in them defending the scales from natural predators as part of a mutualistic relationship. Ant activity, characterized by their rapid movement along vine trunks to access the infested canes, is a sign of scale pest presence (Kabashima & Dreistadt, 2014).

In the modern viticulture context, Integrated Pest Management (IPM) strategies are crucial for ensuring sustainable grape production while reducing the adverse impacts of pest control on the environment. Pertot et al. (2017) highlighted the importance of applying IPM practices in order to promote sustainable pest management approaches (Pertot et al., 2017). IPM strategies integrate biological, cultural, mechanical, and minimal chemical interventions, tailored to the specific ecosystem and pest dynamics of the vineyard.

Biological control relays on natural predators and parasitoids of vineyard pests, reducing the need for chemical pesticides and fostering a balanced ecosystem (Daane et al., 2018). Another example of innovative and effective control practices is provided by Gonçalves et al. (2022), who investigated the application of deep learning technologies on edge devices to automate the identification and quantification of pests using sticky traps in vineyards. Their research demonstrated the effectiveness of the SSD ResNet50 model in accurately identifying a variety of insect species, showing that the deployment of AI-powered methodologies could enhance the efficiency of pest monitoring processes in viticulture. This technology potentially supports the implementation of Integrated Pest Management (IPM) strategies by enabling more timely and informed decision-making (Gonçalves et al., 2022).

Biological control of soft scales, such as *Pulvinaria vitis*, is a key strategy of integrated pest management (IPM) and the framework for sustainable viticulture. Relying on natural enemies to control insect populations is an eco-friendly alternative to the use of chemicals, supporting the goals of protecting the environment and reducing pesticide use. The role of natural predators in the reduction of soft scale populations is accentuated by Rakimov et al. (2015), who advocate for enhancing biodiversity among insect communities as a method of biological control. By fostering a diverse ecosystem of beneficial insects, the reliance on chemical interventions can be reduced, promoting a more sustainable approach to pest management (Rakimov et al., 2015). For example, lady bugs, lacewings, and parasitic wasps are known to target and reduce soft scale numbers effectively (Pertot et al., 2017). Among the natural enemies, parasitoid wasps from the families Aphelinidae and Encyrtidae have been identified as particularly efficacious against soft scale pests, like *Pulvinaria vitis*. These are laying eggs either on or within the soft scales, then the wasp larvae consume the scale insect from within, causing its death (Wang et al., 2019). In a comprehensive study of soft scale parasitism, Abd-Rabou (2011) discovered that *Coccophagus scutellaris* was an efficent parasitic wasp for soft scale insects from Pulvinaria family (Abd-Rabou, 2011). Masten Milek et al. (2009), also reported *Chilocorus bipustulatus* L. and *Exochomus quadripustulatus* L. (fam. Coccinellidae) as predators and *Coccophagus lycimnia* (Walker) (fam. Aphelinidae) as parasitoid of Pulvinaria species (Masten Milek et al., 2009). Paraschiv (2023), studies investigate the efficacy of entomopathogenic nematodes, *Steinernema carpocapsae* (Weiser), *S. feltiae* (Filipjev), and *Heterorhabditis bacteriophora* (Poinar) as biocontrol agents against young females of the Pulvinaria sp. in laboratory settings. These nematodes have shown significant virulence, with *Steinernema carpocapsae*, achieving mortality rates above 90% (Paraschiv, 2023).

Soft scales are occasionally preyed upon by other beetles, hemipterans, thrips, flies, caterpillars, mites, and spiders (Kosztarab, 1996; Rakimov et al., 2015; Camacho & Chong, 2015). Lady bugs (Figure 7) were also reported as soft scale predators, indicating a broader ecological network of possibilities for pest control (Lowery, 2020). Two species of ladybugs (Coccinellidae) *Adalia bipunctata* (L.) and *Exochomus quadripustulatus* (L.), were found to be predators of some scale insects (Paraschiv, 2023). Additionally, bird species such as English sparrows and several warblers, which consume mature soft scales, have been observed to play a crucial role in mitigating infestations (Lowery, 2020).

The mutualistic relationship between soft scales and ants, facilitated by the exchange of honeydew for protection against natural enemies, presents a unique challenge to pests control efforts. Effective ant management, therefore, becomes a critical component of enhancing the efficacy of biological control agents (Kabashima & Dreistadt, 2014).


Figure 7. Ladybugs feeding on *Pulvinaria vitis* nymphs (a, b); ant protecting *Pulvinaria vitis* (c)

Ants have the ability to disrupt their natural competitors by attacking them in order to protect their food source, so if the ants are excluded, there will result an increased population of soft scales specific predators (Camacho & Chong, 2015). Using sugar baits could represent an effective management strategy to distract ants from guarding the scale insects (Beltrà et al., 2017). The use of toxic baits based on boric acid and hydramethylnon has been used for controlling ants, such as *Linepithema micans*, resulting effective in reducing their activity and indirectly controlling scale bugs population (Nondillo et al., 2016).

A key technique for enhancing biodiversity among insect communities in vineyards involves the use of cover crops, which provide habitat and alternative food sources for beneficial insects, increasing their abundance and diversity (Winter et al., 2018). Additionally, planting permanent vegetation such as hedgerows and flower strips within and around vineyards can offer refuge and resources for a variety of insect species, including natural enemies of grapevine pests (Landis et al., 2000). These measures aid beneficial arthropods and enhance the ecological health of the vineyard area. Reducing the usage of broad-spectrum pesticides can help protect non target beneficial insects and promote natural pest management methods (Letourneau et al., 2009). Integrating these approaches, a more resilient agroecosystem that supports a rich community of beneficial insects, enhancing both pest control and pollination, can be created (Tomoiagă, 2022).

