






Review

Life History Traits of the Pentatomidae (Hemiptera) for the Development of Pest Management Tools

Elisa Pal ^{1,2,*} , Jeremy D. Allison ^{1,2,3} , Brett P. Hurley ^{1,2} , Bernard Slippers ^{2,4}  and Gerda Fourie ^{2,4} 

¹ Department of Zoology and Entomology, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Pretoria 0002, South Africa; jeremy.allison@canada.ca (J.D.A.); brett.hurley@fabi.up.ac.za (B.P.H.)

² African Centre of Chemical Ecology, Innovation Africa Campus, University of Pretoria, Pretoria 0002, South Africa; bernard.slippers@fabi.up.ac.za (B.S.); gerda1.fourie@fabi.up.ac.za (G.F.)

³ Natural Resources Canada-Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON P6A 2E5, Canada

⁴ Department of Biochemistry, Genetics and Microbiology, Forestry and Agricultural Biotechnology Institute (FABI), University of Pretoria, Pretoria 0002, South Africa

* Correspondence: elisa.pal@fabi.up.ac.za; Tel.: +27-62-349-7125

Abstract: Knowledge of the biology of a pest is essential for building sustainable management programmes. Pentatomidae have a hemimetabolous life cycle with egg, nymphal, and adult life stages, which differ in morphological, ecological, and behavioural traits. Some of these traits, such as mating behaviour, pheromones (alarm and aggregation pheromones) and the acquisition of gut symbionts can be targeted for pest management strategies. Here, we review the available literature on these life history traits of the Pentatomidae with potential for use in management programmes. Pheromone-mediated aggregation and the disruption of symbiont acquisition are two important targets for Pentatomidae control. Other traits such as the use of alarm pheromones for enhancing natural enemies and substrate-borne vibration for mating disruption deserve further consideration. Colour vision and flight ability are still poorly studied, despite their potential importance for stink bug management.

Keywords: stink bugs; behaviour; pheromones; symbionts; IPM



Citation: Pal, E.; Allison, J.D.; Hurley, B.P.; Slippers, B.; Fourie, G. Life History Traits of the Pentatomidae (Hemiptera) for the Development of Pest Management Tools. *Forests* **2023**, *14*, 861. <https://doi.org/10.3390/f14050861>

Academic Editor: Young-Seuk Park

Received: 17 March 2023

Revised: 20 April 2023

Accepted: 20 April 2023

Published: 22 April 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

Pentatomidae, commonly known as shield or stink bugs, is the largest family in the Pentatomoidea, which is known to contain a considerable number of economically important pest species [1–3]. Divided into eight subfamilies, the Pentatomidae represents the third-largest Heteropteran family [1,4]. Pentatomidae are mostly phytophagous and polyphagous, with the exception of predatory species of the subfamily Asopinae [1–4]. Phytophagous pentatomids are a major concern for many agricultural systems, damaging crops through direct feeding and by transmitting plant pathogens [1,3], whereas predatory pentatomids are considered to be beneficial, as they prey on various insect pest species [5]. This review focuses on phytophagous stink bugs.

Chemical control programs have been the principal approach for managing stink bugs [6,7]. Despite these management efforts, populations continue to surpass damage thresholds, and the development of insecticide resistance has been observed [6]. To reduce the use of insecticides, behaviourally based management and monitoring programs need to be further developed. These require knowledge of the biological and behavioural traits of stink bugs [5–8].

The Pentatomidae have hemimetabolous development with an egg, nymphal, and adult stage, and can have multiple generations per year (Figure 1). Five nymphal instars occur in the Pentatomidae. The first instars are generally gregarious, inactive, and remain on top of or near the eggshells. The first instars do not feed on host plants but acquire

specific symbionts by ingesting secretions covering the shells. These bacterial symbionts are thus vertically transmitted from females via the egg surface [9–11]. The acquisition of these symbionts plays a beneficial role in the fitness of the insect host, especially in survival and development, and detoxification of their food [12–14]. As the nymphs pass through instars, they gradually and progressively disperse. The size of the nymphs increases throughout the different stadia and the growth of the wing pads starts during the fourth and fifth instar. During the adult stage, the bug possesses fully developed wings; reproduction begins after the passage to adulthood and completion of sexual maturation, with typical precopulatory and copulatory behaviours combining chemical and vibrational signals [6].

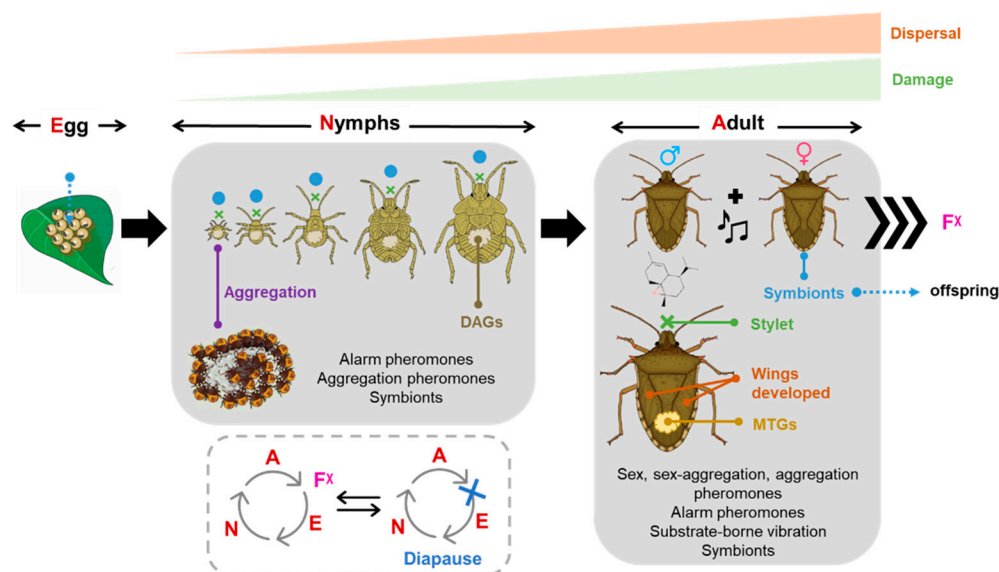


Figure 1. Schematic drawing showing various traits associated with the life cycle of the Pentatomidae, which can be targeted for pest management. The chemical molecule represents the sex, sex–aggregation or aggregation pheromones, and the musical note represents the vibrational signals (F^x: number of generations; DAGs: dorsal abdominal scent glands; MTGs: metathoracic scent glands).

Pentatomids are well known for producing a wide variety of chemicals during their life cycle, such as sex, alarm, and aggregation pheromones [15–17]. Sex–aggregation pheromones are defined as compounds that are produced by one sex that attract both sexes for mating purposes, whereas sex pheromones attract only the opposite sex. Compounds that are produced by one sex that attract both sexes, including nymphs, for behaviours other than mating are considered aggregation pheromones [18]. In all pentatomid species for which pheromones (sex, sex–aggregation, aggregation) have been identified, males are responsible for production [16,17]. However, the distinction between sex–aggregation and aggregation pheromone can be difficult and requires rigorous bioassays demonstrating the behavioural responses of conspecifics to specific compounds [16]. Thus, in cases where there was not sufficient empirical work to determine which designation is correct, we refer to these as aggregation pheromones.

Traits other than chemical signals can also be considered when developing control strategies (Figure 1). Recent advances in understanding the vertical transmission of symbionts and manipulation of transmission offer new possibilities for controlling Pentatomidae [19]. For example, the removal of symbionts can lead to a strong negative effect on insect fitness [10,12,20–24]. Furthermore, several studies have been conducted on vibratory communication (closely associated with stink bug courtship) in order to develop pest control methods that exploit this communication mode [25].

Recent advances in understanding stink bug biology through their symbionts, pheromones, and other traits (e.g., colour vision, flying behaviour) offer new opportunities for the development of integrated pest management tactics. However, their utilisation is still

limited to a few stink bug species, and the complexity and time required to develop commercial applications of these behavioural tools remains a major challenge. Here, we summarise the currently available knowledge of the mating behaviour, alarm and aggregation pheromones, and symbionts within the Pentatomidae, with emphasis on their potential to be exploited for the development of stink bug pest management tactics.

2. Vibratory and Pheromone Signals in Stink Bug Mating

Substrate-borne vibrations are prevalent in insects [26–29]. In the Pentatomidae, these have been described in 36 species [30,31]. Substrate-borne communication has been well studied in the model species *Nezara viridula* (L.), where it is closely associated with their mating behaviour [30,32].

In stink bugs, mating behaviour is mediated by chemical and vibrational signals and involves long-range mate location and close-range courtship behaviour [30–34]. This bimodal communication starts at long distance with the emission of the male pheromone which attracts females towards the chemical signal and can result in aggregations of females on the same host plant or in areas surrounding the calling males [33]. At close range, the male pheromone stimulates the female to start her vibratory calling (e.g., Female Calling Song, FCS). The FCS triggers the male to search for the calling female [35,36]. The male walks on the plant towards the source of vibration and answers with his calling and courtship songs (e.g., Male Calling Song, MSC and Male Courtship Song, MCrS) [37]. The rhythmic FCS repetitions create a vibrational signal which guides the male towards the female, even when complex plant architecture is involved [36]. The vibratory signals of stink bugs are characterised by low frequencies (around 100 Hz) with narrow spectral peaks which are well tuned with the resonance properties of host plants, which act as low-pass filters [38,39]. These characteristics enable short-range communication and facilitate mate location [35,36].

Interference of stink bug communication using substrate-borne vibratory signals has been explored for pest management [25,40]. For example, a few studies have been conducted that explore the use of vibratory signals as a repellent, a mating disruption strategy, and for population monitoring. A vibratory disturbance of 100 Hz can affect communication between males and females of *N. viridula* by decreasing the number of males responding to female calling songs and by reducing the number of males responding to the courtship song [41]. Although disturbance did not affect the production of female calling songs or the location of females by males, females changed the rhythm and the dominant frequency of their songs to avoid overlap with artificial external disturbances. Similar results have also been observed in *Euchistus heros* (F.) [42]. Although the properties of the plant tissues strongly influence vibrational transmission, other factors can also significantly disturb transmission processes. Several studies demonstrated that biotic noise could modify the temporal structure, the frequency, or the amplitude of signals and negatively affect the behavioural responses of conspecifics [41,43,44]. Other abiotic factors such as wind and raindrops have also been suggested as a source of disturbance for stink bug vibratory communication [30].



