

AperTO - Archivio Istituzionale Open Access dell'Università di Torino

Halyomorpha halys, a serious threat for hazelnut in newly invaded areas

This is the author's manuscript

Original Citation:

Availability:

This version is available <http://hdl.handle.net/2318/1664159> since 2020-04-06T18:49:40Z

Published version:

DOI:10.1007/s10340-017-0937-x

Terms of use:

Open Access

Anyone can freely access the full text of works made available as "Open Access". Works made available under a Creative Commons license can be used according to the terms and conditions of said license. Use of all other works requires consent of the right holder (author or publisher) if not exempted from copyright protection by the applicable law.

(Article begins on next page)

1 ***Halyomorpha halys*, a serious threat for hazelnut in newly invaded areas**

2

3 Lara Bosco, Silvia T. Moraglio, Luciana Tavella

4

5 Dipartimento di Scienze Agrarie, Forestali e Alimentari (DISAFA), ULF Entomologia

6 Generale e Applicata, University of Torino, Largo P. Braccini 2, 10095 Grugliasco (TO), Italy

7

8 Corresponding author: Luciana Tavella

9 Phone +39 011 6708533, fax +39 011 6708535, email luciana.tavella@unito.it

10

11 **Abstract**

12 Following its first detection, *Halyomorpha halys* has become a key pest in many crops in NW
13 Italy. In this area, one of the most important crops is hazelnut, in which the species can cause
14 severe damage through feeding on nuts. Therefore, semi-field trials were carried out in NW
15 Italy to compare the harmfulness of *H. halys* with that of the local hazelnut bug species, such
16 as *Gonocerus acuteangulatus*, *Nezara viridula*, and *Palomena prasina*. Additionally, a 2-year
17 field survey was conducted in hazel groves in NW Italy and W Georgia, another important
18 hazelnut cropping area, to assess the presence and abundance of the new invasive species and
19 to evaluate the damage at harvest. Monitoring was carried out by plant beating and by
20 commercial traps throughout the growing season. In semi-field trials, *H. halys* was the most
21 harmful species, causing the highest damage in kernels, and was able to survive and
22 reproduce at higher rates. During field surveys in NW Italy, *H. halys* was sampled in groves
23 late in the season in 2015 and, with higher populations, throughout the season in 2016. In W
24 Georgia, bug population levels consistently increased in the 2-year period, resulting in a
25 significant increase of damage at harvest in 2016. A similar trend is hence expected also in
26 NW Italy in the following years. Moreover, data on individuals collected in different points of
27 the hazelnut groves confirmed the border-driven behavior of this pest, leading to
28 consideration of potential integrated pest management solutions.

29

30 **Key words:** Brown marmorated stink bug, Semi-field trials, Field surveys, Damage
31 evaluation, NW Italy, W Georgia

32

33 **Key message:**

- 34
 - *Halyomorpha halys* has become a serious pest in NW Italy.

- 35
- In semi-field trials, *H. halys* was more harmful than common hazelnut pest bug
- 36
- species because of greater damage on kernels and maximum survival and reproductive
- 37
- rates.
- 38
- In field surveys, in NW Italy *H. halys* was scarcely found in 2015-2016, whereas in W
- 39
- Georgia its population consistently increased in 2016, resulting in significantly higher
- 40
- damage.
- 41
- A similar trend is hence expected on hazelnut in NW Italy in the following years.
- 42
- 43

44 **Introduction**

45 Different bug species belonging to the families Coreidae and Pentatomidae (Hemiptera:
46 Heteroptera) are responsible for economic damage to hazelnut in the main producing areas of
47 Europe and Turkey (Moraglio et al. 2014; Tuncer et al. 2014; Erper et al. 2016). Adults and
48 nymphs can cause different types of damage in relation to the period when they feed on the
49 nuts: early attacks during nut development, i.e., in May-early June, lead to an increase of seed
50 abortion and early nut drop, while later attacks during kernel growth, i.e., in mid-June-
51 August, determine symptoms on kernels, such as whitish or brownish spots, spongy tissue,
52 and surface depression (Boselli 1932; Tavella et al. 2001a, 2003). Damage on kernels result
53 from an injection of saliva rich of enzymes during feeding, which changes kernel composition
54 (Vaccino et al. 2008; Memoli et al. 2017). Currently, *Gonocerus acuteangulatus* (Goeze)
55 (Hemiptera: Coreidae), *Nezara viridula* (L.), and *Palomena prasina* (L.) (Hemiptera:
56 Pentatomidae) are the primary insect pests of hazelnut in Europe and Turkey (Tuncer et al.
57 2005; Romero et al. 2009; Moraglio et al. 2014).

58 Besides the well-known hazelnut bugs, the recent invasion of the exotic brown marmorated
59 stink bug *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) represents a serious threat to
60 hazelnut in Europe and Turkey, as already observed in North America, where this species has
61 also been producing economic losses in hazelnut crops. In semi-field trials carried out in
62 Oregon, *H. halys* caused damage on different hazelnut cultivars throughout the entire period
63 of nut and kernel development (Hedstrom et al. 2014). Therefore, one purpose of our study
64 was to investigate the potential of *H. halys* to damage the local hazelnut cultivar in Piedmont
65 (NW Italy), in comparison with the main indigenous bug species, such as the most widespread
66 *G. acuteangulatus* and *P. prasina* (Sonnati et al. 2009) and the occasionally found *N. viridula*
67 (authors' personal observation).

68 Since the first report of *H. halys* in Europe more than 10 years ago, the species has recently
69 become an important fruit pest in many agroecosystems (Haye et al. 2015b). In Italy, the
70 second hazelnut-producing country worldwide (data of 2014, FAOSTAT 2017), the exotic
71 pest was first recorded in the Emilia Romagna in 2012 (Maistrello et al. 2013) and in the
72 Piedmont in 2013 (Pansa et al. 2013). In this latter region of NW Italy, where hazelnut is
73 widely cultivated and still increasing, *H. halys* has been causing severe damage and high
74 economic losses in apple, nectarine, pear, and nashi pear (Pansa et al. 2015; Candian et al.
75 unpublished data) as well as in corn (Rancati et al. 2017). By contrast, only a few data are
76 available about the presence and abundance of *H. halys* in Georgia (Gapon 2016), the third
77 hazelnut-producing country worldwide after Turkey and Italy (data of 2014, FAOSTAT

78 2017). Hazelnut is an important traditional nut crop in different Georgian zones, such as the
79 regions Abkhazia, Adjara, Samegrelo, Guria, Imereti, and Kakheti (Mirotadze et al. 2009).
80 Therefore, another purpose of this study was to assess the presence, abundance, and
81 harmfulness of *H. halys* by plant beating, use of traps, and damage evaluation in commercial
82 hazel groves in NW Italy, in the Piedmont region, and in W Georgia, in the Samegrelo region,
83 during 2015-2016.

84 The overall objectives of this study are: (1) comparing the damage caused by different
85 hazelnut bugs, (2) comparing their survival and reproduction on hazelnut under semi-field
86 conditions, (3) assessing the presence and abundance of *H. halys*, and (4) evaluating the
87 damage to hazelnut production due to bug feeding in two important growing regions in Italy
88 and Georgia.

