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Overview of the *Halyomorpha halys* (Stål, 1855): Key Traits and Control Measures. Threats to agricultural crops in Bulgaria

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Abstract: *The Brown Marmorated Stink Bug (BMSB), Halyomorpha halys (Stål, 1855) (Hemiptera: Pentatomidae), is one of the most dangerous, invasive agricultural pests globally, causing significant economic losses. This review synthesizes current scientific research on its taxonomy, morphology, biology, ecology, and management, with a focus on the invasion in Europe and the status in Bulgaria. The analysis confirms that H. halis, an invasive pest native to East Asia and established in our country since 2016, is already causing damage to agricultural crops. Key factors for its spread are extreme polyphagy (over 300 host species), its overwintering behavior (entering buildings and vehicles, facilitating anthropochory), and high reproductive potential. Temperature requirements (lower developmental threshold ≈14.2°C and ≈538 DD for a full cycle) and data from the region strongly indicate that species is univoltine or has one and a partial second generation in the main agricultural regions of Bulgaria. Climate change is expected to expand the areas supporting bivoltinism and increase population pressure. Effective management is impossible without implementing an integrated approach (IPM), focusing on behavioral tactics (monitoring at crop borders with pheromone attractants) and urgently researching the potential for biological control with the egg parasitoid Trissolcus japonicus, which is already established adventively in other parts of Europe.*

Keywords: *Halyomorpha halys* (Stål, 1855), invasive species, polyphagy, biological control, climate models, integrated approach (IPM)

Introduction

The Brown Marmorated Stink Bug (BMSB), *Halyomorpha halys* (Stål, 1855) (Hemiptera: Pentatomidae), is an invasive species originating from East Asia (China, Japan, Korea, and Taiwan). Over the last three decades, it has established itself as one of the most significant agricultural pests and as a “nuisance pest” globally [1]. The

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economic impact of the BMSB is devastating. In the USA, in 2010, the species caused losses of $37 million US dollars just to apples in the Mid-Atlantic region, with some stone fruit producers reporting a reduction in harvest of over 90% [2]. In Europe, particularly in Italy, damages to fruit growing were estimated at approximately 590 million Euros for 2019 alone [3]. The success of the *H. halys* invasion is due to a combination of biological and ecological factors. Firstly, it is extremely polyphagous, having been recorded feeding on over 300 plant species from nearly 50 families, including a wide range of economically important fruit species, vegetables, and field crops. Secondly, its overwintering behavior (diapause) causes it to seek dry, protected shelters, which often leads to massive aggregations in human structures [4]. These features not only turn it into a socially significant problem in urban environments but are also the main mechanism for its rapid intercontinental spread in cargo containers and vehicles. The appearance of the species in Europe and its recent official establishment in Bulgaria (since 2016) [5] necessitate an urgent need for a comprehensive scientific review. This overview aims to analyze contemporary knowledge regarding the taxonomy, biology, ecology, and management methods of *H. halys*. By synthesizing the global experience, this overview provides a contextual framework for risk assessment and the development of scientifically grounded management strategies, adapted to the specific conditions in Bulgaria.

The global scientific literature dedicated to *H. halys* reports significant development in the research on this pest. Entomologists from its native range in Asia (China, Japan, Korea) provide fundamental data on the species' biology and its natural enemies, as well as innovative theories and new control methods. Global research on the BMSB is catalyzed primarily by economic damage. In the USA, where the species reached outbreak levels around 2010, it necessitated more serious attention on this problem. The second major research hub is Europe, following the pest's detection in Switzerland and Italy. International efforts are concentrated on tracking genetic diversity and invasion routes, including analyses across 12 countries. Belgium and Serbia confirm multiple and ongoing introductions from Asia and from already-established European populations. In Bulgaria, research is still comparatively scarce, despite serious work being undertaken in this area.

