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Review of the *Halyomorpha halys* (Stal, 1855) (Hemiptera: Heteroptera: Pentatomidae) in Georgia: Distribution, biology and management

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A B S T R A C T

Halyomorpha halys (Stal, 1855) (Hemiptera: Heteroptera: Pentatomidae) invasion in Georgia territory first observed in 2015 year. In 2016-2019 an outbreak of *H. halys* resulting huge economic losses which negatively affected to the income of small-scale farmers as well as the Georgian economy. The article reviews the bioecological characteristics of the insect at various locations, such as in Georgia, other invaded areas and its natural distribution range of *H. halys* . This article describes the life history, food specialization, economic importance of *H. halys*. Also the recent results of studies on *H. halys* natural enemies, control tools and management strategies are incorporated to the article. In the face of climate change, the risks of insect outbreaks increase from year to year. Invasive agricultural pests such as *H. halys* pose a major threat to agriculture crop production and food security. To have a comprehensive information about *H. halys* has a huge importance to effectively plan and implement measures without or with minimal adverse environmental impact.

Key words: *Halyomorpha halys*, distribution, biology, natural enemies, management

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Introduction

The brown marmorated stink bug, Halyomorpha halys (Stål) (Hemiptera: Pentatomidae), is an invasive species native to China, Japan, Korea, and Taiwan [1]. Insect is highly polyphagous species, feeding on and damaging diverse plants, including field crops, vegetables, tree fruits, and ornamentals [2].

Synonymy

Halyomorpha halys (Stal, 1855) (*Pentatoma halys* Stål (1855), *Poecilometis mistus* Uhler, 1860; *Dalpada brevis* Walker, 1867; *D. remota* Walker, 1867). Distribution area: Anhui, Fujian, Guangdong, Guangxi, Guizhou, Hebei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Neu Monggol, Shaanxi. Shanxi, Sichuan, Taiwan, Xizang, Yunnan, Zhejiang. Also recorded from Korea and Japan [3].

This species has had a long and confusing history. It has appeared in the literature under *Halyomorpha halys* and all three junior synonyms; in fact, it appears that many workers in Japan still refer to it as *H. mista*. It has also frequently been confused with *H. picus*, an Indian species. Josifov & Kerzhner (1978) [4] determined that only one species of *Halyomorpha* is present in eastern China, Japan, and Korea, and it is different from *H. picus;* the oldest available name is *H. halys* (Stal) [3].

Allochthonous distribution in the world

In the last 30 years, the species was detected in different parts of the world, mainly in North America and Europe (global distribution recently summarized by Leskey and Nielsen (2018) [5]. The first record of established population out of the native range dates in 1996 in Pennsylvania, USA, although prior to its establishment, *H. halys* was reported first time in 1973 [1]. This invasive species has spread across 43 states of the US and two provinces in Canada since it was first officially detected in Pennsylvania in 2001 [6].

From 2017, this invasive species has been detected in almost all states of USA, includng Alaska and Hawaii, lacking only in Oklahoma and Louisiana [7, 8, 9]. In North America *H. halys* is reported also in southern Canada, where it was firstly intercepted in the Province of British Columbia in 1993, when a specimen was found in a shipment originating from Asia [10]. In South America *H. halys* is recorded from Chile, where it was intercepted for the first time in 2011 and later 2017 near Santiago [11] and finally, in the Caribbean basin countries were find.

In Asia, out of the native range, *H. halys* is quoted for India, reported in the 2014–2015 by Nikam & More (2016) [12]. However, this record is likely a misidentification with a different species [13].

In Pace Oceania some sporadic records are known from New Zealand, when it was introduce for the first time in 1999 [14], Australia, when it was introduce for the first time in 2005 [15], and Guam island, where a single specimen was collected in a hotel room in 2013 [16]. In Africa the species is not documented, but the record for Egypt of H. picus [17] could be a misidentification for *H. halys* according to Aukema et al. (2013) [18] and Hemala and Kment (2017)[19]. But in Japan and China, outbreaks there are not fixed. Most Complete data on the distribution of this species are given at EPPO Global Database (2022) [20].

Distribution in Europe

The other continent where *H. halys* has become a pest is Europe, where the oldest records date back to 2004: in that year *H. halys* was found in Liechtenstein [21] and Switzerland [22]. Subsequently, it colonized many Swiss territories [22,23] and some years later it spread into neighbouring countries: in southern Germany in 2011 [24] and in France in 2012 [25,26, 27], also its in Corsica [7]. 2007 *H.halys* occurred in other European countries, in Italy [28,29] and in 2011 in Athens, Greece [30].

Until now, many countries in Europe have been added to the list of those where the *H.halys* occurs: in 2013 it was firstly recorded in Hungary [31] and in Krasnodar, Russia [32], in 2015 in Austria [33], Serbia [34], Romania [35], in 2016 in Spain [29], Slovakia [19], Bulgaria [36], and Georgia, Abkhazia [32], and in 2017 in Slovenia [9], Turkey [37] and Croatia [38]. Moreover, [39] reports that H. halys was founded twice in Great Britain, one in 2010 in London, in association with passenger luggage flown in from the USA, and the other in 2013 in North Yorkshire, associated with a consignment of stone imported from China.

Forecast of range expansion in the Russian Federation and neighboring countries [32] predicted a high probability that the *H.halyes* could spread in Eastern Europe between the 40th and 50th parallels or even up to the 60th parallel, at least populate the entire North Caucasus, the Rostov region, the south of the Volgograd region, as well as neighboring countries: Ukraine, Moldova, Bulgaria, southern Poland, also Armenia, Azerbaijan and Turkey. These findings are based on the work of [40], which used the Maximum Entropy methods (MaxEnt) and Genetic Algorithm for Rule Set Production (GARP) methods. According model of distribution of H,halys shows that more suitable areas for its distribution located between latitudes 30° and 50° and including parts of Europe, North America, Australia, the New Zealand, part of Africa (Fig. 1) [40].

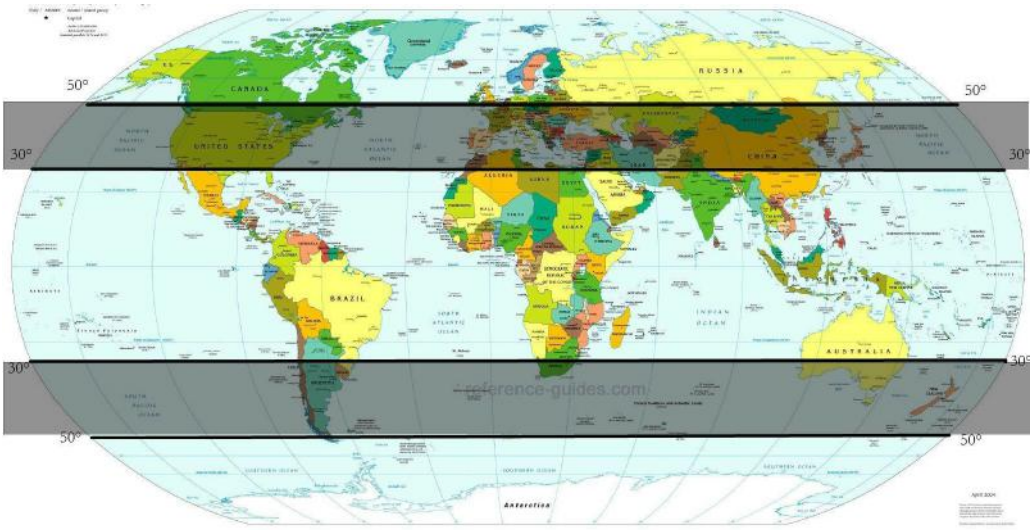

Fig. 1. ***S****uitable areas for Halyomorpha halys distribution between latitudes 30° and 50° Source: Wine for Rookies, Inc*

Distribution in Georgia

In Georgia, *Halyomorpha halys* (Hemiptera: Pentatomidae – formerly EPPO Alert List) was identified for the first time in October 2016. About its outbreak in Georgia was reported in the municipality of Khobi (Samegrelo-Zemo Svaneti region), as well as in Pitsunda (Abkhazia) [32]. However, it is noted that the presence of the bug had already been observed in 2015. This is the first time that *H. halys* is reported from Georgia [20].

It is not completely clear how the bug entered in Russia. There is an assumption [32] that this species was brought (probably from Italy) to one of the Russian Black Sea ports with planting material of ornamental plants for landscaping the facilities of the XXII Olympic Winter Games, similar to what happened in the case of the boxwood moth *Cydalima perspectalis* (Walker, 1859) (Lepidoptera, Pyraloidea: Crambidae) [41]. This assumption is also dictated by the fact that the same time, in neighboring countries (Moldova, Ukraine and Turkey) the *H.halys* was not found. And already from Russia the bug spread *to Abkhazia* and Georgia. Based on the available data, it can be assumed that the *H.halys* spread throughout the territory of the Krasnodar Territory at a speed of 100–150 km per year [42].

Zhimerikin V.N and Guliy V.V. (2014) suggested that the Sochi City Administrative Okrug (territory of Greater Sochi) may be a place appearance of the *H.halys* in Russia. Its larvae were found in the city in August 2014 [44]. The author of the article studied 1 adult's specimen (female) with labeled "Russia, Sochi, Central District, 28.IX.2014. Koval A.G. leg". There are reports that this species appeared in the Sochi region no later than 2013 [32]. From the second half of 2015 mass reproduction of the bug began in the Sochi urban district, which led in 2016 to large losses in the harvest of fruit and subtropical crops [45].

