Available on IVES Conference Series vine & wine

DOI : https://doi.org/10.58233/xBugumP4

Emerging pest pressures in viticulture: a brief review of *Argyrotaenia Ljungiana* in Eastern Europe

Ioana Sorina Giurcă[1] , Liliana Lucia Tomoiagă[1] , Maria Doinița Muntean[1], Horia Silviu Răcoare[1], Alexandra Doina Sîrbu[1], Veronica Sanda Chedea[1], Maria Comșa[1]

[1] Research and Development Station for Viticulture and Oenology Blaj, Blaj, Alba County, 2nd Gh. Barițiu Street, 515400, Phone: 0258711623, Fax: 025871062; scdvv.blaj@asas.ro

*Corresponding authors: tirnovean.ioana@gmail.com; comsa_m@yahoo.com

Abstract. As viticulture faces increasing threats from emerging pests, understanding and dealing with new infestations is crucial. This review arises from the recent detection of an uncommon pest in an area where its presence had not been previously reported. In the Târnave vineyard, Romania, the detection of *Argyrotaenia ljungiana*, has raised concerns among grape producers. Belonging to the family Tortricidae, *Argyrotaenia ljungiana* is characterised by light brown forewings with darker lateral bands. Its larvae are pale green with yellowish-brown heads, feeding on grapevine leaves and clusters. *Argyrotaenia ljungiana* typically has two to three generations per year, with larvae overwintering in the pupal stage within vine bark and debris. This one increases the risk of crop loss alongside existing grape moth pests such as *Lobesia botrana* and *Eupoecilia ambiguella*. The moths cause direct damage to grape clusters by larval feeding and create favourable conditions for the spread of *Botrytis cinerea*. The situation is further complicated by climate change, which can alter pest life cycles and intensify pathogen pressure. To address these challenges, integrated management practices must be refined. Regular monitoring, pheromone-based trapping, and biological controls (e.g., parasitoids) should be combined with targeted chemical interventions only when pest thresholds are exceeded. Enhancing vineyard biodiversity through habitat management, cover crops, and refuges for beneficial insects can strengthen ecosystem resilience. By closely tracking the spread *of Argyrotaenia ljungiana* and its interactions with existing pests and diseases, growers can adapt their management approaches to sustain grape production while minimising environmental impact. Implementing these strategies is essential to protect grapevine health and ensure the sustainability of grape production under evolving environmental conditions.

1. Introduction

This review aims to synthesize global knowledge about *Argyrotaenia ljungiana* (Thunberg, 1797) as a grapevine pest and address knowledge gaps regarding its impact and control in Eastern European vineyards. By reviewing existing research and drawing comparisons with similar grapevine pests, the study provides insights into potential IPM strategies for the Târnave vineyards and surrounding areas.

Recent data from the International Organisation of Vine and Wine (OIV) indicate that global wine production fell to its lowest level in over 60 years in 2024, largely due to extreme climatic conditions and associated disease pressure [1]. Romania was not spared; its wine production dropped nearly 20% compared to 2023, reflecting a combination of late frosts, heavy rainfall, and pest-related stress [1]. As grapevines face growing environmental pressures, effective pest surveillance and regionally tailored integrated pest management (IPM) strategies are essential for maintaining sustainable viticultural productivity.

In recent years, the emergence of new grapevine pests in traditionally unaffected regions has become a growing concern for viticulture. Moth pests pose an important threat to grape production worldwide. Primarily through larval feeding on grape clusters, these pests cause damage that results in direct yield losses and increased vulnerability to fungal infections such as *Botrytis cinerea*. Economic consequences can be significant; for example, research in Greece has shown that Lobesia botrana alone caused yield losses of up to 27% per hectare [2]. The need for effective eradication efforts and IPM strategies is also highlighted by research from Mendoza, Argentina, which found that moth-related damage can reduce grape production by up to 8% [3].

A. ljungiana, commonly known as the grape tortrix, belongs to the family Tortricidae (order Lepidoptera), which encompasses a substantial group of moths that are economically significant to agriculture. Tortricidae moths, also referred to as "leafrollers," comprise approximately 10,000 identified species globally [4], and are recognizable by their compact, folded-wing posture and leaf-rolling larval behavior [5]. The variation in wing patterning, including both cryptic and aposematic coloration, provides important ecological and taxonomic information [6].

Although historically considered a minor pest in most European vineyards, *A. ljungiana* can cause significant damage under favorable conditions, especially by feeding on grape clusters, reducing both yield and quality. This species is often overshadowed in pest management discussions by *Lobesia botrana* and *Eupoecilia ambiguella*, but emerging evidence suggests it deserves more atention [7, 8]. In Romania, *A. ljungiana* was recently identified in the Târnave vineyard, raising alarms due to the vineyard's importance in high-quality wine production. The species had previously only been listed in Romania by Razowski (1987), where it was recorded in the Remetea region [9].

The recent confirmation of *A. ljungiana* in Târnave parallels similar observations in other parts of Eastern and Central Europe [7]. Most research has historically focused on populations in Italy and France, but new records are emerging in Bulgaria and Romania. Notably, the larvae cause direct cluster damage and may facilitate *Botrytis cinerea* infection through their feeding wounds [8]. These developments underscore the need to better understand the ecology of *A. ljungiana* and its potential to impact Eastern European viticulture.

Recent ecological modeling supports the hypothesis that generalist moths like *A. ljungiana* may benefit from climate change habitat shifts, particularly in vineyards adopting biodiversity based management strategies [10]. This review synthesizes existing global and regional research on *A. ljungiana*, highlighting knowledge gaps and proposing directions for future IPM development, with a particular focus on Eastern European vineyards.

2. Biology and Life Cycle

2.1. Taxonomy and Classification

A. ljungiana (Thunberg, 1797), commonly referred to as the grape tortrix, belongs to the family Tortricidae within the order Lepidoptera, which encompasses a large group of moths known for their economic impact on crops. The classification follows: Kingdom Animalia, Phylum Arthropoda, Class Insecta, Order Lepidoptera, Superfamily Tortricoidea, and Family Tortricidae.