Discovery, Origin, and History of Spread

Taxonomic Description and Origin. The BMSB was officially described for the first time by the Swedish entomologist Carl Stål in 1855 under the name *Pentatoma halys*. Subsequently, its taxonomic status was revised, and the species was transferred to the genus *Halyomorpha*, with the valid name today being *Halyomorpha halys* (Stål, 1855) [6]. Several synonyms have been established, including *Poecilometis mistus* (Uhler, 1860), *Dalpada brevis* (Walker, 1867), and *Dalpada remota* (Walker, 1867). The native range of *H. halys* covers East Asia, specifically China, Japan, the Korean Peninsula, and Taiwan [7].

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Global Invasion: North America. The first documented introduction of *H. halys* outside its native range was in the USA. Although the official scientific publication documenting the species in North America is by Hoebeke and Carter, who identified specimens from Allentown, Pennsylvania, collected in 2001, analyses show that the species was likely present in the area from the mid-1990s. [1].

Global Invasion: Europe. In Europe, the spread follows a similar pattern. The first data establishing a reproducing population (including eggs and nymphs) is from Wermelinger et al. They documented findings from 2007 in Zurich, Switzerland. However, similar to the situation in the USA, later studies retrospectively established earlier, but unrecognized at the time, findings - from Liechtenstein (2004) and even from Switzerland itself (2004) [8]. This discrepancy between the initial arrival (e.g., 2004) and the official scientific reporting (2007–2008) represents the so-called "lag phase." The data suggest that this lag period is largely due to the initial incorrect identification of *H. halys* with local, similar stink bug species, particularly *Rhaphigaster nebulosa* [9]. This pattern is critically important because it suggests that by the time the Brown Marmorated Stink Bug is "officially" registered in a new country, it is already established, reproducing, and it is too late for easy eradication. Following its discovery in Switzerland, the species began a rapid expansion across the entire continent, with key first registrations including Greece (2011) [10], France (2012) [11], Italy (2012) [12], Hungary (2013) [13], Slovenia (2018) [14], Romania (2015) [15], and Russia/Georgia (2015–2016) [16].

Pathways of Introduction. The spread of *H. halys* is not due to natural dispersion but is almost entirely a result of accidental introduction associated with human activity. The species is an "*adept hitchhiker*" that benefits from the global commercial network. Its behavior of seeking dry and protected places for overwintering causes it to hide in cargo containers, vehicles, machinery, and packaged goods. Genetic studies of European populations confirm scenarios of multiple introductions [17], not only directly from Asia but also through secondary invasions from already established European populations.

Spread and Status in Bulgaria. The first official scientific publication reporting the presence of *H. halys* on the territory of Bulgaria is by Simov (2016) in the journal Ecologica Montenegrina. This publication reports finding on September 16, 2016 [5]. Subsequent scientific studies confirm its presence and expansion of its range. In 2019, specimens were collected from the Plovdiv region to conduct laboratory studies of its life cycle. The species has also been registered in agrocoenoses, such as in oil-bearing rose plantations in the Kazanlak Valley. Initial reports of damage caused to agricultural crops in Bulgaria already exist [18]. The invasion in Bulgaria is happening in the context of the broader spread in the Balkan Peninsula, following the discovery of the species in neighboring countries such as Greece (2011) [10], Romania (2015) [15], Serbia (2015) [19] and preceding its discovery in North Macedonia (2020) [20]. Bulgaria's geographical location, situated between countries with already registered populations, suggests that the invasion in the country is unlikely to be the result of a single,

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isolated event. It is more likely that the Bulgarian population represents one formed through multiple introductions from various sources: both from neighboring Balkan countries (via land transport) and directly through international trade. A similar scenario is confirmed in other European regions [17]. If this is proven for Bulgaria as well, the higher genetic variability could mean higher adaptability of the population and greater difficulty in its management.

Systematic Position and Taxonomy

The systematic position of the Brown Marmorated Stink Bug is as follows [6]: Kingdom: *Animalia*, Phylum: *Arthropoda*, Class: *Insecta*, Order: *Hemiptera*, Suborder: *Heteroptera*, Family: *Pentatomidae*, Genus: *Halyomorpha*, Species: *Halyomorpha halys* (Stål, 1855) Figure 1.