In 2017-2018 for investigation of hazelnuts orchids the *H.halys* were detected in the Guria, Samegrelo, Adjarja and Imerety Regions of Western Georgia [46,47,48]. About distribution bug the same regions, were reported other scientist from Georgia as well [49-52]. At present Insect ivied and distribute in some municipals of Eastern Georgia, where hazelnut orchards are cultivated [52]. The distribution of *H.halys* in territory of Georgia given in Figure 2.

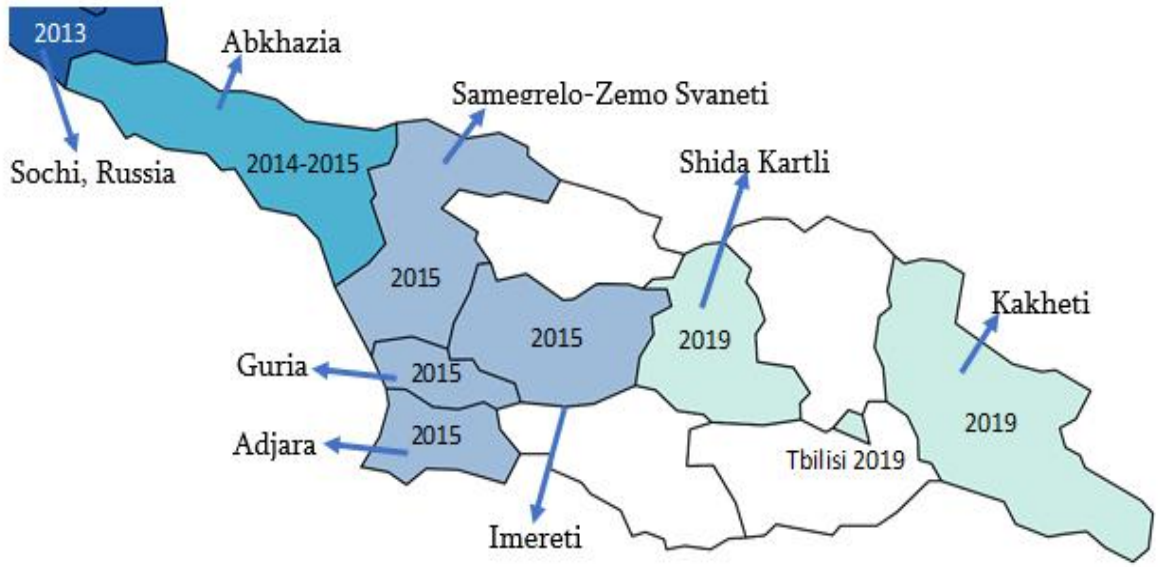

Fig. 2. *Halyomoprha halys distribution in Georgia according years*

The situation of *Halyomorpha halys* in Georgian neighbors countries can be described as follows: In Azerbaijan, it is distributed in the Cheki-Zakatala (East part border with Georgia), Lankaran and Absheron zones, where nut-fruits grow, especially walnuts (hazelnuts) and subtropical crops damages [53]; First record on the *H. halys* in Turkey was 2017. This agricultural pest was detected in Kemalpaşa District of Artvin Province located in the Eastern Black Sea Region near the Georgian border [54]. However, information about this insect in Armenia no reported, only findings information as a hypothesis its distribution are given on the work of [40].

Life cycles

The brown marmorated stink bug, like all stink bugs, is a hemimetabolous insect and a multivoltine species, development from egg to adult takes approximately 40 to 60 days, depending on temperature and photoperiod. After hatching, first instar nymphs may aggregate around the egg clutch before molting and dispersing to feed. Adults can produce multiple egg clutches throughout their lifespan. Winter diapause is a crucial component of the brown marmorated stink bug life cycle. Bugs respond to shortening day length during fall by entering into diapause. During this period adult reproductive activity ceases as the stink bugs conserve resources to survive the winter. Only adults enter diapause and survive through the winter.increased temperatures and day length in the spring signal an end to the dormant period, and adult brown marmorated stink bugs will leave their overwintering sites in search of food. In warmer climates several generations per year are possible, though in most of its North American range the brown marmorated stink bug has one to two generations per year [55 - 61].

As a mention *H. halys* is a multivoltine species [62], in some geographical range, The life cycle is commonly characterized by one or two generations [61,58], but in Southern China four to six generations are assumed to occur [62] . Pre-reproductive adults overwinter in large number and they often use human houses as overwintering sites, with a documented case of 26,205 individuals in a single house during a 181-day study [63]. Adults entering houses are a strong nuisance not only for their abundance, but also for the unpleasant odor they emit when disturbed [64]. This behavior leads to a variety of pest impacts also for the human life [65], which add to the problems that *H. halys* causes to agricultural, horticultural and silvicultural hosts [10].

In Georgia, two generations of *H. halys* are commonly presented (Angelina), as a three generation reviewed [66] in Western Georgia (WG), that Black Sea region characterized by subtropical climate, with warm weather and humidity, which is favorable for this pest insect and help its develop and rapidly growing population.

H.halys biology involves pest development in three stages (egg, nymph and adult phase) and are following: (1). The pest overwinters in the adult (imago) phase; (2). Adults phase copulation begins two weeks after diapause; (3). Eggs are laid by adults and continue at intervals throughout the life of the female to the end. There are observed pyramidal cluster mostly containing 28 eggs (average 26.27, st.dev- 4.20), but we are fined clusters with minimal number of eggs - 12, and maximunm - 32. On average 80.8 % of the laid eggs were hatched successfully. Under optimal conditions one female lays up to 400 eggs. Eggs are laid on the underside of the host plant leaf and they are white color; (4). The first nymphs hatch from eggs after 4-5 days; (5). The pest has 5 nymphal phases. Each lasts one week, at room temperature according to its change; (6). Adult and nymphs characherizaied with active movement and feeding. They are easy move on the vegetative parts of the plant, fly and feed by Fruits. The pest is characterized by the pierce-sucking mouthparts; (7). An adult insect infest almost all parts of the plant, especially the fruits. The damages part became necrosed, hardened and the crop loses its agricultural significance; (8).

There is two [66] or three [66]] Generations of *H. halys* in Georgia. The number of generations depends not only on the length of the day, but also on the temperature, because under suitable temperature conditions the development of the *H. halys* is faster [68], this process is also facilitated by the diversity of host plants [69] and air relative humidity [70]. Therefore in the humid subtropical regions of WG - Guria and Samegrelo, in 2018 three generations were observed: the first generation egg-laying began in the early of May and lasted until the middle of May. Due to worming climate with annual average temperature 12 ^{o}C, (Climate Risk Country Profile: Georgia, 2021) and wide range of wild and cultivated host plants, *H. halys* populations develops within 32 days from egg to adult. The second generation emeges in the first decade of July and lasted until early August. Third generation occurs second decade of August and for mid of October they are entering to diapause.

Food specialization and harmful activity

The marble bug is a broad polyphage and feeds on flowers, stems, leaves and fruits of plants 49 families [14]. In the Sochi region and in Abkhazia 32 plant species from 16 families were recorded, on which the bug fed [71]. Of the cultivated plants, Rosaceae are the most harmful. Harm caused by the marble bug in the region of humid subtropics of Russia and Abkhazia, especially noticeable on fruit and

vegetable crops: on the surface of fruits and leaves of apple and pear trees in places of punctures necrosis, corking is formed, under the skin – dry cottony tissue, the taste of the fruit deteriorates, the surface becomes bumpy; on citrus and persimmon leads to underdevelopment and premature fall of the fruit; on grapes - the berries do not develop and fall off; on hazelnuts, it damages nuts at the stage of milky-wax ripeness, leading to the cessation of the development of the kernel; on corn grains do not develop. Damage can be aggravated by secondary infections. So, for example, on pepper and tomato fruit rot develops at the puncture sites [6,45]. Bugs also can transmit phytoplasmoses causes pathogen [72].

In a review of the Asian literature [58] revealed in native range 106 host plants distributed in 45 families, while [68] reported 51 hosts in 32 families in Europe and [73] quoted 73 species of plants ranging from annual crops to landscape trees only in the state of Pennsylvania. Now, over 251 species of host plants are cited in literature for this bug [74] and it is considered a severe agricultural and horticultural pest [7]. Feeding may occur on leaves, shoots, stems and even through the bark of trees such as maple and catalpa [6]. However, both nymphs and adults preferentially feed on developing and ripe fruits and seeds of their host plant [75]. This mode of feeding, and preference for fruits, directly leads to economic damage to a wide range of crops.

In Georgia 2018-2021 years, during observation twelve plants species as host of *H. halys* were identified: Eriobotrya japonica, Laurus nobilis, Actinidia sp., Agave sp., Solenostemon sp., Pueraria sp., Rubus canescens, Sambucus ebulus, Convolvulus sp., Robinia pseudoacacia, Tradescantia sp., Pteris cretica. They are not included as host plants of this insect in CABI, EPPO, and official lists of the Ministry of Environment Protection and Agriculture of Georgia [46].

In its native range, it is considered an occasional pest of fruit trees and soybean, Glycine max (L.) Merr. (Fabales: Fabaceae), as well as a nuisance pest during the winter [76 – 85].