Substrate-borne vibrations not only affect communication between partners but can also affect the reproductive behaviour of insects [45]. Pure tone vibrations (75–200 Hz) mechanically transmitted to plants significantly (>90%) decreased copulation in *E. heros* by inhibiting male calling and searching for females [46]. In addition, a reduction in fecundity and fertility has also been observed in females exposed to background noise for 24 h, despite the fact that they had been mated. Although this hypothesis remains to be tested, the authors suggested that the background noise could induce stress, resulting in shorter copulation periods and/or a reduction in the efficiency of sperm transfer. A recent study [47] investigated the potential of female rival signals for mating disruption in *E. heros*, *Chinavia ubica* (Rolston) and *Chinavia impicticornis* (Stål). In the presence of rival female signals, fewer males were able to reach females, and a significant reduction in copulating

pairs was observed. These results suggest that female rival signals could be used to disrupt mating of stink bugs.

Indirect effects of vibratory signals, such as the attraction of parasitoids and predators, may also contribute to the regulation of stink bug populations. Predators and parasitoids can use stimuli associated with stink bug prey/hosts to search for and locate stink bugs [26]. For example, the egg parasitoid *Telenomus podisi* (Ashmead) has been shown to be attracted to vibratory signals from *E. heros* [48,49]. Laumann et al. [49] demonstrated that *T. podisi* remained for longer on leaves vibrated by natural or artificial female songs, compared to non-vibrated leaves or leaves vibrated by male songs. These studies suggest that the in situ behavioural response to host female vibratory signals increases the probability of *T. podisi* locating host eggs. Nevertheless, attraction of natural enemies to synthetic vibrational and pheromonal signals does not necessarily imply parasitism. An additional concern is that negative consequences for biological control (i.e., attracting and misleading with no reward) can also be observed [50]. Thus, caution needs to be taken when using these stimuli in pest control.

The detection and monitoring of insect communication with automatic acoustic devices has been investigated in a few species [25,51,52]. For example, algorithms using Gaussian mixture models (GMM), or probabilistic neural networks (PNN) have been used for the identification and detection of Cicadidae [53], as well as the vibratory signals produced by red palm weevils [54]. In both studies, the mathematical models were over 94% accurate. Other methods such as linear prediction cepstral coefficient feature vectors and a multilayer perceptron classifier have also shown potential for vibratory discrimination of leafhoppers [55]. Similarly, the incorporation of an automatic acoustic device has been proposed for stink bug identification and detection [56]. PNN and GMM models were able to identify and discriminate the vibratory signals of *Euschistus servus* (Say) and *N. viridula* species from incidental noise (e.g., locomotion, feeding or tunnelling) with an accuracy, in most cases, higher than 90%. Although this study was conducted under laboratory conditions, thus excluding abiotic noises such as wind and vibrations by other organisms, the results suggest that the method has potential for monitoring stink bugs and improving levels of control realised by pest management programmes.

Sex and aggregation pheromones have been identified in approximately 50 species where the pattern of responses is divided between those that appear to attract only females, and those that attract both sexes, as well as nymphs when this has been tested (Table 1) [16,17,57,58]. The only exception is for *Piezodorus hybneri* (Westwood); its pheromone appears to be bifunctional, acting either as a sex or aggregation pheromone, depending on the time of the year [59,60]. In comparison, sex-aggregation pheromones have only been identified for a few species (Table 1). To date, only male stink bugs have been observed to produce these pheromones. Sex pheromones have been described in various Pentatomidae tribes and consist, in general, of a blend of at least two compounds. For example, among the Anestini tribe, methyl (*E,Z,Z*)-2,4,6-decatrienoate was identified as the main sex pheromone compound in *Thyanta perditor* (F.) and *Thyanta pallidovirens* (Stål), along with the sesquiterpenes (+)- α -curcumene, (-)-zingiberene, and (-)- β -sesquiphellandrene [61,62]. Similar methyl esters have been reported to act as sex pheromones in other tribes. In the Carpocorini tribe, methyl 2,6,10-trimethyltridecanoate has been identified as a sex pheromone for *E. heros* [63–65], *Euschistus obscurus* (Palisot) [63,64] and *Agroecus griseus* (Dallas) [66]. In Edessinae, the only known sex pheromone is for *Edessa meditabunda* (Fabricius), where methyl 4,8,12-trimethylpentadecanoate and methyl 4,8,12-trimethyltetradecanoate constitute the major and minor compounds in this species, respectively [67]. Other compounds such as sesquiterpenoids have been reported to act as sex pheromones in Pentatomidae. For example, the sex pheromone of *Tibraca limbativentris* (Stål) is a mixture (7:3) of two isomers of 1,10-bisaboladien-3-ol (i.e., zingiberenol) [68,69], where the main compound alone and the mixture are attractive to females in the field [70]. An isomer of zingiberenol has also been described in the sex pheromone of *Oebalus pœcilus* (Dallas) [71].

Table 1. Defensive compounds and alarm pheromones (D), sex pheromones (S), aggregation pheromones (Ag), and sex–aggregation pheromones (SAg) identified in phytophagous Pentatomidae (list adapted and updated from Borges and Blassioli-Moraes [17] and Weber et al. 2018 [16]. For each of these pheromones, information regarding the life stage and the sex emitting the pheromones is indicated. For the alarm pheromones,  and  indicate adults and nymphs, respectively, whereas the sex, sex–aggregation and aggregation pheromones are emitted by males (“M”). Information regarding the life stage and the sex (males (M); females (F); nymphs (n)) of responder(s) to the alarm, sex, aggregation, or sex–aggregation pheromones are also listed if behavioural studies have been conducted, with red, green, and grey indicating the degree of response (red = does not respond to the pheromone, green = responds to the pheromone, grey = response has not been tested). In terms of compounds listed for each pheromone, only the most abundant compound is listed for the alarm pheromones, except for species in which bioassays have been conducted. For these species, all the compounds (as well as the instar and sex emitter) are listed, and the most abundant compound is underlined. For the sex pheromones, aggregation pheromones and sex–aggregation pheromones all compounds assayed are listed.












Pheromone ¹	Emitter	Responder	Compounds ²	References
Dinidorinae: Dinidorini				
<i>Aspongopus</i> sp.				
D			(E)-2-Hexenal	[72]
D			<i>Coridus janus</i> (E)-2-Hexenal	[73]
D			<i>Cyclopelta siccifolia</i> (E)-2-Hexenal	[74]
Discocephalinae: Discocephalini				
<i>Antiteuchus innocens</i>				
D			Undecane (M, F)	[75]
D			Undecane (1st–5th instar)	[75]
Discocephalinae: Ochlerini				
<i>Lincus malevolus</i>				
D			Undecane (M, F); (E)-4-oxo-2-decenal (F)	[76]
<i>Lincus spurcus</i>				
D			Undecane (M, F)	[76]
D			Undecane (5th instar)	[77]
Edessinae				
<i>Edessa meditabunda</i>				
S	M	M, F, n	Methyl 4,8,12-trimethylpentadecanoate	[67,78]
D			Undecane (1st–2nd instar)	[79]
<i>Edessa rufomarginata</i>				
D			Undecane	[80]
Pentatominae: Aeliini				
<i>Aelia fieberi</i>				
D			(E)-2-Decenal (M, F)	[81]
Pentatominae: Antestiini				
<i>Plautia stali</i>				
Ag	M	M, F, n	Methyl (2E,4E,6Z)-2,4,6-decatrienoate	[82]
<i>Thyanta custator accera</i>				
?	M		Methyl (2E,4Z,6Z)-2,4,6-decatrienoate; (+)- α -curcumene; (–)-zingiberene; (–)- β -sesquiphellandrene	[61]

Table 1. Cont.


















Pheromone ¹	Emitter	Responder	Compounds ²	References
			<i>Thyanta pallidovirens</i>	
S	M	M, F, n	Methyl (2E,4Z,6Z)-2,4,6-decatrienoate; (+)- α -curcumene; (-)-zingiberene; (-)- β -sesquiphellandrene	[61,83]
D			Tridecane (M, F)	[61]
D			Tridecane (1st–2nd instar)	[84]
			<i>Thyanta perditor</i>	
S	M	M, F, n	Methyl (2E,4E,6Z)-2,4,6-decatrienoate	[62]
D			Tridecane (M, F)	[62]
D			Tridecane (1st–2nd instar)	[79]
			Pentatominae: Bathycoliini	
			<i>Bathycolia distincta</i>	
D		M, F, n	(E)-2-Hexenal; 4-oxo-(E)-2-hexenal; (E)-2-decenal; (E)-2-decenyl acetate; tridecane; dodecane	[85]
			Pentatominae: Cappaeni	
			<i>Caura rufiventris</i>	
D			Tridecane	[72]
			<i>Halyomorpha halys</i>	
Ag	M	M, F, n	Isomers of murgantiol (10,11-Epoxy-1- bisabolen-3-ol)	[86,87]
D			Tridecane (M, F)	[86,88–91]
D			Tridecane (3rd–5th instar)	[86,88]
D	M, F, n	M, F, n	(E)-2-Decenal	[92]
			<i>Veterna patula</i>	
D			Tridecane	[72]
			Pentatominae: Carpocorini	
			<i>Agroecus griseus</i>	
S	M	M, F, n	Methyl 2,6,10 trimethyltridecanoate	[66]
D			Tridecane	[66,93]
D			Tridecane (1st–5th instar)	[66]
			<i>Carpocoris fuscispinus</i>	
D			Tridecane (M, F)	[94]
			<i>Cosmopepla bimaculate</i>	
D			Tridecane (M, F)	[95]
			<i>Euschistus biformis</i>	
D			Tridecane	[96]
			<i>Euschistus conspersus</i>	
Ag	M	M, F, n	Methyl (2E,4Z)-2,4-decadienoate; methyl (2E,4E)-decadienoate; geranylacetone	[97]
D			Tridecane (1st–2nd instar)	[84]
			<i>Euschistus heros</i>	
S	M	M, F, n	Methyl 2,6,10 trimethyltridecanoate; methyl (2E,4Z)-2,4-decadienoate; methyl 2,6,10-trimethyldodecanoate	[63,65,98]
D		M, F, n	(E)-2-Hexenal; 4-oxo-(E)-2-hexenal; hexenoic acid; (E)-2-hexenyl acetate; 2-octenal; (E)-2-octen-1-ol; nonanal; (E)-2-heptenyl acetate; (E)-2-decenal; (E)-2-octenyl acetate; tridecane; tetradecane; (E)-2-decenyl acetate; tridecanal; tetradecanal; pentadecane	[99–101]
D			Tridecane (1st–4th instar); tetradecanal (5th instar)	[79,96,99]

Table 1. Cont.