In Europe, *H. halys* is often confused with several native species from the family Pentatomidae, which have similar morphology and coloration. The most common and significant misidentification is with *Rhaphigaster nebulosa* (Poda, 1761), which, as mentioned, contributed to the delay in the early detection of the invasion [9]. Other species with which confusion is possible include *Dolycoris baccarum* (Linnaeus, 1758) (Forest Bug) and *Pentatoma rufipes* (Linnaeus, 1758) [9]. Currently, there are no serious taxonomic problems or debates regarding the species *H. halys*, but high genetic variability is noted within the invasive populations [21], which is a reflection of their origin from multiple introductions.

Morphology and Systematic Characters

Accurate morphological identification is crucial for monitoring and early detection. Adult individuals of *H. halys* are 12–17 mm in length, have the characteristic "shield-like" shape of the family, and possess a marbled brown coloration [9].

Key Diagnostic Features of Adults

For the reliable differentiation of *H. halys* from similar European species, attention should be paid to the following features:

- **Antennae:** This is the most reliable diagnostic feature. The antennae of *H. halys* have two distinct, light (white) bands on the last two segments [1, 13, 18]. Specifically, the light bands are located at the base of the 5th (last) segment and at the base and apex of the 4th segment [9]. In *R. nebulosa*, the light bands on the 4th and 5th segments are separated by a dark ring. *D. baccarum* has light bands on each segment, and the antennae are covered in hairs [1, 13, 18].

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- **Ventral Spine:** *H. halys* lacks a pronounced spine on the lower (ventral) side of the abdomen. *R. nebulosa* has a very characteristic, long spine directed forward from the base of the abdomen [9].
- **Pronotum ("Shoulders"):** In *H. halys*, the edges of the pronotum are rounded and smooth. In other species (e.g., *Pentatoma rufipes*), they can be pointed or curved [1, 13, 18].
- **Connexivum (Edge of the abdomen):** The edge of the abdomen, visible at the sides of the wings, in *H. halys* has distinct alternating light and dark bands [1, 13, 18].
- **Wing Membrane:** The membranous part of the forewings in *H. halys* is brown, without clear dark spots [1, 13, 18] or with slightly elongated dark spots. In *R. nebulosa*, this part has distinct, rounded dark spots [9].

Nymphs and Eggs

H. halys passes through 5 nymphal instars before reaching maturity. The first-instar nymphs are yellow-orange with black patterns and remain aggregated around the egg cluster [1, 9, 18]. Later instars become darker, with spiny projections on the body and very characteristic white bands on the legs and antennae. The eggs are barrel-shaped, pale green or white in color. Females lay them in groups (clusters), usually containing 20–30 eggs, most often on the underside of leaves.

A synthesis of the key differences is presented in table 1. Providing clear diagnostic features is the practical solution to overcome the "lag-phase" problem caused by misidentification, which has hindered the early detection of the invasion in other European countries [1, 9, 13, 18].

Table 1. Diagnostic characters distinguishing *Halyomorpha halys* (Stål, 1855) from similar European Pentatomidae species

Character	***H. halys*** **(Stål)**	***Rh. nebulosa*** **(Poda)**	***D. baccarum*** **(L.)**
Antennae (4th/5th segment)	Two broad white bands (on 4th and 5th segments)	Pale rings separated by dark ring	Hairy; pale bands on each segment
Ventral spine	Absent	Present (long, forward-pointing)	Absent
Pronotum (“Shoulders”)	Rounded, smooth	Slightly pointed	Rounded
Wing membrane	Brown, with elongated dark spots	Transparent with distinct rounded dark spots	Transparent
Antennae (4th/5th segment)	Two broad white bands (on 4th and 5th segments)	Pale rings separated by dark ring	Hairy; pale bands on each segment

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Sexual Dimorphism

- **Males** (Figure 2): At the apex of their abdomen (on the ventral side), males possess a clearly visible, sclerotized (hard), and convex structure called the genital capsule (pygophore). It appears as a distinct, rounded, or sub-quadrate segment.
- **Females** (Figure 3): Females lack this external capsule. Their genital structures are more retracted and do not form a protruding capsule, but rather terminate in a slight cleft at the end of the abdominal segments [2, 13, 18, 22].