While the focus shifts towards reducing dependence on chemical pesticides, their use remains a necessary part of an IPM. Selective insecticides that minimize harm to non-target species and the environment, including oil-based products, have shown efficacy in managing soft scale infestations on grapevines (Mansour et al., 2017). When using chemical treatments, it is essential to follow label instructions and consider the potential impact on non-target species, including beneficial insects and pollinators, as well as the potential for resistance development in the pest population. It is important to note that the timing of insecticide application is crucial for maximizing efficacy and minimizing the impact on beneficial insects, also treatments are usually more effective when applied early in the season, targeting the crawler stage before they settle and form protective waxy coatings (Lowery, 2020).

Phillips et al. reported in 1962 an example of chemical treatment that disrupted the natural biological control of *Pulvinaria vitis* and lead to serious outbreaks. The widespread application of DDT, which frequently was used in an insufficient quantity to kill the scale pest, but adequate to kill its natural parasites, exacerbated and prolonged the outbreak from Niagara Peninsula in 1945 (Phillips et al., 1962).

The resistance of grapevine pests to chemical treatments is an increasingly complex issue, with studies showing varying effectiveness of both chemical and natural resistance inducers. To understand the resistance of grapevine pests, specifically soft scales, to insecticides, the study of Quesada et al. (2018) is offering valuable insights that could aid in the development of efficient strategies for managing soft scales. His study highlights the biological variability among scale insect species and how it can lead to differences in susceptibility to various insecticides. The research found that bifenthrin and pyriproxyfen were the most effective insecticides for soft scale insects. The article also discusses how the duration of crawler activity can decrease the efficacy of insecticides, emphasizing the importance of timing in the application of treatments (Quesada et al., 2018). Systemic insecticides successfully control specific scale insect species with a single annual application (Camacho & Chong, 2015). The application is usually done right before the crawler emerges to maximize the concentration of active chemicals in the plant tissues.

Neonicotinoids, although offering advantages like flexibility and long-lasting effects, should be cautiously used due to their potential harm to pollinator health and their involvement in spider mite outbreaks (Camacho, 2015).

Targeting crawlers and settled first instars, which lack or have only a thin protective wax layer, may result in a greater efficacy, given that the body of older nymphs and adults with soft scales is covered in a layer of wax that is impenetrable to aqueous insecticide solutions (Kosztarab, 1996; Marotta, 1997; Camacho & Chong, 2015).

Research conducted by Wallingford et al. (2015) demonstrates the effectiveness of insecticide applications, specifically acetamiprid and spirotetramat, in controlling the vector insects from the Coccidae family. It has been demonstrated that this insecticide significantly reduces populations of *Pseudococcus maritimus,* a mealybug species, in vineyards (Wallingford et al., 2015). While not directly related to *Pulvinaria vitis*, the effectiveness of spirotetramat on mealybugs suggests it could be effective for controlling soft scale insects as well, given their similar habits(Wallingford et al., 2015).

For the management of the crawler stage in Pulvinaria infestations, malathion and insectcidal soap have been identified as effective treatments (Lowery, 2020). Continuous monitoring and potential repeat applications are necessary as long as crawler activity is detected. Furthermore, Movento™ (spirotetramat) has been approved for use on grapevine within the growing season specifically for soft scale control, although its application on table grapes is not advised (Lowery, 2020).

An alternative for chemical treatments could be the use of botanical extracts and essential oils. However, more comprehensive studies including field application and phytotoxicity tests are needed to fully realize the potential of botanical compounds in controlling grapevine soft scales and other pests (Peschiutta et al., 2018). Additionally, monitoring or mating disruption of soft scales with pheromone baits could represent a solution for *Pulvinaria vitis* population control, but this method is not available at the moment (Camacho & Chong, 2015).

The cultural control is also important in IPM by making the environment less favourable to pest development and reproduction. Proper fertilization, pruning, and irrigation maintain plant vigour, promote plant tolerance to pest damage, and reduce sap-sucking insect population growth (Kabashima & Dreistadt, 2014). However, few studies have demonstrated the efficacy and underlying mechanism of these cultural management practices (Camacho & Chong, 2015). IPM strategies should take in account that, modifying vineyard management and soil conservation practices can indirectly influence soft scale dynamics by affecting grapevine health and resilience. Techniques such as cover cropping, mulching, and the application of organic amendments have been shown to improve soil health and grapevine vigour, potentially reducing the susceptibility to pest infestations (Cataldo et al., 2021; Payen et al., 2021). Camacho, 2015 stated that nutrients in the soil and the plant also affect the severity of scale insect infestation. It has been demonstrated that plants provided with more nitrogen, potassium, and organic compost amendments could support more severe scale infestations, than poorly fertilized plants (Camacho, 2015).

Improvement and adaptation of IPM strategies might include adopting proven technologies from other areas or exploring new methods of pest control, such as the use of natural substances (Santos et al., 2020), AI-powered technologies and pheromone mating disruption. The effective management of these pests is a dynamic process, requiring constant vigilance, innovation, and the ability to adapt, as both pests and diseases can evolve in response to the environment and the control measures implemented by vinegrowers (Santos et al., 2020).

## CLIMATE CHANGE INFLUENCE

Global climate change, marked by increasing temperatures and shifting precipitation patterns, is expected to intensify over the coming decades. These changes are anticipated to alter the geographic distribution of grapevine varieties and rootstocks, as temperature plays a central role in determining viable cultivation areas, phenophases, the yield and quality of grape production, diseases and grapevine pest distribution (Colibaba et al., 2024). By influencing the phenology and pest dynamics, the context of climate change imposes revised pest management strategies to address the increased pest pressure on grapevine crops.

