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Review Article

The expanding impact of pentatomoid bugs: drivers, challenges, and innovations in Integrated Pest Management (IPM)

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With 10 tables

Abstract: Stink bugs (Pentatomidae) and related species of pentatomoids (Scutelleridae and Tessaratomidae) are known to damage crops as either major or minor pests. For various reasons, their negative impacts have recently grown worldwide. This increasing importance of stink bugs is due to a myriad of reasons, especially the overuse of insecticides, the increase in global temperatures, the diversification of agriculture ("green-bridge"), and the international trades of agricultural goods. Although farmers continue to spray a range of traditional insecticides, the global negative side effects of their overuse demand better sustainable management. Among the appropriate tools available, biological control using egg parasitoids has the greatest potential for further development in the majority of regions. In addition, the adoption of semiochemicals, insecticides from botanical sources, genetic manipulations (e.g., RNAi and CRISPR), and genetically modified biological control agents should be major components of stink bug management in the future, supported by monitoring and forecasting (e.g., adoption of trapping or satellite image analysis). This integrated approach will ensure efficient sustainable stink bug management that balances economic viability and ecological health.

Keywords: sustainable pest control; invasive species; biological control; pesticide resistance; Heteroptera; Pentatomidae; global trade and invasiveness; climate-driven pest expansion

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1 Introduction

This review focuses on economically important pest species of stink bugs (Hemiptera: Heteroptera: Pentatomidae) and closely related families (Scutelleridae and Tessaratomidae) all included in the superfamily Pentatomoidea that affect crop and food production worldwide. Pentatomidae is the largest family in the Pentatomoidea, containing 940 genera and 4,949 species. It is the third largest family within Heteroptera and one of the most diverse groups of hemimetabolous insects (Rider et al. 2018).

Although it is impossible to give a precise number of pentatomoid pests that attack cultivated plants, a significant portion is found attacking commodity crops. Some species are major pests, severely damaging extensively cultivated areas in different parts of the world, whereas others are classified as minor pests (Schaefer & Panizzi 2000; Grazia & Schwertner 2024). Damaged commodities include cotton, maize, rice, soybean, wheat, among others, including vegetables and fruit trees. They thus impact food production and, consequently, the global economy. A few other economically significant families closely related to the Pentatomidae (within Pentatomoidea) are included in this review.

Therefore, in the following sections, we detail the major pentatomoid pests worldwide. We present and discuss their damage and economic impact to the most relevant crops of each region; approaches to mitigate their impact by the most important control strategies; and the global common challenges and perspectives on how to develop sustainable integrated pest management (IPM).

2 Pentatomoid pests worldwide

Phytophagous pentatomoid species cause direct yield loss to crops and reduce production in various ways (Tables 1–10). Adults and nymphs feed by inserting their stylets into the plant and extracting plant fluids. Damage is primarily caused by adults and last instars. Their injury includes the loss of plant fluids and turgor pressure, the injection of destructive digestive enzymes which triggers the deformation and abortion of seed and fruiting structures, and delayed plant maturation (McPherson 2018; McPherson & McPherson 2000; Panizzi et al. 2000). Feeding injury consequently affects the quality and appearance of grains, fruits, and plant seedlings (Waterhouse & Sands 2001). Leaves and shoots are also damaged (e.g., *Edessa meditabunda* [F.] to soybean and potato plants – Panizzi et al. [2000]). Feeding by pentatomoids also may result in the transmission of viruses, phytoplasmas, and bacterial and fungal pathogens that can lead to secondary infections, negatively affecting crop yield and quality (Esquivel & Bell 2021). Next, we discuss the most important species of Pentatomoidea for the different continents and the tools used to manage them, so that we can identify common challenges and experiences across the world.

2.1 South America (Argentina and Brazil)[1,20] (authors)

In most of South America, favorable climatic conditions support intensive agriculture for most of the year. They create a green-bridge that offers a constant source of food favoring pentatomoid outbreaks, especially of polyphagous species, making these pests (Table 1) among the most important and most difficult to be managed in the field (Bueno et al. 2024a).

Soybean is the most widely cultivated crop in South America, with areas of more than 45 million ha cultivated in Brazil (1st in world production) and 18 million ha in Argentina (3rd in world production). Soybean favors stink bugs reproduction and their dispersion to neighboring crops such as cotton (Sosa-Gómez et al. 2020), which has a longer growing season. Also, maize and wheat, cultivated in the same field after the harvest of soybean, supports stink bugs population growth all year (Panizzi & Lucini 2024). Consequently, their importance has increased in recent years not only on soybean but also on cotton, maize, wheat, and on other minor crops cultivated close to soybean (Sosa-Gómez et al. 2020; Panizzi et al. 2022).

With the adoption of genetically modified (GM) soybean, Roundup Ready (RR) became the most cultivated soybean cultivars (Bueno et al. 2025). The elimination of some common weeds in soybean fields, which used to be important for *Nezara viridula* (L.), has made this species less abundant and, in some years, even rare (Panizzi et al. 2022). It used to be, by contrast, the most important stink bug species from 1960s until the early 1990s. These new conditions (e.g., multiple crop systems, no-tillage with crop residues remaining on the soil, change in weed management, and general temperature elevation), however, favor the population growth of the Neotropical brown stink bug, *Euschistus heros* (F.), which has become the primary major pest in this agroecosystem (Panizzi & Lucini 2024).

Other stink bug pests' worth of mention in South America are the endemic ones that infest rice, including *Tibraca limbativentris* Stål, which is a main pest feeding on stalks that can reduce seed yield to almost 50% (Krinski & Foerster (2017). Species of *Oebalus* spp. and *Mormidea* spp. also feed on rice, but, in general, the damage is minor than observed for *T. limbativentris* (Panizzi et al. 2000).

As with most of the other regions of the world discussed in this review, traditional insecticides still provide the main control strategy for managing stink bugs outbreaks in South American countries (Moreira et al. 2024). In addition, seed treatment for protecting the initial plant development of maize from the endemic species *Diceraeus* (*Dichelops*) *melacanthus* (Dallas) injury also has been generally adopted (Silva et al. 2019).

More recently, "greener" tools to control stink bugs have been researched and adopted in the field, reducing the spray of traditional chemicals (Bueno et al. 2024a, b). Among the most recent sustainable and effective alternatives for managing stink bugs in Brazil is the mass release of the egg parasitoid *Telenomus podisi* Ashmead, against *E. heros*, which

Table 1. Main pest pentatomoid species in South America (Argentina and Brazil) and their damage to different crops.

Species	Crops	Damage inflicted	Source
Arvelius albopunctatus	Tomato.	Minor damages, generally not requiring application of control measures.	Panizzi et al. (2000)
Chinavia (= *Acrosternum*) spp.	Soybean.	Minor damages, generally not requiring application of control measures.	Panizzi et al. (2000)
Diceraeus furcatus, D. melacanthus	Cotton, maize, soybean, wheat.	Great damage potential on soybean; feeding on maize seedlings results in necrosis, yellowing, leaf deformation, and plant tillering; damage varies from 11% to 100%.	Panizzi & Lucini (2019); Silva et al. (2021)
Edessa meditabunda	Soybean.	Minor damage.	Panizzi et al. (2000)
Euschistus heros	Cotton, maize, soybean, wheat.	Reduction up to 25% of cotton lint; up to 30% of soybean yield; responsible for up to 60% of all insecticides used on soybean. Minor damage on maize and wheat.	Sosa-Gómez et al. (2020); Bueno et al. (2024a); Moreira et al. (2024); Panizzi & Lucini (2024); Saldanha et al. (2024)
Mormidea spp.	Rice.	Minor damage.	Panizzi et al. (2000)
Nezara viridula	Soybean.	Main soybean pest in 1960s–1990s, today minor pest.	Panizzi et al. (2000); Panizzi et al. (2022)
Oebalus spp.	Rice	Minor pest.	Panizzi et al. (2000)
Tibraca limbativentris	Rice.	Main pest with seed yield reduction 17 to 44%.	Krinski & Foerster (2017)

can achieve up to 90% egg parasitism in the field (Bueno et al. 2024b). This parasitoid has been commercialized in Brazil since 2019, initially at small scale, but with constant new biocontrol industries entering the market. Moreover, the spray of entomopathogens (i.e., fungi) against pest stink bugs and conservation biological control through weed management and landscape modeling is gaining momentum in the Neotropics, reflecting the increasing adoption of IPM (Bueno et al. 2023a, Panizzi & Lucini 2024).