Figure 1. Dorsal view of adult specimen of *H. halys*

Figure 2. Ventral view of the abdominal apex (male)

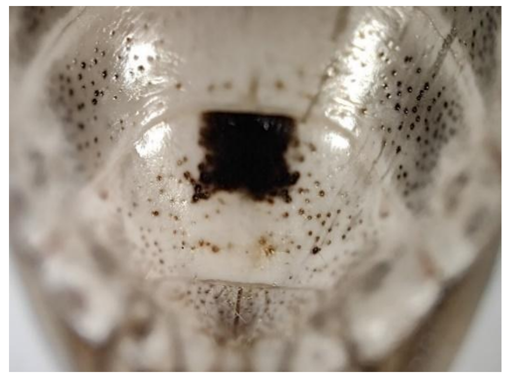

Figure 3. Ventral view of the abdominal apex (female)

Biology and Development

Life Cycle and Voltinism. The number of generations per year (voltinism) in *H. halys* is highly plastic and depends directly on climatic conditions, specifically on accumulated temperature sums. In its native range, the species varies from one or two generations in Northern China and Japan to four to six generations in Southern China. In the regions where it has subsequently spread, a similar dependence on geographic latitude and climate is observed. In the USA, the species is predominantly univoltine in the northern states (e.g., Pennsylvania, New York), but bivoltine in the more southern ones (e.g., Virginia, North Carolina) [23]. In Europe, the pattern repeats: *H. halys* is predominantly univoltine in the cooler climate of Switzerland [8], although in exceptionally warm years (e.g., 2018), a second generation has also been observed. In contrast, in warmer regions like Italy [12] and Slovenia, the species is stably bivoltine, with the two generations often overlapping [24].

Phenological, adults become active in spring (April-May). Nymphal stages are observed until late summer (mid-September). The new generation of adults (which will overwinter) appears in late summer and autumn (August-October) [7].

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Temperature Dependencies and Degree-Day (DD) Models

The development of *H. halys*, like all poikilothermic organisms, is directly dependent on temperature. This allows its phenology to be modeled using temperature sums (degree-days, DD). Several studies have defined the key thermal parameters:

- **Development Thresholds:** The lower development threshold (Lower Development Threshold, LDT) is calculated at ≈14.3°C. The upper development threshold is ≈35.8°C– 35.9°C [25].
- **Optimal Temperature:** The optimal temperature for development is around 27.8°C, and for the fastest population growth (parameter Rm) it is in the range of 25–30°C [25].
- **Temperature Sums (DD):** The most widely cited model, based on [26, 27], calculates that the complete life cycle from egg to adult requires 537.6 DD (at LDT 14.1°C). A study in Slovenia, using a slightly lower LDT (12.2°C), arrived at very similar values: 530.9 DD for the first generation and 545.2 DD for the second generation [24]. Before females begin to lay eggs (pre-oviposition period), an additional accumulation of ≈68 DD to 119 DD is required [26, 27].

These data are essential for predicting the number of generations. The laboratory study conducted on a population of *H. halys* from Plovdiv, Bulgaria, provides the first local data. At a constant temperature of 25±2°C, development from egg to adult took approximately 44 days (5 days embryonic + 39 days nymphal development) [18]. A simple extrapolation of these data shows a high degree of correspondence with international models. Using the established LDT of 14.2°C [25], the calculated temperature sum for the Plovdiv population is 479 DD (25°C – 14.2°C x 44 days). This value is very close to the reported 530–545 DD [24] Table 2. This correspondence is key, as it confirms that the biological parameters of the Bulgarian population are in accordance with those used in international models. Considering that the climate in some agricultural regions of Bulgaria is comparable to or warmer than that in Slovenia or Northern Italy [12] (where the species is stably bivoltine), it can be confidently assumed that *H. halys* has the potential to develop two generations per year in certain southern parts of Bulgaria.