89

90 **Material and method**

91 *Harmfulness of H. halys in comparison with other hazelnut bug species*

92 In 2015, semi-field trials were carried out in a commercial hazel grove untreated with
93 insecticides, located in Magliano Alfieri (province of Cuneo, 44°45'46.50"N, 8° 3'13.56"E,
94 205 m a.s.l.), planted with the local cultivar Tonda Gentile delle Langhe. In the trials, the
95 following four species were tested: the newly introduced *H. halys* and the commonly present
96 *G. acuteangulatus*, *N. viridula*, and *P. prasina*.

97 Insect collection and rearing

98 Starting from April, adults and nymphs of the tested bug species were collected from different
99 wild or cultivated host plants [*Rhamnus cathartica* (L.) (Rhamnaceae), *Cornus sanguinea* L.
100 (Cornaceae), *Crataegus monogyna* Jacq., *Prunus* spp., and *Rosa* spp. (Rosaceae) for *G.*
101 *acuteangulatus* and *P. prasina*, *Sambucus nigra* L. (Caprifoliaceae) for *N. viridula*; peach and
102 pear for *H. halys*]. Field-collected adults and nymphs were then transferred to the laboratory
103 where they were reared in net cages (930 × 475 × 475 mm) (MegaView Science Co., Ltd,
104 Taichung City, Taiwan) containing broad bean seedlings [*Vicia faba* L. (Fabaceae)], fresh
105 fruits, and shelled hazelnuts. Mass rearing was performed in climatic chambers at 24 ± 1°C
106 and RH 65 ± 5%, with an L/D of 16:8 h.

107 Hazel branch caging and insect insertion

108 To prevent insect damage to nuts in early June, 300 hazel branches with at least four clusters
109 of fruits were caged inside sleeve cages of polythene net (730 mm in length, 170 mm in
110 diameter, and 60-mesh grid) [Artes Politecnica, Schio (VI), Italy], supported by an inner
111 cylinder of a plastic net (310 mm in length, 165 mm in diameter). On the tree, each cage was

112 closed with a twist tie proximally at one end around the branch and distally at the other end
113 over the top of the branch.
114 Single specimens of the tested bug species were inserted in the cages on July 3, i.e., when
115 nuts of the cultivar Tonda Gentile delle Langhe have reached the final volume and kernels are
116 in an advanced stage of development (Guidone et al. 2007), enabling the bugs to cause greater
117 damage (Tavella et al. 2001b, 2003). Specifically, 30 males and 30 females of *H. halys*, *G.*
118 *acuteangulatus*, and *N. viridula* and 60 nymphs (fourth- and fifth-instar nymphs) of *P.*
119 *prasina* were individually encaged in 240 cages and left until harvest time, i.e., mid-August.
120 For *P. prasina*, late instars nymphs were used, since adults were not available in the required
121 numbers. Out of 60 remaining cages, 30 cages were discarded since the isolated branches
122 were found dried out or had only few hazelnuts due to the physiological fruit drop, while in
123 the other 30 cages, no insects were inserted to obtain data for undamaged hazelnuts.

124 Damage evaluation at harvest

125 On August 4, just before the harvest time, all the cages were removed and brought to the
126 laboratory, where the nuts contained in each cage were collected separately and stored at 5°C
127 until they were shelled. The kernels were examined to detect any bug damage symptoms (i.e.,
128 alterations evident only on the seed, consisting of whitish or brownish spots, spongy tissue,
129 surface depressions). Damage assessment was done following the procedure generally used
130 by nut processing industries. First, the kernels were separated into two categories: with
131 evident symptoms of bug damage on the surface (external damage) and without any
132 symptoms on the surface. The nuts with the external damage are usually immediately
133 discarded by processing industry. Subsequently, the latter kernels were cut into four parts to
134 detect the presence of possible internal symptoms, not evident on the surface, and separated
135 into two further categories: with internal symptoms of bug damage (internal damage) and
136 healthy. All damaged kernels were further divided into two categories: with spongy and only
137 white tissue (white) or with brown tissue or both white and brown tissues (brown). The brown
138 category in particular affects the commercial quality of kernels in industrial chain processes.
139 Additionally, shriveled and rotten or moldy kernels were also recorded, as well as blank nuts.
140 The cages containing dried-out branches or only blank nuts were discarded.
141 Proportions of damaged kernels in total kernels and of kernel showing external and brown
142 symptoms within damaged kernels in each cage were compared among species via a binomial
143 distribution model with a logit link function, using the general linear model (GLM) procedure
144 of the software IBM SPSS® Statistics 22 (IBM Corp., NY, USA). The two outcomes of each
145 of the three binomial analysis were: (1) damaged versus non-damaged kernels, (2) kernels

146 showing external versus internal damage within all damaged kernels, and (3) kernels showing
147 brown versus white damage within all damaged kernels. Means were then separated at
148 $P < 0.05$ using the Bonferroni test under the GLM procedure.

149 Insect survival in the cages

150 During the trials, the insects were checked weekly for survival. All dead specimens were
151 recorded and replaced with new ones of the same species and sex. After their removal and
152 transfer to the laboratory on August 4, the cages were inspected to check for insect survival
153 and the presence of eggs and nymphs. Percentages of replacement (i.e., the insects introduced
154 to replace the dead ones) were arcsine square-root-transformed and analyzed with one-way
155 ANOVA, using the sex/stage (i.e., male, female, or female with offspring) within the same
156 species as the main factor. Subsequently, when any difference in mortality was found between
157 sex/stage within the species, species was used as the main factor. Means were separated at
158 $P < 0.05$ using Tukey's test. Total numbers of nymphs per each cage containing offspring
159 were analyzed with one-way ANOVA, using species as the main factor. Means were then
160 separated at $P < 0.05$ using Tukey's test. The software IBM SPSS® Statistics 22 (IBM Corp.,
161 NY, USA) was used for all analyses.

162

163 ***Field monitoring of bugs and damage evaluation***

164 To assess the presence and abundance of bug species, a 2-year (2015–2016) field survey was
165 carried out in five commercial hazel groves, of which three were located in NW Italy
166 (Piedmont region) and two in W Georgia (Samegrelo region). In these two regions, both
167 grove size and the agroecosystem were different. In NW Italy, the three groves were
168 integrated in a heterogeneous landscape, composed of various cultivations, such as cherry,
169 peach, and pear orchards, vineyards, vegetable crops. On the borders of these groves, there
170 were wild plants well known as host plants for hazel bugs, such as *C. sanguinea*, *Prunus* spp.,
171 and *Pyrus* spp. In addition, favorite hosts of the bugs, in particular of *G. acuteangulatus* (i.e.,
172 *C. sanguinea*, *R. cathartica*, and *Rosa canina* L.) (Schaefer and Mitchell 1983, Werner 2007,
173 Moraglio et al. 2014), had been planted in four groups in the corners of each orchard in 2014.
174 In W Georgia, the two groves were integrated in a simplified landscape (i.e., a large hazelnut
175 cropping area of about 300 ha), surrounded by other hazelnut groves, and characterized by the
176 presence of wild *Cornus* sp., *Rubus* sp., and *Cryptomeria japonica* (Thunb. ex L.f.) D. Don on
177 some borders. Sites, hazelnut cultivars, pest management, and wild plants grown in the
178 surroundings of the groves are reported in Table 1.