Temperature records in viticultural areas reveal that during the growing seasons from 1950 to 2000 the mean temperature has increased by about 1.6-1.8°C in Europe and 1.2-1.4°C worldwide (Venios et al., 2020). Changes in grapevine growth and physiological development have been well documented in correlation with rising temperatures in recent decades (Jones & Davis, 2000; Duchêne et al., 2010; Santos et al., 2020).

In light of anticipated changes in climate, wine-producing regions may face heightened pest and disease threats, necessitating increased efforts in plant protection at a time when reducing the environmental impact of such treatments is crucial. A detailed simulation study, as reported by Santos et al. (2020), investigating the potential variations in insect pest resilience according to geographical latitude, found a decrease in resilience near the equator and an increase resilience in regions located beyond the 30° latitude lines (Santos et al., 2020). Observations over the past thirty years regarding pests affecting grapevines have revealed changes in the timing of grape berry moth activities, alterations in the geographic distribution of leafhoppers that transmit grapevine diseases, and an expansion in the habitat of grapevine mealybugs (Santos et al., 2020).

Scale insects, including *Pulvinaria vitis*, presents a high degree of sensitivity to temperature fluctuations due to their poikilothermic nature (Skendžić et al., 2021). This sensitivity has significant implications for their metabolic rates, reproductive capacity, survival, and dispersal capabilities, potentially affecting their geographic range and population dynamics. As noted by Skendžić et al. (2021), such changes could result in increased pest pressures across new areas and a wider range of host plants (Skendžić et al., 2021). Robinet & Roques (2010) further elucidate that rising temperatures may enhance winter survival and accelerate development rates, leading to a faster progression through life stages and possibly more generations per year. Instead, elevated temperatures could increase metabolic rates without a corresponding rise in fertility or survival, indicating a complex relationship between temperature and insect physiology. Climate change could allow *Pulvinaria vitis* to colonize previously unsuitable regions due to warmer conditions, highlighting the complex impact of climate change on the distribution and life history of this grapevine pest (Robinet & Roques, 2010; Skendžić et al., 2021).

Climate change can lead to earlier onset of phenological stages in grapevines, potentially altering the synchrony between grapevines and the lifecycle of pests like *Pulvinaria vitis* (Reineke & Thiéry, 2016). Warmer temperatures may speed up the development cycles of both grapevines and pests, but not necessarily in synchrony. This could affect the timing and intensity of pest infestations, complicating existing management strategies (Reineke & Thiéry, 2016). Furthermore, elevated $CO_2$ levels, higher temperatures, and changing precipitation regimes can directly impact pest populations by extending their geographic range into areas previously unsuitable due to climatic conditions. This includes the potential for increased *Pulvinaria vitis* activity in cooler viticultural regions that become warmer and more hospitable to pests under climate change scenarios (Blanco-Ward et al., 2021; Castex et al., 2023). One potential consequence of climate change-induced temperature increases is the facilitation of more pest generations per growing season. Furthermore, this could be compensated by the anticipation of earlier fruit maturation and harvest dates, which would restrict the harmful effects of late-season pest generations (Caffarra et al., 2012). Shifts in tritrophic relations due to climate change are also concerning for Integrated Pest Management (IPM), as natural enemies of pests may suffer from warmer temperatures, affecting their synchronization with pest populations. Understanding these changes at various levels and their linkages is crucial for adapting IPM strategies to future climatic conditions (Castex et al., 2018). Continues research and monitoring are essential to understand the evolving relationship between grapevine and pests like *Pulvinaria vitis* in the context of global warming, ensuring the sustainability of viticulture in a changing climate (Biasi et al., 2019; Comșa et al., 2022). The adaptive practices should be introducing the use of resistant grapevine varieties, adapting the management strategies to cope with heat and water stress, and implementing innovative pest and disease management scheme in order to reduce the use of pesticides (Pertot et al., 2017). A comprehensive 21-year study conducted in the southern region of Romania has provided evidence of significant climatic changes impacting viticulture, specifically grape yield and quality (Zaldea et al., 2021). This research underscores the regional implications of climate change on viticulture. Further investigations into the climatic conditions affecting viticulture in Romania have highlighted a trend towards higher minimum temperatures during winter, alongside considerable variability in thermal conditions. Such alterations in key viticultural climatic indices, including the Huglin and Winkler indices, point to a transition towards warmer growing seasons, which could lead to mass outbreaks of scales pests on grapevine (Bucur et al., 2019; Zaldea et al., 2021).

Similar climate changes have also been reported in Târnave vineyard by (Răcoare et al., 2022) and (Chedea et al., 2021). Târnave vineyard is the most prestigious and appreciated viticultural area of Transylvania and it is located in the central-north-vest region of Romania. Between 2000 and 2020, compared to the reference period of 1975-2007 the Târnave vineyard experienced a significant climatic shift, with the average annual temperature rising by 1-1.5°C; annual useful temperatures increased by more than 200°C; the length of the active vegetation period has increased by approx. 15-20 days and the frost periods (late spring and early autumn frosts) have reduced considerable (Chedea et al., 2021). These environmental changes, may have facilitated faster development cycles and higher survival rates of *Pulvinaria vitis*, aligning with the species' thermal preferences and may also have disrupted the phenological synchrony between grapevines and their pests easing the expansion of *Pulvinaria vitis* populations. In the last few years, more and more wine growers from this area have signalled the presence of *Pulvinaria vitis* outbreaks and they have serious concerns regarding the economic impact on the grape production. We are currently collecting data and investigating this matter.