The Argyrotaenia genus includes over 100 species, many of which are known to be polyphagous pests in fruit crops and ornamentals across America and Europe. Notably, *A. franciscana* and *A. sphaleropa* have been recorded on grapevine in North and South America, respectively, with feeding damage observed on leaves and clusters under high population pressure [4, 14, 20]. Although *A. ljungiana* has historically been associated with orchards and heather landscapes in Europe, its increasing adaptation to vineyards echoes a broader pattern within the genus. This genus-level flexibility and ecological adaptability may explain *A. ljungiana* recent rise in viticultural systems undergoing agroecological transition and reduced pesticide use [1, 4].

A. ljungiana has also been synonymized under names such as *Argyrotaenia pulchellana* (Haworth, 1811) and *Eulia pulchellana*, among other names. Modern taxonomic consensus confirms that the Argyrotaenia genus includes over 100 species, many of which are known to be polyphagous pests in fruit crops and ornamentals across the Americas and Europe. Notably, *A. franciscana* and *A. sphaleropa* have been recorded on grapevine in North and South America, respectively, with feeding damage observed on leaves and clusters under high population pressure [4, 13, 20]. Although *A. ljungiana* has historically been associated with orchards and heather landscapes in Europe, its increasing adaptation to vineyards echoes a broader pattern within the genus. This genus-level flexibility and ecological breadth may explain *A. ljungiana*'s recent rise in viticultural systems undergoing agroecological transition and reduced pesticide use [34]. *Argyrotaenia pulchellana* is the same species as *A. ljungiana* [12,14], so these names are used interchangeably in historical sources. The species is sometimes also called the "heather tortrix" in English, alluding to its frequent occurrence on heather (*Calluna vulgaris*) in its native [13].These synonyms are essential for recognizing the historical context and regional variations within the species taxonomy.

Tortricidae, or the leafroller moths, comprises a large and diverse family within the Lepidoptera order with over 11,000 described species worldwide. It is one of the most diverse and economically important moth families due to the large number of species that it comprises [14]. Tortricid moths are unique when at rest since they fold their wings over their bodies, creating a rounded shape. This moths come with a diversity of wing colors ranging from dull browns and grays for some species to quite bright for diurnal species [15].

2.2. Distribution, habitat and host plants

A. ljungiana is widely distributed across the Palearctic region. Its range spans most of Europe (from the British Isles and Scandinavia to the Mediterranean Basin) and extends through Western and Central Asia into parts of East Asia [16]. Within this broad geographic range, *A. ljungiana* is typically associated with temperate environments and is found in both natural and cultivated landscapes, including meadows, forest edges, heathlands, and agricultural systems.

An early report of *A. ljungiana* in North America was traced to a misidentification; an indigenous North American leafroller had been mistaken for *A. ljungiana* [17]. Thus, *A. ljungiana* is not considered established in the Americas and is currently designated as an exotic quarantine pest by the United States Department of Agriculture [18].

Within Europe, *A. ljungiana* inhabits a diverse range of ecological zones, from lowland heath and moorland habitats to cultivated areas. In viticultural regions, its presence might have been frequently underreported due to its similarity to other grapevine moth pests such as *Lobesia botrana* and *Eupoecilia ambiguella*, compared to which it presents lower population density. Nevertheless, the species is present in Eastern European vineyards, including Romania, where it has been documented as part of the leafroller complex affecting grapevines [20].

Research in the Târnave vineyard has shown that tortricid activity, including that of *Lobesia botrana* and *Eupoecilia ambiguella*, is closely linked to microclimate, cultivar selection, and seasonal variability [21]. These findings suggest that *A. ljungiana* may follow similar ecological patterns, with vineyard altitude, proximity to wild host plants, and cultivar sensitivity influencing its presence and population development.

The species is highly polyphagous. While *Vitis vinifera* is a confirmed host in European viticulture, *A. ljungiana* also feeds on a wide range of woody and herbaceous plants, including Rubus spp., Malus domestica, Prunus spp., Fragaria, and various species within the Asteraceae, Rosaceae, and Ericaceae families [22, 23]. Unlike *Lobesia botrana* and *Eupoecilia ambiguella*, which are closely synchronized with grape phenology, *A. ljungiana* displays greater ecological flexibility. This broad host range likely contributes to the persistence of *A. ljungiana* populations in vineyards located near forested or uncultivated zones, where alternative host plants may act as reservoirs [28].

A. ljungiana does not typically dominate tortricid populations in vineyards but can become locally abundant under the right conditions. Its capacity to complete multiple generations per year and shift between hosts contributes to its resilience in agroecological mosaics. As vineyards shift toward more sustainable, biodiversity-focused management, with hedgerows, cover crops, grassed alleys, and forest margins, the surrounding landscape becomes more favorable to generalist moths [51, 52].

Given its polyphagous nature and climatic adaptability, *A. ljungiana* may represent an underestimated risk in Eastern European viticulture under changing environmental conditions, where EU agri-environmental policies and Common Agricultural Policy (CAP) funding schemes have increasingly promoted biodiversity-oriented practices, such as maintaining hedgerows, encouraging ground cover, and reducing insecticide inputs. These agroecological mosaics support a wider range of non-crop host plants and microhabitats, which may favor the persistence and spillover of polyphagous pests like *A. ljungiana*. Understanding how such landscape-level changes interact with pest ecology is essential for the design of future integrated pest management (IPM) strategies in the region [24,71].

2.3. Morphology and identification

2.3.1. Egg and larval morphology

Eggs are laid in flat, overlapping clusters, typically on the upper leaf surface. They are initially yellowish, turning translucent as they grow [27]. A single egg cluster may contain 40–50 eggs, making early-stage detection in the field challenging.

The larvae are pale green, slender, and cylindrical, growing to 10–15 mm in length depending on host plant and environmental conditions [27, 28]. The head capsule is yellowish-brown, and the prothoracic shield is yellow-green. A key diagnostic trait is the presence of an anal comb with 6–8 teeth, placing it in the subfamily Tortricinae [30].

In the initial instars, the larvae skeletonize leaf tissue between the veins. As they grow, they begin to roll or tie leaves using silk, creating protective shelters in which they continue to feed. In some hosts, larval feeding can cause extensive defoliation, though this is not common in vineyards [31].