Insect damages wild, ornamental and cultivated plants. They manly feed on pome, stone, nut, legume fruits. The signs of *H. halys* feeding range from the multiple punctures in the hull (endocarp) to the formation of the necrotic tissues on the shell (endocarp), hull (exocarp and pericarp) and the kernel (endosperm) of the fruit [86]. Damaged fruits have necrotic spots or blotches, grooves and brownish discolorations. In Asia, *H. halys* is considered as causing significant damage to soybean and various horticultural crops. In Japan, apple crops have increasingly been damaged by *H. halys*. Forest trees are also known hosts of *H. halys*. However, in Japan *H. halys* is considered as a pest in nurseries producing seeds of cedar and cypress because it can feed on cones. In the USA, damage caused by *H. halys* was initially reported in suburban or urban environments on woody ornamentals (e.g. *Buddleia davidii, Paulownia tomentosa*) and backyard peach and pear trees. However in 2006, commercial fruit growers started to report damage in apple and pear orchards in eastern Pennsylvania and western New Jersey. In Pennsylvania, high populations were also found in soybean crops but without significant damage. *H. halys* is considered as a vector of Paulownia witches' broom phytoplasma in Asia.

In addition to plant damage, *H. halys* can be a nuisance to humans because at the end of autumn, adults can aggregate in buildings and houses (on walls, window and door frames) seeking overwintering sites. When disturbed or crushed they discharge a characteristic pungent odour (unpleasant and long lasting!). In the USA, many homeowners are complaining about this nuisance.

Damage and Economic Importance

Many studies have shown that stink bugs in the family Pentatomidae can be serious economic pests of food crops and ornamental plants around the world [87,88]. Worldwide, this family contains almost 900 genera and around 5000 species [89]. Many pentatomids cause significant damage to hazelnut crops in Europe, Turkey and Georgia [90]. In particular, stink bug pests of cultivated hazelnuts (Corylus avel-lana L., Fagales: Corylaceae) occur in the leading commercial hazelnut producing countries of Turkey [91] and Italy [92]. Studies in Turkey report feeding damage to hazelnut kernels by *Palomena prasina* L. (Hemiptera: Pentato-midae) in the form of kernel abortion, malformation, and the occurrence of dry, necrotic tissue [93]. According [94], hazelnut in northwestern Italy was damaged by seven species of Pentatomidae.

In Asia *H. halys* causes significant damage to many economically important crops In Japan, outbreak populations of *H. halys* on apple [95-98], pear, plum, satsuma mandarin, and grape [95] have been reported, with damage characteristics and levels varying among crops. In 2010, high densities of *H. halys* caused as much as 100%

crop loss in some apple and peach orchards in the Eastern USA [5]. In Italy some early maturing pear cultivars damage at harvest reached more than 50% [99] Economic damage on pepper crops has been reported in Europe from the Canton Aargau in Switzerland [100], In 2016 52.7–68.6 million US dollars losses in hazelnut crops which caused by *H. halys* in Georgia [101].

In Georgia, Due to lack of specific natural enemies, high reproduction ability, wide host range, and favorable climate conditions, effective overwintering strategies, increased population rate of *H. halys* that caused huge economic losses in agricultural crop production [102]. In 2016 The most affected was hazelnut production were economical loss reached 60 milion dollars [101] . Although In 2017, compared to 2016, revenue from hazelnut exports fell by $ 54 million [103]. In 2019, the fight against *H. halys* was declared successful [104], which led to an increase in hazelnut production [105].

Natural enemies

Brown marmorated stink bug parasites or predators, entomopathogens have the potential to provide landscape-scale control of this pest in the future. Since the establishment of the, *H. halys* in North America and Europe, there has been a large, multi-group effort to characterize the composition and impact of the indigenous community of arthropod natural enemies attacking this invasive pest.

Native predators

The list of native natural enemies that attack brown marmorated stink bug includes other species of insects, spiders, and even some birds and mammals. However, insects and spiders are largely recognized as the most important group of natural enemies of BMSB [106].

Wide variety of generalist predators that consume H.*yalys* eggs have Identified in the USA. The list includes certain species of crickets, katydids, ground beetles, lady beetles, earwigs, ants, assassin bugs, mantids, and jumping spiders, as well as less familiar insects such as minute pirate bugs, lacewings, and damsel bugs [107].

The community of indigenous generalist predators consuming *H. halys* eggs is very diverse, made up of many species with a variety of modes of feeding. Morrison et al. (2016) [108] identified four distinct predation ‘‘syndromes’’ on H. halys eggs using laboratory observations of over 25 predator taxa: (1) complete chewing—eggs completely removed from substrate; (2) incomplete chewing—egg shell debris from predated eggs remains on substrate; (3) stylet sucking—presence of a feeding sheath in eggs drained of their contents; and (4) punctured sucking—a hole or slit in hollowed-out eggs. In the laboratory, the most efficient predators were katydids (Orthoptera: Tettigoniidae), ground beetles (Coleoptera: Carabidae), crickets (Orthoptera: Gryllidae), earwigs (Dermaptera: Forficulidae), and jumping spiders (Araneae: Salticidae) [109]

Predators attacking *H. halys* adults and nymphs in Europe and North America have not been extensively studied. In one study of the nest-provisioning wasp *Bicyrtes quadrifasciata* (Say) (Hymenoptera: Crabronidae) in the northeastern USA, H. halys nymphs made up 96% of the prey provided to developing offspring [110]. Another crabronid wasp, *Astata unicolor* Say, was also observed preying on *H. halys* nymphs. Jones (2013) [111] commonly observed predation of H. halys adults and nymphs by the wheel bug Arilus cristatus (L.) (Hemiptera: Reduviidae) in Maryland, USA. Predation of adult H. halys by praying mantids (Mantodea: Mantidae) has also been observed on a number of occasions in the USA.

Interestingly, only one unpublished study has gathered some information on the consumption of newly emerged (1st instar) H. halys nymphs, which are clustered on egg masses for several days and potentially vulnerable as they are relatively immobile and soft-bodied. That study observed the highest predation of freshly emerged first instar nymphs in the laboratory by field-collected Carabidae (89% of nymphs emerged were eaten), predatory Pentatomidae (88%), Salticidae (35%), and Reduviidae (26%;) [112].

According to Kharabadze et al., (2022) [113] *Hierodula transcaucasica* Brunner von Wattenwyl, 1878 were observed as a predator of *H.halys* in Georgia. Predation of the adults and nymphs of *H. transcaucasica* was documented after they underwent starvation periods. The 3rd instar nymph of *H. transcaucasica* preyed on the 1st instar *H. halys* nymphs, while adult *H. transcaucasica* attacked adult of *H. halys*. A maximum number of *H. halys* (7 insect) were eaten by an adult *H. transcaucasica* on the first day, and in this case, the same number of nymphs (7 insects) were observed within the first hours of the experiment.

Parasitoids

Since the impact of native natural enemies on invasive *H. halys* populations in Europe and North America is generally low, *H. halys* was identified as a promising target for classical biological control. Surveys for natural enemies that have co-evolved with *H. halys* in its native range revealed that it is mostly attacked by egg parasitoids, among which the samurai wasp, *Trissolcus japonicus*, was identified as the most promising candidate for classical biological control.

In China, *Trissolcus japonicus*,[114] a parasitoid wasp species in the family Scelionidae, is a primary predator [115]. In the United States, Europe, and New Zealand, *Trissolcus japonicus* is a focus of biological control programs against *H.halys*. in 2014, two adventive populations were found in the United States during surveys to identify which North American parasitoids might be attacking brown marmorated stink bug.[116,117] Subsequent genetic testing showed these wild populations were self-introduced: they were not related to each other, or to a laboratory strain being studied in quarantine. [118 - 121] An adventive European population was discovered during similar surveys in Switzerland in 2017 [122].

Trissolcus japonicus is a tiny wasp that parasitizes the eggs of various stink bug species. It was first collected from China and brought back to quarantine facilities in the US for evaluation, as a potential biological control agent. Host-specific tests have indicated that *T. japonicus* prefers to parasitize *H.halys* eggs over eggs of other stink bug species.

Abram et al., (2017) [112] reported that *H. halys* and other stink bug species data from the USA supports the hypothesis that the relative prevalence of different parasitoid species associated with *H. halys* eggs is habitat-dependent [123,124].

Three principal groups of hymenopteran parasitoids attack *H. halys* eggs in invaded areas of North America and Europe: Scelionidae (Telenomus, Trissolcus, and Gryon spp.), Eupelmidae (Anastatus spp.), and Encyrtidae (Ooencyrtus spp.). The host range of the scelionids were detected , especially Telenomus (podisi group) and Trissolcus spp., tends to be restricted to stink bugs (Hemiptera: Pentatomidae) [125-129].

Scelionid parasitoids of stink bug eggs have stereotyped behavior, remaining on the patch for several hours after oviposition and engaging in aggressive inter- and intraspecific contests with other parasitoids [130]). Eupelmids and encyrtids found attacking H. halys are likely to be generalists that attack multiple families of insect hosts and some species are facultative hyperparasitoids [131,132]

According to Japoshvili et al.(2021) [133], five species of *Trissolcus* Ashmead (Hymenoptera: Scelionidae), which are known parasitoids of Pentatomidae, were identifed. Four of these *(T. belenus* (Walker), *T. colemani* (Crawford), *T. scutellaris* (Thomson)) and *T. semistriatus* (Nees) are documented for the first time from Georgia, and two are new records for the Caucasus region. Also, *Anastatus bifasciatus* was recorded from Georgia as a *H. halys* eggs parasitoid [134] and as a native species considered for potential biocontrol in Europe [135].