Pheromone ¹	Emitter	Responder	Compounds ²	References
?	M		<i>Euschistus ictericus</i> Methyl (2E,4Z)-2,4-decadienoate; methyl (2E,4E)-decadienoate	[97]
S	M	M, F, n	<i>Euschistus obscurus</i> Methyl (2E,4Z)-2,4-decadienoate; methyl 2,6,10-trimethyltridecanoate; methyl 2,6,10-trimethyldodecanoate; methyl (2E,4E)-decadienoate	[63,64]
Ag	M	M, F, n	<i>Euschistus politus</i> Methyl (2E,4Z)-2,4-decadienoate; methyl (2E,4E)-decadienoate	[97]
Ag	M	M, F, n	<i>Euschistus servus</i> Methyl (2E,4Z)-2,4-decadienoate; methyl (2E,4E)-decadienoate; geranylacetone	[97]
D			(E)-2-Hexenal	[102]
Ag	M	M, F, n	<i>Euschistus tristigmus</i> Methyl (2E,4Z)-2,4-decadienoate; geranylacetone; decanoic acid	[97]
D			Hexanal	[102]
D			Tridecane (1st–5th instar)	[79]
D			<i>Dichelops melacanthus</i> Tridecane (M, F); 4-oxo-(E)-2-hexenal (M, F)	[99,100,103]
D			4-Oxo-(E)-2-hexenal (5th instar)	[99]
Ag	M	M, F, n	<i>Dolycoris baccarum</i> α -Bisabolol *; trans- α -bergamotene *; (S)- β -bisabolene *	[104]
D			Tridecane (M, F); hexenal	[105,106]
Ag	M	M, F, n	<i>Mormidea v-luteum</i> Isomers of zingiberenol (cis-(1S,4R,1'S)-zingiberenol; trans-(1R,4R,1'S)-zingiberenol); murgantiol *; sesquiperitol	[107]
S	M	M, F, n	<i>Oebalus poecilus</i> Isomer of zingiberenol ((1S,4R,1'S)-4-(1',5'-dimethylhex-4'-enyl)-1-methylcyclohex-2-en-1-ol)	[71]
D			<i>Oebalus pugnax</i> Tridecane	[108]
S	M	M, F, n	<i>Tibraca limbativentris</i> Isomers of zingiberenol ((3S,6S,7R)-1,10-bisaboladien-3-ol; (3R,6S,7R)-1,10-bisaboladien-3-ol); sesquiperitol	[68,69]
Pentatominae: Eysarcorini				
Ag	M	M ⁽³⁾ , F, n	<i>Eysarcoris lewisi</i> Sesquisabinen-1-ol	[109,110]
?	M		<i>Eysarcoris parvus</i> (Z)-exo- α -Bergamotene	[111]
Pentatominae: Halyini				
D			<i>Apodiphus amygdali</i> 4-Oxo-(E)-2-hexenal	[112]
D			4-Oxo-(E)-2-hexenal (1st–5th instar)	[112]
D			<i>Brochymena quadripustulata</i> (E)-2-Hexenal	[113]
D			<i>Erthesina fullo</i> Tridecane (M, F)	[114]
D			<i>Poecilometris strigatus</i> (E)-2-Hexenal; (E)-2-octenal	[115]

Table 1. Cont.


















Pheromone ¹	Emitter	Responder	Compounds ²	References
			Pentatominae: Myrocheini <i>Delegorguella lautus</i>	
D			Tridecane	[72]
			Pentatominae: Nezarini <i>Chinavia aseada</i>	
?	M		<i>cis</i> -(Z)-Bisabolene epoxide; <i>trans</i> -(Z)-bisabolene epoxide; (Z)- α -bisabolene	[116]
D			(Z)-4-Nonenal	[102]
D			Tridecane (1st–2nd instar)	[79]
			<i>Chinavia hilaris</i>	
S	M	M, F, n	<i>cis</i> -(Z)-Bisabolene epoxide; <i>trans</i> -(Z)-bisabolene epoxide	[117]
D			(E)-2-Hexenal	[102]
D			Tridecane (1st–2nd instar)	[84]
			<i>Chinavia impicticornis</i>	
S	M	M, F, n	<i>trans</i> -(Z)-Bisabolene epoxide; <i>cis</i> -(Z)-bisabolene epoxide	[118]
D			Tridecane (M); 4-oxo-(E)-2-hexenal (F)	[99,118]
D			4-Oxo-(E)-2-hexenal (5th instar)	[99]
			<i>Chinavia marginata</i>	
?	M		<i>trans</i> -(Z)-Bisabolene epoxide; <i>cis</i> -(Z)-bisabolene epoxide	[119]
			<i>Chinavia ubica</i>	
S	M	M, F, n	<i>trans</i> -(Z)-Bisabolene epoxide; <i>cis</i> -(Z)-bisabolene epoxide	[118]
D			Tridecane (M, F)	[99,100,118]
D			4-Oxo-(E)-2-hexenal (5th instar)	[99]
			<i>Chlorochroa ligata</i>	
S	M	M ⁽³⁾ , F, n	Methyl (E)-6,2,3-dihydrofarnesoate; methyl farnesoate; methyl (E)-5-2,6,10-trimethyl-5,9-undecadienoate	[120,121]
D			Tridecane (M, F)	[122]
D			Tridecane (5th instar)	[122]
			<i>Chlorochroa sayi</i>	
S Ag	M	M, F, n	Methyl geranate; methyl citronellate; methyl farnesoate	[120,123]
D			Tridecane (M, F)	[122]
D			4-Oxo-(E)-2-hexenal (5th instar)	[122]
			<i>Chlorochroa uhleri</i>	
Ag	M	M, F, n	Methyl geranate; methyl citronellate; methyl farnesoate	[120,121]
D			Tridecane (M, F)	[122]
			<i>Nezara antennata</i>	
?	M		(Z)- α -Bisabolene; <i>trans</i> -(Z)-bisabolene epoxide; <i>cis</i> -(Z)-bisabolene epoxide; (E)-nerolidol	[116]
D			(E)-2-Decenal (M, F)	[81]
			<i>Nezara viridula</i>	
Ag	M	M, F, n	<i>trans</i> -(Z)-Bisabolene epoxide; <i>cis</i> -(Z)-bisabolene epoxide; (Z)- α -bisabolene; (E)-nerolidol	[98,116,124–128]
D		M, F, n	Tridecane; (E)-2-decenal; (E)-2-decenyl acetate; (E)-2-hexenal; (E)-2-hexenyl acetate; dodecane	[124,129–131]
D		n	4-Oxo-(E)-2-decenal (1st instar); tetradecane (2nd instar); tridecane (2nd–5th instar); (E)-2-hexenal	[79,84,132,133]

Table 1. Cont.




















Pheromone ¹	Emitter	Responder	Compounds ²	References
			<i>Palomena viridissima</i>	
D			Unknown carbonyl compound	[106]
			Pentatominae: Pentatomini	
			<i>Pallantia macunaima</i>	
S	M	M, F, n	(6R,10S)-Pallantione	[134]
D			Tridecane (M, F)	[93,135]
D			(E)-4-Oxo-2-hexenal (1st instar) Tridecane (2nd–5th instar)	[135]
			<i>Pellaea stictica</i>	
P	M	M, F, n	Isomers of 2,4,8,13-tetramethyltetradecan-1-ol	[136,137]
D			(Z)-4-tridecene	[93]
			<i>Rhaphigaster nebulosa</i>	
D			Tridecane (M, F)	[138]
			Pentatominae: Piezodorini	
			<i>Piezodorus guildinii</i>	
S	M	M, F, n	(7R)-(+)- β -sesquiphellandrene	[139]
D			(E)-4-oxo-2-hexenal (M, F)	[99,140]
D			Unknown (5th instar)	[99]
			<i>Piezodorus hybneri</i>	
SAg	M	M, F, n	β -Sesquiphellandrene *; (R)-15-hexadecanolide; methyl (Z)-8-hexadecenoate	[59,60]
			<i>Piezodorus teretipes</i>	
D			(E)-2-Hexenal	[141]
			Pentatominae: Rhynchocorini	
			<i>Biprorulus bibax</i>	
SAg	M	M, F, n	Biprolure ((3R,4S',1'E)-3,4-bis(1'-buteny1)tetrahydro-2-furano; linalool; isomers of farnesol; nerolidol	[142–146]
D			Tridecane	[147]
			<i>Vitellus insularis</i>	
D			Tridecane	[148]
			Pentatominae: Strachiini	
			<i>Bagrada hiliaris</i>	
Ag	M	M, F, n	(E)-2-octenyl acetate	[149,150]
			<i>Eurydema oleraceum</i>	
D			(E)-2-Octenal; (E)-2-hexenal	[102,151]
			<i>Eurydema pulchrum</i>	
D		n	(E)-2-Hexenal (1st–3rd instar); tridecane	[133]
			<i>Eurydema rugosa</i>	
Ag	M	M, F, n	(E)-2-Hexenal	[152]
D		n	(E)-2-Hexenal (2nd–3rd instar); tridecane	[133]
			<i>Eurydema ventrale</i>	
D			(2E,6E)-Octadienedial; (E)-2-octenal	[102,151]
			<i>Murgantia histrionica</i>	
			Isomers of murgantiol	
Ag	M	M, F, n	((3S,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol; (3S,6S,7R,10R)-10,11-epoxy-1-bisabolen-3-ol)	[153–155]
D			(2E,6E)-Octadienedial	[151]

Table 1. Cont.