Field collected larvae (Fig. 2) exhibit the typical pale green color with yellowish-brown head capsule and anal comb consistent with diagnostic features. Accurate larval identification is critical for early detection, especially in mixed tortricid infestations.

Figure 1. Larva of *Argyrotaenia ljungiana* on a green stem. Source: © Andrey Ponomarev via iNaturalist / CABI (CC BY-NC 4.0).

Figure 2. Specimen collected from infested grape berries in Târnave vineyard, Romania (photo by author, 2024).

2.3.2. Pupal morphology

Pupation occurs within rolled leaves, among plant debris, or in bark crevices, depending on the habitat and host plant [28, 23]. Pupae measure around 8–10 mm long and change from pale brown to dark brown during development [30, 31]. The species overwinters in the pupal stage, typically sheltered within fallen plant leaves or pruning debris [30].

2.3.3. The adult morphology

Adult *A. ljungiana* moths are small and intricately patterned, with wing lengths ranging from 12 to 16 mm [25, 9, 26]. The forewings can have a variety of colors, typically displaying a shiny silvery-white or light brown ground hue with dark or reddish-brown lateral bands that can be reticulated or oblique. The hindwings range from straw-colored to cream-gray and appear half-transparent with fine fringe hairs. A distinctive morphological trait of the adult is the possession of two elevated tufts, which facilitates identification [26, 9]. The adult displays the typical tortricid resting posture with wings folded over the body, creating a bell-shaped silhouette [29].
Figure 3. shows a stock image of an adult specimen photographed in Hertfordshire, UK, and Figure 4 presents an adult collected in the Târnave vineyard (Romania).

Figure 3. Stock image of adult *Argyrotaenia ljungiana* from Hertfordshire, UK, July 2021 (©Ben Sale via CABI Compendium, CC BY 2.0).

Figure 4. Adult moth emerged from lab-reared sample, captured in Târnave vineyard, 2024 (photo by author, 2024).

Field identification can be challenging because of its resemblance to other tortricid species, including *Lobesia botrana* and *Eupoecilia ambiguella*. Genitalia examination or molecular confirmation may be required for accurate diagnosis, especially in areas where several tortricids coexist [23].

2.4. Life cycle

A. ljungiana exhibits a flexible, multivoltine life cycle that varies depending on climate and host availability. In cooler areas of its distribution, such as northern and alpine zones, the species is typically univoltine, completing one generation per year [29]. In most temperate parts of Europe, particularly in central and western viticultural zones, it is bivoltine, while in warmer Mediterranean regions, a partial or complete third generation may develop during hot summers [23].

Observations in southern European vineyards confirm that two generations occur frequently, with a third developing in particularly warm seasons. The generational plasticity makes it more challenging to manage pests by prolonging the vulnerability window of the crop [23].
All *A. ljungiana* populations overwinter in the pupal stage [27]. Overwintering and pupation sites differ according to habitat. They develop within rolled leaves, pruning debris, and have even been known to overwinter inside bark crevices of perennial hosts like grapevines [28,9].

In springtime, adult emergence is commonly coincident with the development of grapevine shoots. Mating is not long after adult eclosion, with females laying eggs in diskshaped masses with around 40–50 eggs, typically on the upper surface of young leaves [27,30]. Egg growth is conditioned by temperature and generally takes around 7–10 days under average conditions. Bentancourt et al. (2003) found that female moths lay the majority of their eggs on the first day post-emergence, with fecundity sharply declining thereafter. This concentrated oviposition pattern implies that early adult control strategies, like pheromone disruption or selective insecticide application, may be more effective in reducing population density [28,69].

The larvae hatch from the egg masses and feed early on by skeletonizing leaf tissue. Older instars feed on grapevine inflorescences and young berries and can cause direct damage and provide entry points for *Botrytis cinerea* [23].

Larval development is significantly influenced by diet quality. Bentancourt et al. (2003) demonstrated that larvae reared on spring leaves—especially from apple trees—developed faster and achieved greater pupal weight than those fed on summer foliage or fruit. Increased pupal weight was positively correlated with fecundity and fertility, highlighting the importance of host plant quality in determining reproductive success and generational dynamics [31].

Temperature and sex influence the duration of larval development. Females typically require more time to reach maturity than males. Bentancourt et al. (2003) also observed that environmental conditions, particularly temperature, affect the number of larval instars, with variability across generations [31].

Figure 5 illustrates the estimated seasonal life cycle of *Argyrotaenia ljungiana* under temperate vineyard conditions typical of Romania, where the species displays a flexible bivoltine pattern. The model reflects how A. ljungiana adapts to seasonal vine phenology and climate, emphasizing the need for timely monitoring and early intervention to reduce population build-up and berry damage later in the season.

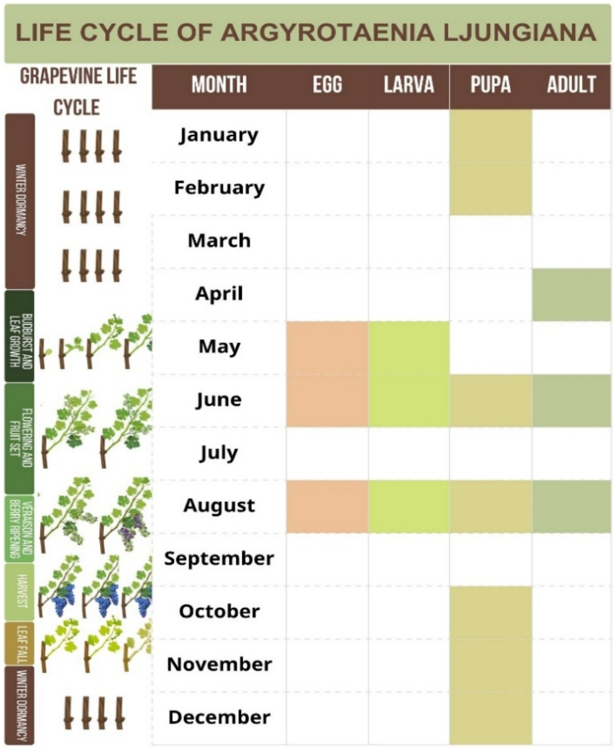

Figure 5. Estimated life cycle of *Argyrotaenia ljungiana* under temperate conditions in Romanian vineyards. Adapted from Gilligan & Epstein (2012), Frérot et al. (1984), Ioriatti et al. (2012), and Zumbado-Ulate et al. (2023).