Table 2: Temperature thresholds (LDT) and sums per degree-days (DD) sums for the development of *H. halys* based on data from various experimental studies

Developmental Stage	LDT (°C)	Required DD	Reference
Full cycle (egg–adult)	14.17	537	[26]
Full cycle (egg–adult)	12.2	530 (G1) / 545 (G2)	[24]
Optimal T° for development	14.3–35.9	Optimum 27°C	[25]
Embryonic development	13.9	53	[26]

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Diapause and Overwintering Behavior

The BMSB overwinters as an adult [28] in a state of facultative diapause. This physiological process of dormancy is induced by environmental cues in autumn, primarily by the shortening photoperiod (day length) and decreasing temperatures [29, 30]. Physiologically, diapause provides the stink bugs with higher cold hardiness, allowing them to survive the winter [31]. Evidence suggests that exposure to low temperatures during diapause may even enhance the fecundity of females the following spring. The behavioral aspect of diapause is key to the species' invasive success. In autumn, in response to induction cues, adults form aggregations and actively seek dry, protected sites for overwintering [32]. In natural conditions, these are crevices in rocks or under the bark of trees. In anthropogenic environments, however, human structures (houses, warehouses, garages) [1] and vehicles (trucks, containers) offer ideal, dry, and moderately protected shelters. It is precisely this behavior that turns *H. halys* into a global invasive species. Its spread is not solely due to natural dispersal (although it is a strong flyer), but to "anthropogenic commensalism." The species uses human infrastructure and the global trade network as a primary vector for intercontinental and intra-national dissemination [4].

Ecology-Environmental and Climate Influence

H. halys is considered an arboreal species (tree-dwelling), frequently found in woody vegetation and forest massifs [33]. These semi-natural habitats (forests, shrubs, hedgerows) are of critical importance, as they serve as a permanent reservoir for the species. From these reservoirs, the stink bugs migrate and colonize surrounding agricultural crops [34]. For this reason, populations are often densest at the interfaces between forest massifs and arable land. It has also been established that its spread follows human infrastructure, such as transport corridors (railways, highways) [35].

Potential Distribution Models and Climate Change

Various ecological niche modeling (ENM) methods have been used to predict the potential range of *H. halys*. The most commonly used are correlative models such as Maxent and GARP, and process-based models such as CLIMEX. They unanimously indicate that temperate latitudes (approximately 30°–50° N) offer high climatic suitability for the species, which includes the greater part of Europe and North America [36]. Interestingly, while correlative models show a risk for Northern Europe, the more conservative, process-based model CLIMEX indicates that under the historical climate (prior to contemporary warming), the United Kingdom, Ireland, and Scandinavia were not at risk of establishment [37]. This is likely because CLIMEX accounts for the need for sufficient accumulated degree-days (DD) to complete at least one generation, which was not possible under the historical climate of these regions. Climate change, however, acts as a powerful accelerator of the invasion.

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Warming will not only permit range expansion northward and to higher altitudes, but it will also fundamentally alter population dynamics [38]. The most significant consequence of warming is the shift in voltinism. A high-resolution CLIMEX model for Switzerland (a climatic analogue for many regions in Bulgaria) predicts that warming will lead to a persistent shift from one (univoltine) to two (bivoltine) generations per year [39]. For Bulgaria, this means that even regions that can currently support only one generation will be able to support two in the near future. This will effectively double the population pressure, extend the phenological window for damage infliction, and escalate the economic threat.

Feeding, Hosts, and Damage

Polyphagy and Host Plants. *H. halys* is one of the most polyphagous invasive insects, recorded on more than 300 host plant species from nearly 50 plant families. This exceptional versatility allows it to thrive in diverse environments: from forest massifs to highly diversified agroecosystems. A key feature of the BMSB feeding is its strong preference for the reproductive parts of plants-fruits, seeds, and pods [40]. This preference explains why the pest's economic impact is disproportionately high: it directly attacks the most valuable, marketable part of the crop.

The main economically important hosts include [40]:

- Fruit crops (*Rosaceae*): Apple, pear, peach, cherry, apricot.
- Nut crops (*Betulaceae*): Hazelnut.
- Vegetables (*Solanaceae, Fabaceae*): Tomato, pepper, eggplant, bean.
- Field crops (*Fabaceae, Poaceae*): Soybean, maize.
- Others: Grapes (*Vitaceae*), olives (*Oleaceae*).

Wild hosts, such as various maple species (*Acer* spp.) [41], play an important role as population reservoirs.