Pheromone ¹	Emitter	Responder	Compounds ²	References
			Podopinae: Graphosomatini	
			<i>Graphosoma lineatum</i>	
D			1-phenanthrenecarboxylic acid (M); tridecane (F); (E)-2-decenal (F)	[156,157]
			<i>Graphosoma rubrolineatum</i>	
D			(E)-2-Decenal (M, F)	[81]
			<i>Graphosoma semipunctatum</i>	
D			Tridecane (M, F)	[158]
			Podopinae: Podopini	
			<i>Scotinophara lurida</i>	
D			(E)-2-Decenal (M, F)	[81]

¹ For compounds where a pheromonal functionality has been assigned but no behavioural study has been conducted, the compounds were isolated from a specific structure where no other function has been observed.

² The most abundant compound of the alarm pheromone can vary among studies, and in these cases, each most abundant compound is listed. ³ Males attraction is unclear. Field tests were suggestive, and the data were limited to confirm the attraction. ? Indicates that it is a putative pheromone. No behavioural bioassays have been conducted to confirm the functionality. * Absolute configuration has not been determined.

In stink bug sex pheromones, the ratio of components appears to be important, with ratios that accurately reflect those produced by males being most attractive. In addition, they are species specific, and can vary with age, physiological status, or among populations [159–162]. For example, Endo et al. (2012) [159] showed that the ratios of the three components in pheromone emissions of *P. hybneri* are variable among individuals and over time. Variation in the pheromone blend has also been observed among *N. viridula* individuals from different geographic populations [116] and within a single population in Australia [162]. Thus, determining the ratio as well as the absolute configuration of the pheromones must be considered when optimizing attractants for monitoring and management purposes.

Field studies have shown that the number of stink bugs recovered in traps baited with sex pheromone does not always correlate with the density of the field population [163]. This is possibly because of sub-optimal trap design. Studies have shown that more pentatomids are observed in the vicinity of traps than inside the traps [97,143], a possible indication that stink bugs require vibrational signals to locate and enter the trap. A trap incorporating olfactory and acoustic stimuli was recently tested in the field for *Halyomorpha halys* (Stal) and demonstrated that the use of vibrations and pheromones can increase the efficacy of pheromone traps [164,165].

3. Alarm Pheromones

Stink bugs are well known for producing odoriferous compounds that play a role in chemical communication and defence [16,17,57,58,96,166]. These volatile compounds are produced and stored in specific glands (DAGs—dorsal abdominal scent glands and MTGs—metathoracic scent glands) according to their life stage (Figure 1) [58,122,127,132,135,166–169]. These glands secrete volatiles through the external efferent thoracic system when insects are disturbed [101,170] and can act as allomones and serve as a defence against natural enemies and microorganisms or mediate alarm or aggregation behaviours among conspecifics [16,96,100]. These compounds are highly conserved across species and are mostly represented by short-chain aliphatic aldehydes, alcohols, esters, alkanes, terpenes, and phenolics (Table 1) [16,57,58,96,99,166].

The use of semiochemicals for behavioural manipulation of natural enemies has been proposed as a tool to improve biological control [171,172]. Natural enemies can exploit the alarm compounds produced by pentatomids as kairomones to locate their hosts [91,173–175]. For example, the egg parasitoids *T. podisi*, *Trissolcus basalisi* (Wollaston) and *Trissolcus japonicus*

(Ashmead) are attracted to (*E*)-2-hexenal, (*E*)-2-decenal, and tridecane, defensive compounds released by their preferred hosts, *E. heros* [175], *N. viridula* [176], and *H. halys* [91], respectively. Each species seems to be able to recognise the compounds produced by their preferred hosts [174]. *Trissolcus basalis* responded preferentially to (*E*)-2-decenal and 4-oxo-(*E*)-2-hexenal, two compounds in *N. viridula* secretions, whereas *T. podisi* preferred (*E*)-2-hexenal and 4-oxo-(*E*)-2-hexenal compounds in the secretions of *E. heros*. Similarly, in field experiments, traps baited with alarm pheromone compounds such as (*E*)-2-hexenal + α -terpineol and 4-oxo-(*E*)-2-hexenal + linalool + tridecane captured the tachinid flies *Euclytia flava* (Townsend) and *Hemyda aurata* (Robineau-Desvoid) [166,177]. Other predators such as chloropid and milichiid flies, as well as spiders, have also been reported to be attracted to alarm pheromone compounds of Pentatomidae. Aldrich and Barros [178] showed the attraction of male crab spiders *Xysticus ferox* (Hentz) to (*E*)-2-octenal and (*E*)-2-decenal and Eisner et al. [179] demonstrated the attraction of chloropid and milichiid flies to chemicals released by crushed Pentatomidae. These flies are also attracted to defensive compounds such as (*E*)-2-hexenal, (*E*)-2-octenal, (*E*)-2-decenal, and hexanal [178,179]. These results suggest that stink bug natural enemies use scent gland secretions to locate their preferred hosts. However, to date, only one study has been conducted on Pentatomidae with the aim of attracting parasitoids with synthetic alarm pheromone to enhance parasitism of stink bug eggs [175]. Areas treated with (*E*)-2-hexenal showed an increase in the abundance of Telenominae with greater intensity of parasitism and an increase in egg predation. The utilisation of alarm pheromone compounds to improve the action of natural enemies has potential, but it needs further study to develop release devices that release effective doses. In addition, effects on natural enemy foraging and host location may be dose dependent, with some doses positively affecting associated behaviours and others negatively. Further research is needed to determine if release devices and dosages can be developed that enhance positive effects without negative effects. The combination with other semiochemicals or with trap crops could also help. In addition to the volatiles emitted from the scent glands, parasitoids of the Pentatomidae can use other cues when searching for eggs, such as volatiles from plants [180,181], volatiles from eggs [182], sex pheromones [177,183], chemicals left by stink bug footprints [184,185], vibratory signals [49], and visual cues [186]. Thus, specific knowledge about the stimuli that mediate interactions between natural enemies and stink bugs is required to improve the effectiveness of applications of semiochemicals in integrated pest control. Strategies such as attract and reward [187,188] or push–pull tactics [189–191], which combine alarm pheromone compounds with habitat manipulation, could improve the action of natural enemies of Pentatomidae.

4. Aggregation Behaviour and Pheromones in Pentatomidae

Aggregation behaviour is a common phenomenon in Heteroptera [192]. In Pentatomidae, aggregations are first observed when stink bug eggs hatch, but also later by adults (Figure 1). These two separate phenomena are likely mediated by entirely different cues and signals. The maintenance of aggregations of first instar pentatomids is mediated by a combination of tactile cues and chemical compounds, which are normally considered as defensive compounds in later instars [79,84,152]. It has been shown that these defensive compounds can also mediate heterospecific aggregation behaviour of first instars [152], suggesting that compounds which mediate aggregation of first instar stink bugs may be conserved among species. In adults, aggregations can be observed at different times of the year. For example, *H. halys* forms aggregations in both summer and winter during diapause. In the summer, aggregations are mediated by aggregation pheromones which attract both sexes and nymphs [87]. The identity of the stimuli that mediate adult overwintering aggregations remains unknown. Tomaya et al. [193] suggested that tactile and olfactory stimuli might be involved, whereas Bedoya et al. [194] demonstrated that the overwintering aggregations are not mediated via vibration signals.

Aggregation pheromones produced by stink bugs are complex and include saturated hydrocarbons, methyl esters, terpenes, and terpenoids [16,17,57,195]. Although these pheromones

are species specific, some similarities among Pentatomidae occur (Table 1) [16,17]. For example, within the Carpocorini tribe, methyl (*E,Z*)-2,4-decadienoate (MDD) has been identified as an aggregation pheromone in five *Euschistus* species including *E. servus*, *Euschistus tristigmus* (Say), *Euschistus politus* (Uhler), *Euschistus conspersus* (Uhler), and *Euschistus ictericus* (L.) [97]. Other methyl esters have also been reported as aggregation pheromones, such as methyl (*E,E,Z*)-2,4,6-decatrienoate (MDT), methyl (*E*)-5-2,6,10-trimethyl-5,9-undecadienoate, and methyl (8*Z*)-8-hexadecenoate produced by *Plautia stali* Scott [82], *Chlorochroa* sp. [121] and *P. hybneri* [59], respectively. Another example is the presence of sesquiterpenoids such as murgantiol (10,11-Epoxy-1-bisabolene-3-ol), where isomers have been identified in *Murgantia histrionica* (Hahn) [153,154], *Halyomorpha halys* (Say) [87], and *Mormidea v-luteum* (Lichtenstein) [107]. Other similar sesquiterpenes and sesquiterpenoids (α -bisabolol, *trans*- α -bergamotene, β -bisabolene and zingiberenol) have also been detected as sex and aggregation pheromones in various Pentatomidae species [68,69,71,104,124]. A recent study revealed that these similarities of sesquiterpene compounds observed in Pentatomidae are linked to a conserved gene function in terpene biosynthesis [196]. Furthermore, attraction to heterospecific pheromones has been observed in Pentatomidae [16]. For example, the pheromone of the Asian species *P. stali* (MDT) attracts other pentatomids such as *Glaucias subpunctatus* (Walker), *H. halys*, and the North American species *C. hilaris*, despite the fact that *H. halys* and *C. hilaris* do not produce this compound. In fact, trap captures of *H. halys* can be synergised by the addition of MDT [197] and this has been observed in different populations globally [198]. Other examples of cross attraction can, however, be attributed to some overlap in pheromone chemistry, as is the case between *Nezara antennata* (Scott) and *N. viridula*, which share their two compounds [116].