Within the framework of ongoing climate change, coupled with the intensification of global trade, it is projected that pest species such as *Pulvinaria vitis* will experience outbreaks and extend their presence to new regions within Romania. The anticipated warmer climate conditions are likely to enhance the survival prospects of this pest, facilitating its expansion towards northern latitudes. Furthermore, the expected increase in temperatures, particularly in areas surrounding human settlements, may lead to a higher presence of such pests in these areas in the near future (Paraschiv, 2023).

## CONCLUSIONS

This review summarizes the state of knowledge regarding the biological aspects and management approaches of the grapevine soft scale pest, *Pulvinaria vitis*, within the context of climate change, while identifying future research needs and gaps.

Having a polyphagous nature and presenting morphological variability depending on the host plant, or environmental conditions, *Pulvinaria vitis* was sometimes confused with other soft scale species. *Pulvinaria vitis* can be hard to identify, especially in the nymphal stages. The adult females can be identified by the cottony ovisacs and the distinctive features of the body: 3-8 mm long, ovoid to circular, dark brown, presenting 3-5 transversal striae.

The phloem-feeding behaviour of *Pulvinaria vitis* impacts the growth and development of the grapevine through direct consumption, but also, it could represent a vector for Grapevine leafroll-associated viruses.

The phenomenon of sooty mold development on the honeydew excreted during their phloem-feeding activities, also represents a significant pathological challenge within viticultural practices. This fungal growth restricts the photosynthesis by obstructing light penetration to the leaf surface and also the respiration and transpiration process.

It has been estimated that the scale insects produce agricultural losses that can globally surpass 1 billion dollars per year (Kozár et al. 2009). In Romania, there are no recent studies regarding the economic impact of *Pulvinaria vitis* on viticulture although in the last few years more and more outbreaks are reported by winegrowers.

Scale insects, including *Pulvinaria vitis*, present a high degree of sensitivity to temperature fluctuations. Recent climate changes consist in temperature rises and precipitation pattern shifts which can accelerate *Pulvinaria vitis* life cycle, increase their winter survival rates, and expand their geographic ranges, potentially leading to more frequent and severe outbreaks.

In order to manage these challenges, the implementation of Integrated Pest Management (IPM) strategies, which include biological, cultural, mechanical, and minimal chemical interventions, is crucial for a sustainable grape production while minimizing environmental impacts. Techniques such as cover cropping, mulching, and applying organic amendments can enhance soil health and grapevine vigour, reducing susceptibility to pest infestations. Adjustments in pesticide application timing are also important in order to reduce the impact on useful fauna and to avoid developing resistance. The evolution of climate change and local conditions must be considered while implementing these strategies.

Continue research in a multidisciplinary approach is essential in the process of elaborating effective IPM strategies to face the future climatic conditions. This could be achieved by integrating knowledge on pest biology, transmission of viruses, targeted insecticide applications, sustainable pest control techniques.

## REFERENCES


Abd-Rabou, S. (2011). Coccophagus scutellaris (Hymenoptera: Aphelinidae): A highly effective biological control agent of soft scale insects (Hemiptera: Coccidae) in Egypt. *Psyche (London)*. https://doi.org/10.1155/2011/431874

Almeida, R. P. P., Daane, K. M., Bell, V. A., Blaisdell, G. K., Cooper, M. L., Herrbach, E., & Pietersen, G. (2013). Ecology and management of grapevine leafroll disease. *Frontiers in Microbiology*, *4*(APR). https://doi.org/10.3389/fmicb.2013.00094

Beltrà, A., Navarro-Campos, C., Calabuig, A., Estopà, L., Wäckers, F., Pekas, A., & Soto, A. (2017). Association between ants (Hymenoptera: Formicidae) and the vine mealybug (Hemiptera: Pseudococcidae) in table-grape vineyards in Eastern Spain. *Pest Management Science*, *73*. https://doi.org/10.1002/ps.4640

Ben-Dov, Y. 1993. *A systematic catalogue of the soft scale insects of the world (Homoptera: Coccoidea: Coccidae) with data on geographical distribution, host plants, biology and economic importance.* Sandhill Crane Press, Inc., Gainesville, FL.

Ben-Dov Y, Miller DR, Gibson GAP (2008). ScaleNet: A Searchable Information System on Scale Insects. Available online: https://scalenet.info/

Biasi, R., Brunori, E., Ferrara, C., & Salvati, L. (2019). Assessing impacts of climate change on phenology and quality traits of Vitis vinifera L.: The contribution of local knowledge. *Plants*, *8*(5). https://doi.org/10.3390/plants8050121

Blanco-Ward, D., Ribeiro, A., Paoletti, E., & Miranda, A. I. (2021). Assessment of tropospheric ozone phytotoxic effects on the grapevine (Vitis vinifera L.): A review. In *Atmospheric Environment* (Vol. 244). Elsevier Ltd. https://doi.org/10.1016/j.atmosenv.2020.117924

Brașoveanu, C., Bodi, G., & Danu, M. (2020). Paleorecords of Domesticated and Wild Grapevine in Romania: a Review. *Botanical Review*, *86*(3–4), 211–233. https://doi.org/10.1007/s12229-020-09223-1

Bucur, G. M., Cojocaru, G. A., & Antoce, A. O. (2019). The climate change influences and trends on the grapevine growing in Southern Romania: A long-term study. *BIO Web of Conferences*, *15*, 01008. https://doi.org/10.1051/bioconf/20191501008

Caffarra, A., Rinaldi, M., Eccel, E., Rossi, V., & Pertot, I. (2012). Modelling the impact of climate change on the interaction between grapevine and its pests and pathogens: European grapevine moth and powdery mildew. *Agriculture, Ecosystems and Environment*, *148*, 89–101. https://doi.org/10.1016/j.agee.2011.11.017

Camacho, E. R. (2015). Life History and Natural Enemies of Parthenolecanium spp. in Four Southeastern States [Clemson University]. In *All Dissertations Dissertations*. https://tigerprints.clemson.edu/all_dissertations

Camacho, E. R., & Chong, J. H. (2015). General biology and current management approaches of soft scale pests (Hemiptera: Coccidae). *Journal of Integrated Pest Management*, *6*(1). https://doi.org/10.1093/jipm/pmv016

Castex, V., Beniston, M., Calanca, P., Fleury, D., & Moreau, J. (2018). Pest management under climate change: The importance of understanding tritrophic relations. *Science of The Total Environment*, *616–617*, 397–407.