179 Monitoring of bugs by plant beating and traps

180 In the surveyed groves, the presence and abundance of *H. halys* and other bug species were
181 assessed on groups of hazel trees in different positions of the grove, by plant beating, and by
182 using traps.

183 Plant beating consisted of scouting the branches of the selected plants over a white nylon
184 tarpaulin (2.5 × 2.2 m) placed on the ground, collecting and counting all the fallen bugs. It
185 was performed early in the morning (5:00-7:00 am) to prevent adults from flying away. In
186 NW Italy, monitoring by plant beating was carried out on July 10 and 27 in 2015 and on July
187 1, 15, and 29 in 2016. In each grove, the sampling was performed on groups of hazel trees
188 located in the center (one and two groups in 2015 and 2016, respectively) and along the
189 borders (four groups, i.e., one per border). In 2015 and in 2016, each group consisted of three
190 plants (total of 15 plants) and four plants (total of 24 plants), respectively. In W Georgia,
191 monitoring by plant beating was carried out on June 10, July 9, and August 5 in 2015 and on
192 June 15 and 28, July 13 and 27, and August 9 in 2016. Due to the large size of the groves (see
193 Table 1), the sampling was performed on groups of trees located at the following three
194 distances from the border with attractive plants: 5 m (i.e., border area), 100 m, 200 m (i.e.,
195 central area). At each distance, three groups of plants were selected, each consisting of two
196 plants (total of 18 plants) and of four plants (total of 36 plants) in 2015 and 2016,
197 respectively.

198 The presence of *H. halys* was also assessed by using commercially available traps, i.e.
199 Rescue[®] (Sterling International, Inc., Spokane, WA, USA) traps in 2015, and Alpha Scents[®]
200 (Alpha Scents, Inc., West Linn, OR, USA) in 2016. The traps were always baited with Alpha
201 Scents[®] lures [methyl (*E,E,Z*)-2,4,6-decatrienoate, *EEZ*-MDT) and used in both years in NW
202 Italy and only in 2016 in W Georgia. In particular, one trap in NW Italy and two traps in W
203 Georgia were placed along the border of each surveyed grove in mid-June and checked every
204 2 weeks until mid-November.

205 Mean numbers of bugs collected per plant and per survey were compared in each grove
206 between the 2 years; in each region across all groves, the same data were compared on the
207 basis of the position of plants (i.e., on the border or in the center in NW Italy, at different
208 distance from the border in W Georgia). Data were analyzed with a Poisson distribution
209 model with a log link function using the GLM procedure of the software IBM SPSS[®]
210 Statistics 22 (IBM Corp., NY, USA). Means were then separated at $P < 0.05$ using the
211 Bonferroni test under the GLM procedure.

212 Damage evaluation at harvest

213 At harvest time, a sample of 1 kg of hazelnuts was manually collected beneath each surveyed
214 tree at each position in the five groves. In 2015, additional nut samples were collected from a
215 further central group of hazel trees in groves 1 and 2 in NW Italy. In the laboratory, hazelnuts
216 were shelled and 300 intact kernels were randomly chosen from each plant and checked for
217 bug damage as described above. As with numbers of bugs collected per plant, also mean
218 proportions of damaged kernels per plant were compared in each grove between the 2 years
219 and in each region overall the groves on the basis of the position of plants with a binomial
220 distribution model (outcomes: damaged versus non-damaged kernels) with a logit link
221 function using the general linear model (GLM) procedure of the software IBM SPSS®
222 Statistics 22 (IBM Corp., NY, USA). Means were then separated at $P < 0.05$ using the
223 Bonferroni test under the GLM procedure.

224

225 **Results**

226 ***Harmfulness of H. halys in comparison with other hazelnut bug species***

227 The mean percentages of kernels exhibiting symptoms due to bug feeding were significantly
228 higher in the cages with all the tested species than in the control; in particular, the values were
229 significantly higher for *H. halys* (75% of analyzed kernels) in comparison with *N. viridula*
230 (57%), *P. prasina* (39%), and *G. acuteangulatus* (39%) (Table 2). For all the tested species,
231 no significant differences were found by comparing the percentages of kernels damaged by
232 males and females within the species (data not shown). Among damaged kernels, *H. halys*
233 and *G. acuteangulatus* showed significantly higher percentages of external symptoms (81 and
234 78%, respectively) in comparison with the other two species, and *G. acuteangulatus* showed
235 significantly higher percentages of brown tissue (93%) in comparison with the other species.
236 The mean percentages of shriveled kernels were significantly higher for *H. halys* and *N.*
237 *viridula* (20% of analyzed kernels), followed by *P. prasina* (10%) and *G. acuteangulatus*
238 (5%), which did not differ significantly from the control (6%). The highest mean percentages
239 of rotten and/or moldy kernels were observed in the cages with *H. halys* (10% of analyzed
240 kernels); *G. acuteangulatus* (5%) and *N. viridula* (6%) showed values not significantly
241 different, while *P. prasina* (1%) did not differ significantly from the control (2%) (Table 2).
242 Some females of *H. halys* ($n = 24$), *G. acuteangulatus* ($n = 8$), and *N. viridula* ($n = 11$) laid
243 eggs inside the cages, and the offspring could survive and develop (Table 3). Such ovipositing
244 females were mostly alive throughout the trials ($n = 23, 4, 10$ for *H. halys*, *G. acuteangulatus*
245 and *N. viridula*, respectively) or replaced only once in the first survey ($n = 1, 4, 1$ for *H. halys*,
246 *G. acuteangulatus* and *N. viridula*, respectively). For *P. prasina*, since the individuals were

247 caged as late instar nymphs, adults emerging into the cages could not mate, and consequently
248 females could not oviposit. The mean number of nymphs per female was significantly higher
249 for *N. viridula* (32.2) compared to *H. halys* (19.6) and *G. acuteangulatus* (12.3) (Table 3).
250 The mean percentages of replacement were not significantly different in the cages with males,
251 females, and females plus nymphs of the same species for *H. halys* (ANOVA: $P = 0.126$;
252 $F_{2,9} = 2.636$), *G. acuteangulatus* (ANOVA: $P = 0.393$; $F_{2,9} = 1.039$), and *N. viridula*
253 (ANOVA: $P = 0.70$; $F_{2,9} = 3.624$) or with nymphs, females, and males for *P. prasina*
254 (ANOVA: $P = 0.564$; $F_{2,9} = 0.610$) (Table 3). Nevertheless, significant differences were found
255 between the mean replacement percentages of the four species. In particular, the lowest and
256 highest rates of insects replaced during surveys were observed for *H. halys* and for *G.*
257 *acuteangulatus*, respectively (Table 3).