Aggregation pheromones have been used in stink bug management to monitor the phenology and abundance of populations. For *H. halys*, the discovery of its aggregation pheromone has facilitated the development of an extensive monitoring program across the United States to define its infestation range and damage to crops [199]. Pyramid traps baited with MDD lures have been used to monitor populations of *E. servus* and *E. tristigmus* in apple and peach orchards [200,201] and for *E. conspersus* on tomatoes [202]. Nevertheless, studies have shown that although pheromone-baited traps can attract stink bugs to their vicinity, the number of captures often does not correlate with populations in the field [159]. For example, in apple and peach orchards, only 50% of *E. servus* attracted within 10 m of traps were captured [201], whereas traps placed on the border of tomato plantations attracted only *E. conspersus* females [159].

The use of stink bug aggregation pheromones in combination with host plants as trap crops has also been examined. A study with *E. conspersus* has shown that if MDD lures are deployed directly on a host plant, such as mullein plants, higher numbers of bugs are attracted and retained on these baited plants [203], demonstrating the potential of using trap crops for stink bug control. This concept of combining aggregation pheromone with host plants was later used on *P. stali*, where eggplants were baited with pheromones and treated with a high rate of systemic insecticide to kill attracted bugs [204]. However, in this study, significant damage to adjacent trees of the main persimmon crop was observed due to a spillover of attracted stink bugs. More recently, this concept was also applied in commercial apple orchards to control *H. halys* [205–207]. Morrison et al. [206] observed better retention of attracted bugs in the area surrounding lures when they were deployed in host plants, suggesting that deployment protocol can limit spillover and damage to untreated plants. Although this approach looks promising for managing *H. halys* and may be a viable option for other stink bug species [207], important economic considerations still exist. In fact, Morrison et al. [207] compared the cost of the attract and kill strategy and grower standard treatment for insect management. Although yield generated by the attract and kill treatments were higher than the standard treatments, the cost of the attract and kill treatments was seven to ten times higher, and as such remains the biggest limitation of this type of management approach.

5. Symbiotic Relationships and Vertical Transmission of Bacteria in Pentatomidae

Symbiotic interactions between bacteria and insects are ubiquitous [208,209] and can be crucial to insect fitness [210,211]. They play an important role in the digestion and detoxification of food, and provide essential nutrients for development, such as amino acids and vitamins often lacking in xylem/phloem sap [210–212]. Gut symbionts also provide protective functions to their host against pathogens and parasites [210,211].

Various bacterial taxa have been identified as Heteroptera symbionts, including Actinobacteria, Alphaproteobacteria, Bacteroidetes, Betaproteobacteria, Firmicutes and Gammaproteobacteria [213], with Gammaproteobacteria representing the most dominant taxa within the Heteroptera suborder [20,214,215]. These symbionts are essential to the growth, development, and survival of the host [215]. The bacteria *Wolbachia* has also been recorded in several pentatomid species; nevertheless, its role in host biology and, as such, its symbiotic impact has been poorly investigated [216]. The microbial gut symbionts among the Pentatomidae have been well described [10,15,19]. The Pentatomidae primarily harbour bacteria related to the *Pantoea* genus (Enterobacteriaceae family) in their midgut [217]. Pentatomidae are sap feeders and have a stylet (i.e., mouthparts modified from mandibles and maxillae) which allows them to pierce into plant tissue to suck xylem/phloem, and these symbionts provide their hosts with nutrients missing in their diets [218,219] and help to detoxify and deactivate plant chemical defences [220]. Reduced genome size (<1 Mb), high AT content and a fast evolutionary rate have been generally observed in bacterial symbionts of stink bugs [218,219,221,222].

Symbionts in the Pentatomidae are vertically transmitted by females to offspring during or after oviposition via physical deposition upon egg masses (e.g., egg smearing) [9,11,223,224]. After hatching, the first instars aggregate on the egg surface and ingest the bacteria by probing the egg chorions [224–226]. The symbionts of Pentatomidae are located extracellularly in tubular outgrowths called crypts or caeca in the posterior region of the midgut (e.g., M4 or V4 section) [11,15,20,224,227]. The establishment of gut bacteria in these crypts occurs directly from the first instar after ingestion of the symbiont [214,224]. Although these crypts can be found in both males and females, they are morphologically enlarged in females, suggesting that these enlarged crypt structures represent a female-specific specialised morphological trait for vertical symbiont transmission in Pentatomidae [227].

Symbiont acquisition failure can impact nymph survival [20,23,224]. Disruption of symbiont acquisition may thus offer pest control opportunities. Methods for disruption of vertical symbiont transmission in the Pentatomidae have been reviewed recently [19]. Different approaches to egg sterilisation have been tested in the laboratory, such as the utilisation of bleach [12,23] or bleach combined with ethanol [10,20,21], or with ethanol and formaldehyde [22,228,229]. Increased mortality, development time and sterility, reduced fecundity, and morphological abnormalities have been observed in pentatomid adults and nymphs, where symbiont acquisition was disrupted by these sterilisation methods [19]. More recently, egg sterilisation has also been successfully used under laboratory and in field conditions to control *H. halys* populations via the suppression of its primary symbiont *Pantoea carbekii* using antimicrobial treatments [24,230,231]. Since some of these products (i.e., Dentamet[®], Keos[®] and Bio-D[®]) are commercially available in Europe for organic farming as micronutrient fertilisers [230], this demonstrates the potential of targeting eggs to reduce population levels in the field.

6. Other Important Traits to Consider for Pest Management

Compared with olfactory stimuli, considerably less is known about the visual ecology of Pentatomidae. A few studies have looked at the effect of trap colour and demonstrated that trap colour influences the number of bugs captured, and this increase might result in better management and improved pest control. It has been shown that large numbers of phytophagous insects respond to yellow [232]. A study in the US observed that unbaited yellow traps captured more native stink bug species than traps painted light and dark green, black, or covered with aluminium foil [233]. However, intermediate results for

Euschistus spp. with yellow traps have been observed in comparison to white and green pyramid traps [200]. For *H. halys*, adults and nymphs seem to be more attracted to black pyramid traps than to yellow, white, green, and clear ones [234], for both plastic and wood traps [205]. Similar results have been obtained with black traps for *Bagrada hilaris* (Burmeister) [235]. Other coloured traps such as purple, white, or red also captured more adult *B. hilaris* than yellow traps, while no effect of trap colour was observed for nymphs. Laboratory and field work on the harlequin bug showed that this species is more attracted to green and black than white, yellow, red, or purple [236].

Artificial light can influence insect phototaxis, with both attraction [237] or repellence [238] being observed. Various studies have been conducted on the incorporation of lights into trapping devices or pest management programs [239,240]. The monitoring of Pentatomidae can often be difficult, but the incorporation of UV light traps can improve the performance of surveillance traps significantly [241]. Additional factors that can influence insect behavioural responses to light include light intensity and wavelengths [239,240,242–244]. In this regard, laboratory and field trials on *H. halys* have been conducted in order to determine optimal wavelengths and light intensities for the use of surveillance [245,246]. Leskey et al. [246] observed that this species was attracted to white (full spectrum of the visible light, 400–700 nm wavelength), blue (approximately 410 nm wavelength), and black (ultraviolet, <400 nm wavelength) fluorescent bulbs. However, in the field, blue and “white” sources were more attractive. Cambridge et al. [245] demonstrated recently that *H. halys* was attracted to “white” light (400–700 nm wavelength) at 75 lx of intensity.

Understanding the dispersal of stink bugs is crucial to the improvement of integrated pest management strategies targeting Pentatomidae pests. Although the Pentatomidae are regarded as heavy insects that have a small wing area in relation to their body weight in comparison to other insects [247], studies on *H. halys* suggest they are active fliers with good flight performance [248,249]. The establishment of stink bug flight potential could inform the development of management strategies which are influenced by stink bug movement, such as the attract and kill strategy [207]. A few laboratory studies have examined stink bug flight capacity using flight mills. A recent study assessed the baseline flight potential of *Euschistus servus* collected over 2 years from different host plants with the longest distance flown of 16 km [248]. Previous work with *H. halys* demonstrated that 85% of individuals could fly up to 5 km in 24 h, with the longest distance of 117 km flown by an individual [248,249]. The effects of starvation, age, mating status, sex and pre-flight weight on flight parameters have been examined on laboratory-reared *H. halys* [249]. This work suggested that only starvation impacted the number of flight bouts and velocity, suggesting that this species has a robust dispersal capacity which may contribute to its success as an invasive species. Multiple parameters can impact flight mill results, such as handling of insects, lack of natural stimuli, increased weight load, and reduced energy expenditure [250,251]; thus, caution needs to be taken when interpreting flight mill data. For example, distances flown by laboratory-reared stink bugs in a study by Aita et al. [252] were lower than the distances flown by stink bugs collected from the field [248,249]. Furthermore, flight response can vary among stink bug species and over the season. For example, *H. halys* exhibits a high flight potential toward the end of the season and before entering diapause, compared to the mid-season [249], whereas *E. servus* has a lower mean flight potential during the mid-season and toward the end of the season [253]. Determining when and how long-distance and short-distance movements of stink bugs occur throughout the growing season could help growers to predict the area of infestation and to implement time- and location-appropriate control strategies.

7. Conclusions

Current management programs for stink bug pests rely on the use of chemical insecticides, which often have hidden costs associated with environmental impacts, effects on human health [254,255], and the selection of resistant pest populations [6]. Additionally, the intensive use of chemicals is often incompatible with biological control and establishment

of natural enemies [256]. Pesticide exposure can negatively impact natural enemies and reduce their biological control services, which can lead to pest resurgence and secondary pest outbreaks [257,258]. Alternative management options are needed [259], but the successful development and implementation of these alternatives usually requires considerable knowledge of pest biology. The development of alternative tactics is particularly difficult for new pests or invasive species due to the limited knowledge we often have of the pest life cycle in these situations.