2.2 North America (Canada, Mexico and USA)[2,3,4]

The average seasonal temperatures in North America have ecological consequences for stink bug ecology that differ from the situation in the Neotropics. Therefore, adult stink bugs, and sometimes nymphs, overwinter beneath ground debris and usually remain inactive for long periods in the colder periods of the year. However, some species may become active when milder temperatures occur during winter (McPherson & McPherson 2000). The insects emerge in the spring and begin feeding and reproducing on various hosts (Table 2) including grasses, herbaceous vegetation, shrubs, and trees. They are attracted primarily to plants with growing shoots and developing seeds or fruits, and will move from host to host as peak reproduction approaches and plants senesce. The number of generations per year in North American ranges from one in the North to five in the extreme South (e.g., south Florida) (McPherson & McPherson 2000).

Among the different species that occur in the continent (Table 2), *Halyomorpha halys* (Stål), a recent invasive species from East Asia, first was detected in North America in 2001 in Allentown, PA, USA. It now has a wide distribution throughout the continent (including USA and Canada) (Nixon et al. 2024; StopBMSB.org 2024) despite still reported as absent or not established in the American states of Alaska, Hawaii, and Wyoming as well as the Canadian provinces of Manitoba and Saskatchewan (EPPO 2025). It is a bivoltine species that overwinters as adults in artificial and natural shelters. *Halyomorpha halys* emerges in the spring and begins feeding primarily on the reproductive structures of plants (i.e., seeds, fruits, and pods) but also has been observed feeding on leaves and tree bark (Hamilton et al. 2018). It is a highly mobile phytophagous species and has been reported from over 175 host plants in North America alone (Hamilton et al. 2018; Bergmann et al. 2023), severely damaging fruits, vegetables, and field crops as soybean (Rolando et al. 2025) among others (EPA 2025). Other invasive species considered of economic importance include *Bagrada hilaris* (Burmeister) (Palumbo et al. 2016), *Murgantia histrionica* (Hahn) (McPherson et al. 2018a) and *Nezara viridula* (L.) (Esquivel et al. 2018).

Although *H. halys* is a major, high-profile invasive pest with a vast host range, *B. hilaris* and *M. histrionica* have been important and dedicated pests of *Brassica* crops. However, the importance of either species in Brassicae are region-specific in the continent. *Nezara viridula* is associated with almost 200 plant species that occur in the region, being of economic importance especially attacking soybean, cotton, and other agricultural crops (Esquivel et al. 2018).

Table 2. Main pest pentatomoid species in North America (Canada, Mexico, and USA) and their damage to different crops.

Species	Crops	Damage inflicted	Source
Bagrada hilaris	Cole crops (Brassicaceae).	Reductions in plant stands; damage to terminal growing points, severely malforming plants.	Bundy et al. (2018a)
Chinavia hilaris	Cotton, maize, soybean, tobacco, various fruits.	Included in the damage below*.	McPherson (1982); McPherson & McPherson (2000); Bundy et al. (2018a); Esquivel et al. (2018); Sisson et al. (2024); Vyavhare et al. (2024)
Chlorochroa ligata *C. sayi*	Alfalfa, barley, bean, beet, cabbage, cotton, lettuce, maize, oat, pea, peach, squash, sorghum, rye, tomato.	Included in the damage below*.	Nixon et al. (2024); Vyavhare et al. (2024)
Euschistus servus *E. variolarius* *E. tristigmus* *E. conspersus*	Alfalfa, apple, maize, peach, pear, pecan, soybean, tomato, wheat.	*Soybean damage over 12.5 billion bushels lost and cost exceeding US$78 billion in insecticide applications in 2023.	McPherson & McPherson (2000)
Halyomorpha halys	Apple, grape, maize, peach, pear, pepper, soybean, tomato.	In 2010, apple alone incurred US$37 m in losses and estimations indicated half of the peach crop lost.	Nixon et al. (2024)
Murgantia histrionica	Bean, broccoli, cabbage, cauliflower, collard, cotton, maize, potato, radish, turnip.	Not reported.	McPherson & McPherson (2000); McPherson et al. (2018a)
Nezara viridula	Cotton, soybean.	Included above	McPherson (1982); McPherson & McPherson (2000); Bundy et al. (2018a); Esquivel et al. (2018); Sisson et al. (2024); Vyavhare et al. (2024)
Oebalus spp.	Barley, maize, oat, rice, rye, sorghum, wheat.	Not reported.	McPherson & McPherson (2000)
Piezodorus guildinii	Soybean.	Soybean damage over 12.5 billion bushels lost and cost exceeding US$78 billion in insecticide applications in 2023.	McPherson (1982); McPherson & McPherson (2000); Bundy et al. (2018a); Esquivel et al. (2018); Sisson et al. (2024); Vyavhare et al. (2024)
Thyanta spp.	Alfalfa, berry, cotton, green bean, maize, pea, pistachio, soybean, sugar beet, tomato.	Limited economic importance.	McPherson & McPherson (2000)

Besides North America, *B. hilaris* also occurs in the Middle East, Africa, Australia, southern Europe, southeast Asia, and more recently in the New World. It is among the most recent invasive stink bugs in the United States, initially reported in California, followed by Nevada, Utah, Arizona, and from New Mexico to Texas (Taylor et al. 2015) later infesting crops also in Hawaii, northern Mexico, and Chile (Albornoz et al. 2024).

Murgantia histrionica is native to Central America and Mexico. It is considered the earliest established stink bug in the United States (McPherson et al. 2018a), and was first reported in 1864 (McPherson & McPherson 2000). Although wide-ranging in distribution, it is primarily a southern species (McPherson et al. 2018b). Different from most of the stink bug species, *M. histrionica* is multivoltine (McPherson 1982). Voltinism is the number of generations an insect has each year, while multivoltinism is the occurrence of more than one full life cycle within a single year (Guthrie et al. 2025). Estimates of the number of complete generations of *M. histrionica* per year ranges from three to eight in the South and from two to five in the North of the USA, with adults usually overwintering (McPherson 1982).

Chinavia hilaris (Say) ranges from Quebec and New England, west through southern Canada and the northern United States to the Pacific Coast, and south and southwest to Florida, Texas, Arizona, and Utah (McPherson & McPherson

2000). It attacks several major crops including soybean, maize, tobacco, cotton, and various fruits. It overwinters as adults preferring leaf litter of deciduous woods although other sites have been reported (McPherson & McPherson 2000). Most investigators consider the species to be bivoltine. It is one of the three main stink bug pests of soybean, the other two being *Euschistus servus* (Say) and *N. viridula* (McPherson & McPherson 2000). Most damage occurs when the host plants are in the reproductive stages (i.e., fruit or pod formation).

Euschistus spp. occur in North America, several of which are economically important (Henry & Froeschner 1988). Four species [i.e., *E. servus*; *E. variolarius* (Palisot de Beauvois); *E. tristigmus* (Say); and *E. conspersus* Uhler] have been of continuing economic importance, particularly *E. servus* (McPherson & McPherson 2000). They are polyphagous, feeding on grasses, shrubs, and trees. They are particularly attracted to plants that are actively producing fruits and pods. These four *Euschistus* species can seriously affect the quality and yield of cultivated agricultural crops such as soybean, wheat, alfalfa, and maize and horticultural crops such as tomato, peach, pear, apple, and pecan (McPherson 1982).

Other species that are economically important but usually less so include *Chlorochroa* spp., *Oebalus* spp., *Piezodorus guildinii* (Westwood), and *Thyanta* spp. They are listed in Table 2 with information on crops attacked and damage.

Control of stink bugs involves a combination of IPM strategies. Chemical control applied at thresholds established for each crop, in combination with proper field scouting, remains the most effectively used for reducing stink bug injury (Vyavhare et al. 2024). Cultural control methods, such as trap crops, removal of weedy hosts, and altered planting dates, also have been used effectively (McPherson & McPherson 2000; Vyavhare et al. 2024). However, trap crops are somewhat less efficient in the arid Southwest where water is a limiting factor (Vyavhare et al. 2024). Biological control also is effective, and a wide range of natural enemies has been used with varying levels of success. These include parasitic tachinid flies (e.g., *Trichopoda pennipes* (F.), *Euthera tentatrix* Loew) and parasitoids (e.g., *Ooencyrtus* sp., *Telenomus podisi, Trissolcus* spp.) that target stink bug eggs and adults (McPherson 2018; Ademokoya et al. 2022). Also, predators target all life stages and include *Collops vittatus* (Say), *Geocoris* spp., *Harmonia axyridis* (Pallas), *Hippodamia convergens* Guérin-Méneville, *Mecaphesa asperata* (Hentz), *Orius insidiosus* (Say), *Oxyopes salticus* (Hentz), *Podisus maculiventris* (Say), *Scymnus* sp., *Sinea diadema* (F.), and *Solenopsis invicta* Buren (Bundy et al. 2018). Nematodes (Mermithidae) also have been detected in adult stink bugs, but these infestations rarely reduce field populations (Esquivel 2011; Kamminga et al. 2012). More recently, Esquivel et al. (2022) demonstrated a bacterium (*Bacillus velezensis* LP16S) significantly reducing mean survival of female *N. viridula.* Stink bug management strategies were reviewed extensively by McPherson & McPherson (2000).