Castex, V., de Cortázar-Atauri, I. G., Beniston, M., Moreau, J., Semenov, M., Stoffel, M., & Calanca, P. (2023). Exploring future changes in synchrony between grapevine (Vitis vinifera) and its major insect pest, Lobesia botrana. *Oeno One*, *57*(1), 161–174. https://doi.org/10.20870/oeno-one.2023.57.1.7250

Cataldo, E., Fucile, M., & Mattii, G. B. (2021). A Review: Soil Management, Sustainable Strategies and Approaches to Improve the Quality of Modern Viticulture. *Agronomy*, *11*(11). https://doi.org/10.3390/agronomy11112359

Chedea, V. S., Dragulinescu, A. M., Tomoiaga, L. L., Balaceanu, C., & Iliescu, M. L. (2021). Climate change and internet of things technologies—sustainable premises of extending the culture of the amurg cultivar in transylvania - a use case for târnave vineyard. *Sustainability (Switzerland)*, *13*(15). https://doi.org/10.3390/su13158170

Chiurciu, I.-A., Zaharia, I., & Soare, E. (2020). Production of wine grapes and cultural traditions related to vine in romania. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development*, *20*, 2020.

Colibaba, L. C., Bosoi, I., Pușcalău, M., Bodale, I., Luchian, C., Rotaru, L., & Cotea, V. V. (2024). Climatic projections vs. grapevine phenology: a regional case study Climatic projections vs. grapevine phenology: a regional case study. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *52*(1), 13381. https://doi.org/10.15835/nbha52113381

Comșa, M., Tomoiagă, L. L., Muntean, M. D., Ivan, M. M., Orian, S. M., Popescu, D. M., & Chedea, V. S. (2022). The Effects of Climate Change on the Activity of the Lobesia botrana and Eupoecilia ambiguella Moths on the Grapevine Cultivars from the Târnave Vineyard. *Sustainability (Switzerland)*, *14*(21). https://doi.org/10.3390/su142114554

Cooper, P. D., Truong, T. T., Keszei, A., Neeman, T., & Webster, K. W. (2023). The Effect of Scale Insects on Growth Parameters of cv. Chardonnay and cv. Sauvignon Blanc Grapevines Grown in a Greenhouse. *International Journal of Molecular Sciences*, *24*(2). https://doi.org/10.3390/ijms24021544

Daane, K. M., Vincent, C., Isaacs, R., & Ioriatti, C. (2018). Entomological Opportunities and Challenges for Sustainable Viticulture in a Global Market. *Annual Reviews*, *63*, 193–214. https://doi.org/10.1146/annurev-ento-010715

Duchêne, E., Huard, F., Dumas, V., Schneider, C., & Merdinoglu, D. (2010). The challenge of adapting grapevine varieties to climate change. *Climate Research*, *41*(3), 193–204. https://doi.org/10.3354/cr00850

Erb, M. (2018). Plant Defenses against Herbivory: Closing the Fitness Gap. *Trends in Plant Science*, 23(3), 187–194. https://doi.org/10.1016/j.tplants.2017.11.005

Fetykó, K., Kozár, F., & Daróczi, K. (2010). Species list of the scale insects (Hemiptera, Coccoidea) of Romania, with new data. *Acta Phytopathologica et Entomologica Hungarica*, *45*(2), 291–302. https://doi.org/10.1556/APhyt.45.2010.2.5

García Morales, M., Denno, B. D., Miller, D. R., Miller, G. L., Ben-Dov, Y., & Hardy, N. B. (2016). ScaleNet: a literature-based model of scale insect biology and systematics. *Database : The Journal of Biological Databases and Curation*, *2016*. https://doi.org/10.1093/ database/bav118

García Morales M, Denno BD, Miller DR, Miller GL, Ben-Dov Y, Hardy NB. 2016. *ScaleNet: A literature-based model of scale insect biology and systematics*. Database. doi: 10.1093/database/bav118. http://scalenet.info [01.02.2024]

Gill, R. J. (1988). *The scale insects of California part I: The soft scales (Homoptera:Coccoidea*.Coccidae)* (Vol. 1). California Department of Food and Agriculture.

Gonçalves, J., Silva, E., Faria, P., Nogueira, T., Ferreira, A., Carlos, C., & Rosado, L. (2022). Edge-Compatible Deep Learning Models for Detection of Pest Outbreaks in Viticulture. *Agronomy*, *12*(12). https://doi.org/10.3390/agronomy12123052

Grapevine. (1997). *World Crop Pests*, *7*(PART B), 323–331. https://doi.org/10.1016/S1572-4379(97)80092-9

Gullan, P. J., & Cook, L. G. (2007). Phylogeny and higher classification of the scale insects (Hemiptera: Sternorrhyncha: Coccoidea)*. *Zootaxa*, *1668*, 413–425. www.mapress.com/zootaxa/

Gullan, P. J., & Martin, J. H. (2009). Sternorrhyncha: (Jumping Plant-Lice, Whiteflies, Aphids, and Scale Insects). *Encyclopedia of Insects*, 957–967. https://doi.org/10.1016/B978-0-12-374144-8.00253-8