2.5. Feeding behaviour and damage

The feeding injury of *A. ljungiana* is directly caused by the larval forms. The larva skeletonizes the leaves in the early instar stages and eats the mesophyll tissue of soft leaves between the veins while leaving the epidermal layer intact. This type of damage appears as small, transparent patches and reduces the photosynthetic surface of the vine, potentially affecting shoot vigour in young plants [27].

As the larvae progress into later instars, they show the common leafroller tendencies of rolling, folding, or webbing leaves together with their silk into protective inclosures. From within these shelters, the larvae continue to feed on leaf tissue in an environment that is protected from predators and environmental extremes [27].

More concerning is the ability of older larvae to shift feeding activity from leaves to reproductive structures. On grapevine, mature larvae may feed directly on grape inflorescences, flowers, and developing berries, particularly during the pre-bloom to early fruit set stages [9,48]. Depending on the stage of infestation, the feeding induces flower abortion, incomplete fruit set, and physical damage on the skin of young berries. Wounds induced by larval feeding serve as entry points for secondary pathogens of primary importance for bunch rot development, in particular among white cultivars with compact clusters under high humid conditions [9].

Though *A. ljungiana* is typically a less concerning pest compared to *Lobesia botrana*, its ecological plasticity and ability to persist in vineyard margins suggest it may play a larger role in crop damage under high population pressure or in vineyards managed with biodiversity-focused practices, which reduce insecticide input and increase habitat complexity [32, 36]. In addition, its cryptic feeding damage and shared phenology with other tortricids make misidentification more likely, meaning its true impact may be underestimated in vineyards where monitoring focuses solely on primary pests [19].

Field observations and literature data support a bivoltine life cycle for *Argyrotaenia ljungiana* in temperate Eastern European vineyards, such as those in Romania. The first adult emergence occurs in April, originating from overwintered pupae sheltered in bark crevices or pruning debris [27,29].These adults initiate the first generation, with larval feeding beginning in May.

By June, first-generation larvae pupate and give rise to a second adult flight, typically peaking in late June to early July [9].Eggs laid by these adults develop into the second-generation larvae visible from July into August. Pupation of this second generation occurs in late August, with adults occasionally emerging in early September.

However, climatic conditions in Romania typically do not favor the full development of a third generation, and many pupae from late summer enter diapause to overwinter [10].

3. Climate change and emerging pest pressures in Eastern European viticulture

Viticulture in Eastern Europe, including Romania, is facing new and evolving pressures due to climate change. In the Târnave vineyard and other Romanian regions, recent climatic shifts, including warmer average temperatures, erratic rainfall patterns, and increased vine stress, are changing the dynamics of pest populations [33, 34]. These conditions not only extend the seasonal activity of existing pests but also allow new or previously minor species to establish and proliferate.

There is a growing concern that climate change is not only intensifying known pest pressures but also enabling the rise of secondary or cryptic pests, particularly in perennial cropping systems like vineyards. This phenomenon is often described as a form of "pest emergence," where insects that previously maintained low population levels or occupied peripheral habitats begin to cause significant damage under changing climatic and agronomic conditions. Warmer winters can improve overwintering survival, while earlier spring onset and longer growing seasons may allow an additional generation per year, factors that together increase pest pressure and challenge existing integrated pest management (IPM) frameworks [35, 9].

As Eastern European vineyards align more closely with EU biodiversity and agroecology policies by introducing grassed alleys, hedgerows, and organic practices, agroecological mosaics may inadvertently favour generalist pests like *A. ljungiana*, which can exploit multiple hosts and overwinter in varied shelters [38, 36].

This growing complexity, requires vineyard managers to use more refined tools. Precision viticulture, built on pest phenology models that incorporate local microclimate and degree-day data, offers a way forward. Existing models for other moth pests have already helped optimise spray timing and predict outbreak peaks [37].

To manage this growing complexity, vineyard managers will need more refined tools. Precision viticulture, built on pest phenology models that incorporate local microclimate and degree-day data, offers a way forward. Existing models for pests like *Lobesia botrana* have already helped optimise spray timing and predict outbreak peaks [47,72]. Similar models tailored to *A. ljungiana* would be an important next step.

The necessity for adaptive management strategies is underscored by the potential impact of climate change on pest dynamics, which can alter the phenology and distribution of vineyard pests, increasing the complexity of pest control and necessitating flexible, climate-resilient approaches [35].

3.1. Comparative climate preference of key tortricid moths and *A. Ljungiana* in Eastern European vineyards

Climate change is significantly reshaping tortricid moth dynamics in vineyards across Eastern Europe. The two most relevant species *Lobesia botrana*, *Eupoecilia ambiguella*, and the emerging *A. ljungiana* exhibit differing climatic preferences and voltinism patterns, which are increasingly influencing their distribution, abundance, and damage potential [38, 39].

3.1.1. *Lobesia botrana*: A warm-climate specialist with high reproductive potential

Lobesia botrana, commonly known as the European grapevine moth, tends to thrive in warm, dry vineyard environments typically found at lower elevations. In Romanian viticultural areas such as Dealu Mare, it regularly completes two to three generations annually, with a possible partial fourth generation emerging during particularly hot summers [40]. This pest moth is especially active in sun-exposed plots planted with susceptible cultivars like Traminer and Chardonnay. As regional summers become hotter and drier, monitorisatin indicate an expansion of *Lobesia botrana* into ares that were previously less suitable for its development [41].

3.1.2. *Eupoecilia ambiguella*: A moisture-loving species losing ground

Eupoecilia ambiguella tends to favour cooler and wetter vineyard microclimates, commonly found at higher elevations or in shaded, humid plots. It is more prevalent in regions such as northern Transylvania and Moldova, and it tends to affect cultivars like Sauvignon Blanc and Rhine Riesling. This moth is typically bivoltine, producing two generations per year [40, 42]. However, as drought events increase and rainfall becomes less predictable, *Eupoecilia ambiguella* populations are declining in many areas, increasingly displaced by the more drought-tolerant *Lobesia botrana* [41].