2.3 Europe (excluding Russia)[5]

Across Europe, multiple species of stink bugs can cause significant damage to different crops (Table 3), being *H. halys*, currently considered the most serious species (Leskey & Nielsen 2018). Recorded in Europe since 2004, *H. halys* has already been detected as far north as the Netherlands, Belgium and the north of Germany (Berteloot et al. 2024a), being established in around 80% of the European countries (Maistrello 2024).

Halyomorpha halys has a wider food range relative to native species (Berteloot et al. 2024a) and is responsible for significant yield loss (Table 3) when not managed properly (Maistrello 2024; Rolando et al. 2025) especially on olive, an important crop in southern Europe, in terms of quantity (e.g., increased fruit drop) and quality (e.g., lower oil quality) (Daher et al. 2023; Sanna et al. 2024). Only in Italy, the economic significance of this pest was evaluated in 600 million euros of estimated losses in 2019 across the northern regions, one of the largest fruit production areas in Europe (Maistrello et al. 2017).

Farmers reacted to this invasive pest by increasing use of broad-spectrum insecticides and approaches such as localized insecticide spray have been proposed for chemical control optimization (Landi et al. 2024). Among alternatives to synthetic insecticides, promising results in field trials with damage reduction have been obtained with repeated applications of products based on sulfur, diatomaceous earth, and kaolin (Scaccini et al. 2024; Chierici et al. 2025). They repel adults and deter feeding and also increase the mortality of nymphs. The application of products with symbiont-targeted activity represents another option. Laboratory investigations considered different types of products (Checchia et al. 2025), but, to date, only applications of a copper biocomplex have been tested in the field, showing positive results in hazelnut orchards (Dho et al. 2025).

Alternatives to chemical control also have been proposed. *Halyomorpha halys* infestation can be favored by semi-natural and urban habitats surrounding fields (Tamburini et al. 2023); thus, physical barriers represented by insect-proof nettings limiting crop colonization, showed high efficacy in reducing pest damage in pome and stone fruit orchards (Candian et al. 2021; Fornasiero et al. 2023). Together with research on the development of efficient control tactics, improvement of monitoring also has been considered with the aim of developing multimodal trapping systems based on the combination of aggregation pheromones and vibrational-calling signals (Fouani et al. 2024) or LEDs emitting UV-A and visible light (Rondoni et al. 2022), as well as testing new lure and dispenser combinations (Giannuzzi et al. 2025).

Innovative monitoring tools also consider the development of automatic trapping systems (Niederprum et al. 2023), real-time monitoring platform (Forresi et al. 2024), remote sensing tools incorporated into unmanned aerial vehicles (UAV) (Palazzetti et al. 2024), and analysis of non-

Table 3. Main pest pentatomoid species in Europe (excluding Russia) and their damage to different crops.

Species	Crops	Damage inflicted	Source
Aelia spp.	Poaceae, especially wheat.	Not reported.	Gibicsár & Keszthelyi (2023)
Bagrada hilaris	Caper.	Not reported.	Guarino et al. (2007)
Eurydema spp.	Cruciferous plants.	Yield loss exceeded 30% in cabbage (up to ~50%).	Trdan et al. (2006)
Halyomorpha halys	Bean, cherry, hazelnut, kiwifruit, maize, olive, pepper, persimmon, pome, soybean, stone fruits, grapevine, tomato.	≥ 70% yield loss. Increased incidence of fruit molds and rots in sweet cherry and grapevine.	Messelink et al. (2020); Maistrello (2024); Rolando et al. (2025)
Nezara viridula	Green bean, maize, pepper, soybean, tomato.	Losses in sweet pepper: 10–15% in 2019.	Vandekerkhove & De Clercq (2004); Streito & Bout (2019); Messelink et al. (2020); Conti et al. (2021); van Hee et al. (2024)
Palomena prasina *Pentatoma rufipes*	Alder, apple, apricot, beech, cherry, hazelnut, pear, plum, oak.	Losses of up to 50%.	Powell (2020); Hamidi et al. (2022)

volatile metabolome and volatilome for fruit damage diagnosis in hazelnut (Squara et al. 2024).

Classical biological control based on the introduction of exotic natural enemies is considered the most promising long-term solution to reduce *H. halys* populations in Europe. For this reason, the regulated introduction of the Asian egg-parasitoid *Trissolcus japonicus* (Ashmead) was initiated in Italy in 2020, while releases of *Trissolcus mitsukurii* (Ashmead) been performed in France since 2022 (Martel et al. 2024). However, adventive populations of *T. mitzukurii* were recorded in Italy since 2016, and those of *T. japonicus* in Switzerland since 2017 (Scaccini et al. 2020).

Besides parasitoids, research shows that the commercially available predators such as *Adalia bipunctata* (L.) (Coleoptera: Coccinellidae) and *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) can potentially control *H. halys*, offering the opportunity of augmentative biocontrol, especially in greenhouses (Berteloot et al. 2024b).

Another invasive stink bug, *B. hilaris*, has been recorded in Italy and Malta. Localized populations, sterile insect technique via gamma irradiation (Paolini et al. 2025) and mating disruption using vibrational signals (Scala et al. 2024) have been proposed against this species and may be used soon.

Among other stink bug species of concern in European agriculture, *N. viridula* is expanding its range northward, likely driven by climate change creating favourable conditions beyond its original distribution in southern Europe (Esquivel et al. 2018; Gard et al. 2022). The insect broad host plant range has facilitated this geographical expansion in eastern Europe (Conti et al. 2021). In Northern Europe, *N. viridula* already causes significant damage to greenhouse vegetables (Table 3). Although *N. viridula* has been established in the United Kingdom since 2003 and recorded on various crops, significant damage has not been reported yet (Salisbury et al. 2009).

Novel imaging approaches have been used to monitor damage by *N. viridula* in soybean (Gibicsár et al. 2024). Also, augmentative biological control based on the egg parasitoid *Trissolcus basalis* (Wollaston) has provided satisfactory control in greenhouses for tomatoes and eggplants, as well as in soybean fields (e.g., Gard et al. 2022). *Chrysoperla carnea* larvae also effectively prey on early instars of *N. viridula*, enhancing control of this pest in greenhouse systems (Berteloot et al. 2024b).

Pentatoma rufipes (L.) is widespread across the Palaearctic, particularly in the United Kingdom, countries of Benelux, Central Europe, and at higher altitudes in the Alps (Table 3) (Powell 2020). It is emerging as a pest of tree fruits in northern Europe and, along with *Palomena prasina* (L.), is considered a secondary pest whose damage often follows outbreaks triggered by inappropriate management (Powell 2020; Hamidi et al. 2022). Following the withdrawal of chlorpyrifos from the market, damage to pears and apples has increased, with symptoms such as fruit deformities and pitting becoming apparent only at harvest or during storage (Powell 2020). In France, *P. rufipes* has caused higher damage on hazelnut comparable to *P. prasina*, exhibiting deeper stylet penetration and more intense feeding during kernel development, along with the formation of distinct necrotic spots (Hamidi et al. 2022).

Monitoring tools are still limited, with no pheromones identified for *P. rufipes*; however, vibrational communication may offer future solutions. Effective chemical controls include lambda-cyhalothrin and spinosad applied when the pest is present in the field. In addition, physical barriers like insect-proof nets could be integrated into pest management (Powell 2020). Biological control often remains underexplored, and in Europe, *T. japonicus* was found to exploit *P. rufipes* eggs (Falagiarda et al. 2023; Haye et al. 2024), although its impact on populations remains unknown.