Entomopathogens

Entomopathogenic microorganisms are one of the promising naturel enemies for control many invertebrate pest. In this case, less information documented about pathogens of *H.halys.* First description a unique microsporidian species that infects the green stink bug, *Chinavia hilaris* and the brown marmorated stink bug - Halyomorpha halys first were observied in US. this microsporidium belong in the genus Nosema, which historically has been characterized by diplokaryotic life stages. This microsporidium is apparently Holarctic in distribution. Nosema maddoxi is native to North America and has also been found in China and South Korea; in North America it infects native stink bugs and *H. halys*.

Morphological, ultrastructural, and ecological features of the microsporidium, together with a molecular phylogeny, establish a new species named *Nosema maddoxi* sp. nov. [136].

A microsporidian pathogen discovered in Georgian of *H. Halys* has been identified as *Nosema maddoxi*. Investigations were carried out during different seasons in three regions of West Georgia in 2018–2019. [137] the highest prevalence of *N. maddoxi* was detected among overwintered adults collected in May in the Guria region. Molecular study was confirmed that this specie is Nosema *madoxi* [138].

First report on entomopathogenic fungi species, that infects *H. halys* were observed in Guria and Samegrelo region of Western

Georgia. In different *H.halys* populations, adults developed mycosis symptoms on the body were observed. Three isolates of entomopathogenic fungus *Beauveria bassiana* and one of *Isaria fumosorosea* were identified [48]. Isolated species were studded in morphological and carried out in molecular identification [139].

Management and control

Current management tactics for *H. halys* mostly rely on insecticide applications [6, 140]. As indigenous parasitoids and predators adapt to *H. halys* and exotic parasitoids continue to spread and establish, biological control is expected to become an increasingly important component of integrated pest management programs.

At present, there are no published studies of how landscape factors or proposed alternative on-farm management practices (e.g., attractand-kill—[141]; trap crops—[142]; border and alternate-row spraying—[143], [144] insecticide-incorporated nets—[140]) influence indigenous natural enemies and their impact H. halys population growth. To assess the effect of these pest management practices on biological control services, future studies will need to integrate accurate measurements of population-level impact with chemical, behavioral, and invasive species ecology.

Numerous methods have been used to demonstrate the relative effectiveness of a broad range of insecticides against *H. halys* adults and nymphs, including treated glass surfaces [143,145,146], direct-contact topical applications (G. K., unpublished data), bean dip feeding bioassays [147], and field efficacy trials [148,149,150,151]. Active ingredients that have been most effective include several pyrethroids (bifenthrin, permethrin, fenpropathrin, and beta-cyfluthrin), neonicotinoids (dinotefuran, clothianidin, and thiamethoxam,), carbamates (methomyl and oxamyl), the organophosphate acephate, and the organochlorine endosulfan. Unfortunately, these insecticides are generally broad-spectrum in their activity; they can be hard on natural enemy populations and quite disruptive to integrated pest management programs [152].

Hazelnuts orchards growers in the Black Sea region, Colchis Lowland of WG, insecticide applications were used. USAID is helping Georgia combat the country's stick bug infestation problems and offers $3.5.[49]. State control program against *H.* halys were obtained since Nowember 2016 In Georgia. Within this program about 110 000 ha of land were treated by pyrethroid insecticides (Bifetrin) per year. Infested plots are treated by thermal fog - with low-volume spraying technology. In 2017, 58, 416, 8 ha of land were treated, In 2018, 790 000 ha and in 2021 a total area of 37,236 hectares has been treated (https://agenda.ge/en/news/2021/2359)

Also, 21 000 pheromone traps (Tracky), were placed for the monitoring purposes, 100 000 phereomones placed for the "attract and kill" stations in the external perimeters of the forests and villages through the country. Large scale farmers were supplied with pyrethroid (Bifetrin) insecticides. Information campaign is carried out systematically, brochures are printed, video clips are made. A hotline has been opened which can be use for getting comprehensive information and consultation around *Halyomorpha halys* . In pursuit of the BMSB monitoring, 8000 pheromone traps were placed throughout the country and 28,818 'attract and kill stations and 5,754 pheromone traps were been installed" (https://agenda.ge/en/news/2021/2359). Also about), Bioecological features *H.halys* and it control mechanisms in Adjara Region of WG, use pheromone traps for the monitoring were report in the publication of Dumbadze and all (2019) [51].

According Burjanadze et al.(2021) [153] against *H. halys* local production of mycopesticiede, trade mark- Bover-Ge™, were tested in laboratory and field condition. It was registered by National food agency (NFA) of Georgia as a biopesticides, which are based on local strain of entomopathogenic fungus *Beauveria bassiana*, isolated from soil of high mountain of Caucasus region. Bover–Ge were tested at a concentration of 1×10^8 conidia/ml against adults, where in laboratory 93.3%, in field 87 % and in migration stage 64% mortality were observed.

The potential of native entomopathogenic nematodes: *Heterorhabditis bacteriophora* (HRB, GEO) and Steinernema borjomiense , *H. bacteriophora* (HRB, IT) and S. apuliae were evaluated agins adults *H.halys* in laboratory, where effectiveness from H. *bacteriophora* (GEO, IT) 53-95.3%, from S. *borjomiense* and *S. apuliae* 40-60% were observed. The present study provides further insights in selection of promising EPN strains to be used against *H.halys* [48].

Conclusion

Halyomorpha halys invaded Georgia in 2015 and by 2016 the mass spread of the pest caused epizootic, huge economical, ecological losses. In 2019, the epizootic outbreak of *Halyomorpha halys* was declared eliminated. Success was achieved through using agro-technical measures, chemical pesticides and pheromones. Scientific studies revealed that local natural enemies predators, parasitoids and pathogenic microorganisms have co-evolved with *H. halys.* Also, testing local isolates of parasitic nematodes and entomopathogenic fungi proved their effectiveness as a control tool against *H. halys*.

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Reference

[1] Hoebeke E.R, Carter M.E, Halyomorpha halys (Stål) (Heteroptera: Pentatomidae): a polyphagous plant pest from Asia newly detected in North America. Proc Entomol Soc Wash, 2003,105:225–237

[2] Bergmann EJ, Venugopal PD, Martinson HM, Raupp MJ, Shrewsbury PM, Host plant use by the invasive Halyomorpha halys (Stål) on woody ornamental trees and shrubs. PLoS One,2016, 11(2):e0149975. https://doi.org/10.1371/journal.pone.0149975

[3] Rider D.A., Zheng L.Y. & Kerzhner I.M. Checklist and nomenclatural notes on the Chinese Pentatomidae (Heteroptera). II. Pentatominae. ZOOSYST. ROSSICA Vol. 11, 2002,135-153.

[4] Josifov, M.V. & Kerzhner, J.M.. Heteroptera aus Korea. II. Tei! (Aradidae, Berytidae, Lygaeidae, Pyrrhocoridae, Rhopalidae, Alydidae, Coreidae, Urostylidae, Acanthosomatidae, Scutelleridae, Pentatomidae, Cydnidae, Plataspidae). Fragm.faun., 23(9), 1978,137-196.

[5] Leskey TC, Nielsen AL (2018) Impact of the invasive brown marmorated stink bug in North America and Europe: history, biology, ecology, and management. Annu Rev Entomol 63:599–618. https://doi.org/10.1146/annurev-ento-020117-043226

[6] Rice KB, Bergh CJ, Bergmann EJ, Biddinger DJ, Dieckhoff C, Dively G, Fraser H, Gariepy TD, Hamilton G, Haye T, Herbert A, Hoelmer KA, Hooks CR, Jones A, Krawczyk G, Kuhar T, Martinson H, Mitchell W, Nielsen AL, Pfeiffer DG, Raupp M, Rodrigues-Saona C, Shearer P, Shrewsbury P, Venugopal PD, Whalen J, Wiman NG, Leskey TC, Tooker JF (2014) Biology, ecology, and management of brown marmorated stink bug (Hemiptera: Pentatomidae). J Integr Pest Manag 5:A1–A13

[7] Kriticos DJ, Kean JM, Phillips CB, Senay SD, Acosta H, Haye T (2017) The potential global distribution of the brown marmorated stink bug, Halyomorpha halys, a critical threat to plant biosecurity. J Pest Sci 90:1033–1043. https://doi.org/10.1007/s10340-017-0869-5

[8] Walgenbach J (ed) (2017) Where is BMSB? Accessed online from: http:// www.stopbmsb.org/ (last update 20 September 2017)

[9] EPPO Global Database (2018) URL: https://gd.eppo.int (last update: 29 April 2018)

[10] Haye T, Gariepy T, Hoelmer K, Rossi JP, Streito JC, Tassus X, Desneux N (2015) Range expansion of the invasive brown marmorated stinkbug, Halyomorpha halys: an increasing threat to field, fruit and vegetable crops worldwide. J Pest Sci 88:665–673. https://doi.org/ 10.1007/s10340-015-0670-2

[11] Faúndez EI, Rider DA (2017) The brown marmorated stink bug Halyomorpha halys (Stål, 1855) (Heteroptera: Pentatomidae) in Chile. Arquivos Entomolóxicos 17:305–307

[12] Nikam KM, More SV (2016) Diversity of insects from Jangamhatti area, Chandgad, Kolhapur district of Maharashtra. Biolife 4(1):209–212

[13] Cianferoni F, Graziani F., Dioli P., Ceccolini F. (2018). Review of the occurrence of Halyomorpha halys (Hemiptera:Heteroptera: Pentatomidae) in Italy, with an update of its European and World distribution. Biologia, 1-9.