Hodgson, C. J., & Peronti, A. L. B. G. (2012). Zootaxa A revision of the wax scale insects (Hemiptera: Sternorrhyncha: Coccoidea: Ceroplastinae) of the Afrotropical Region. *Zootaxa*, *3372*, 1–265. www.mapress.com/zootaxa/

Hommay, G., Alliaume, A., Reinbold, C., & Herrbach, E. (2021). Transmission of Grapevine leafroll-associated virus-1 (Ampelovirus) and Grapevine virus A (Vitivirus) by the Cottony Grape Scale, Pulvinaria vitis (Hemiptera: Coccidae). *Viruses 2021, Vol. 13, Page 2081*, *13*(10), 2081. https://doi.org/10.3390/V13102081

Hommay, G., Wiss, L., Chadoeuf, J., Le Maguet, J., Beuve, M., & Herrbach, E. (2019). Gone with the wind: Aerial dispersal of Parthenolecanium corni crawlers in a newly planted grapevine plot. *Annals of Applied Biology*, *174*(3), 372–387. https://doi.org/10.1111/aab.12505

Irimia, L. M., Patriche, C. V., & Roșca, B. (2018). Climate change impact on climate suitability for wine production in Romania. *Theoretical and Applied Climatology*, *133*(1–2), 1–14. https://doi.org/10.1007/s00704-017-2156-z

Jansen, M. (2000). The species of Pulvinaria in The Netherlands. *AMST*, *60*(1), 1–11.

Jones, G. V., & Davis, R. E. (2000). Using a synoptic climatological approach to understand climate-viticulture relationships. *International Journal of Climatology*, *20*(8), 813–837.

Kabashima, J. N., & Dreistadt, S. H. (2014). Integrated Pest Management for Home Gardeners and Landscape Professionals - Scales. *Statewide Integrated Pest Management Program*.

Komárek, M., Čadková, E., Chrastný, V., Bordas, F., & Bollinger, J. C. (2010). Contamination of vineyard soils with fungicides: A review of environmental and toxicological aspects. In *Environment International* (Vol. 36, Issue 1, pp. 138–151). Elsevier Ltd.

Kosztarab, M. (1996). *Scale insects of northeastern North America: identification, biology, and distribution.* Virginia Museum of Natural History.

Kosztarab, M. 1997. Ornamentals and house plants, pp. 357–365. In Y. Ben-Dov and C. J. Hodgson (eds.), Soft scale insects: Their biology, natural enemies and control, vol. 7B. Elsevier Science B.V., Amsterdam, The Netherlands.

Kosztarab, & F. Kozár. (1988). *Scale Insects of Central Europe* (Dr W Junk Publishers).

Kozár, F., Konczné Benedicty, Z., Fetykó, K., Kiss, B., & Szita, É. (2013). An annotated update of the scale insect checklist of Hungary (Hemiptera, Coccoidea). *ZooKeys*, *309*, 49–66. https://doi.org/10.3897/zookeys.309.5318

Landis, D. A., Wratten, S. D., & Gurr, G. M. (2000). Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annu. Rev. Entomol.*, *45*, 175–201.

Letourneau, D. K., Jedlicka, J. A., Bothwell, S. G., & Moreno, C. R. (2009). Effects of natural enemy biodiversity on the suppression of arthropod herbivores in terrestrial ecosystems. *Annual Review of Ecology, Evolution, and Systematics*, *40*, 573–592.

Lowery, T. D. (2020). Insect & mite pests of grape. In *Crop Protection Best Practices Guide for Grapes for British Columbia Growers*.

Malumphy, J. P. (1991). *A morphological and experimental investigation of the Pulvinaria vitis complex in Europe*. University of London.

Malumphy, C., & John, B. (2012). Scale insects and whiteflies (Hemiptera: Coccoidea and Aleyrodoidea) of Watsonian Kent; with a discussion on the impact of naturalised non-native species. *Article in British Journal of Entomology & Natural History*, 15–46. https://www.researchgate.net/publication/311344460

Malumphy, C., & Kahrer, A. (2011). New data on the scale insects (Hemiptera: Coccoidea) of Vienna, including one invasive species new for Austria. *Beiträge Zur Entomofaunistik*, 47–60. www.biologiezentrum.at

Mansour, R., Grissa-Lebdi, K., Suma, P., Mazzeo, G., & Russo, A. (2017). Key scale insects (Hemiptera: Coccoidea) of high economic importance in a mediterranean area: Host plants, bio-ecological characteristics, natural enemies and pest management strategies – a review. *Plant Protection Science*, *53*(1), 1–14. https://doi.org/10.17221/53/2016-PPS

Marotta, S. (1997). General life history. In Y. Ben-Dov & C. J. Hodgson (Eds.), *Soft scale insects: Their biology,* *natural enemies and control* (Vol. 7A, pp. 251–255). Elsevier Science B.V.

Masten Milek, T., Bjeliš, M., & Šimala, M. (2008). Intensity of scale insects infestation in relation to grapevine variety and soil type in Croatia. *Source: Cereal Research Communications*, *36*, 1735–1738. https://doi.org/10.2307/90003059

Masten Milek Tatjana, Marjana Ivezic, & Mladen Simala. (2009). The genus Pulvinaria Targioni Tozzetti,1866 (HEMIPTERA: COCCOIDEA: COCCIDAE) with special regard to Pulvinaria Hydrangea Steinweden, 1946 as a newly recorded species in the fauna of Croatia. *Nat. Croat.*, *18*(2), 267–278.