Other native stink bugs, such as *Aelia* spp. and *Eurydema* spp. can inflict significant crop damage in Europe (Stankevych et al. 2021; Gibicsár & Keszthelyi 2023). Although varying across years and locations, greater negative impacts have been observed in certain areas and plant phenological stages when *Eurydema* spp. densities are high (Stankevych et al. 2021). Several hymenopteran egg parasitoids and dipteran mobile-stage parasitoids were associated with native *Aelia* spp. and *Eurydema* spp. (Moraglio et al. 2021), but their use in augmentative biological control program requires further investigations. In the case of *Eurydema* spp., for which effective parasitoids often are lacking, control strategies should integrate pest abundance, spatial dynamics, and economic thresholds combined with targeted insecticide use and agronomic practices such as crop rotation and cruciferous weed removal (Stankevych et al. 2021). Additionally, synthetic plant volatiles with attractant potential may serve as complementary monitoring or control tools (Koczor & Tóth 2023).

2.4 Eastern Europe and North Asia (Russia)[6,7,8,9,10]

Despite its vast territory, Russia has a relatively low diversity of pentatomoids with only 152 species, likely due to the predominantly cool climate across most of the country (Gapon 2024). In the 20th century, pentatomoids were considered secondary pests in Russia. Only 24 species from the genera *Aelia, Carpocoris, Dolycoris, Eurydema, Graphosoma, Codophila, Palomena, Rubiconia, Pentatoma*, and *Piezodorus* were considered pests. Among them, 12 species were distributed throughout the whole country, three were restricted to its European part, and nine were confined to the Asian part (Putshkov 1972; Gapon 2024). Then, 10–15 pentatomoids were considered to be economically important, but only periodically (Putshkov 1972).

Since the late 20th century, however, an increase in the population density and harmfulness of pentatomoids have been observed in Russia (Karpun et al. 2022). Nevertheless, only a few species (Table 4) currently are considered important agricultural pests. Comprehensive assessments of the economic damage caused by them at the national or regional levels are lacking; most studies evaluate damage at a local scale without monetary estimates; often only parameters of the pest's population density or yield reduction are reported. The most important pests of Pentatomidae and Scutelleridae in Russia in the 21st century are briefly overviewed in this section.

Nezara viridula was known as a rare species in natural ecosystems in the south-west of the European part of Russia (Krasnodar Krai) since the late 19th century (Horváth 1899). However, since 2006, this pest has been recorded in southern European Russia (Table 4).

Halyomorpha halys was first recorded in Russia in 2014 in the south of its European part (Mityushev 2016, Musolin et al. 2022). This highly polyphagous pest feeds on over 100 plant species from 48 families in this area (Zakharchenko et al. 2020).

Dolycoris baccarum (L.) has been recorded damaging different plants (Table 4). In several regions of Russia, an increase in the population density of *D. baccarum* and *Carpocoris purpureipennis* (De Geer) in winter wheat has been noted; their numbers have even surpassed those of *Eurygaster integriceps* Puton, the primary pest of cereal crops in the country (Kapustkina & Frolov 2022).

Species of the genus *Eurydema* are pests of vegetable, oilseed, and industrial crops in the family Brassicaceae and are widespread throughout Russia (Gapon 2024). In the southern Asian part of Russia (Omsk Region), the damage caused by *Eurydema oleracea* (L.) and *Eurydema ventralis* Kolenati to white cabbage plantations is so severe that the use of plant protection measures is deemed necessary (Gayvas & Kling 2019). In the northern European part of Russia, the infestation of white mustard by *E. ventralis, E. oleracea*, and *Eurydema ornata* (L.) reached 20.5–30.0% with a population density of 3–5 nymphs or adults per plant (Vasilyeva 2018).

Three species of the genus *Aelia* (*A. acuminata* L., *A. rostrata* Boheman, and *A. sibirica* Reuter) remain potential threats to cereal crops, primarily to spring and winter wheats, in Russia (Grichanov 2024). However, only *A. acuminata* is considered a major pest of cereal crops, whereas the others are minor (Naas et al. 2014). Salivary enzymes of these species reduce seed quality less than those of *E. integriceps* (Sosedov et al. 1969), but when 10% of grains are damaged the deterioration of gluten quality becomes evident (Gurova 1976).

In many cases, multiple species can simultaneously cause damage acting as a species complex. Thus, reports indicated that a complex of *D. baccarum, Carpocoris fuscispinus* (Boheman), *Piezodorus lituratus* F., and *P. prasina* caused soybean yield losses of 10.6–18.5% in the Krasnodar Krai (Pushnya et al. 2018). Furthermore, a pest complex consisting of *D. baccarum, C. fuscispinus, P. lituratus, P. prasina, N. viridula*, and *P. rufipes* is recognized as the most harmful to tobacco crops (Plotnikova et al. 2019).

Six species of the genus *Eurygaster* (Scutelleridae) are known in Russia and are significantly more harmful than pentatomids (Neimorovets 2019, 2020; Gapon 2024). Among them, *E. integriceps* has the greatest economic significance (Pavlyushin et al. 2015). This species is included in the list of the most damaging wheat pests in the country (VIZR Working Group 2010). The proportion of wheat grain damaged by *E. integriceps* greatly varies (0.2–73.4%) (Pavlyushin et al. 2015; Kapustkina & Khilevskiy 2020; Kapustkina & Frolov 2022). The total economic losses caused to wheat by this pest were estimated to be 350–500 million USD per year (Rylko 2010 [2011]). Barley yield losses can amount to 20–30% (Kapustkina & Frolov 2022).

Table 4. Main pest pentatomoid species in Eastern Europe and North Asia (Russia) and their damage to different crops.

Species	Crops	Damage inflicted	Source
Aelia acuminata *A. klugii* *A. rostrata* *A. sibirica*	Cereal crops.	Not reported.	Gapon (2024)
Carpocoris purpureipennis	Diverse crops.	Not reported.	Putshkov (1972); Karpun et al. (2022)
Dolycoris baccarum	Diverse crops.	Not reported.	Putshkov (1972); Karpun et al. (2022)
Eurydema oleracea *E. ventralis* *E. ornata* *E. maracandica*	Brassicaceae	Not reported.	Putshkov (1972); Karpun et al. (2022)
Graphosoma lineatum	Apiaceae.	Not reported.	Putshkov (1972); Karpun et al. (2022)
Pentatoma rufipes	Fruit crops.	Damage bolls of oil flax, resulting in boll death; reduce seed quality; yield reduction and cereals of 0.061 t/ha or 1.2%.	Putshkov (1972); Karpun et al. (2022)
Dolycoris baccarum	Sunflower, flax, alfalfa, cereal crops.	Not reported.	Semerenko (2019); Bushneva & Dolgov (2021); Chenikalova & Lebedeva (2023); Shpanev & Kapustkina (2023)
Eurygaster austriaca	Cereal crops	Not reported.	Putshkov (1972)
E. integriceps *E. maura*	Cereal crops.	The proportion of damaged wheat grains varies from 0.2–12% to 40–73.4%. Barley losses can reach 20–30%.	Putshkov (1972); Neimorovets (2020);Zhivykh et al. (2025) [as *E. integriceps*]
E. maura	Cereal crops.	In recent years, an increase in *E. maura* populations was observed in the Altai Krai. The negative effect of *E. maura* saliva on flour quality is the same as in *E. integriceps*.	Putshkov (1972); Kapustkina & Nefedova (2015) [as *E. integriceps*]; Neimorovets (2020); Govorov et al. (2023, 2024) [as *E. integriceps*]; Zhivykh et al. (2025) [as *E. integriceps*]
Halyomorpha halys	Bean, citrus, fig, hazelnut, maize, pepper, persimmon, pome fruits, stone fruits, sweet tomato.	Hazelnut kernels fail to develop properly; deformed fruits fail to ripen.	Musolin et al. (2018, 2022); Zakharchenko et al. (2020)
Nezara viridula	Alfalfa, apple, cucumber, eggplant, grape, pepper, raspberry, soybean, tobacco, tomato.	Damaging up to 38.6% of soybean pods; tomato yield losses of 30–70%.	Pushnya et al. (2017); Plotnikova et al. (2019); Karpun et al. (2022); Chenikalova & Lebedeva (2023)
Palomena prasina	Legumes, mustard, rowan trees, soybean, sugar beet, tobacco.	Minor damage.	Pushnya et al. (2018); Vasilyeva (2018); Plotnikova et al. (2019); Chervyakova & Keldysh (2022)

The damage caused by *Eurygaster maura* (L.) has been reported in the Yaroslavl and Nizhny Novgorod Regions (Pogorelov 1965). In recent years, an increase in *E. maura* populations has been observed in the Altai Krai (Zhivykh et al. 2025). No economic threshold criteria have been developed for this species, and the thresholds used for *E. integriceps* are applied instead.