258

259 ***Field monitoring of bugs and damage evaluation***

260 Monitoring of bugs by plant beating and traps

261 In NW Italy, *H. halys* was not found in the samples taken by plant beating in 2015 (0%;
262 $n = 134$), while it represented 3% of total collected bugs in 2016 ($n = 272$). In particular,
263 adults and nymphs of this species were collected in mid- and late July in a group of plants on
264 the border near the attractive plants planted in 2014, in both groves 1 and 3. The other bug
265 species were *G. acuteangulatus*, *N. viridula*, and *P. prasina*, which were sampled by plant
266 beating in variable amounts in the surveyed groves. For all Italian sites, average numbers of
267 bugs per plant were 1.48 ± 0.65 in 2015 and 2.01 ± 1.22 in 2016 (Table 4). By using traps, in
268 2015, specimens of *H. halys* were captured only in grove 3, namely, eight nymphs on
269 September 15 and one adult plus 59 nymphs on October 8. In 2016, higher numbers of
270 specimens were collected in groves 1 and 3 from late August or early September, respectively
271 (Fig. 1). High numbers of insects were trapped during October; the numbers then decreased
272 during early (grove 1) or late November (grove 3) (Fig. 1).

273 In W Georgia, *H. halys* represented 67 and 84% of total sampled bugs in 2015 ($n = 45$) and in
274 2016 ($n = 829$), respectively. Specimens of this species were collected on hazel starting from
275 July 9 in 2015 and from June 15 in 2016. Overall, the 45% of total collected specimens were
276 nymphs ($n = 735$). Average numbers of bugs per plant were 0.46 ± 0.06 in 2015 and
277 2.83 ± 1.43 in 2016 (Table 5). Therefore, there was an evident increase of bugs between the 2
278 years, essentially corresponding to the increase of *H. halys* compared to the other bug species
279 (Table 5). In particular, the following three species were also collected on hazelnut in W
280 Georgia: *G. acuteangulatus* (17 and 2% of total bugs in 2015 and 2016, respectively), *N.*

281 *viridula* (7 and 12% of total bugs in 2015 and 2016, respectively), and *P. prasina* (7 and 1%
282 of total bugs in 2015 and 2016, respectively). By traps (placed only in 2016), the first
283 specimens of *H. halys* were captured in late June (grove 4) and in mid-July (grove 5) (Fig. 1).
284 Then, in grove 4, the captures suddenly increased between late July and early September;
285 afterward, they started to decrease. In grove 5, the highest mean values of insects were
286 recorded in early September, while in the previous dates, on average 11.5 bugs per trap were
287 captured (Fig. 1).

288 Population levels were variable in relation to the plant position in the orchards. In NW Italy,
289 the mean numbers of bugs per plant were significantly higher in the groups of plants on the
290 borders than in the center of the surveyed hazel groves, in both 2015 and 2016 (Table 4). In
291 W Georgia, a marked gradient of population levels was observed, starting from the border
292 towards the center of the orchards, especially in 2016, when the mean values were
293 significantly higher than in 2015 (Table 5).

294 Damage evaluation at harvest

295 In NW Italy, the percentages of kernels exhibiting symptoms due to bug feeding in the three
296 hazel groves surveyed in both years ranged, on average, between 7.8 and 19.4% (Table 4).
297 Consistent with the results of bugs sampled by plant beating, the kernels collected from the
298 groups of plants located in the center of the orchard were significantly less damaged than
299 those collected along the borders (Table 4).

300 In W Georgia, the mean percentages of kernels showing symptoms of damage caused by bugs
301 increased strongly from 2015 to 2016, from 4.3 to 51.3% in grove 4 and from 1.4 to 26.6% in
302 grove 5 (Table 5). In 2016, the highest percentages of damage were recorded in kernels
303 collected from the groups of plants along the border, and a marked gradient from the border
304 toward the center of the orchard was evident (Table 5).

305

306 **Discussion and Conclusions**

307 In the semi-field trials, the symptoms on kernels resulting from *H. halys* feeding were similar
308 to those caused by the other tested species as well as to those observed in similar trials
309 performed on local cultivars in Oregon (Hedstrom et al. 2014). Nevertheless, in our trials, the
310 newly introduced species was the most harmful one in comparison with the common hazelnut
311 bugs. Among the categories of symptoms (i.e., external or internal damage, white or brown
312 tissues), we defined within damaged kernels, *H. halys* caused mainly external damage,
313 together with *G. acuteangulatus*, and brown tissue symptoms, and such categories particularly
314 affect the commercial quality of kernels, especially in nuts used in processed foods. In the

315 cages with *H. halys* and with *N. viridula*, the highest percentages of shriveled hazelnuts were
316 also found, probably due to feeding during kernel expansion (Hedstrom et al. 2014).

317 Additionally, in the cages with *H. halys*, the highest percentages of moldy and/or rotten
318 hazelnuts were recorded; hence, an indirect damage due to secondary pathogenic infections
319 through the punctures on kernels and/or to transmission with the feeding stylets cannot be
320 excluded (Rice et al. 2014). The role played by *H. halys* on this indirect damage needs to be
321 further investigated, as well as its contribution to the increase of blank nuts when it feeds on
322 hazelnuts before shell and kernel expansion (Hedstrom et al. 2014). In our trials, blank nuts
323 were not considered, since bugs fed on hazelnuts from kernel expansion to the harvest,
324 therefore resulting in kernel malformations and/or spongy or corky symptoms.

325 In NW Italy, from its first report in 2013, *H. halys* has significantly spread, becoming
326 worrisome, and caused economic losses in stone and pome fruits as well as cereals (Pansa et
327 al. 2013, 2015; Rancati et al. 2017), whereas it was rarely observed on hazelnut until 2015.
328 During field surveys in 2015, few adults and nymphs were sampled in the groves, while their
329 numbers increased in 2016; however, the damage at harvest was similar in the 2 years and
330 probably caused by the other bug species. The augmentation of infestations on hazelnut in the
331 following growing seasons is expected, as suggested by the outbreaks of *H. halys* already
332 observed in the early 2017 growing season (personal observation).

333 In W Georgia, *H. halys* was first observed in the hazelnut groves in 2015, and the proportion
334 of the field-collected specimens (69% of total sampled hazel bugs) was by far greater than
335 that observed in NW Italy. However, during the 2016 season, populations were significantly
336 higher than in the previous season, which is consistent with the first outbreaks of the exotic
337 species recorded in Georgia in the same year (Gapon 2016). In fact, in our study, the first
338 serious damage on hazelnut was reported in 2016, with mean percentages of damaged kernels
339 of 51 and 27% in 2016 versus 4 and 1% in 2015, in groves 4 and 5, respectively.

340 The high percentages of nymphs found through plant beating indicate that hazelnut can serve
341 both as feeding and reproductive host for *H. halys*, while on other host plants, only or mostly
342 adults are observed (Acebes-Doria et al. 2016; Zobel et al. 2016). In addition, *H. halys*
343 showed the highest percentages of survivors as well as of females laying eggs in the cages,
344 further suggesting the suitability of hazelnut as a host plant.