Masten-Milek, T., Šimala, M., Korić, B., & Bjeliš, M. (2007). Status of scale insects (Coccoidea), family Coccidae, on grapes in 2006.In Croatia with emphasis on rarity of second generation of Parthenolecanium corni (Bouche) and Parthenolecanium persicae (Fabricius). *Zbornik Predavanj in Referatov 8. Slovenskega Posvetovanja o Varstvu Rastlin Radenci*, *8*, 326–329.

Muntean, M. D., Drăgulinescu, A. M., Tomoiagă, L. L., Comșa, M., Răcoare, H. S., Sîrbu, A. D., & Chedea, V. S. (2022). Fungal Grapevine Trunk Diseases in Romanian Vineyards in the Context of the International Situation. *Pathogens 2022, Vol. 11, Page 1006*, *11*(9), 1006. https://doi.org/10.3390/PATHOGENS11091006

Munteanu, D. (2018). *IN MEMORIAM* (Vol. 63).

Nondillo, A., Andzeiewski, S., Fialho, F. B., Bueno, O. C., & Botton, M. (2016). Control of Linepithema micans (Hymenoptera: Formicidae) and Eurhizococcus brasiliensis (Hemiptera: Margarodidae) in Vineyards Using Toxic Baits. *Journal of Economic Entomology*, *109*(4), 1660–1666. https://doi.org/10.1093/jee/tow127

Ntzani, E. E., Ntritsos G, C. M., Evangelou, E., & Tzoulaki, I. (2017). Literature review on epidemiological studies linking exposure to pesticides and health effects. *EFSA Supporting Publications*, *10*(10). https://doi.org/10.2903/sp.efsa.2013.en-497

Paraschiv, M. (2023). First Record of the Invasive Scale Insect, *Pulvinaria hydrangeae* Steinweden, 1946 (Hemiptera: Coccomorpha: Coccidae) in Romania. *Insects*, *14*(4). https://doi.org/10.3390/insects14040345

Payen, F. T., Sykes, A., Aitkenhead, M., Alexander, P., Moran, D., & MacLeod, M. (2021). Soil organic carbon sequestration rates in vineyard agroecosystems under different soil management practices: A meta-analysis. *Journal of Cleaner Production*, *290*, 125736. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.125736

Pellizzari G. (1997). Species of *Pulvinaria* which are pests on grapevine. In Y. Ben-Dov & C.J. Hodgson (Eds.), *Soft Scale Insects-Their Biology, Natural Enemies and Control* (pp. 323–331). Elsevier Science.

Pertot, I., Caffi, T., Rossi, V., Mugnai, L., Hoffmann, C., Grando, M. S., Gary, C., Lafond, D., Duso, C., Thiery, D., Mazzoni, V., & Anfora, G. (2017). A critical review of plant protection tools for reducing pesticide use on grapevine and new perspectives for the implementation of IPM in viticulture. *Crop Protection*, *97*, 70–84. https://doi.org/10.1016/j.cropro.2016.11.025

Phillips, J. H. H. (1962). Description of the Immature Stages of Pulvinaria vitis (L.) and P. innumerabilis (Rathvon) (Homoptera: Coccoidea), with Notes on the Habits of these Species in Ontario, Canada. *The Canadian Entomologist*, *94*(5), 497–502. https://doi.org/10.4039/ENT94497-5

Phillips, J. H. H. (1963a). Life History and Ecology of Pulvinaria vitis (L.) (Hemiptera: Coccoidea), the Cottony Scale Attacking Peach in Ontario. *The Canadian Entomologist* , *95*, 372–407.

Phillips, J. H. H. (1963b). Life History and Ecology of Pulvinaria vitis (L.) (Hemiptera: Coccoidea), the Cottony Scale Attacking Peach in Ontario1. *The Canadian Entomologist*, *95*(4), 372–407. https://doi.org/10.4039/ENT95372-4

Phillips, J. H. H., Putman, W. L., & Herne, D. C. (1962). Some Effects of DDT on Pulvinaria vitis (L.) (Homoptera: Coccidae) Infesting Peach in Ontario. *The Canadian Entomologist*, *94*(5), 449–458. https://doi.org/10.4039/ENT94449-5

Pörtner, O., Roberts, D. C., Tignor, M., Poloczanska, E. S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Löschke, S., Möller, V., Okem, A., & B. Rama. (2022). *Climate Change 2022 Impacts, Adaptation and Vulnerability.*

Quesada, C. R., Witte, A., & Sadof, C. S. (2018). Factors influencing insecticide efficacy against armored and soft scales. *HortTechnology*, *28*(3), 267–275. https://doi.org/10.21273/HORTTECH03993-18

Răcoare, H. S., Iliescu, M. L., Tomoiagă, L. L., Comșa, M., Sîrbu, A. D., Doinița Muntean, M., & Chedea, V. S. (2022). The grapevine phenology and the climate changes in Tarnave vineyard. *Scientific Papers. Series B, Horticulture. Vol. LXVI, No. 1*. https://www.onvpv.ro/sites/default/files/

Rakimov, A., Hoffmann, A. A., & Malipatil, M. B. (2015). Natural enemies of soft scale insects (Hemiptera: Coccoidea: Coccidae) in Australian vineyards. *Australian Journal of Grape and Wine Research*, *21*(2), 302–310. https://doi.org/10.1111/AJGW.12134

Reineke, A., & Thiéry, D. (2016). Grapevine insect pests and their natural enemies in the age of global warming. In *Journal of Pest Science* (Vol. 89, Issue 2, pp. 313–328). Springer Verlag. https://doi.org/10.1007/s10340-016-0761-8

Robinet, C., & Roques, A. (2010). Direct impacts of recent climate warming on insect populations. In *Integrative Zoology* (Vol. 5, Issue 2, pp. 132–142). https://doi.org/10.1111/j.1749-4877.2010.00196.x