In Russia, management of pentatomoids pests involves agronomic practices (i.e., selection of resistant crop varieties, crop rotation), biological control (introduction of egg parasitoids of the genus *Trissolcus*), treatment with essential oils, bacterial insecticides, and avermectins (Plotnikova et al. 2019; Pushnya et al. 2021).

Chemical control includes pyrethroids and neonicotinoids (Zakharchenko & Karpun 2019) but they officially are approved for use only against *H. halys* and *Aelia* spp. (State Catalog 2025). For the control of *E. integriceps* and *E. maura*, biological pesticides (based on *Bacillus thuringi-*

ensis, Beauveria bassiana, Streptomyces spp.) and chemical pesticides (neonicotinoids, pyrethroids, organophosphates, and organofluorine compounds) are primarily used (State Catalog 2025).

Pheromone traps are used solely for *H. halys* (Sinitsyna et al. 2019). No specific eradication measures are currently implemented for *Aelia* species; they are suppressed indirectly during treatments against *E. integriceps* and through agronomic practices (e.g., autumn plowing, weed control). For *E. integriceps*, control methods have been developed using biocontrol agents, sex pheromones, and various agricultural techniques (Kapustkina & Frolov 2022). The use of pest-resistant wheat varieties has also been proposed (Pavlyushin et al. 2015).

2.5 Asia (Iran, Iraq, Syria, and Türkiye)[11]

Several species of pentatomoids from the genera *Aelia, Carpocoris* and *Dolycoris* cause significant yield reductions on cereal production (wheat and barley) each year in the Middle East countries (Table 5). In Iran, Iraq, Syria, and Türkiye, they are usually found feeding on wild grasses (genera *Agrostis, Avena, Bromus, Dactylis, Festuca, Lolium* and *Poa*). However, in the absence of those original wild hosts, they can feed, develop and, consequently, damage cultivated cereals, especially wheat varieties. Wheat and, to a lesser extent, barley production make up the basic part of the main diet in those countries, which makes the Pentatomoidea pests that damage those crops of major economic importance.

A long-term study of population dynamics of *Aelia furcula* Fieber in wheat fields in Iran, during outbreaks of this pest, has indicated that its population density is majorly determined by biotic factors including especially natural parasitism and predation. Climatic conditions, especially temperature and rain, also played an important role in the population dynamic of the insect. Frequently, the high environmental temperatures favor the development of *Aelia* spp. Fecundity and longevity of these insects are greater on wheat compared to barley. Thus, these insects mainly attack wheat cultivations including fields close to barley (Javahery 1995).

Aelia furcula in the mountainous wheat fields of western Iran is found both on cultivated wheat and wild grasses. Their eggs are usually parasitized by different species from the family Scelionidae, including *Trissolcus grandis* Thomson, *Trissolcus semistriatus* Ness, *Trissolcus vassilievi* Mayr and *Trissolcus rufiventris* (Mayr), while their nymnphs and adults are parasitized by some Tachinidae (Diptera) (Javahery 1995, 1996). However, a long history of application of chemical insecticides on cultivated fields has been severely impairing these biocontrol agents and favored stink bug outbreaks.

The use of insecticides against cereal stink pests started during the Second World War in Iran and have continued to date, and it has increased to be applied from 50,000 ha in 1968 to over 1.5 M ha in 2024 in Iran alone. Increased insecticide use led, ultimately, to pest outbreaks, with 2–10 overwintered adults and 20–200 nymphs per square meter being recorded. Consequently, the adoption of IPM, including more sustainable pest management, is urgently needed (Javahery 1996).

2.6 Asia (Japan)[12,13]

In Japan, agricultural pentatomoid pests are divided into rice, fruit, and bean/vegetable pests (Table 6). In rice, the major impact from those pests is the discoloration of grains (known as “pecky rice”) due to proliferation of microorganisms that have invaded the surface of brown rice from the feeding sites (Kiritani 2007). Pecky rice bugs have rapidly become a serious problem in the country since the 1970s because rice is graded according to the percentage of discolored rice grains in brown rice. Although most pecky rice bugs belong to the families of non-pentatomoid Alydidae or Miridae, some species from the family Pentatomidae also are known as pecky rice bugs (Kiritani 2007). Most of these species produce two or more generations per year in Japan but they cannot complete their life cycles only in the rice field (Tabuchi et al. 2023). They live outside the rice fields feeding on weeds (mostly Poaceae) and begin to invade rice fields usually from mid-July to early August (Kitagami & Nishino 2003).

Table 5. Main pest pentatomoid species in Asia (Iran, Iraq, Syria, and Türkiye) and their damage to different crops.

Species	Crops	Damage inflicted	Source
Aelia acuminata *A. furcula* *A. rostrata* *A. virgata* *Carpocoris* spp. *Dolycoris* spp.	Barley, wheat.	Causes the stems to wither and die before the formation of heads; reduces gluten quality, impairing baking quality of the flour.	Neimorovets (2020)
E. integriceps *E. maura*	Cereal crops.	Not reported.	Neimorovets (2020)

Table 6. Main pest pentatomoid species in Asia (Japan) and their damage to different crops.

Species	Crops	Damage inflicted	Source
Eysarcoris aeneus *E. lewisi* *E. ventralis*	Rice.	Discolored grains (pecky rice); damage around US$15–20 million/year, together with damage caused by *Niphe elongata*.	Tabuchi et al. (2023)
Glaucias subpunctatus *H. halys*	Fruit trees.	Deformation and fruit drop.	Kiritani (2007)
Nezara antennata *N. viridula*	Chinese cabbage, potato, soybean, tomato.	Deformation of the fruits or leaves; reduced seed quality and yield.	Umeya & Okada (2003); Tabuchi et al. (2023)
Niphe elongata	Rice.	Discolored grains (pecky rice); damage around US$15–20 million/year, together with damage caused by *Eysarcoris aeneus, E. lewisi*, and *E. ventralis*.	Tabuchi et al. (2023)
Plautia stali	Fruit trees.	Deformation and fruit drop.	Kiritani (2007)
Piezodorus hybneri	Soybean.	Reduced seed quality and yield.	Kiritani (2007)

Outbreaks of the endemic stink bug *Niphe elongata* (Dallas) have become more noticeable since the early 2000s with the shift to early rice cultivation (Ota et al. 2020). In general, weeding around rice fields with careful timing before and after rice ear emergence is highly effective in controlling the population density of pecky rice bugs (Teramoto 2003). After the ear emergence, registered insecticides (e.g., organophosphates, synthetic pyrethroids, organosilicons, and neonicotinoids) should be applied at the right time to control any bugs present (Sakakibara 2014).

Weed removal around rice fields before and after ear emergence is, however, not effective for *N. elongata*, because this species has a very low tendency to use weeds as hosts, and adults that leave their overwintering sites (e.g., under fallen leaves at forest edges) fly directly into rice fields immediately after ear emergence to lay eggs (Torikai & Higuchi 2022). In addition, *N. viridula* can also produce some generations on rice and soybean, and the recent increase in the occurrence of this species may be partly due to the shift to early rice cultivation, which gives this species a longer growing season (Kiritani 2011; Endo et al. 2022). In some cultivated plants such as Chinese cabbage, potato, soybean, and tomato *N. viridula* cause deformation of the fruits and/or leaves, and reduce seed quality and yield (Umeya & Okada 2003; Tabuchi et al. 2023).

Pentatomoids also are pests of fruits. As the fruits ripen, adults fly into orchards from other locations and feed on fruits such as apples, mandarins, peaches, pears, persimmons, and plums (Umeya & Okada 2003). Damaged fruits are sometimes deformed and drop prematurely.

The bugs rarely reproduce on these fruits and use other plants as hosts for their nymphs. In Japan, cedar and cypress trees are widely planted for forestry, and the seeds in their cones are suitable as food for nymphs of the endemic species *Plautia stali* Scott and *Glaucias subpunctatus* (Walker). As a result, the occurrence of these species varies greatly with the annual fluctuations in the cones of these conifers (Mishiro 2024). As the number of sucking marks per cypress cone starts to decline it means that the bugs are about to start leaving the conifers (Tsutsumi 2001).

Pentatomoids causing damage to fruits first became a major problem in 1973 in Japan, and outbreaks have occurred frequently since then (Toyama 2014). Over the past three decades, alerts and warnings concerning these bugs have been issued in many prefectures in the country (Mishiro 2024). In the long term, the trend of frequent outbreaks of these bugs is expected to continue due to the social situation in which these conifers are left uncut.