Mechanism of Damage. *H. halys* (all nymphal instars after the first, and adults) inflicts damage using piercing-sucking mouthparts [40] in table 3. The feeding process involves piercing the plant surface (e.g., the fruit peel), injecting digestive enzymes (saliva), and subsequently sucking up the liquefied plant fluids [42].

This mechanism leads to characteristic symptoms on the fruits:

- Suberization (Corking): In response to the injected enzymes, the tissue beneath the feeding site becomes hard, dry, and corky in texture [40].
- Necrotic spots: Dead, sunken areas appear on the surface [42].
- Deliquescence: The interior of the fruit (the flesh) can break down and liquefy [42].
- Gummosis: In stone fruits (e.g., peaches), secretion of resin (gum) from the feeding site is often observed. [42].

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- Premature drop: Severely damaged fruits often drop prematurely [43].
- Deformations: Early feeding on young fruits leads to severe deformations and stunted growth [44].

Table 3. List of the main economically important host plants for *H. halys* in Europe and the type of damage

Plant Family	Crop	Damaged Plant Part	Typical Damage Symptoms
Rosaceae	Apple, Pear	Fruit	Suberization, necrotic spots, deformation
Rosaceae	Peach, Cherry	Fruit	Gummosis, suberization, premature fruit drop
Solanaceae	Tomato, Pepper	Fruit	Necrotic spots, deformation, discoloration
Fabaceae	Soybean, Bean	Pod/Seed	Undeveloped seeds, necrosis, pod abscission
Betulaceae	Hazelnut	Kernel	Necrosis, empty nuts, premature drop
Vitaceae	Grape	Berry	Off-flavors in wine, secondary rots
Oleaceae	Olive	Fruit	Deformation, necrosis, premature fruit drop

Natural Enemies and Opportunities for Biological Control

In its invasive ranges in Europe and North America, *H. halys* benefits from the lack of co-evolved natural enemies. Local (indigenous) predators and parasitoids demonstrate very low efficacy and are not adapted to overcome the stink bug's defense mechanisms, thus failing to exert significant control over its populations [45]. In the pest's native range in Asia, however, populations are effectively controlled by specialized egg parasitoids from the family Scelionidae (Hymenoptera). The most important and effective species identified as key biological control agents are *Trissolcus japonicus* (Ashmead) (the so-called "Samurai Wasp") and *Trissolcus mitsukurii* (Ashmead) [46]. *T. japonicus* is considered the primary candidate for classical biological control programs (the deliberate introduction of a natural enemy). However, an interesting and unexpected phenomenon is changing the dynamics of biological control. *Trissolcus japonicus* has been discovered establishing accidentally (adventively), without deliberate release, in numerous regions, following the invasion of its host, *H. halys*. These adventive populations have been confirmed in the USA (since 2014) [47], Canada (2018) [48], Italy [46], and Germany (2020) [49].

Management and Monitoring

Monitoring. Effective monitoring is the foundation of any IPM program. For *H. halys*, visual inspections and beating methods are used, but the most effective are traps utilizing pheromone attractants. Following the

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identification of the male aggregation pheromone [40], effective commercial lures are available on the market. They are most commonly used in pyramid traps or sticky traps [50]. Recent research indicates that the highest efficacy is achieved with so-called "multimodal traps." These combine the chemical attractant (pheromone) with a light source (e.g., LED or UV-A light). The effect of the two stimuli is synergistic, significantly increasing the catch compared to traps using only pheromone or only light [51].

Integrated Pest Management (IPM). Managing *H. halys* is extremely difficult due to its polyphagy and mobility.