345 Across all field surveys, irrespective of the grove, region, and year, the highest numbers of
346 bugs per plant, and also of *H. halys*, were collected in the groups of plants along the borders
347 of the orchards compared to those in the center. Even considering the high heterogeneity of
348 the two areas, this result confirms that the invading population of *H. halys* establishes on wild

349 or cultivated host plants grown in the surroundings and migrates into the hazel crop area
350 throughout the season, as already reported for other crops (Leskey et al. 2012; Rice et al.
351 2014). This perimeter-driven behavior could be exploited by using perimeter applications of
352 insecticides to control *H. halys* in the borders, as suggested for other fruit crops (Blaauw et al.
353 2015). To increase efficiency, the perimeter treatment could be coupled with the use of
354 attractive plants (e.g., grown on the borders of the grove not used for vehicle movement) to
355 manage the pest populations outside the crop (Mathews et al. 2017; Nielsen et al. 2016;
356 Soergel et al. 2015).

357 Commercially available traps and lures can be useful tools for monitoring and detection,
358 decision making, and management strategies. In our study captures varied substantially
359 among sites during the sampling period, but generally peaked in the late season (mid-August
360 to early October), consistently with other studies carried out using commercially available
361 lures (combination of aggregation pheromone *EEZ*-MDT) (Weber et al. 2017). Only in one
362 orchard in W Georgia, earlier captures we recorded from mid-June come from overwintering
363 populations. Differences in the captures may reflect the size of the overwintering population
364 in the general vicinity of the traps (Bergh et al. 2017), but earlier peaks are also typical of
365 higher population years (Weber et al. 2017), as well as affected by lure composition. Both
366 these factors can be at the base of the significant increase in 2017 of early captures by traps on
367 hazelnut in both NW Italy and W Georgia (personal observation). Therefore, the traps can
368 also be used in hazelnut crops to develop and apply thresholds to trigger management
369 decisions which ultimately reduce insecticide usage.

370 Broad-spectrum insecticides can provide an effective control of *H. halys*, but only if they are
371 applied directly on the insects (Kuhar and Kamminga 2017; Leskey et al. 2012; Rice et al.
372 2014). Therefore, multiple applications are needed for bug control throughout the season,
373 nullifying the integrated pest management programs largely adopted in NW Italy. Moreover,
374 due to the scarcity of active ingredients authorized on hazelnut crops in Italy, the repeated
375 application of insecticides such as pyrethroids would be particularly detrimental for secondary
376 pest outbreaks (e.g., spider mites, aphids, mealybugs) and for the community of beneficial
377 species (AliNiazee, 1998). Additionally, in some areas (e.g., in Georgia and Turkey), few
378 local farms are equipped for the application of pesticides at the level required for a successful
379 management of *H. halys*. Moreover, chemical treatments are not always feasible due to
380 several factors such as strongly sloping land, non-rational management of plantations (e.g.
381 irregular tree spacing, high number of branches per plant, uncontrolled growth of suckers),
382 and excessive tree height and canopy density.

383 In a perspective of reduction or avoidance of chemicals and preservation of a relatively stable
384 agroecosystem, such as the hazelnut orchard, alternative pest management strategies should
385 be further developed and tailored for the peculiar characteristics of the considered hazel
386 groves (geographical area, size of the orchards, surroundings, agroecosystem traits, etc.). As
387 observed in apple orchards (Morrison et al. 2016), the attract-and-kill strategy, using a few
388 trees intensively baited with pheromone and sprayed on a weekly basis with insecticides
389 efficacious against *H. halys*, could reduce the area treated with an insecticide. This strategy
390 should be evaluated also for hazelnut, even if it is currently not cost effective due to the high
391 costs of the intensive usage of lures (Weber et al. 2017). Moreover, as a long-term solution,
392 biological control with the natural enemy complex of *H. halys*, native or introduced, could
393 play a role in managing this pest, especially in organic farming systems. In particular,
394 hymenopteran egg parasitoids within the genera *Anastatus* (Eupelmidae), *Ooencyrtus*
395 (Encyrtidae), *Trissolcus*, and *Telenomus* (Scelionidae) are under evaluation for *H. halys*
396 control (Dieckhoff et al. 2017; Haye et al. 2015a; Herlihy et al. 2016; Ogburn et al. 2016).
397

398 **Author Contribution**

399 LT conceived and designed the research. LB and STM conducted the experiments, analyzed
400 the data, and wrote the manuscript. All authors read and approved the final manuscript.

401

402 **Acknowledgements**

403 We thank Giuseppe Castello (Soremartec Italia), Andrea Castagna, and the entire AgriGeorgia
404 team for technical support and help with field work in W Georgia. This research was funded
405 by Soremartec Italia (Ferrero Group).

406

407 **Compliance with ethical standards**

408 **Conflict of Interest** The authors declare that they have no conflict of interest.

409

410

411 **Tables and Figures**

412

413 **Table 1** Localization and characteristics of the five hazel groves surveyed in NW Italy

414 (Piedmont) and W Georgia (Samegrelo) during 2015 and 2016

Hazel grove	Location	Cultivar/ pest management	Size (m ²)	Bordering host plants
1	Italy, Piedmont, Asti (44°54'35.59"N, 8°15'43.26"E; 129 m a.s.l.)	TGdL ^a / organic	4950	<i>Cornus sanguinea</i>
2	Italy, Piedmont, Cossano Belbo (CN) (44°38'27.53"N, 8°11'54.06"E; 460 m a.s.l.)	TGdL/ conventional	5527	<i>Prunus avium</i> <i>Prunus persica</i> <i>Pyrus malus</i>
3	Italy, Piedmont, Magliano Alfieri (AT) (44°45'46.50"N, 8° 3'13.56"E; 205 m a.s.l.)	TGdL/ no insecticide treatments	3200	<i>Cornus sanguinea</i>
4	Georgia, Samegrelo, Chitatskari (42°27'18.21"N, 41°52'18.68"E; 60 m a.s.l.)	Tonda di Giffoni/ conventional	71200	<i>Cornus</i> sp. <i>Rubus</i> sp. <i>Cryptomeria japonica</i>
5	Georgia, Samegrelo, Chitatskari (42°26'50.0"N, 41°51'52.41"E; 60 m a.s.l.)	Anakliuri/ conventional	183200	<i>Cornus</i> sp. <i>Rubus</i> sp. <i>Cryptomeria japonica</i>

415 ^a: Tonda Gentile delle Langhe cultivar

416

417 **Table 2** Mean percentages (\pm SE) of kernels damaged by bugs, shriveled, and moldy per cage in the presence of the tested bug species and in the
 418 absence of insects (control)

Species	No. of cages ^a	No. of nuts ^b	% Of total damaged kernels ^c	% On total damaged kernels ^d		% Of other defects	
				External	Brown	Shriveled	Moldy/rotten
<i>Halyomorpha halys</i>	54	532	74.82 \pm 4.14 a	80.53 \pm 3.24 a	87.69 \pm 2.24 b	19.60 \pm 3.06 a	10.22 \pm 2.44 a
<i>Gonocerus acuteangulatus</i>	53	580	39.07 \pm 4.49 c	78.02 \pm 4.28 a	92.59 \pm 3.42 a	5.08 \pm 1.80 c	5.50 \pm 1.39 ab
<i>Nezara viridula</i>	58	579	57.03 \pm 4.31 b	61.67 \pm 4.21 b	80.39 \pm 3.43 b	19.73 \pm 3.96 a	6.03 \pm 1.71 b
<i>Palomena prasina</i>	59	568	39.49 \pm 3.94 c	56.79 \pm 5.01 b	84.72 \pm 3.91 b	10.26 \pm 2.75 b	0.75 \pm 0.33 c
Control	30	295	0.00 \pm 0.00 d	-	-	5.91 \pm 3.68 c	1.56 \pm 1.23 c
GLM	Wald χ^2		81708.480	72.323	18.988	69.459	38.313
	<i>df</i>		3	3	3	4	4
	<i>P</i>		<0.001	<0.001	<0.001	<0.001	<0.001

419 In each column, values followed by the same letter are not significantly different (Bonferroni test, $P < 0.05$, under GLM procedure with binomial
 420 distribution and logit link)

421 ^aTotal number of cages (excluding cages containing only blank nuts)

422 ^bTotal number of analyzed kernels

423 ^c% Of total damaged kernels on total number of analyzed kernels.