Although *H. halys* has become a serious agricultural pest in Europe and North America (Hamilton et al. 2018, Nixon et al. 2024), it is mostly known as a household and nuisance pest in Japan (Kobayashi & Kimura 1969) despite it had been recognized as a fruit pest in the country early in the 20th century (Sasaki 1905). The fact that *H. halys* is the main pest in the neighboring countries of Korea and China, as pointed out in this review, and not in Japan is unclear and demands future investigations.

To prevent bugs from entering fruit orchard, it is effective to cover the entire orchard with nets not only against stink bug but also to protect crops from bird damage, strong winds, and hail (Matsuda et al. 2006). It is also effective to turn on yellow fluorescent lights at night and to apply film mulch (Suzuki 2006). When stink bugs are detected in the orchard, pyrethroids and neonicotinoids should be sprayed as soon as possible (Mishiro 2024). Fruit bagging also can reduce stink bug damage (Toyama 2014).

Stink bugs also are important pests of beans and vegetables in Japan (Umeya & Okada 2003). *Nezara viridula*, growing in rice fields, sometimes invades bean and vegetable fields (Sakakibara 2014). Large-scale cultivation will eventually have to be sprayed with registered insecticides (e.g., pyrethroids, neonicotinoids, and organophosphates) (Komori et al. 1995).

2.7 Asia (Korea)[14]

Until the mid-1990s, pentatomoid populations in Korea were relatively low and considered secondary pests. Their populations have since increased significantly to the extent that failure to manage them causes significant yield reduction (Lim 2013). The reasons behind the most recent emergence of pentatomoids as major pests of various crops, including legumes and fruit trees (Table 7), remain unclear, although several factors have been proposed. These include increased overwintering survival due to warmer winter temperatures, a shift in dominant tree species within forest ecosystems towards deciduous broadleaf trees that provide suitable overwintering sites, and the diversification of crops in agricultural areas, leading to a greater availability of host plants (green-bridge) (Lim 2013; Lee et al. 2015). Among the stink bug species increasing in Korea, *H. halys*, and *P. stali* have exhibited the highest population densities, becoming the most economically important pests.

Several stink bug species are known to damage soybean and fruit trees in Korea (Table 7). The application of three insecticides on soybean at different plant developmental stages (fenitrothion EC in R4 stage, bifenthrin WP in R5-R6 stage, and clothianidin SG in R7 stage) showed the most effective control achieving an efficiency of only 63.2% but reducing seed damage (Lee et al. 2023a). Similarly, for controlling stink bugs in apple orchards, growers generally depend on chemical applications, which begin in June when *H. halys*, and *P. stali* start damaging the fruit directly (Kim et al. 2019). Due to the lack of more sustainable effective control, it is recommended to spray during July and August to prevent severe apple fruit damage at harvest (Kim et al. 2019).

In rice paddies, the occurrence of *Scotinophara lurida* (Burmeister) was first reported in 7,112 ha in 1999. With the nationwide expansion of farming, its occurrence area has increased significantly reaching 40,506 ha by 2020. Farmers rely on chemical insecticides, among which carbosulfan, phenthoate, etofenprox, and dinotefuran have been found to be effective for control in fields under either flooded or drained conditions (Lee et al. 2024). Control using botanical insecticides that have shown insecticidal activity against the bug have also been reported: Derris extract (60%) with clove oil (10%), garlic extract (80%), monkshood (40%) and pyrethrum (4%) extract, neem extract (62%), and sophora (70%) and pyrethrum (2%) extract (Lee et al. 2023b). Another species of stink bug causing pecky grains in rice is *Eysarcoris aeneus* (Scopoli) (Lee et al. 2009; Seo et al. 2020).

2.8 Asia (China)[15]

The population dynamics and management of pest pentatomoids in China (Table 8) are all profoundly influenced by crop type and the diversity of agro-climatic zones and cropping systems (Lu et al. 2024). Key hotspot regions include the Huanghuaihai region, southern China, and northwestern China. Major host crops include rice, cotton, orchards (e.g., apple, kiwifruit, peach, pear), and tea. The most damaging species among the Pentatomoidea are *Tessaratoma papillosa* (Drury) and *H. halys* (Yao et al. 2021; Lu et al. 2024; Zhang et al. 2025).

Litchi and longan are prestigious native fruits in China, and their production are in a rise in recent years. *Tessaratoma papillosa* (Table 8) is one of the most prevalent pests in litchi and longan-growing regions and is widely distributed in Fujian, Guangdong, Guangxi, Sichuan, Taiwan, and Yunnan provinces (Yao et al. 2021). Both adults and nymphs feed on sap from tender shoots, flower clusters, and young fruits (Yao et al. 2021).

Halyomorpha halys (Table 8) is native to China and feeds on over 300 plant species, including apple, apricot, cherry, crabapple, hawthorn, kidney bean, peach, pear, soybean, sugar beet (Zhang et al. 2025). Besides polyphagous, *H. halys* also exhibits gregarious behavior, complex over-

Table 7. Main pest pentatomoid species in Asia (Korea) and their damage to different crops.

Species	Crops	Damage inflicted	Source
Dolycoris baccarum *Halyomorpha halys* *Piezodorus hybneri* *Plautia stali*	Soybean.	Suck leaves and pods of soybean resulting in reduced seed production and seed germination	Lee et al. (2023a); Paik et al. (2007)
Carbula putoni *Chinavia hilaris* *Dolycoris baccarum* *Halyomorpha halys* *Nezara antennata* *Plautia stali*	Fruit trees (apple, citrus, kiwifruit, olive, persimmon, stone fruits).	Unnormal growth and premature fruit drop. Affected areas exhibit depressions and water-soaked lesions	Choi et al. (2023); Kim et al. (2015, 2016, 2018, 2019); Lee et al. (2015); Yang et al. (2019)
Eysarcoris aeneus *Scotinophara lurida*	Rice.	Suppress plant height and tillering. Lead to leaf wilting, whitehead formation, and the occurrence of spotted or discolored pecky grains	Lee et al. (2009, 2023b)

Table 8. Main pest pentatomoid species in Asia (China) and their damage to different crops.

Species	Crops	Damage inflicted	Source
D. baccarum *Erthesina fullo*	Crops.	Rarely requiring control.	Lu et al. (2024)
H. halys	Apple, apricot, cherry, crabapple, hawthorn, kidney bean, kiwi, peach, pear, soybean, sugar beet.	Leaf yellowing; premature defoliation; tree weakening; fruit damage rates reach 30–90% in pears, 50% in peaches, and 20–40% in apples; approximately 30% yield loss in kiwifruit.	Zhang et al. (2025)
N. viridula	Crops.	Rarely requiring control.	Lu et al. (2024)
Tessaratoma papillosa	Litchi, longan.	Necrosis in floral organs, young leaves, and fruits; flower and fruit drop; yield losses of 70–90% (30,000–60,000 metric tons of litchi and longan).	Yao et al. (2021)

wintering sites, lack of diapause, and strong pesticide resistance (Xu et al. 2020).

China currently advocates and practices IPM strategies centered on green control to achieve economic, ecological, and social benefits. Key approaches include natural enemies (e.g., parasitoids, predators and entomopathogens) utilization by means of augmentative release. A classic example is the successful use of a hymenopteran, *Anastatus fulloi* Sheng & Wang (in the past misidentified as *Anastatus japonicus*), to control litchi stink bugs since the 1960s. The average rate of parasitism of *T. papillosa* by *A. fulloi* was 87–91% (Li et al. 2014). Recent researches further refine parasitoid selection for managing *H. halys* in China. *Trissolcus comperei* (Crawford) has been identified as a promising new biological control agent, demonstrated by its high emergence rate and female-biased offspring when parasitizing *H. halys* (Shang et al. 2024). Furthermore, *Anastatus gansuensis* Chen & Zang and *Anastatus shichengensis* Sheng & Wang are considered well-suited for inoculative control due to their high female progeny production, whereas *Anastatus meilingensis* Sheng & Yu, *A. japonicus*, and *A. shichengensis* may be preferable for inundative releases because of their high host-killing capacity (Chen et al. 2025). Complementing these direct introduction strategies, behavioral manipulation tactics such as "push-pull strategies" – which employ repellent or attractive volatile compounds from functional plants – are also being developed for *H. halys* management (Xu et al. 2020).

2.9 Oceania (Australia)[16,17,18]

Australian cropping and horticulture are largely confined to the coastal and subcoastal areas in the east (extending westwards into South Australia and as far south as Tasmania), parts of the monsoonal north, and the south-west of the continent. The climate ranges from tropical in the north to temperate in the south, with the western part of the latter being Mediterranean, allowing the development and outbreak of several Pentatomoidea species in cultivated fields (Table 9).