[14] Duthie C., Risk Analysis of Halyomorpha

halys (Brown Marmorated Stink Bug) on all pathways. Ministry for Primary Industries, Wellington, 2012, 51 pp

[15] Walker K (2011) Brown marmorated stink bug (Halyomorpha halys). AM Available online: PaDIL - http://www.padil.gov.au. (last update 25 November 2011)

[16] Moore A., Brown marmorated stink bug Halyomorpha halys (Stal 1855) (Hemiptera: Pentatomidae). Guam New Invasive Species Alert, 2014, (1):1–2

[17] Gadalla SM (2004) New records of Pentatomomorpha (Hemiptera) from Egypt. Journal of Union of Arab Biologists, A, Zoology 21:43–58

[18] Aukema B, Rieger C, Rabitsch W (2013) Catalogue of the Heteroptera of the Palaearctic Region. Vol. 6. Supplement. The Netherlands Entomological Society, Ede, 629 pp

[19] Hemala V, Kment P (2017) First record of Halyomorpha halys and mass occurrence of Nezara viridula in Slovakia. Plant Prot Sci 4:247–253 https://doi.org/10.17221/166/2016-pps

[20] *Eppo Global Database*. Halyomorpha halys (HALYHA)[World distribution]| EPPO Global Database. (n.d.). Retrieved June 19, 2022, from https://gd.eppo.int/taxon/HALYHA/distribution

[21] Arnold K (2009) Halyomorpha halys (Stål, 1855), eine für die europäische Fauna neu nachgewiesene Wanzenart (Insecta: Heteroptera, Pentatomidae, Pentatominae, Cappaeini). Mitt Thür Entomologenverband 16(1):19

[22] Haye T, Wyniger D, Gariepy TD (2014) Recent range expansion of brown marmorated stink bug in Europe. In: Müller G, Pospichil R, Robinson W (eds) Proceedings of the eighth international conference on urban pests, Veszprém, Hungary, pp 309–314

[23] Wyniger D, Kment P (2010) Key for the separation of Halyomorpha halys (Stål) from similar-appearing pentatomids (Insecta: Heteroptera: Pentatomidae) occurring in Central Europe, with new Swiss records. Mitt Schweiz Entomol Ges 83:261–270

[24] Heckmann R (2012) Erster Nachweis von Halyomorpha halys (Stål, 1855) (Heteroptera: Pentatomidae) für Deutschland. Heteropteron 36:17–18

[25] Callot H, Brua C (2013) Halyomorpha halys (Stål, 1855), la Punaise diabolique, nouvelle espèce pour la faune de France (Heteroptera Pentatomidae). L'Entomologiste 69(2):69–71

[26] Garrouste R, Nel P, Nel A, Horellou A, Pluot-Sigwalt D (2015) Halyomorpha halys (Stål 1855) en Île de France (Hemiptera: Pentatomidae: Pentatominae): surveillons la punaise diabolique. Ann Soc Entomol Fr (NS) 50(3–4)(2014):257–259. https://doi.org/ 10.1080/00379271.2014.990250

[27] Maurel J-P, Blaye G, Valladares L, Roinel É, Cochard PO (2016) Halyomorpha halys (Stål, 1855), la punaise diabolique en France, à Toulouse (Heteroptera; Pentatomidae). Carnets Natures 3:21–25

[28] Maistrello L, Dioli P, Vaccari G, Nannini R, Bortolotti P, Caruso S, Costi E, Montermini A, Casoli L, Bariselli M (2014) Primi rinvenimenti in Italia della cimice esotica Halyomorpha halys, una nuova minaccia per la frutticoltura. ATTI Giornate Fitopatologiche 1:283–288

[29] Dioli P, Leo P, Maistrello L (2016) Prime segnalazioni in Spagna e in Sardegna della specie aliena Halyomorpha halys (Stål, 1855) e note sulla sua distribuzione in Europa (Hemiptera, Pentatomidae). Rev gad Entom 7(1):539–548

[30] Milonas PG, Partsinevelos PK (2014) First report of brown marmorated stink bug Halyomorpha halys Stål (Hemiptera: Pentatomidae) in Greece. Bull OEPP/EPPO 44:183–186. https://doi.org/10.1111/epp.12129

[31] Vétek G, Papp V, Haltrich A, Rédei DA (2014) First record of the brown marmorated stink bug, Halyomorpha halys (Hemiptera: Heteroptera: Pentatomidae), in Hungary, with description of the genitalia of both sexes. Zootaxa 3780(1):194–200. https://doi.org/ 10.11646/zootaxa.3780.1.8

[32] Gapon DA (2016) First records of the brown marmorated stink bug Halyomorpha halys (Stål, 1855) (Heteroptera, Pentatomidae) in Russia, Abkhazia, and Georgia. Entomol Rev 96(8):1086–1088. https://doi.org/10.1134/s001387381608011x

[33] Rabitsch W, Friebe GJ (2015) From the west and from the east? First records of Halyomorpha halys (Stål, 1855)

(Hemiptera: Heteroptera: Pentatomidae) in Vorarlberg and Vienna, Austria. Beiträge zur Entomofaunistik 16:115–139

[34] Šeat J. (2015) Halyomorpha halys (Stål, 1855) (Heteroptera: Pentatomidae) a new invasive species in Serbia. Acta Entomol Serb 20:167–171.

[35] Macavei Laura Ioana, Bâeþan R., Oltean I., FlorianT., Varga M., Costi E., Maistrello Lara, 2015. Firstdetection of Halyomorpha halys Stål, a new invasivespecies with ahigh potential of damage on agriculturalcrops in Romania. Lucrãri ªtiinþifice seria Agronomie,58, (1):105-108.

[36] Simov N (2016) The invasive brown marmorated stink bug Halyomorpha halys (Stål, 1855) (Heteroptera: Pentatomidae) already in Bulgaria. Ecol Mont 9:51–53.

[37] Çerçi B, Koçak Ö (2017) Further contribution to the Heteroptera (Hemiptera) fauna of Turkey with a new synonymy. Acta Biologica Turcica 30(4):121–127

[38] Šapina I, Šerić Jelaska L (2018) First report of invasive brown marmorated stink bug Halyomorpha halys (Stål, 1855) in Croatia. EPPO Bull 48(1):138–143

[39] Malumphy C (2014) Second interception of Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) in Britain. Het News 21:4–5

[40] Zhu G., Bu W., Gao Y., Liu G. Potential geographic distribution of brown marmorated stink bug invasion (Halyomorpha halys) // PLOS One. 2012. Vol. 7, N 2. e31246

[41] Eskin N.B., Bibin A.R. Focus of the Box Tree Moth in a Yew-Box Grove. Kavkaz zapovednyi. 2014. N 8 (124). P. 7. (In Russian)

[42] Neimorovets V.V. (2018). Brown marmorated stink bug *Halyomorpha halys* (Heteroptera: Pentatomidae): morphology, biology, distribution and threats to agriculturein the Russian Federation (Analytical review). Plant Protection News, 1(95), p. 11–16

[43] Zhimerikin, V.N., Guliy, V.V. (2014). Brown marmorated stink bug. Protection and quarantine of plants, 4, 40-43. (InRussian)

[44] Mityushev I.M. First case of detection of the Marmorated stink bug in Russia. Zashchita i karantin rasteniy. 2016. N 3. P. 48. (In Russian). On the approval of the unified list of quarantine items of the Eurasian Economic Union. 2016. URL: https://docs.eaeunion.org/docs/en-us/01213201/cncd_06032017_158 (accessed: 28.01.2018). (In Russian)

[45] Karpun NN, Protsenko V.E. Marmorated stink bug (Halyomorpha halys Stål.) appeared in the humid subtropics of Russia and Abkhazia. VNIITsiSK. 2016. Published: 25.10.2016. URL: http://vniisubtrop.ru/novosti/769-mramornyjklop-halyomorpha-halys-st-l-poyavilsya-vo-vlazhnykh-subtropikakhrossii-i-abkhazii.html (accessed: 28.12.2017). (In Russian)

[46] Kharabadze N.,. Chkhaidze N, Lobjanidze M.,. Burjanadze M. Biological agents for the control of Brown Marmorated Stink Bug (BMSB) Halyomorpha halys in Georgia. International Conference “Brown Marmorated Stink Bug (BMSB) Phytosanitary Regulatory Framework “. March 11-14, 2019. Tbilisi, Georgia

[47] Burjanadze M., Kharabadze N., Chkhaidze N., Entomopathogenic fungi and nematodes as biocontrol agents of brown marmorated stink bug – Halyomorpha halys in Georgia. Book of abstracts VIII Congress on Plant Protection, p-91. Zlatibor, Serbia, November 2019, 25-29

[48] Burjanadze M., Gorgadze O., De Luca F., Troccoli A., Lortkipanidze M., Kharabadze N., Arjevanidze M., Fanelli E., Tarasco E. (2020). Potential of native entomopathogenic nematodes for the control of brown marmorated stink bug Halyomorpha halys in Georgia. Biocontrol Science and Technology2020-06-08T06:47:44Z DOI: 10.1080/09583157.2020.1776217