Pentatomidae have specific traits which are promising targets for pest management. The presence of sex and aggregation pheromones is one example. Despite the fact that these pheromones have been identified for several species, their use in pest management is still restricted to monitoring the phenology and abundance of a few major stink bug species. Nevertheless, management tactics such as mass trapping and trap cropping have been improved with the commercialisation of various aggregation pheromone lures. Preliminary results suggest that the attract and kill tactic has potential and warrants additional research [206,207]. Although this tactic is promising, the costs linked with the synthesis and production of compounds, along with the deployment of pheromone devices, are still an obstacle limiting the commercial implementation of this method.

Recent advances in genomics and transcriptomics of stink bugs [260–263], along with new technologies such as reverse chemical ecology [264] or CRISPR-Cas9 [265,266], should facilitate the identification and functional characterisation of semiochemicals and their biosynthetic pathways. This could, in turn, lead to alternative options for synthesis of pheromone compounds in the future. CRISPR-Cas9, as a tool for genome editing, targeting for example pheromone and odour-related genes, genes involved in sexual reproduction or insecticide resistance, could also become a viable option for pest management in the future. In terms of this, research should focus on the development of these gene knockout systems in non-model organisms, similar to Cagliari et al. 2020 [266] who developed this for *E. heros*. Biosafety concerns in terms of the release of genetically transformed insects, which range from the risk of non-target effects if hybridisation (gene flow) can occur between target and non-target species, to the ecological impact on a niche if the target is removed from the environment [267], also exist and represent major challenges to the use of these technologies.

In parallel, precision agriculture methods for detection of pests or crop injury have also evolved, and electronic nose (E-nose) technology using semiochemicals has been developed. Various E-noses have been tested to detect stink bug damage on cotton [56,268,269], and more recently to detect *E. heros* sex pheromone [270]. This new technology may well offer a cheaper and new alternative method for stink bug detection in the future. Finally, it is important to also underline the potential of plant volatiles in combination with pheromones to improve trapping and trap cropping methods in pest management [271]. The use of aggregation pheromones in Pentatomidae offers this opportunity, and this has been recently investigated with *H. halys* [207] and *M. histrionica* [272]. Further research should therefore focus on this underexplored topic for stink bug pest management.

Disruption of symbiont acquisition is another interesting target. Some active substances are already commercially available as antimicrobials or fertilisers, and their utilisation is allowed in organic farming as a sustainable option [230,231]. This method therefore seems promising, although practical aspects still need to be addressed in terms of application, rate, and cost. In addition, questions regarding its applicability to other cropping systems as well as other stink bug species, and the long-term effects of these fertilisers on the cropping system, also need further attention before commercial implementation.

Other traits of the Pentatomidae that can be targeted for pest management are the utilisation of alarm pheromones for enhancing natural enemies [175], and the use of substrate-borne vibration for mating disruption [45,47] and surveillance [164,165]. To date, there is no study which shows that the utilisation of alarm pheromone for enhancing natural enemies can suppress the utilisation of insecticides, but these volatiles might be valuable as complementary tools to minimise insecticide spraying. Precautions may also need to be taken, as some of these volatiles have antifungal effects and their utilisation

might interfere with the use of entomopathogenic fungi as biological control agents [100]. Novel methods such as attract and reward [186] have not been tested in Pentatomidae, and future studies should focus on this aspect, whereas the use of vibrational signals and pheromones in a bimodal trap can increase trap captures and might have utility for mass trapping of stink bugs. Finally, the visual ecology and flight behaviour of Pentatomidae are still poorly studied. Colour preferences may improve the accuracy of mass-trapping and surveillance activities. In addition, advances in stink bug genomics and transcriptomics can help to determine which visual genes occur among Pentatomidae and which colours stink bugs can see. Currently, opsin genes have only been described in one Pentatomidae species [273,274], illustrating that we are far from truly understanding their visual ecology. Finally, knowledge regarding dispersal capacity is another important component for pest monitoring, especially for control tactics such as attract and kill or push and pull methods which rely on pest movement.

While many of these tools are still in the early stages of development, they offer valuable targets for improved and more sustainable Integrated Pest Management systems that should receive more focused attention.

Author Contributions: Conceptualisation, E.P.; methodology, E.P.; validation, E.P. and G.F.; formal analysis, E.P.; investigation, E.P.; writing—original draft preparation, E.P.; writing—review and editing, J.D.A., B.P.H., B.S. and G.F.; supervision, J.D.A., B.P.H., B.S. and G.F.; project administration, E.P.; funding acquisition, B.S. and G.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the University of Pretoria, the Forestry and Agricultural Biotechnology Institute (FABI), the DSI-NRF Centre of Excellence in Plant Health Biotechnology (CPHB grant number 40945), Macadamia South Africa NPC (SAMAC) and NRF Thuthuka (grant number TTK180409318747).

Data Availability Statement: Not applicable.

Acknowledgments: This study was made possible by the Forestry and Agricultural Biotechnology Institute and the African Centre of Chemical Ecology at the University of Pretoria.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

- McPherson, J.E.; Robert, M. General introduction to stink bugs. In *Stink Bugs of Economic Importance in America North of Mexico*, 1st ed.; CRC Press: Boca Raton, FL, USA, 2000; pp. 1–6.
- McPherson, J.E.; Bundy, C.S.; Wheeler, A.G. Overview of the superfamily Pentatomoidea. In *Invasive Stink Bugs and Related Species (Pentatomoidea): Biology, Higher Systematics, Semiochemistry, and Management*; CRC Press: Boca Raton, FL, USA, 2018; pp. 3–22.
- Panizzi, A.R.; McPherson, J.E.; James, D.G.; Javahery, M.; McPherson, R.M. Stink bugs (Pentatomidae). In *Heteroptera of Economic Importance*, 1st ed.; Schaefer, C.W., Panizzi, A.R., Eds.; CRC Press: Boca Raton, FL, USA, 2000; pp. 421–474.
- Schuh, R.T.; Slater, J.A. Chapter 73 Pentatomidae. In *True Bugs of the World (Hemiptera: Heteroptera). Classification and Natural History*; Schuh, R.T., Slater, J.A., Eds.; Siri Scientific Press: Rochdale, UK, 1995; Volume 8, pp. 229–233.
- Grazia, J.; Schwertner, C.F. *Stink Bug Classification, Phylogeny, Biology and Reproductive Behavior*, 1st ed.; Čokl, A., Borges, M., Eds.; CRC Press: Boca Raton, FL, USA, 2017; pp. 1–30.
- Sosa-Gómez, D.R.; Corrêa-Ferreira, B.S.; Kraemer, B.; Pasini, A.; Husch, P.E.; Delfino Vieira, C.E.; Reis Martinez, C.B.; Negrão Lopes, I.O. Prevalence, damage, management and insecticide resistance of stink bug populations (Hemiptera: Pentatomidae) in commodity crops. *Agric. For. Entomol.* **2020**, *22*, 99–118. [[CrossRef](#)]
- Greene, J.K.; Baum, J.A.; Benson, E.P.; Bundy, C.S.; Jones, W.A.; Kennedy, G.G.; McPherson, J.E.; Musser, F.R.; Reay-Jones, F.P.F.; Toews, M.D.; et al. General insect management. In *Invasive Stink Bugs and Related Species (Pentatomoidea)*; McPherson, J.E., Ed.; CRC Press: Boca Raton, FL, USA, 2018; pp. 729–774.
- Horowitz, A.R.; Ellsworth, P.C.; Ishaaya, I. Biorational pest control—An Overview. In *Biorational Control of Arthropod Pests: Application and Resistance Management*; Springer: Dordrecht, The Netherlands, 2009; pp. 1–20.
- Abe, Y.; Mishiro, K.; Takashi, M. Symbiont of brown-winged green bug, *Plautia stali* Scott. *Jpn. J. Appl. Entomol. Zool.* **1995**, *39*, 109–115. [[CrossRef](#)]
- Prado, S.S.; Almeida, R.P.P. Role of symbiotic gut bacteria in the development of *Acrosternum hilare* and *Murgantia histrionica*. *Entomol. Exp. Appl.* **2009**, *132*, 21–29. [[CrossRef](#)]