Among the different heteropteran pests present, *N. viridula* (Brier 2007; Knight & Gurr 2007), *Musgraveia sulsiventris* (Stål) (Waterhouse & Sands 2001), and *Dictyotus caenosus* (Westwood) are among the most important species for their damage potential and the crops impacted. The latter two species are Australian endemics. Less importantly, *Piezodorus hybneri* (Gmelin) and *Plautia affinis* Dallas are pests of summer pulses.

Nezara viridula differs in having a ranking by crop (HIA 2021) with it being a moderate priority in the cultivation of beetroot and leafy brassica vegetables (e.g., bok choy and kale, among others) (HIA 2020a), green beans, peppers (capsicum and chilli), sweet corn and zucchini. However, it has low priority in brassica vegetables (e.g., cabbage, cauliflower) (HIA 2020b), carrots, celery, cucumber, eggplant, peas (green, snow and sugar snap), lettuce (head and leafy), okra, spinach, silverbeet, and squash.

Similarly to other regions of the world discussed in this review, the most important control measures adopted by Australian farmers include chemical sprays and biocontrol strategies. With respect to insecticides, Australian growers currently use neonicotinoids, synthetic pyrethroids and organophosphates (APVMA 2025). These methods require continual adjustment, considering possible appearance of resistant stink bug populations and altered agronomic practices (Waterhouse & Sands 2001). Early sowing that partially avoids stink bug incidence, and avoiding cultivation of the same or different susceptible crops in sequence are recommended strategies for mitigating damage in summer pulses (Brier 2007).

Foreign parasitoids have been introduced against selected species, especially against *N. viridula*, with the level of success achieved being debatable. The scelionids *T. basalis* and *Trissolcus mitsukurii* (Ashmead) and, tachinid fly *Trichopoda giacomellii* (Blanchard) been introduced against *N. viridula*. In addition, local parasitoids are known to attack the indigenous heteropteran pests (Loch & Walter 1999). Although biological control success has been claimed for *N. viridula* in other parts of the world, this is not the case

Table 9. Main pest pentatomoid species in Oceania (Australia) and their damage to different crops.

Species	Crops	Damage inflicted	Source
Anaxilaus vesiculosus	Rice.	Not reported.	Stevens et al. (2008)
Biprorulus bibax	Citrus.	Not reported.	Mo (2006); Fattore & Mo (2023)
Dictyotus caenosus	Cotton.	> 2–3% seed damage incurs significant price penalties.	Kahn (2004)
Eysarcoris sp.	Adzuki bean, cowpea, mungbean, navybean, soybean.	Not reported.	Brier et al. (2008)
Eysarcoris trimaculatus	Rice.	Not reported.	Stevens et al. (2008)
Musgraveia sulciventris	Citrus.	Not reported.	Mo (2006); Fattore & Mo (2023)
N. viridula	Adzuki bean, cowpea, mungbean, navy bean, soybean.	> 2–3% seed damage incurs significant price penalties.	Brier et al. (2008)
N. viridula	Berries (blue, black, raspberry).	Not reported.	Simpson & Leong (2023)
N. viridula	Cotton.	Not reported.	Kahn (2004)
N. viridula	Rice.	Not reported.	Stevens et al. (2008)
N. viridula	Maize.	Not reported.	GRDC (2017)
Piezodorus oceanicus	Adzuki bean, cowpea, mungbean, navy bean, soybean.	> 2–3% seed damage incurs significant price penalties.	Brier et al. (2008)
Plautia affinis	Berries (blue, black, raspberry).	Not reported.	Simpson & Leong (2023)

for Australia and the current pest status of the species does demand intervention. See Loch & Walter (1999) for parasitism levels of nine pentatomid species in Australian soybean, including *N. viridula*, in which parasitism levels were lowest. In addition, no selective alternative control techniques are available and, biopesticides have not been investigated sufficiently (Portilla et al. 2024).

A major problem with pentatomoid pests in Australia is their patchy and unpredictable appearance (Brookes et al. 2020), making them difficult to target with localized treatments. Also, these insects cause significant economic damage even at the low densities at which they are usually found (Brier 2007). This latter feature of their ecology does suggest that even relatively low levels of added suppression might be sufficient to manage them to economically acceptable levels. For example, targeted biocontrol releases could, if deployed accurately at the spatial scale and time at which the pests appear, provide sufficient economical control.

2.10 Africa[19]

Although pentatomoids (Table 10) are considered important agricultural pests in Africa, attacking several crops, reports in Southern Africa of their impact are mostly in relation to valuable fruit orchards including mango, litchi, avocado, and macadamia. They cause significant yield reduction and economic loss in the South African macadamia industry (Schoeman 2013; Sonnekus et al. 2022). Among 21 species of stink bugs found in macadamia orchards (Sonnekus et al. 2022), *Bathycoelia natalicola* (Distant) was the predominant pentatomid, capable of causing substantial economic losses through kernel damage (Schoeman 2013; Grové 2022) at very low action thresholds (ca. 0.4 bugs/tree) (Schoeman 2013).

Arguably the most notable species from a distribution and recognition standpoint in Africa is the endemic *N. viridula* (McPherson & McPherson 2000; Schaefer & Panizzi 2000). Distribution of *N. viridula* in Africa spans from both north and south of the Sahelian region to include West, Eastern, Southern, and North Africa. This expansive distribution is aided partly by its strong flight capabilities as well as human activities, favoring the pest outbreaks that damage many important agricultural crops (Table 10) (see review by Schaefer & Panizzi 2000) and, like other Pentatomidae, it feeds mainly on the reproductive parts of crops that have higher N content, thus depriving the plants of a valuable nutrient pathway.

Nezara viridula usually feeds on fruit, pods and seeds; this results in their distinct malformation, which drastically reduces market value and germination (Ntonifor & Jackai 1994). The damage to leaves by *N. viridula* may render the plants moribund, making them more susceptible to disease (Hori 2000). Crops attacked include cotton, cowpea, maize, peanuts, soybean, and tomato.

The other common species in West Africa is *C. hilaris*, which is a slightly larger insect than *N. viridula.* Despite being bigger, the damage *C. hilaris* causes is similar to *N. viridula*, but *C. hilaris* reported diet is somewhat limited

Table 10. Main pest pentatomoid species in Africa and their damage to different crops.

Species	Crops	Damage inflicted	Source
Bathycoelia natalicola	Macadamia.	Kernel damage.	Schoeman (2013)
Bagrada hilaris	Diverse crops.	Not reported.	Nicolas et al. (2024)
Eurygaster spp.	Mostly cereals.	Not reported.	Nicolas et al. (2024)
E. integriceps	Cereal crops.	Not reported.	Neimorovets (2020)
E. maura	Cereal crops.	Not reported.	Neimorovets (2020)
H. halys	Diverse crops.	Not reported.	Nicolas et al. (2024)
N. viridula	Cotton, cowpea, maize, peanuts, soybean, tomato.	Malformation of fruits, pods, and seeds; reduced seed viability and market value.	Ntonifor & Jackai (1994)

to cereals (maize and sorghum), *Phaseolus* beans, and sunflower (Kamminga et al. 2012).

A much smaller stink bug that feeds on similar crops is *Piezodorus guildinii* (Westwood). Quantifying their associated economic loss is often difficult, mainly because of the lack of systematic pest monitoring and the occurrence of multiple overlapping pests that injury the same plants.

Species from the family Scutelleridae (*Eurygaster* spp.) are major agricultural pests in North Africa (mostly on cereals) as are several pentatomid species that also cause severe crop damage, including *H. halys*, and *B. hilaris*. Their range of occurrence has increased to include Sudan, Egypt, Ethiopia and Kenya. *Bagrada hilaris, N. viridula* and a number of other Pentatomidae have also been recently reported in the Comoros Island off the coast of Africa (Nicholas et al. 2024).

In some African cultures, stink bugs are not merely pests but also a valuable food source (Dzerefos et al. 2014). In those countries these insects are integrated to local diets as a crunchy, protein-rich snack that contributes to the rich culinary heritage of the region (Teffo et al. 2007). In Southern Africa, in particular Malawi and Zimbabwe, the endemic edible species, *Encosternum* (= *Haplosterna*) *delegorguei* Spinola (Tessaratomidae), locally known as "harurwa", has been a staple for generations (Teffo et al. 2007). Among the Venda people of Limpopo and the Mapulana of Mpumalanga, these insects are considered a delicacy and are valued for their protein content, vitamins, and micro-elements (Teffo et al. 2007). The consumption of stink bugs is also reported from other regions of the world, including Asia (van Huis 2013).