[49] Meskhi N. Monitoring and control strategy of Brown marmorated stink bug (*Halyomorpha halys*) in Georgia. National Food Agency Report, 07.09.2017, Tbilisi, Georgia

[50] Jakely E. & Nikolashvili A. (2019). The results of bioecological study of brown marmorated stink bug -Halyomorpha halys(Stal) in the conditions of Western Georgia. Georgian Academy of Agricultural Sciences Bulletin, N1 (41), 70-75

[51] Dumbadze G., Gokturk T , Jgenti L. , Chelidze N. (2019). Distribution of Brown Marmorated Stink Bug (Halyomorpha halys), Bioecological Features and Control Mechanisms in Batumi (Georgia). SETSCI Conference Proceedings 4 (6), 539-542,

2019
[52] Japoshvili G, Arabuli T, Salakaia M, Tskaruashvili Z, Kirkitadze G, Talamas E (2022) Surveys for Halyomorpha halys (Stål)(Hemiptera: Pentatomidae) and its biocontrol potential by parasitic wasps in the Republic of Georgia (Sakartvelo). Phytoparasitica 50(1), 127-13
[53] Mamedov Z.M (2018). Brown marmorated sting bug (Halyomorpha halys Stal.) the pest of orchard, forest and decorative trees in Azerbaijan. Georgian Academy of Agricultural Sciences Bulletin, N2 (40), 88-89
[54] Güncan, A.; Gümüş, E. (2019). Brown marmorated stink bug, Halyomorpha halys (Stål, 1855) (Hemiptera: Heteroptera, Pentatomidae), a new and important pest in Turkey. Journal Entomological News, 128, 2, 204-210
[55] Penca C, Hodges AC. 2018. "First report of brown marmorated stink bug (Hemiptera: Pentatomidae) reproduction and localized establishment in Florida." Florida Entomologist 101(4): 4p
[56] Penca, C. & Hodges, A., (2019). Brown marmorated stink bug, Halyomorpha Halys (Stål) (Insecta: Hemiptera: Pentatomidae). EDIS, 2019(1). https://doi.org/10.32473/edis-in623-2019
[57] Cira, T. M., R. C. Vennette, J. Aigner, T. Kuhar, D. E. Mullins, S. E. Gabbert, and W. D. Hutchison. 2015. Cold tolerance of Halyomorpha halys (Hemiptera: Pentatomidae) across geographic and temporal scales. Environ. Entomol. DOI: 10.1093/ee/nvv220
[58] Lee D-H, Short BD, Joseph SV, Bergh JC, Leskey TC (2013) Review of the biology, ecology, and management of Halyomorpha halys (Hemiptera: Pentatomidae) in China, Japan, and the Republic of Korea. Environ Entomol 42:627–641. https://doi.org/10.1603/ en1300
[59] Lee, D.-H., & Leskey, T. C. (2015). Flight behavior of foraging and overwintering brown marmorated stink bug,Halyomorpha Halys(Hemiptera: Pentatomidae). Bulletin of Entomological Research, 105(5), 566–573. https://doi.org/10.1017/s0007485315000462
[60] Lee, D.-H., A. L. Nielsen, and T. C. Leskey.. Dispersal capacity and behavior of nymphal stages of Halyomorpha halys (Hemiptera: Pentatomidae) evaluated under laboratory and field conditions. J. Insect Behav. 27, 2014, 639-651.
[61] Nielsen, A. L., G. C. Hamilton, and D. Matadha. 2008. Developmental rate estimation and life table analysis for Halyomorpha halys (Hemiptera: Pentatomidae). Environ. Entomol. 37:348 355.
[62] Hoffman, W. E. 1931. A pentatomid pest of growing beans in south China. Peking Nat. Hist. Bull. 5: 25Ð27
[63] Inkley, D. B. 2012. Characteristics of home invasion by the brown marmorated stink bug (Hemiptera: Pentatomidae). J. Entomol. Sci. 47: 125Ð130.
[64] Mertz, T. L., Jacobs, S. B., Craig, T. J., & Ishmael, F. T. (2012). The brown marmorated stinkbug as a new aeroallergen. Journal of Allergy and Clinical Immunology, 130(4). https://doi.org/10.1016/j.jaci.2012.06.016
[65] Kagen, S.L. Inhalant allergy to arthropods. Clinical Reviews in Allergy 8, 99–125 (1990). https://doi.org/10.1007/BF02914439
[66] Kharabadze N, Tsiklauri N, Burjanadze M, Chkhaidze N, (2022): Resistance of Georgian Hazelnut (Corylus L.) to Brown Marmorated Stink Bug – Halyomorpha halys (Stål) , Journal of Nuts. in press
[67] Murvanidze M, Krawczyk G, Inasaridze N, Dekanoidze L, Samsonadze N, Macharashvili M, Shengelaia S (2018) Preliminary data on the biology of brown marmorated stink bug Halyomorpha halys (Hemiptera, Pentatomidae) in Georgia. Turkish Journal of Zoology,42(6) 617-624, https://doi:10.3906/zoo-1802-34Haye T, Abdallah S, Gariepy T, Wyniger D (2014 a) Phenology, life table analysis, and temperature requirements of the invasive brown marmorated stink bug, Halyomorpha halys, in Europe. J Pest Sci 87(3):407–418. https://doi.org/10.1007/s10340-014-0560-z
[68] Acebes A.L.D., Leskey T., Bergh J. C., Host Plant Effects on Halyomorpha halys (Hemiptera: Pentatomidae) Nymphal Development and Survivorship, Environmental Entomology, Volume 45, Issue 3, June 2016, Pages 663–670, https://doi.org/10.1093/ee/nvw018

[69] Khadka, A., Hodges, A. C., Leppla, N. C., & Tillman, P. G. (2020). The effects of relative humidity on Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) egg hatch, nymph survival, and adult reproduction. *The Florida Entomologist*, *103*(1), 136–138. https://www.jstor.org/stable/48610645

[70] Musolin D.M. Heteroptera: Pentatomoidea: variety of seasonal adaptations, control mechanisms seasonal development and climate change responses. Thesis for a degree Doctors of Biological Science. St. Petersburg. 2017,pp. 435 (in: Russian)

[71] Jones, J. R., and Lambdin, P. L. 2009. New county and state records for Tennessee of an exotic pest, Halyomorpha halys (Hemiptera: Pentatomidae), with potential economic and ecological implications. Florida Entomol. 92: 177-179.

[72] Bernon, G., Biology of Halyomorpha halys, the Brown Marmorated Stink Bug (BMSB). Final Report – USDA APHISCPHST 2004, 17 pp

[73] Bergmann, E, Bernhard, KM, Bernon, G, Bickerton, M, Gill, S, Gonzales, C, Hamilton, GC, Hedstrom,C, Kamminga, K & Koplinka-Loehr, C 2015, Host plants of the brown marmorated stink bug in the US, www.stopbmsb.org/where-is-bmsb/host-plants/ .

[74] Martinson HM, Venugopal PD, Bergmann EJ, Shrewsbury PM, Raupp MJ. Fruit availability influencesthe seasonal abundance of invasive stink bugs in ornamental tree nurseries. J Pest Sci. 2015; 88: 461–468. doi: 10.1007/s10340-015-0677-8

[75] Takahashi, S. 1930. Halyomorpha picus Fab., pp. 617Ð 620. In Insect Pests on Fruit Trees

[76] Hoffman, W. E. 1931. A pentatomid pest of growing beans in South China. Peking Nat. Hist. Bull. 5: 25Ð26

[77] Saito, Y., S. Saito, Y. Ohmori, and K. Yamada. 1964. Studies on bionomics of the bean bugs occurring in mountain areas, with particular reference to that of Halyomorpha picus and to the insecticidal tests in laboratory and Þeld. Jpn. J. Sanit. Zool. 15: 7Ð16

[78] Kobayashi, T., and S. Kimura. 1969. The studies on the biology and control of house-entering stink bugs. Part 1. The actual state of the hibernation of stink bugs in houses. Bull. Tohoku Natl. Agric. Exp. St. Morioka 37: 123Ð138

[79] Chung, B. K., S. W. Kang, and J. H. Kwon. 1995. Damages, occurrences and control of hemipterous insects in nonastringent persimmon orchards. J. Agric. Sci. 37: 376Ð382.

[80] Funayama, K. 1996. Sucking injury on apple fruit by the adult of brown marmorated stinkbug Halyomorpha mista (Uhler). Annu. Rep. Plant Prot. North. Jpn. 47: 140Ð142

[81] Watanabe, K. 1996. Characteristic of damages of Lygocoris (Apolygus) lucorum (Meyer-Dur) (Heteroptera: Miridae) and Halyomorpha halys (Stål) (Heteroptera: Pentatomidae) on cherry. Annu. Rep. Plant Prot. North. Jpn. 47: 143Ð144

[82] Choi, D. S., K. C. Kim, and K. C. Lim. 2000. The status of spot damage and fruit piercing pests on Yuzu (Citrus junos) fruit. Korean J. Appl. Entomol. 39: 259Ð266.