3.1.3. Argyrotaenia *ljungiana*: A flexible generalist on the rise

A. ljungiana, while historically more associated with orchards, is now emerging as a relevant pest in vineyards. Unlike the other two species, it demonstrates significant ecological flexibility and is not strictly tied to grapevine phenology. Observations suggest that it is bivoltine in most Romanian conditions but can develop a third generation in particularly warm years [8, 36]. Larvae feed not only on berries but also on leaves and inflorescences, which broadens their impact window. Moreover, this species overwinters in varied microhabitats such as bark crevices, fallen leaves, and pruning debris, giving it resilience under diverse management regimes. Its rising presence is particularly noticeable in organic or low-input systems where insecticide pressure is reduced [32, 36].

In Table 1, a comparative synthesis is presented regarding the ecological preferences and behavioral traits of *Lobesia botrana*, *Eupoecilia ambiguella*, and *Argyrotaenia ljungiana*. This analysis emphasizes how species specific risk periods are influenced by climate suitability, vineyard exposure, and production systems, helping intervention strategies.

CRITERIA	*Lobesia botrana*	*Eupoecilia ambiguella*	*Argyrotaenia ljungiana*
FLIGHT ACTIVITY	Dusk to early night	Crepuscular and early night	Late afternoon to dusk
CLIMATE PREFERENCE	Warm, dry	Cool, humid	Broad tolerance; generalist
PREFERRED VINEYARD SITE	Sun-exposed, lower slopes	Shady, higher altitude plots	Mid to upper slopes, mixed canopy
SYSTEM ASSOCIATION	Conventional, integrated	Integrated, shaded vineyards	Organic, biodiverse, low-input

Table 1. Comparative of the two relevant moths to Eastern European viticulture and *A. ljungiana* (Adapted from: Ioriatti et al. 2012, Schmidt et al. 2012, Comșa et al. 2022, Zumbado-Ulate et al. 2023)

4. Tortricid moths as grapevine pests in Eastern Europe and Romania

Among the most important grapevine pests across Europe, especially in areas where climate and host availability support several generations per season, are tortricid moths (Lepidoptera: Tortricidae). *Lobesia botrana* (European grapevine moth) and *Eupoecilia ambiguella*, are the main species of concern in Eastern Europe [9].

In many Eastern European countries, climate change is facilitating shifts in pest dynamics. Rising temperatures and milder winters have led to earlier flight periods and increased voltinism, particularly in species like *Lobesia botrana*, which can now complete up to four generations per year in some southern zones [43].

Tortricid pressure is more evenly distributed in the Transylvanian Plateau, particularly in the Târnave region, which has a combination of hilly terrain and temperate microclimates. Because of the cooler, wetter conditions, *E. ambiguella* has historically been more prevalent here. However, climatic instability and changes in vineyard management techniques (such as introducing biodiversity corridors and reducing pesticide input) have might make it easier for generalist and secondary pests like *A. ljungiana* to proliferate .

The historical and ongoing presence of *A. ljungiana*, also referenced in older literature as *Argyrotaenia pulchellana*, has been confirmed in several viticultural regions of Central and Eastern Europe. Though not always consistently monitored, the species has been occasionally documented in grape-growing areas of Austria, Hungary, Slovenia, and Northern Italy, often as a minor tortricid pest alongside more dominant species [49,50].

In France, early vineyard detections occurred in the Languedoc region during the 1950s, where the species began appearing in low densities on grapevines. More recently, infestations have become more consistent in Alsace, a region closely bordering Switzerland, where *A. ljungiana* is long-established. These shifts are thought to reflect both increased monitoring sensitivity and climatic suitability [23, 44].

In Austria, *A. pulchellana* was noted as an occasional pest causing damage similar to *L. botrana* and *E. ambiguella* in viticultural monitoring surveys during the 1980s and 1990s (Arn & Louis, 1997). More recently, climate change modelling has suggested that warming trends may enhance the suitability of Austrian vineyards for additional tortricid pests, including *A. ljungiana*, although targeted surveillance is still limited [36].

In Northern Italy, *A. pulchellana* has been studied more closely due to its overlap with key orchard crops. Pheromone-based studies in the Emilia-Romagna region have shown adult male captures in vineyards and orchards and attempted to relate these findings to larval infestation levels [45]. These studies confirmed vineyard presence but also noted sporadic population peaks linked to microclimatic conditions and orchard adjacency.

In Slovenia, though no large-scale infestation reports exist, *A. ljungiana* is included in tortricid biodiversity assessments due to Slovenia's ecological overlap with Italian and Austrian vineyard regions. Its occurrence has been noted as part of the mixed tortricid moth fauna affecting local grapevines [46].

In Hungary, direct entomological reports of *A. ljungiana* in vineyards are scarce; however, its close relatives within Argyrotaenia have been recorded. Risk assessments suggest that increasing temperatures and shifts in agroecological practices may facilitate its establishment in southern Hungarian wine regions. Surveillance systems currently focus more on *L. botrana* and viral vectors but may underestimate the presence of secondary pests like *A. ljungiana* [47].

In Romania, the earliest documented record of *A. ljungiana* was from Remetea, as listed in Razowski's national Lepidoptera checklist (1987) [11]. Recent surveillance confirms its presence in the Târnave vineyard, where its population may be favoured by biodiversity-enhancing vineyard practices and increasingly mild winters .

Modelling studies evaluating invasive risk have shown that *A. ljungiana* has moderate potential for establishment in viticultural areas with fluctuating moisture levels and warm summers—characteristics increasingly typical of Romanian vineyards [36].

5. Monitoring and management strategies

As viticultural climates in Eastern Europe become increasingly variable, integrated pest management (IPM) strategies must adapt to address both established and emerging pest species. This fact underscores the need for pest control strategies that combine biological, chemical, and cultural methods with climate-informed risk assessment. This chapter outlines current practices and knowledge gaps in monitoring and managing tortricid moths under Eastern European conditions.