Salinari, F., Giosuè, S., Tubiello, F. N., Rettori, A., Rossi, V., Spanna, F., Rosenzweig, C., & Gullino, M. L. (2006). Downy mildew (*Plasmopara viticola*) epidemics on grapevine under climate change. *Global Change Biology*, *12*(7), 1299–1307. https://doi.org/10.1111/j.1365-2486.2006.01175.x

Sanders, J. G. (1909). The identity and synonymy of some of our soft scale-insects. In *Aubert and Noc in Compo Rend. Soc. BioI* (Vol. 66). http://jee.oxfordjournals.org/

Santos, J. A., Fraga, H., Malheiro, A. C., Moutinho-Pereira, J., Dinis, L. T., Correia, C., Moriondo, M., Leolini, L., Dibari, C., Costafreda-Aumedes, S., Kartschall, T., Menz, C., Molitor, D., Junk, J., Beyer, M., & Schultz, H. R. (2020). A review of the potential climate change impacts and adaptation options for European viticulture. In *Applied Sciences (Switzerland)* (Vol. 10, Issue 9). MDPI AG. https://doi.org/10.3390/app10093092

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The Impact of Climate Change on Agricultural Insect Pests. *Insects 2021, Vol. 12, Page 440*, *12*(5), 440. https://doi.org/10.3390/INSECTS12050440

Statista. (2023). *Vineyard surface area under reconstruction and conversion in Romania 2008-2023*.

Steinweden, J. B. (1929). Bases for the generic classification of the Coccoid family Coccidae. *Ann. Ent. Soc. Amer.*, *22*(2), 197–245. https://doi.org/10.1093/aesa/22.2.197

Tanaka, H. (2020). Redescriptions of three species of *Pulvinaria* (Hemiptera: Coccomorpha: Coccidae) in Japan. *Zootaxa*, *4779*(1), 131–141. https://doi.org/10.11646/zootaxa.4779.1.10

Tanaka, H., & Kamitani, S. (2020). Review of the *Pulvinaria* (Hemiptera: Coccomorpha: Coccidae) species of the Ryukyu Islands, Japan. *Zootaxa*, *4868*(3), 408–422. https://doi.org/10.11646/zootaxa.4868.3.5

Tataridas, A., Kanatas, P., & Travlos, I. (2022). Streamlining Agroecological Management of Invasive Plant Species: The Case of Solanum elaeagnifolium Cav. In *Diversity* (Vol. 14, Issue 12). MDPI. https://doi.org/10.3390/d14121101

Tomoiagă, L. L ,(2022). The impact of agroecological practices on the biodiversity of arthropod fauna in Târnave vineyard. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca*, *79*(1), 74–80.

Tomoiagă Liliana. (2006). *Bolile și dăunătorii viței de vie/ Diseases and pests of the grapevine*. Ed. Mediamira.

Venios, X., Korkas, E., Nisiotou, A., & Banilas, G. (2020). Grapevine responses to heat stress and global warming. In *Plants* (Vol. 9, Issue 12, pp. 1–15). MDPI AG. https://doi.org/10.3390/plants9121754

Völkl, W., Woodring, J., Fischer, M., Lorenz, M.W. & Hoffmann, K.H. (1999) Ant-aphid mutualisms: the impact of honeydew production and honeydew sugar composition on ant preferences. Oecologia, 118(4), 483–491.

Vranjic, J. A. (1997). Effects on Host Plant. *Y. Ben-Dov and C. J. Hodgson, Soft Scale Insects: Their Biology, Natural Enemies and Control, Elsevier Science B.V.*, *7A*, 323–336.

Wallingford, A. K., Fuchs, M. F., Martinson, T., Hesler, S., & Loeb, G. M. (2015). Slowing the spread of grapevine leafroll-associated viruses in commercial vineyards with insecticide control of the vector, *Pseudococcus maritimus* (Hemiptera: Pseudococcidae). *Journal of Insect Science*, *15*(1). https://doi.org/10.1093/jisesa/iev094

Wäckers, F.L. (2000) Do oligosaccharides reduce the suitability of honeydew for predators and parasitoids, A further facet to the function of insect-synthesized honeydew sugars. Oikos, 90(1), 197–201.

WANG, Z. zhi, LIU, Y. quan, SHI, M., HUANG, J. hua, & CHEN, X. xin. (2019). Parasitoid wasps as effective biological control agents. In *Journal of Integrative Agriculture* (Vol. 18, Issue 4, pp. 705–715). Editorial Department of Scientia Agricultura Sinica. https://doi.org/10.1016/S2095-3119(18)62078-7

Winter, S., Bauer, T., Strauss, P., Kratschmer, S., Paredes, D., Popescu, D., Landa, B., Guzmán, G., Gómez, J. A., Guernion, M., Zaller, J. G., & Batáry, P. (2018). Effects of vegetation management intensity on biodiversity and ecosystem services in vineyards: A meta-analysis. In *Journal of Applied Ecology* (Vol. 55, Issue 5, pp. 2484–2495). Blackwell Publishing Ltd. https://doi.org/10.1111/1365-2664.13124

Zaldea, G., Nechita, A., Damian, D., Ghiur, A. D., & Cotea, V. V. (2021). Climate changes in recent decades, the evolution of the drought phenomenon and their influence on vineyards in north-eastern Romania. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *49*(4). https://doi.org/10.15835/NBHA49412448

Zogli, P., Pingault, L., Grover, S., & Louis, J. (2020). Ento(o)mics: the intersection of 'omic' approaches to decipher plant defense against sap-sucking insect pests. *Current Opinion in Plant Biology*, *56*, 153–161. https://doi.org/10.1016/j.pbi.2020.06.002