424 ^d% Of kernels showing external (versus internal) and brown (versus white) symptoms on total damaged kernels

425 **Table 3** Numbers of cages with females, females plus nymphs (i.e., females laying eggs in the
 426 cages), males, and nymphs of the tested bug species: mean numbers (\pm SE) per female of
 427 nymphs developed in the cages (offspring): percentages of the specimens replaced during
 428 weekly surveys (% of replacement, mean \pm SE per survey) and of the specimens alive
 429 throughout the trials, therefore never replaced (% of survival), in 2015

Species	Stage/sex	No.	Offspring (mean per cage)	% Of replacement	% Of survival
<i>Halyomorpha</i>	females + nymphs	24	19.58\pm1.62 b	1.04 \pm 0.01	95.83
<i>halys</i>	females	7		14.29 \pm 0.06	42.86
	males	29		5.17 \pm 0.03	75.86
	total	60		4.58\pm0.02 a	80.00
<i>Gonocerus</i>	females + nymphs	8	12.25\pm3.73 b	15.63 \pm 0.06	50.00
<i>acuteangulatus</i>	females	24		26.04 \pm 0.06	41.67
	males	26		17.31 \pm 0.03	65.38
	total	58		20.69\pm0.04 b	53.45
<i>Nezara viridula</i>	females + nymphs	11	32.18\pm5.20 a	4.55 \pm 0.03	81.82
	females	19		10.27 \pm 0.03	62.50
	males	29		15.52 \pm 0.04	55.17
	total	59		11.83\pm0.03 ab	62.50
<i>Palomena</i>	nymphs	5		12.50 \pm 0.13	50.00
<i>prasina</i>	nymphs (emerg. female)	29		6.29 \pm 0.04	77.78
	nymphs (emerg. male)	27		13.89 \pm 0.04	55.56
	total	61		10.06\pm0.03 ab	65.52
ANOVA	<i>F</i>		7.797	4.199	
	<i>df</i>		2; 40	3; 12	
	<i>P</i>		0.001	0.030	

430 In each column, values in bold followed by the same letter are not significantly different
 431 (Tukey's test, $P < 0.05$)

432

433

434 **Table 4** Mean numbers (\pm SE) of hazel bugs total collected per plant and per date and mean percentages (\pm SE) of damaged kernels per plant
 435 ($n = 300$) in each grove, on the borders, and in the center across all three hazel groves surveyed in NW Italy (Piedmont) during 2015 and 2016

Grove/ position	Mean n. of bugs per plant per date (% of <i>H. halys</i>)		GLM			Mean % of damaged kernels per plant		GLM		
	2015	2016	Wald χ^2	df	P	2015	2016	Wald χ^2	df	P
<i>Grove</i>										
1	2.77 \pm 0.96	1.04 \pm 0.23 (5.33%)	37.596	1	<0.001	19.42 \pm 2.76	19.44 \pm 2.55	0.002	1	0.966
2	0.70 \pm 0.24	0.47 \pm 0.11	2.011	1	0.156	7.82 \pm 1.13	16.47 \pm 2.60	242.383	1	<0.001
3	0.97 \pm 0.26	4.53 \pm 0.98	58.702	1	<0.001	13.98 \pm 1.18	14.58 \pm 1.58	0.664	1	0.415
<i>Position</i>										
Border	1.78 \pm 0.43	2.03 \pm 0.36				6.51 \pm 0.74	5.66 \pm 0.61			
Centre	0.28 \pm 0.14	0.47 \pm 0.11				2.60 \pm 0.30	3.07 \pm 0.58			
GLM										
Wald χ^2	16.581	54.411				368.105	314.177			
df	1	1				1	1			
P	<0.001	<0.001				<0.001	<0.001			

436 GLM procedure was performed with Poisson distribution and log link for number of bugs, with binomial distribution and logit link for
 437 percentage of damaged kernels

438
 439

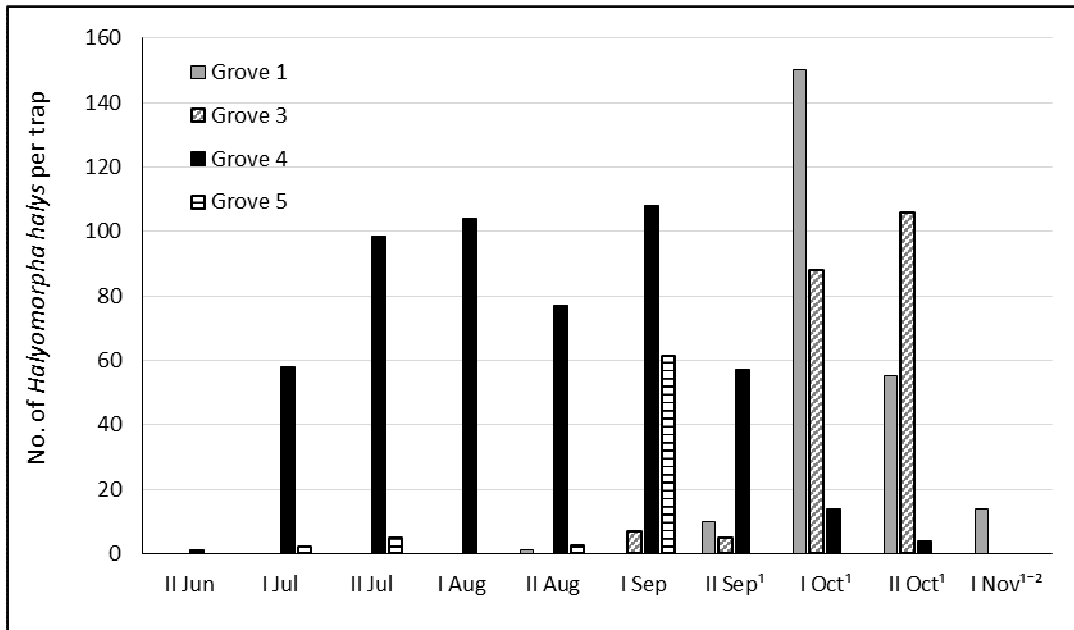
440 **Table 5** Mean numbers (\pm SE) of hazel bugs total collected per plant and per date and percentages (\pm SE) of damaged kernels by bugs per plant,
 441 in each grove, and overall in the different groups of plants in the two hazel groves surveyed in W Georgia (Samegrelo) during 2015 and 2016