5.1. Monitoring Techniques

Monitoring is the foundation of any effective pest management program, particularly in perennial systems like vineyards where early detection and precise timing are critical. For *A. ljungiana*, as well as other tortricid moths, effective monitoring relies on a combination of pheromone-based trapping, visual inspection and phenological models. However, *A. ljungiana* poses additional challenges due to its emerging status and subtle field symptoms.

5.1.1. Pheromone Trapping

Pheromone traps are widely used to monitor adult moth flight activity. *A. ljungiana*, lures based on (E,E)-8,10-tetradecadien-1-yl acetates have been developed and applied in Southern and Western Europe to track seasonal flight curves and to support spray timing [53,54]. These lures enable precise tracking of seasonal flight curves, with peak captures typically occurring during twilight hours when male moths are most active [67].

Although pheromone traps are standard for *L. botrana* and *E. ambiguella*, *A. ljungiana* specificity can be compromised by cross-attraction or misidentification [68]. Recent advancements include dual-component dispensers that combine species-specific ratios (e.g., 9:1 Z9-14:Ac/Z11-14:Ac) with physical trap modifications. Green delta traps baited with these lures reduced non-target captures by 42% compared to transparent designs in Czech trials [59].

5.1.2. Visual Inspection

Field scouting for larval shelters is essential, especially for *A. ljungiana*, which often remains undetected due to its webbing and feeding inside rolled or skeletonized leaves. Confirming active infestations involves checking for damage to young leaves and clusters or the presence of silk-bound shelters on inflorescences [59]. Visual inspection also helps differentiate between larval stages of different tortricids, which can be morphologically similar.

5.1.3. Innovative technologies in pest monitoring

Recent advancements in artificial intelligence (AI) have created new opportunities for pest monitoring in vineyards, providing enhanced accuracy and efficiency compared to conventional methods. A noticeable example is the application of deep learning algorithms on edge devices for the automated detection and evaluation of pests captured on sticky traps. Gonçalves et al. (2022) illustrated the successful application of the SSD ResNet50 model for the identification of various vineyard insect species in situ, significantly diminishing the labour required for manual monitoring and facilitating faster decision-making [62,71]. These AI-driven systems offer significant potential for under-monitored species like *A. ljungiana*. The inclusion of these tools into IPM frameworks could be essential for climate-smart viticulture and precision pest control.

5.1.4. Phenology Models Degree-Day Accumulations and microclimate integration

Phenological models based on degree-day accumulation have been established for *L. botrana* and *E. ambiguella* but are not yet validated for *A. ljungiana* [70]. This hinders predictive management and increases reliance on frequent monitoring.

5.1.5. Microclimate data significantly enhance model accuracy

Canopy-level sensors: Measure temperature gradients influencing larval development rates, which vary by 18–35 days between shaded and sun-exposed vines [56].

Soil temperature monitoring: Predicts overwintering pupal emergence, with soil warming above 12°C triggering synchronized adult flights.

In Emilia-Romagna, Italy, integration of DD models with pheromone trap data enabled prediction of larval hatch within ±3 days, optimizing Bacillus thuringiensis applications [60].

Eastern European viticulture requires regionally adapted tools. Prioritizing the development of commercial lures with reduced cross-attraction and expanding DD model calibration to Romanian climates will be critical for sustainable management. Future research should explore eDNA sampling from leaf surfaces to enable non-invasive population tracking [72].

5.2. Control strategies

5.2.1. Chemical Control

While *A. ljungiana* does not cause yet significant damage to grapevione to warrant specific chemical control measures [60,61], it can be indirectly controlled by managing more damaging tortricid pests like *Cydia pomonella*, *L. botrana*, and *E. ambiguella* [62]. Insecticides commonly used include insect growth regulators such as fenoxycarb and diflubenzuron, and various pyrethroids [14,63]. Preparations of *Bacillus thuringiensis* are also effective against leafrollers, enhancing the effect of beneficial arthropods in orchards [64,65]. These compounds act primarily on newly hatched larvae and must be carefully timed to coincide with peak egg hatch periods for optimal efficacy.

Biological insecticides such as *Bacillus thuringiensis* subsp. *kurstaki* (Bt) are effective against early larval stages and have shown good results in vineyards with integrated or organic management systems [64,65]. Bt has the added advantage of preserving natural enemies and beneficial arthropod fauna. Its effectiveness, however, depends heavily on correct timing and environmental conditions — particularly UV radiation and humidity, which influence persistence on foliage.

Overlap of generations and microclimate driven development may reduce efficacy if spray timing is not carefully calibrated to life stage.

Selective insecticides and rotation among different modes of action are critical to avoid resistance build-up.

5.2.2. Biological Control

Biological control using natural enemies is a vital component of IPM. Natural enemies of torticid moths include parasitic wasps, such as *Trichogramma* species, and general predators like spiders, contributing to the natural control of *A. ljungiana* populations [66, 61, 71]. Generalist predators, such as spiders, lacewings, and earwigs, play an important role in suppressing young larvae, especially in vineyards with high structural complexity (e.g. hedgerows, cover crops, ground vegetation). Encouraging such predators through conservation biocontrol measures (e.g. flowering strips, minimal tillage) strengthens resilience to population surges [51].

Fungi like *Beauveria pseudobassiana* and *Metarhizium anisopliae* have been trialed against *L. botrana* with success and may hold promise for *A. ljungiana* as well [67,68]. Application during overwintering periods enhances contact efficacy.

5.2.3. Integrated Pest Management (IPM)

An effective IPM approach combines chemical, biological, and mechanical methods to achieve sustainable control.

Key practices include:

<u>Monitoring and Threshold Setting:</u>

Regular monitoring using pheromone traps and visual inspections helps determine pest populations. Thresholds based on trap counts and observed damage guide intervention decisions, optimizing control efforts and reducing unnecessary pesticide applications [61].

<u>Selective Pesticide Application:</u>

When pesticide use is necessary, selective, low-toxicity insecticides target *A. ljungiana* while minimizing impact on beneficial organisms [44].