11. Prado, S.S.; Rubinoff, D.; Almeida, R.P.P. Vertical transmission of a pentatomid caeca-associated symbiont. *Entomol. Exp. Appl.* **2006**, *99*, 577–585. [[CrossRef](#)]
12. Bistolas, K.S.I.; Sakamoto, R.I.; Fernandes, J.A.M.; Goffredi, S.K. Symbiont polyphyly, co-evolution, and necessity in pentatomid stinkbugs from Costa Rica. *Front. Microbiol.* **2014**, *5*, 349. [[CrossRef](#)] [[PubMed](#)]
13. Douglas, A.E. Microbial brokers of insect-plant interactions revisited. *J. Chem. Ecol.* **2013**, *39*, 952–961. [[CrossRef](#)]
14. Prado, S.S.; Almeida, R.P.P. Phylogenetic placement of pentatomid stink bug gut symbionts. *Curr. Microbiol.* **2009**, *58*, 64–69. [[CrossRef](#)]
15. Kikuchi, Y.; Prado, S.S.; Jenkins, T.M. Symbiotic microorganisms associated with Pentatomoidea. In *Invasive Stink Bugs and Related Species (Pentatomoidea): Biology, Higher Systematics, Semiochemistry, and Management*; CRC Press: Boca Raton, FL, USA, 2018; pp. 643–674.
16. Weber, D.C.; Khirman, A.; Blassioli-Moraes, M.C.; Millar, J.G. Semiochemistry of Pentatomoidea. In *Invasive Stink Bugs and Related Species (Pentatomoidea): Biology, Higher Systematics, Semiochemistry, and Management*; CRC Press: Boca Raton, FL, USA, 2018; pp. 677–726.
17. Borges, M.; Blassioli-Moraes, M.C. The semiochemistry of Pentatomidae. In *Stink Bugs: Biorational Control Based on Communication Processes*; Čokl, A., Borges, M., Eds.; CRC Press: Boca Raton, FL, USA, 2017; pp. 116–124.
18. Cardé, R.T. Defining attraction and aggregation pheromones: Teleological versus functional perspectives. *J. Chem. Ecol.* **2014**, *40*, 519–520. [[CrossRef](#)] [[PubMed](#)]
19. Gonella, E.; Orrù, B.; Marasco, R.; Daffonchio, D.; Alma, A. Disruption of host-symbiont associations for the symbiotic control and management of pentatomid agricultural pests—A Review. *Front. Microbiol.* **2020**, *11*, 547031. [[CrossRef](#)]
20. Karamipour, N.; Fathipour, Y.; Mehrabadi, M. Gammaproteobacteria as essential primary symbionts in the striped shield bug, *Graphosoma lineatum* (Hemiptera: Pentatomidae). *Sci. Rep.* **2016**, *6*, 33168. [[CrossRef](#)] [[PubMed](#)]
21. Kashkouli, M.; Fathipour, Y.; Mehrabadi, M. Potential management tactics for pistachio stink bugs, *Brachynema germari*, *Acrosternum heegeri* and *Acrosternum arabicum* (Hemiptera: Pentatomidae): High temperature and chemical surface sterilants leading to symbiont suppression. *J. Econ. Entomol.* **2019**, *112*, 244–254. [[CrossRef](#)]
22. Kikuchi, Y.; Hosokawa, T.; Nikoh, N.; Fukatsu, T. Gut symbiotic bacteria in the cabbage bugs *Eurydema rugosa* and *Eurydema dominulus* (Heteroptera: Pentatomidae). *Appl. Entomol. Zool.* **2012**, *47*, 1–8. [[CrossRef](#)]
23. Taylor, C.M.; Coffey, P.L.; Delay, B.D.; Dively, G.P. The importance of gut symbionts in the development of the brown marmorated stink bug, *Halyomorpha halys* (Stål). *PLoS ONE* **2014**, *9*, e90312. [[CrossRef](#)] [[PubMed](#)]
24. Taylor, C.; Johnson, V.; Dively, G. Assessing the use of antimicrobials to sterilize brown marmorated stink bug egg masses and prevent symbiont acquisition. *J. Pest Sci.* **2017**, *90*, 1287–1294. [[CrossRef](#)]
25. Laumann, R.A.; Maccagnan, D.H.B.; Čokl, A. Use of vibratory signals for stink bug monitoring and control. In *Stink Bugs: Biorational Control Based on Communication Processes*; CRC Press: Boca Raton, FL, USA, 2017; pp. 226–245.
26. Cocroft, R.B.; Rodríguez, R.L. The behavioral ecology of insect vibrational communication. *BioScience* **2005**, *55*, 323–334. [[CrossRef](#)]
27. Claridge, M. Insect sounds and communication—An introduction. In *Insect Sounds and Communication: Physiology, Behaviour, Ecology and Evolution*, 1st ed.; Drosopoulos, S., Claridge, M.F., Eds.; CRC Press: Boca Raton, FL, USA, 2005; pp. 3–9.
28. Hill, P.; Lakes-Harlan, R.; Mazzoni, V.; Narins, P.M.; Virant-Doberlet, M.; Wessel, A. (Eds.) *Biotremology: Studying Vibrational Behavior*; Springer International Publishing: Berlin/Heidelberg, Germany, 2019; Volume 8, pp. 3–49.
29. Hill, P.S.M. Vibration and animal communication: A Review. *Am. Zool.* **2001**, *41*, 1135–1142. [[CrossRef](#)]
30. Čokl, A.; Žunič-Kosi, A.; Virant-Doberlet, M. Stink bug communication network and environment. In *Stink Bugs: Biorational Control Based on Communication Processes*; Čokl, A., Borges, M., Eds.; CRC Press: Boca Raton, FL, USA, 2017; pp. 165–179.
31. Čokl, A.; Žunič-Kosi, A.; Stritih-Peljhan, N.; Blassioli-Moraes, M.C.; Laumann, R.A.; Borges, M. Stink bug communication and signal detection in a plant environment. *Insects* **2021**, *12*, 1058. [[CrossRef](#)]
32. Čokl, A.; Žunič-Kosi, A.; Laumann, R.A. Stink bug communication with multimodal signals transmitted through air and substrate. *Emerg. Sci. J.* **2019**, *3*, 407–424. [[CrossRef](#)]
33. Borges, M.; Jepson, P.C.; Howse, P.E. Long-range mate location and close-range courtship behaviour of the Green stink bug, *Nezara viridula* and its mediation by sex pheromones. *Entomol. Exp. Appl.* **1987**, *44*, 205–212. [[CrossRef](#)]
34. Čokl, A.; Virant-Doberlet, M. Communication with substrate-borne signals in small plant-dwelling insects. *Annu. Rev. Entomol.* **2003**, *48*, 29–50. [[CrossRef](#)]
35. Čokl, A.; Virant-Doberlet, M.; McDowell, A. Vibrational directionality in the southern green stink bug, *Nezara viridula* (L.), is mediated by female song. *Anim. Behav.* **1999**, *58*, 1277–1283. [[CrossRef](#)]
36. Ota, D.; Čokl, A. Mate location in the southern green stink bug, *Nezara viridula* (Heteroptera: Pentatomidae), mediated through substrate-borne signals on ivy. *J. Insect Behav.* **1991**, *4*, 441–447. [[CrossRef](#)]
37. Čokl, A.; Virant-Doberlet, M.; Stritih, N. The structure and function of songs emitted by southern green stink bugs from Brazil, Florida, Italy and Slovenia. *Physiol. Entomol.* **2000**, *25*, 196–205. [[CrossRef](#)]
38. Čokl, A.; Virant-Doberlet, M.; Zorovic, M. Sense organs involved in the vibratory communication of bugs. In *Insect Sounds and Communication*; Drosopoulos, S., Claridge, M.F., Eds.; CRC Press Taylor & Francis Group: Boca Raton, FL, USA, 2005; pp. 71–80.
39. Čokl, A.; Zorović, M.; Millar, J.G. Vibrational communication along plants by the stink bugs *Nezara viridula* and *Murgantia histrionica*. *Behav. Process.* **2007**, *75*, 40–54. [[CrossRef](#)] [[PubMed](#)]