Grove/ Position ^a	No. bugs per plant per date (% of <i>H. halys</i>)		GLM			% Of damaged kernels		GLM		
	2015	2016	Wald χ^2	<i>df</i>	<i>P</i>	2015	2016	Wald χ^2	<i>df</i>	<i>P</i>
<i>Grove</i>										
4	0.46 \pm 0.16 (68.42%)	1.44 \pm 0.38 (89.27%)	11.963	1	<0.001	1.43 \pm 0.17	26.63 \pm 2.36	1301.845	1	<0.001
5	0.46 \pm 0.19 (65.38%)	4.22 \pm 2.10 (82.53%)	50.578	1	0.001	4.25 \pm 0.51	51.31 \pm 2.84	3338.852	1	<0.001
<i>Position</i>										
5 m	0.89 \pm 0.23	6.50 \pm 3.06 a				3.58 \pm 0.77 a	55.78 \pm 3.49 a			
100 m	0.83 \pm 0.23	1.63 \pm 0.59 b				2.39 \pm 0.30 b	33.28 \pm 4.10 b			
200 m	0.00 \pm 0.00	0.38 \pm 0.15 c				3.00 \pm 0.82 ab	27.85 \pm 1.71 c			
GLM										
Wald χ^2	1.445	117.020				17.070	972.285			
<i>df</i>	1	2				2	2			
<i>P</i>	0.229	<0.001				<0.001	<0.001			

442 In each column, values per position followed by the same letter are not significantly different (Bonferroni test, $P < 0.05$, under GLM procedure).

443 GLM procedure was performed with Poisson distribution and log link for number of bugs, with binomial distribution and logit link for

444 percentage of damaged kernels



446

447 **Fig. 1** Numbers of adults of *Halyomorpha halys* captured per pheromone trap in the hazel
 448 groves 1 and 3 in NW Italy (Piedmont) and 4 and 5 in W Georgia (Samegrelo) during 2016. In
 449 the x-axis, the Roman numerals I and II referred to the first and the second half of the month,
 450 respectively. ¹Missing data for grove 5; ²missing data for grove 4

451

452 **References**

- 453 Acebes-Doria AL, Leskey TC, Bergh JC (2016) Host plant effects on *Halyomorpha halys*
454 (Hemiptera: Pentatomidae) nymphal development and survivorship. *Environ Entomol*
455 45(3):663-670
- 456 AliNiazee MT (1998) Ecology and management of hazelnut pests. *Annu Rev Entomol*
457 43(1):395-419
- 458 Bergh JC, Morrison WR III, Joseph SV, Leskey TC (2017) Characterizing spring emergence
459 of adult *Halyomorpha halys* using experimental overwintering shelters and commercial
460 pheromone traps. *Entomol Exp Appl* 162:336–345
- 461 Blaauw BR, Polk D, Nielsen AL (2015) IPM-CPR for peaches: incorporating
462 behaviorally-based methods to manage *Halyomorpha halys* and key pests in peach. *Pest*
463 *Manag Sci* 71(11):1513-1522
- 464 Boselli FB (1932) Studio biologico degli Emitteri che attaccano le nocciuole in Sicilia.
465 *Bollettino del Laboratorio di Zoologia Generale e Agraria di Portici* 26:1–309
- 466 Dieckhoff C, Tatman KM, Hoelmer KA (2017) Natural biological control of *Halyomorpha*
467 *halys* by native egg parasitoids: a multi-year survey in northern Delaware. *J Pest Sci*
468 Special Issue: The brown marmorated stink bug *Halyomorpha halys* an emerging pest of
469 global concern. *J Pest Sci* 90(4):1143-1158
- 470 Erper İ, Saruhan İ, Akca İ, Aksoy HM, Tuncer C (2016) Evaluation of some
471 entomopathogenic fungi for controlling the green shield bug, *Palomena prasina* L.
472 (Heteroptera: Pentatomidae). *Egypt J Biol Pest Co* 26(3):573
- 473 FAOSTAT database: <http://www.fao.org/faostat/en/#data/QC>. Accessed 20 Jan 2017.
- 474 Gapon DA (2016) First records of the brown marmorated stink bug *Halyomorpha halys* (Stål,
475 1855) (Heteroptera, Pentatomidae) in Russia, Abkhazia, and Georgia. *Entomol Rev*
476 96:1086–1088
- 477 Guidone L, Valentini N, Rolle L, Me G, Tavella L (2007) Early nut development as a
478 resistance factor to the attacks of *Curculio nucum* (Coleoptera: Curculionidae). *Ann Appl*
479 *Biol* 150(3):323-329
- 480 Haye T, Fischer S, Zhang J, Garipey T (2015a) Can native egg parasitoids adopt the invasive
481 brown marmorated stink bug, *Halyomorpha halys* (Heteroptera: Pentatomidae), in Europe?
482 *J Pest Sci* 88(4):693-705
- 483 Haye T, Garipey T, Hoelmer K, Rossi JP, Streito JC, Tassus X, Desneux N (2015b) Range
484 expansion of the invasive brown marmorated stinkbug, *Halyomorpha halys*: an increasing
485 threat to field, fruit and vegetable crops worldwide. *J Pest Sci* 88(4):665-673

486 Hedstrom CS, Shearer PW, Miller JC, Walton VM (2014) The effects of kernel feeding by
487 *Halyomorpha halys* (Hemiptera: Pentatomidae) on commercial hazelnuts. J Econ Entomol
488 107(5):1858-1865

489 Herlihy MV, Talamas EJ, Weber DC (2016) Attack and success of native and exotic
490 parasitoids on eggs of *Halyomorpha halys* in three Maryland habitats. PLoS ONE
491 11(3):e0150275. <https://doi.org/10.1371/journal.pone.0150275>

492 Kuhar TP, Kamminga K (2017) Review of the chemical control research on *Halyomorpha*
493 *halys* in the USA. J Pest Sci Special Issue: The brown marmorated stink bug *Halyomorpha*
494 *halys* an emerging pest of global concern. J Pest Sci 90(4):1021-1031

495 Leskey TC, Short BD, Butler BR, Wright SE (2012) Impact of the invasive brown
496 marmorated stink bug, *Halyomorpha halys* (Stål), in mid-Atlantic tree fruit orchards in the
497 United States: case studies of commercial management. Psyche 2012:1-14.
498 <https://doi.org/10.1155/2012/535062>