<u>Biocontrol Integration:</u>

Synchronizing biological control measures with pesticide use minimizes resistance development and prolongs the effectiveness of both methods. Applying entomopathogenic fungi during the pest's overwintering phase can be coordinated with other IPM tactics for sustainable population control [50].

6. Conclusion

Climate change, shifting agronomic practices, and increasing emphasis on biodiversity are reshaping pest dynamics in Eastern European vineyards. Rising average temperatures, unpredictable rainfall patterns, and milder winters are altering the timing, distribution, and intensity of insect pest populations. These changes have expanded the geographic and temporal windows in which pests can develop, often increasing the number of generations per year and enhancing overwintering survival. At the same time, the adoption of organic farming systems, reduced pesticide use, and implementation of EU agri-environmental schemes, such as biodiversity corridors, inter-row vegetation, and hedgerow restoration, are modifying vineyard microclimates and trophic interactions. While these practices promote ecological resilience, they can also create favorable conditions for generalist or secondary pests like *A. ljungiana* to persist and proliferate.

A. ljungiana is emerging as a resilient and adaptable pest, particularly in viticultural areas undergoing ecological transition. This review underscores the species' resilience, driven by its flexible voltinism, broad host range, and capacity to overwinter in multiple refuges. Its ability to remain cryptic, both in the field and in monitoring programs, further complicates detection and intervention.

As more growers shift toward organic and agroecological methods, reliance on biological controls and precise timing will be key. This moth’s behavior suggests that without early detection and locally adapted tools, its populations could quietly increase in vulnerable regions. Eastern European vineyards, such as those in Romania's Târnave region, are particularly vulnerable due to increasing climate instability and the rapid implementation of biodiversity-friendly practices. To prevent that, surveillance systems need to improve. Species-specific thresholds, regional forecasting, and better diagnostics (including molecular tools) are essential. As *A. ljungiana* adapts to vineyard ecosystems, growers will need to adapt too, not just react.

In the end, this review isn't just about one moth. It's about how pest pressure in vineyards is becoming more complex and how ignoring the "minor pests" today could turn into major problems tomorrow.

7. References

1. OIV, *2024 Statistical Report on World Vitiviniculture* (International Organisation of Vine and Wine, Paris, 2025)
2. T. Moschos, *Int. J. Pest Manag.* **52**, 141 (2006)
3. G. Puga, W. Umberger, A. Gennari, *J. Wine Econ.* **15**, 394 (2020)
4. J.C. Regier, C. Mitter, A. Zwick, A.L. Bazinet, M.P. Cummings, A.Y. Kawahara et al., *PLoS ONE* **7**, (2012)
5. S.R. Schachat, R.L. Brown, *BMC Evol. Biol.* **16**, 68 (2016)
6. J. Šíchová, P. Nguyen, M. Dalíková, F. Marec, *PLoS ONE* **8**, (2013)
7. M. Retallack, D. Mackay, L. Thomson, M. Keller, *Trans. R. Soc. S. Aust.* **142**, 130 (2018)
8. J. Moreau, C. Villemant, B. Benrey, D. Thiéry, *Biol. Control* **54**, 300 (2010)
9. C. Ioriatti, A. Lucchi, L.G. Varela, in *Insects and Diseases of Mediterranean Vineyards* (Eds. N. Bostanian, C. Vincent, R. Isaacs), 339–359 (Springer, 2012)
10. H. Zumbado-Ulate, T. Schartel, G. Simmons, M. Daugherty, *NeoBiota* **87**, 173 (2023)
11. J. Razowski, *Check List of Lepidoptera in Romania* (Museum of Natural History, Kraków, 1987)
12. A. Ö. Koçak, M. Kemal, Misc. Pap. Cent. Entomol. Stud. **143**, 1 (2018)
13. M. Meijerman, S. Ulenberg, Zool. Meded. **74**, 45 (2000)
14. T. M. Gilligan, J. W. Brown, J. Baixeras, *Online World Catalogue of the Tortricidae* (2020), https://www.tortricid.net
15. S. R. Schachat, R. L. Brown, J. Lepid. Soc. **70**, 282 (2016)
16. EPPO, Argyrotaenia ljungiana (Lepidoptera: Tortricidae), EPPO Global Database (2022), https://gd.eppo.int
17. J.D. Bradley, W.G. Tremewan, A. Smith, *British Tortricoid Moths: Cochylidae and Tortricidae* (Ray Society, London, 1973)
18. APHIS, *Pest Alert: Argyrotaenia ljungiana* (grape tortrix moth), United States Department of Agriculture, Animal and Plant Health Inspection Service (2022), https://www.aphis.usda.gov
19. H. Alipanah, J. Entomol. Res. **33**, 371 (2009)
20. M. Comșa, L.L. Tomoiagă, M.D. Muntean, M.M. Ivan, S.M. Orian, D.M. Popescu, V.S. Chedea, *Sustainability* **14**, 14554 (2022)
21. J.W. Brown, G.S. Robinson, J.A. Powell, *Food Plant Database of the Leafrollers of the World (Lepidoptera: Tortricidae)*, USDA Systematic Entomology Laboratory (2008)
22. C. Ioriatti, A. Lucchi, L.G. Varela, in *Insects and Diseases of Mediterranean Vineyards* (Eds. N. Bostanian, C. Vincent, R. Isaacs), 339–359 (Springer, 2012)
23. S. Schmidt, J. Németh, M. Schmitz, R. Krehan, Mitt. Dtsch. Ges. Allg. Angew. Entomol. **18**, 283 (2012)
24. European Commission, Agri-environmental indicators – Agrobiodiversity, Eurostat (2023), https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_agrobiodiversity
25. J.D. Bradley, W.G. Tremewan, A. Smith, *British Tortricoid Moths: Cochylidae and Tortricidae* (Ray Society, London, 1973)
26. E.G. Hancock, K.P. Bland, *Entomol. Rec. J. Var.* **127**, 185 (2015)
27. T.M. Gilligan, M. Epstein, *Tortricids of Agricultural Importance: Argyrotaenia ljungiana* (USDA Identification Tool, 2012)
28. C.M. Bentancourt, I.B. Scatoni, A. Gonzalez, J. Franco, *Neotrop. Entomol.* **32**, 57 (2003)
29. B. Frérot, J. Bouchard, J. Chambon, *Environ. Entomol.* **13**, 1293 (1984)
30. A.M. Meneguim, C.L. Hohmann, *Neotrop. Entomol.* **36**, 948 (2007)
31. C.M. Bentancourt, I.B. Scatoni, A. Gonzalez, J. Franco, *Neotrop. Entomol.* **32**, 57 (2003)
32. A. Rusch, L. Muneret, D. Thiéry, *Agron. Sustain. Dev.* **38**, 1 (2018)
33. J. Eitzinger, M. Stastna, Z. Zalud, M. Dubrovský, *Clim. Res.* **52**, 129 (2012)
34. I.S. Giurca, L.L. Tomoiagă, M.D. Muntean, M. Comșa, A.D. Sîrbu, H.S. Răcoare, V.S. Chedea, *Sci. Pap. Ser. B Hortic.* **68**, 300 (2024)
35. C. Reis, J.A. Santos, F. Gonçalves, C. Carlos, *OENO One* **55**, 335 (2021)