[83] Tada, N., M. Yoshida, and Y. Sato. 2001. Monitoring of forecasting for stink bugs in apple 2. The possibility of forecasting with aggregation pheromone. Annu. Rep. Plant Prot. North. Jpn. 52: 227Ð229

[84] Funayama, K. 2002. Comparison of the susceptibility to injury of apple cultivars by stink bugs. Jpn. J. Appl. Entomol. Zool. 46: 37Ð40

[85] Rijal Jhalendra and Sudan Gyawaly, (2018) Characterizing Brown Marmorated Stink Bug Injury in Almond, a New Host Crop in California. Insects · DOI: 10.3390/insects9040126

[86] Hedstrom C. S., Shearer P. W., Miller J. C., Walton V. M., The Effects of Kernel Feeding by *Halyomorpha halys* (Hemiptera: Pentatomidae) on Commercial Hazelnuts, *Journal of Economic Entomology*, Volume 107, Issue 5, 1 October 2014, Pages 1858–1865, https://doi.org/10.1603/EC14263

[87] Tuncer C, Saruhan İ, Akça İ (2014) Seasonal occurrence and species composition of true bugs in hazelnut orchards. Acta Hortic 1052:263–268.

[88] Grazia, J., Panizzi, A.R., Greve, C., Schwertner, C.F., Campos, L.A., Garbelotto, T. de A., et al. 2015. Stink Bugs (Pentatomidae). In: True Bugs (Heteroptera)

of the Neotropics, pp. 681–756. Springer, Dordrecht

[89] Bosco L, Moraglio ST & Tavella L (2018) Halyomorpha halys, a serious threat for hazelnut in newly invaded areas. Journal of Pest Science 91: 661–670.

[90] Tuncer C. Saruhan I. Akca I. 2005. The insect pest problem affecting hazelnut kernel quality in turkey. In. Tous J. Rovira M. Romera A.Proceedings of the VI International Congress on Hazelnut14 June 2004Tarragona-Reus, Spain686: 367–376.

[91]. Tavella L. Arzone A. Sargiotto C. Sonnati C. 1997. Coreidae and Pentatomidae harmful to hazelnuts in northern Italy (Rhynchota: Heteroptera). Acta Hort. 445: 503–509.

[92] Saruhan I. Tuncer C. 2010. Research on damage rate and type of green shieldbug (Palomena prasina L. Heteroptera: Pentatomidae) on hazelnut. Anadolu Tarım Bilimleri Dergisi. 25: 75–83.

[93] Tavella L., Arzone A., Miaja M.L., Sonnati C., Influence of bug (Heteroptera, Coreidae and Pentatomidae) feeding activity on hazelnut in northwestern Italy, Acta Hort. 2001, 556(556):461-468, DOI: 10.17660/ActaHortic.2001.556.68

[94] Oda M. Sugiura T. Nakanishi Y. Uesumi Y. 1980. Ecological studies of stink bugs attacking fruit trees. Report 1: the prevalence of seasonal observations by light trap, and the ecology on the occurrence of fruit trees and mulberry under field observations. Bull. Nara Agric. Exp. Stn. 11: 53–62.

[95] Yanagi T. Hagihara Y. 1980. Ecology of the brown marmorated stink bug. Plant Prot. 34: 315–321

[96] Funayama K. 2003. Outbreak and control of stink bugs in apple orchards. Jpn. Agric. Tech. 47: 35–39.

[97] Ohira Y. 2003. Outbreak of the stink bugs attacking fruit trees in 2002. Plant Prot. 57: 164–168.

[98] Bariselli M., R.Bugiani, and L.Maistrello (2016) Distribution and damage caused by Halyomorpha halys in Italy. Bulletin OEPP/EPPO Bulletin (2016) 0 (0), 1–3, ISSN 0250-8052. DOI: 10.1111/epp.12289.

[99] Sauer C (2012) Die Marmorierte Baumwanze tritt neu im Deutschschweizer Gemu¨sebau auf. Extension Gemu¨sebau, Forschungsanstalt Agroscope Changins-Wa¨denswil, Gemu¨sebau Info 28(12):4–5

[100] National Food Agency, Ministry of Agriculture of Georgia report presented on 20 November 2016; http://www.moa.gov.ge/

[101] Burjanadze Medea, Kharabadze Natalia, Chkhidze Nona (2020): Testing local isolates of entomopathogenic microorganisms against Brown Marmorated Stink Bug Halyomorpha halys in Georgia, BIO Web of Conferences 18, 00006, IV All-Russian Plant Protection Congress, https://doi.org/10.1051/bioconf/20201800006

[102] Ministry of finance of Georgia, https://mof.ge/images/File/biujetis-kanoni2018/II-wardgena/matrica.pdf

[103] Ministry of Environmental Protection and Agriculture of Georgia. News | Ministry of Environmental Protection and Agriculture of Georgia. (n.d.). Retrieved June 3, 2022, from https://mepa.gov.ge/En/News/Details/11703/

[104] National Statistics Office of Georgia. Agriculture - Production of Permanent Crops . (2022, June 3). Retrieved June 3, 2022, from https://www.geostat.ge/en/modules/categories/196/agriculture

[105] Jones, A.L., D.E. Jennings, C.R.R. Hooks, and P.M. Shrewsbury. 2014. Sentinel eggs underestimate rates of parasitism of the exotic brown marmorated stink bug, Halyomorpha halys. Biol. Control 78:61–66; DOI: 10.1016/ Journal of Biocontrol, http://dx.doi.org/10.1016/j.biocontrol.2014.07.011

[106] (https://entomology.ces.ncsu.edu/biological-control-of-brown-marmorated-stink-bug/#predators)

[107] Morrison WR III, Mathews CR, Leskey TC (2016) Frequency, efficiency, and physical characteristics of predation by generalist predators of brown marmorated stink bug (Hemiptera: Pentatomidae) eggs. Biol Control 97:120–130

[108] Abram PK, Doyon J, Brodeur J, Gariépy TD & Boivin G Susceptibility of Halyomorpha halys (Hemiptera: Pentatomidae) eggs to different life stages of three generalist predators. Canadian Entomologist 147,2014, 222–226.

[109] Biddinger, D.J., Surcică, A. & Joshi, N.K. (2017) A native predator utilisingthe invasive brown marmorated stink bug, Halyomorpha

halys(Hemiptera: Pentatomidae) as a food source. Biocontrol Science and Technology, 27(7), 903–907. https://doi.org/10.1080/09583157.2017.1354247

[110] Jones, A.L. (2013) Indigenous natural enemies of the invasive brown mar-morated stink bug, Halyomorpha halys (Hemiptera: Pentatomidae).Master of Science, College Park, Department of Entomology, University of Maryland.

[111] Abram, P.K., Hoelmer, K.A., Acebes-Doria, A., Andrews, H., Beers, E.H.,Bergh, J.C. et al. (2017) Indigenous arthropod natural enemies of theinvasive brown marmorated stink bug in North America and Europe. Journal of Pest Science, 90(4), 1009–1020

[112] Kharabadze, N., Chkhaidze, N., Abramishvili, T. et al. First report of Hierodula transcaucasica (Brunner von Wattenwyl, 1878) predation on the Halyomorpha halys (Stål, 1855) in Georgia. Int J Trop Insect Sci (2022). https://doi.org/10.1007/s42690-022-00826-2.

[113] Talamas E.; Buffington M.; Hoelmer K., New synonymy of Trissolcus halyomorphae Yang, Journal of Hymenoptera Research. 33, 2013, 113–117. doi:10.3897/jhr.33.5627.

[114] Pfeiffer, D. G., (March 30, 2009). "Brown Marmorated Stink Bug". Fact Sheet. Virginia Tech Department of Entomology. Retrieved February 24, 2011.

[115] Talamas,E.J. Herlihy, M. V.; Dieckhoff, Christine; Hoelmer, Kim A.; Buffington, Matthew; Bon, Marie-Claude; Weber, Donald C. (2015). "Trissolcus japonicus (Ashmead) (Hymenoptera, Scelionidae) emerges in North America". Journal of Hymenoptera Research. 43: 119–128. doi:10.3897/jhr.43.4661. ISSN 1314-2607.

[116] Herlihy M. V., Talamas E. J, Weber D. C., (2016). "Attack and Success of Native and Exotic Parasitoids on Eggs of Halyomorpha halys in Three Maryland Habitats". PLOS ONE. 11 (3): e0150275. Bibcode:2016PLoSO..1150275H. doi:10.1371/journal.pone.0150275. ISSN 1932-6203. PMC 4794195. PMID 26983012.

[117] Milnes, Joshua M.; Wiman, Nik G.; Talamas, Elijah J.; Brunner, Jay F.; Hoelmer, Kim A.; Buffington, Matthew L.; Beers, Elizabeth H. (2016). "Discovery of an Exotic Egg Parasitoid of the Brown Marmorated Stink Bug, Halyomorpha halys (Stål) in the Pacific Northwest". Proceedings of the Entomological Society of Washington. 118 (3): 466–470. doi:10.4289/0013-8797.118.3.466. ISSN 0013-8797. S2CID 89561247.

[118] Szűcs, Marianna; Gut, Larry; Wilson, Julianna; Pote, John (July 24, 2019). "Biological control of brown marmorated stink bug in Michigan". Michigan State University, Department of Entymology. Retrieved December 3, 2019.

[119] Jentsch, Peter (Winter 2017). "Expanding the Range of the Samurai Wasp, Trissolcus japonicus, in New York Orchards" (PDF). Fruit Quarterly. New York State Horticultural Society. 25 (4). Retrieved December 3, 2019.

[120] Jentsch, Peter J. (March 13, 2019). "Citizen Science Efforts for Redistribution of Samurai Wasp in NYS". Cornell University, Department of Entomology, Hudson Valley Laboratory. Retrieved December 3, 2019.