- Chemical Control: This remains the primary method for reacting to high densities. Pyrethroids and neonicotinoids are predominantly used, but they have numerous limitations: short efficacy (due to rapid degradation or the need for direct contact), risk of resistance development, negative environmental impacts on pollinators and natural enemies, and increasing regulatory bans (especially in the EU) [52].
- Mechanical Control: In very high-value crops (e.g., apples, nectarines, vineyards), the use of exclusion nets has proven to be a very effective, albeit expensive, method for completely excluding the pest [52].
- Behavioral IPM: This is the most modern and sustainable approach, which utilizes knowledge of the pest's behavior:
- "Attract-and-Kill": Using multimodal traps for mass trapping and population reduction [53].
- Border Treatments: This approach is based on the ecological observation that *H. halys* spends part of its cycle in wild habitats (forests, hedgerows) [54] and migrates from them into agricultural crops, concentrating along their borders. Placing pheromone traps along the borders of orchards can further concentrate the pest in these locations [55]. This allows farmers to apply insecticides only to the border rows, instead of spraying the entire plantation. This strategy drastically reduces pesticide costs, labor, and the environmental footprint, while simultaneously providing crop protection [4]. This predictable migration to crop borders is the pest's "Achilles' heel" and a key element in its sustainable management.

Risks and possible scenarios for the BMSB to become an economically significant pest in Bulgaria. Based on the data collected, two main scenarios for the future impact of *H. halys* in Bulgaria can be outlined.

Scenario A: Pessimistic (Reactive).

In this scenario, continued climate warming leads to the permanent establishment of two generations (bivoltinism) in Bulgaria's key agricultural regions, as predicted by models for similar climatic zones. Population pressure increases exponentially, repeating the experience of Slovenia and Italy. This leads to severe, recurrent economic damage to primary Bulgarian crops such as tomatoes, peppers, apples, peaches, vineyards, hazelnuts, and even the oil-bearing rose. In response, the sector relies mainly on reactive, calendar-based sprayings with

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broad-spectrum insecticides. This leads to increased costs, resistance development, and negative ecological consequences.

Scenario B: Optimistic (Integrated and Proactive).

In this scenario, proactive measures are implemented. A national monitoring program based on pheromone traps is established. The rapid adoption of IPM strategies is encouraged, particularly the behavioral approach of "border treatments." Simultaneously, targeted surveys are undertaken to establish the possible adventive presence of *Trissolcus japonicus*. In the long term, the successful establishment (planned or adventive) of biological control leads to population suppression. In this scenario, *H. halys* stabilizes from a major to a manageable pest, and the economic impact is limited through integrated, science-based measures.

Knowledge Gaps and Future Research

To realize Scenario B in Bulgaria, the following critical knowledge gaps must be urgently filled:

1. Local Phenology: The data from Plovdiv is an excellent start, but urgent validation of DD models with field data from different regions of Bulgaria is necessary. Developing voltinism maps for the country is of paramount importance for forecasting.
2. Population Genetics: The genetic diversity of the Bulgarian populations must be investigated. Confirming the "genetic melting pot" hypothesis by identifying the origin of the invasion (or invasions) [56] is key to understanding the pest's adaptive potential.
3. Local Natural Enemies: It is necessary to investigate whether local Bulgarian egg parasitoids are attacking (even with low efficacy) the eggs of *H. halys*.
4. Status of *Trissolcus japonicus*: This is the most urgent question. Targeted field surveys must be immediately conducted to determine if *T. japonicus* has already arrived adventively in Bulgaria, as has occurred in neighboring regions.
5. Economic Assessment: There is a lack of any published estimates of the economic damage caused by *H. halys* in Bulgaria. This data is essential for mobilizing resources and prioritizing management.

Conclusion

The Brown Marmorated Stink Bug, *H. halys*, is no longer a future threat but a firmly established invasive species on the territory of Bulgaria. Its unique biology, combining extreme polyphagy and highly effective anthropogenic dispersal, defines it as a "dual threat": both economic to agriculture and social in urban environments. The synthesis of international data on its thermal requirements and the first Bulgarian laboratory data indicates that the species has the potential for two generations in the vast majority of the country's agricultural

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regions. This capacity, which is the basis of its explosive population growth, is only expected to expand and intensify as a result of climate change.

Managing this pest is impossible by relying solely on conventional chemical methods. Future success depends on the rapid implementation of intelligent, integrated strategies (IPM) that prioritize behavioral tactics—such as monitoring and treating plantation borders. Concurrently, the Bulgarian scientific community must urgently focus on researching the potential for biological control, and more specifically, on searching for and potentially utilizing *Trissolcus japonicus*.

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