The default tactic of pest management for stink bugs has been the application of conventional chemical insecticides, much like the rest of the world as shown in this review. The main insecticides used are pyrethroids, organophosphates, and neonicotinoids targeting the entire pest complex (Schoeman 2011, 2014). Overall, the polyphagous feeding behavior of stink bugs worldwide presents challenges to their control (McPherson & McPherson 2000; Panizzi et al. 2000). Nevertheless, to reduce the insecticide impact on the continent, there is ongoing research in South Africa on development of treatment thresholds to reduce the use of chemicals, and increase the use of biological control of *E. delegorguei* in macadamia orchards with a goal of reducing dependence on insecticides. Control measures using biological methods have involved the introduction of parasitic wasps from the family Scelionidae, specifically those in the genera *Trissolcus* and *Ooencyrtus* as they are considered effective. Pheromones, and the fungus *Beauveria bassiana* also are considered in managing stink bugs. New and current methods developed for one species and region can usually have cross-species and cross-regional application in Africa and elsewhere especially among related species.

3 Global common challenges, experiences, and recent innovations to manage pest pentatomoid bugs

As seen in the different regions of the world, pentatomoid bugs (mostly Pentatomidae and related species within Pentatomoidea) have been considered pests of a myriad of cultivated plants worldwide (McPherson & McPherson 2000; Panizzi et al. 2000) causing varying levels of economic injury. However, more recently, their growing importance worldwide imposes new challenges in mitigating their economic impact (Panizzi et al. 2022). Factors contributing to the increased impact of pentatomoid bugs as pests results from the overuse of traditional non-selective insecticides; increase in temperatures around the world (climate change); diversification of agriculture worldwide with constant offering of plant hosts for longer periods of time during the year (green-bridge); and increased international trade of agricultural goods.

Despite the importance of insecticides in controlling pentatomoid pests (Moreira et al. 2024), the overreliance on traditional chemicals in agriculture has increased concerns about their negative side effects worldwide related both to human health and the environment (Gong et al. 2023). The overuse of insecticides against stink bug has led to several undesirable negative side effects such as reducing biocontrol agents

(Torres & Bueno 2018), pollinators (Santos et al. 2018), and selecting resistant populations (Tibola et al. 2021). Instead of mitigating stink bugs across the world, insecticide overuse has frequently favored pentatomoid resurgence and/or outbreaks of secondary pests (Bueno et al. 2021). In Brazil, for instance, the excessive use of neonicotinoids and some pyrethroids applied against stink bugs have been related to increased outbreaks of mites in soybean fields (Reichert et al. 2024). Consequently, replacing traditional insecticides to control pentatomoids with more sustainable strategies has become a global goal (Bueno et al. 2023a).

Among the innovative control strategies worth mentioning is the potential use of genetic mechanisms such as RNAi (Ribonucleic Acid interference) and CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats). RNAi technology is a mechanism of gene silencing mediated by double stranded RNAs (dsRNAs) molecules that are processed into single-strand small interfering RNA (siRNA) by the RNA Induced Silencing Complex (RISC), which binds to the target complementary mRNA, leading to its degradation or blocking protein translation. The technology has been successfully used under laboratory conditions to knockdown target genes of different pest species of stink bugs, such as *E. heros* and *H. halys* with promising results to control also in the field (see greater details and references in Maktura et al. [2024]).

The CRISPR is a genome editing tool that has been used to manipulate pest species of stink bugs. It allows to obtain information on the genes functions and ongoing studies are concentrated in genome editing and delivery methods, efficiencies, and off-target effects. As biotechnology advances, tools such as the CRISPR appear as a promising strategy for pest control (see greater details and references in Pagliarini et al. [2024]).

Although the impact of increasing temperatures on insect biology varies from species to species, overall, these temperatures have caused pentatomoid populations to grow faster and infest fields earlier in the crop season. Additionally, increased temperatures have allowed some species to invade new areas not exploited before (Chen et al. 2024). Increasing injury by pentatomoids have intensified particularly in northern regions (Musolin 2007; Karpun et al. 2022). For example, since the beginning of the 21st century, a decline in *E. integriceps* populations has been observed in the south of Russia, although its population density fluctuates close to the economic damage threshold. This trend likely is influenced by the gradual increase in average monthly winter temperatures (Neimorovets 2024) that negatively affect the survival of bugs in their overwintering sites. On the other hand, there is a persistent trend of range expansion toward the North and East in many species (Musolin 2007; Pavlyushin et al. 2015). Climate change also might lead to an increase in the population and harmful activity of *E. maura* in Western Siberia.

Global climate change often favors the spread of invasive species as the rise in temperature increases the development of additional generations of pests, which can contribute to further spread and increase the harmfulness of such species (Pajač-Beus et al. 2024). Under these conditions, several species such as *G. subpunctatus* (Kiritani 2007) and *N. viridula* (Musolin 2007; Yukawa et al. 2009) have expanded their overwintering ranges and increased their winter survival rates resulting in increased crop damage. Longer growing seasons due to climate change also have resulted in an increase in annual generations of pest stink bugs (Kiritani 2007). Therefore, more research is needed to understand changes in stink bug population dynamics and sustainable control strategies for future pest outbreaks in a climate changing environment.

Although some pentatomoid species enter winter dormancy to survive between crop seasons, other species, especially in tropical and subtropical regions, rely on the availability of alternate hosts (weeds, volunteer plants or double cropping) to survive between seasons. This constant availability of hosts to the insects (including stink bugs), is often referred to as a green-bridge and tends to favor generalist species. For instance, the soybean (summer)–maize (fall/winter) crop succession has been adopted widely in the Neotropics favoring the stink bug population that begins developing on soybean and continues feeding on maize plants after the soybean harvest (Queiroz et al. 2025). The presence and timing of the green-bridge is often critical in determining risks of early season stink bug outbreaks in arable crops. Mitigating its occurrence is essential to reduce the problem. Globalization and increasing trade in plant commodities likely will contribute to the introduction of new invasive pentatomoids (Karpun et al. 2022, Musolin et al. 2022).

4 Final considerations and concluding remarks

Sustainable methods of control for stink bugs and related species in the Pentatomoidea are urgently needed across the world due to their increasing impact on agricultural crops. We no longer can rely on the massive use of traditional chemical insecticides as the main control strategy in view of the detrimental side effects, the fast selection for insecticide-resistant stink bug populations, and the environmental costs involved. Biological control has been increasingly used against stink bugs, but new sustainable tools are urgently needed to be used in addition to the biological control agents.

Research efforts over the years have contributed to the development and implementation of IPM programs, which have been well-documented in the literature (e.g., Bueno et al. 2023a, b). These IPM programs aim to mitigate our dependency on traditional chemicals by encouraging other control strategies such as biological control, host plant resistance, and plant-derived insecticides (botanical insecticides). Despite all the benefits provided, IPM is not adopted in the intensity it should be, yet.

More recently, the adoption of egg parasitoids to control stink bugs have been increasing due to improvements on the rearing and releasing process of the wasps, reaching successful results, especially in Europe and the Neotropics. The rearing on artificial eggs, being extensively studied in these regions and elsewhere, will certainly boost the adoption of those parasitoids even more in close future at reduced costs.

Other non-chemical control strategies also may be effective in certain situations. The use of nets to protect whole crops has been successful but restricted to small fields and highly-valued crops such as fruit orchards in Europe or Japan. Overall, green strategies in development for pentatomoids such as RNAi based control and genetically modified or edited plants and insects (such as CRISPR) certainly will be a great addition to the other IPM tactics to better manage these pests in the future.

In conclusion, despite the continuous use of traditional insecticides as one of the primary tools available to control pentatomoid pests, modern and more sustainable control strategies are gaining momentum. This can be measured by the strong shift in the approach of traditional chemical companies to reduce the focus on harmful broad-spectrum chemicals and to concentrate on developing alternate sustainable control measures. These methods include increased research efforts on semiochemicals, insecticides from botanical sources, genetic mechanisms, and development and production of biological control agents. As we make progress with these research targets, we come closer to achieving development and implementation of effective and sustainable holistic IPM programs. Effective pest control requires a thorough understanding of pest life cycles and biological traits, and how these adaptations interact with their environment, supported by precise monitoring and forecasting technologies (Lu et al. 2024). Coordinated application of multiple control measures (agricultural, biological, chemical, and physical) are essential to maximize efficacy. This integrated approach will ensure sustainable pentatomoid management while balancing economic viability and ecological health.

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