[121] Stahl, Judith; Tortorici, Francesco; Pontini, Marianna; Bon, Marie-Claude; Hoelmer, Kim; Marazzi, Cristina; Tavella, Luciana; Haye, Tim (2018). "First discovery of adventive populations of Trissolcus japonicus in Europe". Journal of Pest Science. 92 (2): 371–379. doi:10.1007/s10340-018-1061- 2. ISSN 1612-4758.

[122] Okuda MS, Yeargan KV (1988) Habitat partitioning by Telenomus podisi and Trissolcus euschisti (Hymenoptera: Scelionidae) between herbaceous and woody host plants. Environ Entomol 17:795–798

[123] Herlihy MV, Talamas EJ, Weber DC (2016) Attack and success of native and exotic parasitoids on eggs of Halyomorpha halys in three Maryland habitats. PLoS ONE 11:e0150275

[124] Johnson N. 1984a. Systematics of Nearctic Telenomus: classification and revisions of the podisi and phymatae groups (Hymenoptera: Scelionidae). Bul-letin of the Ohio Biological Survey 6(3): 1-113.

[125] Johnson N. 1984b. Revision of the Nearctic species of the Trissolcus flavipesgroup (Hymenoptera: Scelionidae). Proceedings of the Entomological Soci-ety of Washington 86: 797- 807.

[126] Johnson N. 1985. Systematics of New World

Trissolcus (Hymenoptera: Scelioni-dae) species related to T. basalis. The Canadian Entomologist 117: 431-445.

[127] Johnson N. 1987a. Systematics of New World Trissolcus, a genus of pentatomidegg-parasites (Hymenoptera: Scelionidae): Neotropical species of the flavi-pes group. Journal of Natural History 21: 285-304.

[128] Johnson N. 1987b. The Neotropical telenomine genus Phanuropsis Girault (Hymenoptera: Scelionidae). Annals of the Entomological Society of America80: 660-663.

[129] Field SA., (1998) Patch exploitation, patch-leaving and pre-emptive patch defence in the parasitoid wasp Trissolcus basalis (Insecta: Scelionidae). Ethology 104:323–338

[130] Cusumano A, Peri E, Amodeo V, McNeil JN, Colazza S (2013)Intraguild interactions between egg parasitoids: window ofopportunity and fitness costs for a facultative hyperparasitoid.PLoS One 8:e64768

[131] Noyes J (2015) Universal Chalcidoidea Database. http://www.nhmacuk/research-curation/projects/chalcidoids/

[132] Japoshvili G. T. Arabuli · M. Salakaia · Z. Tskaruashvili · G. Kirkitadze · E. Talamas.(2021). Surveys for Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) and its biocontrol potential by parasitic wasps in the Republic of Georgia (Sakartvelo). Phytoparasitica, 1-11. https://doi.org/10.1007/s12600-021-00949-1

[133] Kereselidze, M., Aleksidze, G., & Haye, T. (2018). First record native parasitoid attacking Halyomorpha halys (Heteroptera: Pentatomidae) in Georgia. Bulletin. Georgian Academy of Agricultural Science, 39, 127–129.

[134] Haye, T., Fischer, S., Zhang, J., & Gariepy, T. (2015 a). Can native egg parasitoids adopt the invasive brown marmorated stink bug, Halyomorpha halys (Heteroptera: Pentatomidae), in Europe? Journal of Pest Science, 88, 693–705

[135] Hajek, A. E., Solter, L. F., Maddox, J. V., Huang, W.-F., Estep, A. S., Krawczyk, G., Weber, D. C.,Hoelmer, K. A., Sanscrainte, N. D., & Becnel, J. J. (2018). Nosema maddoxi sp. Nov. (microsporidia, Nosematidae), a widespread pathogen of the green stink bug Chinavia hilaris (Say) and the brown marmorated stink bug Halyomorpha halys (Stål). Journal of Eukaryotic Microbiology, 65 (3), 315–330. https://doi.org/10.1111/jeu.12475

[136] Kereselidze, M., Pilarska, D., & Linde, A. (2019). First record of a microsporidium in the population of brown marmorated stink bug Halyomorpha halys (Stål, 1855) (Heteroptera: Pentatomidae) in the Republic of Georgia, cta Zoologica Bulgarica 2019 Vol 71 No. 3 pp. 427-432;

[137] Kereselidze Manana, Pilarska Daniela, Linde Andreas, Sanscrainte Neil D. & Hajek Ann E. (2020): Nosemamaddoxi infecting the brown marmorated Stink bug, Halyomorpha halys (Stål) (Hemiptera: Pentatomidae), in the Republic of Georgia, Biocontrol Science and Technology, DOI: 10.1080/09583157.2020.1787346

[138] Burjanadze M., Jaronski S., Koridze K., Supatashvili A.(2018). Diversity of entomopathogenic fungi from Kintrishi National Area forest ecosystem of Georgia". Invertebrate Pathology and Microbial Control and the 51st Annual Meeting of the Society for Invertebrate Pathology, 12th -16th August, Gold Coast, Australia.

[139] Kuhar, T.P., Kamminga, K. Review of the chemical control research on Halyomorpha halys in the USA. J Pest Sci 90, 1021–1031 (2017). https://doi.org/10.1007/s10340-017-0859-7

[140] Morrison WR III, Lee DH, Short BD, Khrimian A, Leskey TC (2016) Establishing the behavioral basis for an attract-and-kill strategy to manage the invasive Halyomorpha halys in apple orchards. J Pest Sci 89:81–96.

[141] Mathews CR, Blaauw B, Dively G, Kotcon J, Moore J, Ogburn E, Pfeiffer DG, Trope T, Walgenbach JF, Welty C, Zinati G, Nielsen AL (2017) Evaluating a polyculture trap crop for organic management of Halyomorpha halys and native stink bugs in peppers. J Pest Sci. doi:10.1007/s10340-017-0838-z.

[142] Leskey TC, Lee DH, Short BD, Wright S.E. (2012) Impact of insecticides on the invasiveHalyomorpha halys (Hemiptera: Pentatomidae): analysis of insecticide lethality. J Econ Entomol 105:1726–1735. doi:10.1603/EC12096

[143] Blaauw BR, Polk D, Nielsen AL (2015) IPM-CPR for peaches: incorporating behaviorally-based methods to manage Halyomorpha halys and key pests in peach. Pest Manag Sci 71:1513–1522

[144] Nielsen A.L. Shearer P.W. Hamilton G.C. 2008. Toxicity of insecticides to Halyomorpha halys (Hemiptera: Pentatomidae) using glass-vial bioassays. J. Econ. Entomol. 101: 1439–1442.

[145] Lee D.H. Wright S.E. Leskey T.C. 2012. Impact of insecticide residue exposure on the invasive pest, Halyomorpha halys (Hemiptera: Pentatomidae): analysis of adult mobility. J. Econ. Entomol. 106: 150–158.

[146] Kuhar T.P. Doughty H. Kamminga K. Lilliston L. 2012. Evaluation of insecticides using bean dip bioassay for control of brown marmorated stink bug, 2011. Arthropod Manag. Tests. 37doi:10.4182/amt.2012.E41

[147] Kuhar T.P. Doughty H. Kamminga K. Wallingford A. Philips C. Aigner J. 2012a. Evaluation of insecticides for the control of brown marmorated stink bug in bell peppers in Virginia experiment 1, 2011. Arthropod Manag. Tests. 37E37doi:10.4182/amt.2012.E37

[148] Kuhar T.P. Doughty H. Kamminga K. Wallingford A. Philips C. Aigner J. 2012b. Evaluation of insecticides for the control of brown marmorated stink bug in bell peppers in Virginia experiment 2, 2011. Arthropod Manag. Tests. 37E38doi: 10.4182/amt.2012.E38

[149] Kuhar T.P. Doughty H. Kamminga K. Wallingford A. Philips C. Aigner J. 2012c. Evaluation of insecticides for the control of brown marmorated stink bug in bell peppers in Virginia experiment 3, 2011. Arthropod Manag. Tests. 37E39doi:10.4182/amt.2012.E39

[150] Kuhar T.P. Doughty H. Kamminga K. Wallingford A. Philips C. Aigner J. 2012d. Evaluation of insecticides for the control of brown marmorated stink bug in bell peppers in Virginia experiment 4, 2011. Arthropod Manag. Tests. 37E40doi:10.4182/amt.2012.E40

[151] Leskey, T. C., G. C. Hamilton, A. L. Nielsen, D. F. Polk, C. Rodriguez-Saona, J. C. Bergh, D. A. Herbert, T. P. Kuhar, D. Pfeiffer, G. P. Dively, C. R. R. Hooks, M. J. Raupp, P. M. Shrewsbury, G. Krawczyk, P. W. Shearer, J. Whalen, C. Koplinka-Loehr, E. Myers, D. B. Inkley, K. Hoelmer, D. H. Lee, and S. E. Wright. 2012a. Pest status of the brown marmorated stink bug, Halyomorpha halys in the USA. Outlooks Pest Manag. 23: 218-226.

[152] Burjanadze M., Kharabadze N., Arjevanidze M.(2021). Bover-Ge – mycopesticedes for the control Brown marmorated stink bug - Halyomorpha halys (Stål) (Hemiptera: Pentatomidae). Annals of Agrarian Science v.19,3, pp 199-204.