499 Maistrello L, Dioli P, Bariselli M (2013) Trovata una cimice esotica dannosa per i frutteti
500 Agricoltura, 67-68 [http://agricoltura.regione.emilia-](http://agricoltura.regione.emilia-romagna.it/fitosanitario/doc/pubblicazioni/articoli/trovata-una-cimice-esotica-dannosa-per-i-frutteti/at_download/file/Agricoltura_6_2013-067-068.pdf)
501 [romagna.it/fitosanitario/doc/pubblicazioni/articoli/trovata-una-cimice-esotica-dannosa-per-](http://agricoltura.regione.emilia-romagna.it/fitosanitario/doc/pubblicazioni/articoli/trovata-una-cimice-esotica-dannosa-per-i-frutteti/at_download/file/Agricoltura_6_2013-067-068.pdf)
502 [i-frutteti/at_download/file/Agricoltura_6_2013-067-068.pdf](http://agricoltura.regione.emilia-romagna.it/fitosanitario/doc/pubblicazioni/articoli/trovata-una-cimice-esotica-dannosa-per-i-frutteti/at_download/file/Agricoltura_6_2013-067-068.pdf). Accessed 25 Jan 2017

503 Mathews CR, Blaauw B, Dively G, Kotcon J, Moore J, Ogburn E, Pfeiffer DG, Trope T,
504 Walgenbach JF, Welty C, Zinati G, Nielsen AL (2017) Evaluating a polyculture trap crop
505 for organic management of *Halyomorpha halys* and native stink bugs in pepper. J Pest Sci
506 Special Issue: The brown marmorated stink bug *Halyomorpha halys* an emerging pest of
507 global concern. J Pest Sci 90(4):1245-1255

508 Memoli A, Albanese D, Esti M, Lombardelli C, Crescitelli A, Di Matteo M, Benucci I (2017)
509 Effect of bug damage and mold contamination on fatty acids and sterols of hazelnut oil.
510 Eur Food Res Technol 243(4):651-658

511 Mirotadze N, Gogitidze V, Mikadze N, Goginava L, Mirotadze M (2009) Agro-ecological
512 zones of hazelnut in Georgia. Acta Hort 845:291-294

513 Moraglio ST, Ingegno BL, Tavella L (2014) Studies on semiochemicals produced by
514 *Gonocerus acteangulatus* for their use as control methods in hazelnut orchards. Acta
515 Hort 1052:281-287

516 Morrison III WR, Lee DH, Short BD, Khrimian A, Leskey TC (2016) Establishing the
517 behavioral basis for an attract-and-kill strategy to manage the invasive *Halyomorpha halys*
518 in apple orchards. J Pest Sci 89(1):81-96

519 Nielsen AL, Dively G, Pote JM, Zinati G, Mathews C (2016) Identifying a potential trap crop
520 for a novel insect pest, *Halyomorpha halys* (Hemiptera: Pentatomidae), in organic farms.
521 Environ Entomol 45(2):472-478

522 Ogburn EC, Bessin R, Dieckhoff C, Dobson R, Grieshop M, Hoelmer KA, et al. (2016)
523 Natural enemy impact on eggs of the invasive brown marmorated stink bug, *Halyomorpha*
524 *halys* (Stål) (Hemiptera: Pentatomidae), in organic agroecosystems: a regional assessment.
525 Biol Control 101:39-51

526 Pansa MG, Asteggiano L, Costamagna C, Vittone G, Tavella L (2013) Primo ritrovamento di
527 *Halyomorpha halys* nei pescheti piemontesi. Inftore Agrario 69(37):60-61

528 Pansa MG, Pizzinat A, Bardella S, Vittone L, Tavella L (2015) *Halyomorpha halys* in
529 Piemonte, prime risposte dal monitoraggio. Inftore Agrario 71(21):48-49

530 Rancati M, Pansa MG, Ghiglione M, Tavella L (2017) Danni da cimice asiatica su mais di
531 secondo raccolto. Inftore Agrario 73(14):1-3

532 Rice KB, Bergh CJ, Bergmann EJ, Biddinger DJ, Dieckhoff C, Dively G, Fraser H, Gariepy
533 T, Hamilton G, Haye T Herbert A, Hoelmer K, Hooks CR (2014) Biology, ecology, and
534 management of brown marmorated stink bug (Hemiptera: Pentatomidae). J Integr Pest
535 Manag 5(4):A1-A13

536 Romero A, Tous J, Martí E (2009) White spots in hazelnut kernel: symptoms, causes and
537 quality loss. Acta Hort 845:607-612

538 Schaefer CW, Mitchell PL (1983) Food plants of the Coreoidea (Hemiptera: Heteroptera).
539 Ann Entomol Soc Am 76:591–615

540 Soergel DC, Ostiguy N, Fleischer SJ, Troyer RR, Rajotte EG, Krawczyk G (2015) Sunflower
541 as a potential trap crop of *Halyomorpha halys* (Hemiptera: Pentatomidae) in pepper fields.
542 Environ Entomol 44(6):1581-1589

543 Sonnati C, Molinari F, Ughini V (2009) Seven years of observation of the presence of
544 different plant bug species in the hazelnut orchards of cultivar 'Tonda Gentile delle Langhe'
545 in Piedmont. Acta Hort 845:543-548

546 Tavella L, Sonnati C, Arzone A, (2001a) Sampling of Coreidae and Pentatomidae
547 (Heteroptera) in hazelnut orchards in Piemonte, northwestern Italy. Informatore
548 Fitopatologico 51(3): 55–59

549 Tavella L, Arzone A, Miaja ML, Sonnati C (2001b) Influence of bug (Heteroptera, Coreidae
550 and Pentatomidae) feeding activity on hazelnut in northwestern Italy. Acta Hort 556:
551 461-468

- 552 Tavella L, Migliardi M, Sonnati C, Miaja ML (2003) Effects of the trophic activity of bugs
553 (Heteroptera Coreidae and Pentatomidae) on hazelnuts referring to the feeding period.
554 Informatore Fitopatologico 53(11): 47–51
- 555 Tuncer C, Saruhan İ, Akça İ (2005) The insect pest problem affecting hazelnut kernel quality
556 in Turkey. Acta Hortic 686: 367-376
- 557 Tuncer C, Saruhan İ, Akça İ (2014) Seasonal occurrence and species composition of true bugs
558 in hazelnut orchards. Acta Hortic 1052:263-268
- 559 Vaccino P, Guidone L, Corbellini M, Tavella L (2008) Detection of damage due to bug
560 feeding on hazelnut and wheat by biochemical techniques. Bull Insectology 61(1):189-190
- 561 Weber DC, Morrison III WR, Khrimian A, Rice KB, Leskey TC, Rodriguez-Saona C, Nielsen
562 AL, Blaauw BR (2017) Chemical ecology of *Halyomorpha halys*: discoveries and
563 applications. J Pest Sci Special Issue: The brown marmorated stink bug *Halyomorpha*
564 *halys* an emerging pest of global concern. J Pest Sci 90(4):989-1008
- 565 Werner DJ (2007) Die Verbreitung der Braunen Randwanze *Gonocerus acuteangulatus*
566 (Goeze, 1778) (Heteroptera: Coreidae) in Deutschland mit Angaben zu ihrer Biologie.
567 Mainzer Naturwissenschaftliches Archiv/Beiheft 31:153-180
- 568 Zobel ES, Hooks CRR, Dively GP (2016) Seasonal abundance, host suitability, and feeding
569 injury of the brown marmorated stink bug, *Halyomorpha halys* (Heteroptera:
570 Pentatomidae), in selected vegetables. J Econ Entomol 109(3):1289-1302