36. H. Zumbado-Ulate, T. Schartel, G. Simmons, M. Daugherty, *NeoBiota* **87**, 173 (2023)
37. A. Caffarra, R. Rinaldi, D. Eccel, *Int. J. Biometeorol.* **56**, 255 (2012)
38. H. Bian, W. Li, S. Yu, J. Mao, Y. Hong, Y. Song, P. Cai, *Insects* **15**, 474 (2024)
39. L. Hufnagel, M. Kocsis, *Appl. Ecol. Environ. Res.* **9**, 43 (2011)
40. M. Comșa, L.L. Tomoiagă, M.D. Muntean, M.M. Ivan, S.M. Orian, D.M. Popescu, V.S. Chedea, *Sustainability* **14**, 14554 (2022)
41. C. Ioriatti, G. Anfora, B. Bagnoli, G. Benelli, A. Lucchi, *Crop Prot.* (2023)
42. H. Arn, F. Louis, *IOBC Bull.* **20**(9), 1 (1997)
43. C. Ioriatti, A. Lucchi, D. Baldessari, D. Pasqualini, Insects **14**, 264 (2023)
44. H. Arn, C. Louis, *Bull. IOBC/WPRS* 20, 1 (1997)
45. G. Faccioli, E. Vergnani, A. Civolani, *Inf. Fitopatol.* 43, 45 (1993)
46. D. Rusjan, *Slovenian Journal of Agricultural Research* 101, **13** (2013)
47. Z. Koczor, R. Tóth, P. Tóth, *Acta Phytopathol. Entomol. Hung.* **48**, 27 (2013)
48. C. Ioriatti, A. Lucchi, L.G. Varela, in *Insects and Diseases of Mediterranean Vineyards* (Eds. Bostanian, N., Vincent, C., Isaacs, R.), 339–359 (2012)
49. H. Arn, C. Louis, *Bull. IOBC/WPRS* 20, 1 (1997)
50. G. Faccioli, E. Vergnani, A. Civolani, *Inf. Fitopatol.* **43**, 45 (1993)
51. D. Rusjan, *Slovenian Journal of Agricultural Research* 101, 13 (2013)
52. Z. Koczor, R. Tóth, P. Tóth, *Acta Phytopathol. Entomol. Hung.* 48, **27** (2013)
53. B. Frérot, M. Renou, P. Lecharpentier, P. Zagatti, Environ. Entomol. **13**, 1293 (1984)
54. M. Antropoli, A. De Cristofaro, G. Rotundo, R. Baraldi, Entomol. Exp. Appl. **70**, 247 (1994)
55. C. Ioriatti, A. Lucchi, J. Chem. Ecol. **42**, 571 (2016)
56. N. Velcheva, *Evaluation of pheromone lures for monitoring*, Institute of Soil Science "N. Pushkarov", Sofia, Bulgaria (2012) ;
57. T. Gilligan, M. Epstein, Tortricids of Agricultural Importance (USDA, Washington, DC, 2012)
58. C. Ioriatti, A. Lucchi, L.G. Varela, in Insects and Diseases of Mediterranean Vineyards (Eds. N. Bostanian, C. Vincent, R. Isaacs), 339–359 (Springer, Dordrecht, 2012)
59. V. Koczor, A. Vuts, Z. Karpati, R. Fail, Flight pattern of grapevine moths and evaluation of pheromone-baited traps in Hungary, Plant Prot. Sci. 60, 165–173 (2024)
60. Pavan, F., Floreani, C., Barro, P., & Zandigiacomo, P. Environ. Entomol. **39**, 1652–1658 (2010).
61. S. Reis, J. Martins, F. Gonçalves, C. Carlos, J.A. Santos, OENO One **55**, 335 (2021)
62. G. Gonçalves, R. Sousa, R. Boaventura-Cunha, L. Gonçalves, Sensors, 22, 9279 (2022)
63. M. Baggiolini, Rev. Suisse Vitic. Arboric. Hortic. **1**, 1 (1961)
64. C. Ioriatti, A. Lucchi, L.G. Varela, in *Insects and Diseases of Mediterranean Vineyards* (Eds. N. Bostanian, C. Vincent, R. Isaacs), 339–359 (Springer, Dordrecht, 2012)
65. C. Ioriatti, A. Lucchi, J. Chem. Ecol. **42**, 571 (2016)
66. L. Blommers, Annu. Rev. Entomol. **39**, 213 (1994)
67. EPPO, EPPO Standards PP2: Good Plant Protection Practice, European and Mediterranean Plant Protection Organization (2002)
68. G. Nicoli, G. Lovisolo, G. Oddone, Acta Hortic. **285**, 249 (1990)
69. W. Bentley, UC IPM Pest Management Guidelines: Grape (UC ANR, 2010)
70. P. Gruys, F. Vaal, IOBC/WPRS Bull. **7**, 151 (1984)
71. J. Aguilera Sammaritano, M. Navarro-Ruiz, M. López-Fernández, Egypt. J. Biol. Pest Control **28**, 102 (2018)
72. F. Altimira, M. Rodríguez, C. Soto, BMC Res. Notes **12**, 406 (2019)