40. Čokl, A.A.; Millar, J.G. Manipulation of insect signaling for monitoring and control of pest insects. In *Biorational Control of Arthropod Pests: Application and Resistance Management*; Ishaaya, I., Horowitz, R.A., Eds.; Springer: Berlin/Heidelberg, Germany, 2009; pp. 279–316.
41. Polajnar, J.; Čokl, A. The effect of vibratory disturbance on sexual behaviour of the southern green stink bug *Nezara viridula* (Heteroptera, Pentatomidae). *Open Life Sci.* **2008**, *3*, 189–197. [[CrossRef](#)]
42. Čokl, A.; Laumann, R.A.; Žunič Kosi, A.; Blassioli-Moraes, M.C.; Virant-Doberlet, M.; Borges, M. Interference of overlapping insect vibratory communication signals: An *Euschistus heros* model. *PLoS ONE* **2015**, *10*, e0130775. [[CrossRef](#)]
43. De Groot, M.; Čokl, A.; Virant-Doberlet, M. Effects of heterospecific and conspecific vibrational signal overlap and signal-to-noise ratio on male responsiveness in *Nezara viridula* (L.). *J. Exp. Biol.* **2010**, *213*, 3213–3222. [[CrossRef](#)]
44. Miklas, N.; Čokl, A.; Renou, M.; Virant-Doberlet, M. Variability of vibratory signals and mate choice selectivity in the southern green stink bug. *Behav. Process.* **2003**, *61*, 131–142. [[CrossRef](#)]
45. Mazzoni, V.; Nieri, R.; Eriksson, A.; Virant-Doberlet, M.; Polajnar, J.; Anfora, G.; Lucchi, A. Mating disruption by vibrational signals: State of the field and perspectives. In *Biotremology: Studying Vibrational Behavior; Animal Signals and Communication*; Hill, P.S.M., Lakes-Harlan, R., Mazzoni, V., Narins, P.M., Virant-Doberlet, M., Wessel, A., Eds.; Springer: Berlin/Heidelberg, Germany, 2019; Volume 6, p. 331.
46. Laumann, R.A.; Maccagnan, D.H.B.; Čokl, A.; Blassioli-Moraes, M.C.; Borges, M. Substrate-borne vibrations disrupt the mating behaviors of the neotropical brown stink bug, *Euschistus heros*: Implications for pest management. *J. Pest Sci.* **2018**, *91*, 995–1004. [[CrossRef](#)]
47. Dias, A.M.; Borges, M.; Blassioli Moraes, M.C.; Lorrán Figueira Coelho, M.; Čokl, A.; Laumann, R.A. Inhibitory copulation effect of vibrational rival female signals of three stink bug species as a tool for mating disruption. *Insects* **2021**, *12*, 177. [[CrossRef](#)]
48. Laumann, R.A.; Moraes, M.C.B.; Čokl, A.; Borges, M. Eavesdropping on sexual vibratory signals of stink bugs (Hemiptera: Pentatomidae) by the egg parasitoid *Telenomus podisi*. *Anim. Behav.* **2007**, *73*, 637–649. [[CrossRef](#)]
49. Laumann, R.A.; Čokl, A.; Lopes, A.P.S.; Ferreira, J.B.C.; Moraes, M.C.B.; Borges, M. Silent singers are not safe: Selective response of a parasitoid to substrate-borne vibratory signals of stink bugs. *Anim. Behav.* **2011**, *82*, 1175–1183. [[CrossRef](#)]
50. Kaplan, I. Attracting carnivorous arthropods with plant volatiles: The future of biocontrol or playing with fire? *Biol. Control* **2012**, *60*, 77–89. [[CrossRef](#)]
51. Mankin, R.W.; Hagstrum, D.W.; Smith, M.T.; Roda, A.L.; Kairo, M.T.K. Perspective and promise: A century of insect acoustic detection and monitoring. *Am. Entomol.* **2011**, *57*, 30–44. [[CrossRef](#)]
52. Mankin, R.W. Applications of acoustics in insect pest management. *CAB Rev.* **2012**, *7*, 1–7. [[CrossRef](#)]
53. Ganchev, T.; Potamitis, I. Automatic acoustic identification of singing insects. *Bioacoustics* **2007**, *16*, 281–328. [[CrossRef](#)]
54. Pinhas, J.; Soroker, V.; Hetzroni, A.; Mizrach, A.; Teicher, M.; Goldberger, J. Automatic acoustic detection of the red palm weevil. *Comput. Electron. Agric.* **2008**, *63*, 131–139. [[CrossRef](#)]
55. Korinšek, G.; Derlink, M.; Virant-Doberlet, M.; Tuma, T. An autonomous system of detecting and attracting leafhopper males using species- and sex-specific substrate borne vibrational signals. *Comput. Electron. Agric.* **2016**, *123*, 29–39. [[CrossRef](#)]
56. Lampson, B.D.; Han, Y.J.; Khalilian, A.; Greene, J.; Mankin, R.W.; Foreman, E.G. Automatic detection and identification of brown stink bug, *Euschistus servus*, and southern green stink bug, *Nezara viridula*, (Heteroptera: Pentatomidae) using intraspecific substrate-borne vibrational signals. *Comput. Electron. Agric.* **2013**, *91*, 154–159. [[CrossRef](#)]
57. Millar, J.G. Pheromones of True Bugs. In *The Chemistry of Pheromones and Other Semiochemicals II*; Schulz, S., Ed.; Springer: Berlin/Heidelberg, Germany, 2005; pp. 37–84. [[CrossRef](#)]
58. Moraes, M.C.B.; Pareja, M.; Laumann, R.A.; Borges, M. The chemical volatiles (semiochemicals) produced by neotropical stink bugs (Hemiptera: Pentatomidae). *Neotrop. Entomol.* **2008**, *37*, 489–505. [[CrossRef](#)]
59. Leal, W.S.; Kuwahara, S.; Shi, X.; Higuchi, H.; Marino, C.E.B.; Ono, M.; Meinwald, J. Male-released sex pheromone of the stink bug *Piezodorus hybneri*. *J. Chem. Ecol.* **1998**, *24*, 1817–1829. [[CrossRef](#)]
60. Endo, N.; Sasaki, R.; Muto, S. Pheromonal cross-attraction in true bugs (Heteroptera): Attraction of *Piezodorus hybneri* (Pentatomidae) to its pheromone versus the pheromone of *Riptortus pedestris* (Alydidae). *Environ. Entomol.* **2010**, *39*, 1973–1979. [[CrossRef](#)] [[PubMed](#)]
61. McBrien, H.L.; Millar, J.G.; Rice, R.E.; McElfresh, J.S.; Cullen, E.; Zalom, F.G. Sex attractant pheromone of the red-shouldered stink bug *Thyanta pallidivirens*: A pheromone blend with multiple redundant components. *J. Chem. Ecol.* **2002**, *28*, 1797–1818. [[CrossRef](#)] [[PubMed](#)]
62. Moraes, M.C.; Millar, J.G.; Laumann, R.A.; Sujii, E.R.; Pires, C.S.; Borges, M. Sex attractant pheromone from the neotropical red-shouldered stink bug, *Thyanta perditor* (F.). *J. Chem. Ecol.* **2005**, *31*, 1415–1427. [[CrossRef](#)] [[PubMed](#)]
63. Aldrich, J.R.; Oliver, J.E.; Lusby, W.R.; Kochansky, J.P.; Borges, M. Identification of male-specific volatiles from nearctic and neotropical stink bugs (Heteroptera: Pentatomidae). *J. Chem. Ecol.* **1994**, *20*, 1103–1111. [[CrossRef](#)]
64. Borges, M.; Aldrich, J.R. Attractant pheromone for nearctic stink bug, *Euschistus obscurus* (Heteroptera: Pentatomidae): Insight into a neotropical relative. *J. Chem. Ecol.* **1994**, *20*, 1095–1102. [[CrossRef](#)]
65. Borges, M.; Mori, K.; Costa, M.L.M.; Sujii, E.R. Behavioural evidence of methyl-2,6,10-trimethyltridecanoate as a sex pheromone of *Euschistus heros* (Het., Pentatomidae). *J. Appl. Entomol.* **1998**, *122*, 335–338. [[CrossRef](#)]
66. Fávaro, C.F.; Santos, T.B.; Zarbin, P.H.G. Defensive compounds and male-produced sex pheromone of the stink bug, *Agroecus griseus*. *J. Chem. Ecol.* **2012**, *38*, 1124–1132. [[CrossRef](#)]

67. Zarbin, P.H.G.; Fávares, C.F.; Vidal, D.M.; Rodrigues, M.A.C.M. Male-produced sex pheromone of the stink bug *Edessa meditabunda*. *J. Chem. Ecol.* **2012**, *38*, 825–835. [[CrossRef](#)]
68. Borges, M.; Birkett, M.; Aldrich, J.R.; Oliver, J.E.; Chiba, M.; Murata, Y.; Laumann, R.A.; Barrigossi, J.A.; Pickett, J.A.; Moraes, M.C.B. Sex attractant pheromone from the rice stalk stink bug, *Tibraca limbativentris* Stal. *J. Chem. Ecol.* **2006**, *32*, 2749–2761. [[CrossRef](#)]
69. Blassioli-Moraes, M.C.; Khrimian, A.; Michereff, M.F.F.; Magalhães, D.M.; Hickel, E.; De Freitas, T.F.S.; Barrigossi, J.A.F.; Laumann, R.A.; Silva, A.T.; Guggilapu, S.D.; et al. Male-produced sex pheromone of *Tibraca limbativentris* revisited: Absolute configurations of zingiberenol stereoisomers and their influence on chemotaxis behavior of conspecific females. *J. Chem. Ecol.* **2020**, *46*, 1–9. [[CrossRef](#)]
70. De Freitas, T.F.S.; Hickel, E.R.; Khrimian, A.; Borges, M.; Michereff, M.F.F.; Barrigossi, J.A.; Laumann, R.A.; Guggilapu, S.D.; Sant’Ana, J.; Blassioli-Moraes, M.C. Field responses of rice stalk stink bug, *Tibraca limbativentris*, to synthetic sex pheromone and isomers of 1,10-Bisaboladien-3-ol. *Neotrop. Entomol.* **2021**, *50*, 282–288. [[CrossRef](#)]
71. De Oliveira, M.W.M.; Borges, M.; Andrade, C.K.Z.; Laumann, R.A.; Barrigossi, J.A.F.; Blassioli-Moraes, M.C. Zingiberenol, (1S,4R,1’S)-4-(1’,5-Dimethylhex-4’-enyl)-1 methylcyclohex-2-en-1-ol, identified as the sex pheromone produced by males of the rice stink bug *Oebalus pocius* (Heteroptera: Pentatomidae). *J. Agric. Food Chem.* **2013**, *61*, 7777–7785. [[CrossRef](#)] [[PubMed](#)]
72. Prestwich, G.D. Composition of the scents of eight east african hemipterans. nymph-adult chemical polymorphism in Coreids. *Ann. Entomol. Soc. Am.* **1976**, *69*, 812–814. [[CrossRef](#)]
73. Gunawardena, N.E.; Herath, H.M.W.K.B. Significance of medium chain-alkanes as accompanying compounds in hemipteran defensive secretions: An investigation based on the defensive secretion of *Coridius janus*. *J. Chem. Ecol.* **1991**, *17*, 2449–2458. [[CrossRef](#)]
74. Sagar, C.V.; Janaiah, C.; Narender, E.R. Volatile constituents of metathoracic scent secretions of adult *Cyclopelta siccifolia* Westwood (Hemiptera: Pentatomidae). *Entomologia* **2000**, *25*, 39–46.
75. Meneses-Arias, M.G.; Cruz-López, L.; Huerta, G.; Rojas, J.C. Volatile compounds emitted by the stink bug *Antiteuchus innocens* (Hemiptera: Pentatomidae). *Fla. Entomol.* **2019**, *102*, 431. [[CrossRef](#)]
76. Nagnan, P.; Cassier, P.; Andre, M.; Llosa, J.F.; Guillaumin, D. Fine structure and physicochemical analysis of the metathoracic scent glands of *Lincus malevolus* (Rolston) and *L. spurcus* (Rolston) (Heteroptera: Pentatomidae). *Int. J. Insect Morphol. Embryol.* **1994**, *23*, 355–370. [[CrossRef](#)]
77. Cassier, P.; Nagnan, P.; Llosa, J.F.; Andre, M.; Guillaumin, D. Fine structure and physicochemical analysis of the nymphal and imaginal scent gland systems of *Lincus spurcus* (Rolston) (Heteroptera: Pentatomidae). *Int. J. Insect Morphol. Embryol.* **1994**, *23*, 371–382. [[CrossRef](#)]
78. Szczerbowski, D.; Schulz, S.; Zarbin, P.H.G. Total synthesis of four stereoisomers of methyl 4,8,12-trimethylpentadecanoate, a major component of the sex pheromone of the stink bug *Edessa meditabunda*. *Org. Biomol. Chem.* **2020**, *18*, 5034–5044. [[CrossRef](#)] [[PubMed](#)]
79. Borges, M.; Aldrich, J.R. Instar-specific defensive secretions of stink bugs (Heteroptera: Pentatomidae). *Experientia* **1992**, *48*, 893–896. [[CrossRef](#)]
80. Howard, J.J.; Wiemer, D.F. The defensive secretion of *Edessa rufomarginata*. *Naturwissenschaften* **1983**, *70*, 202–203. [[CrossRef](#)]
81. Tsuyuki, T.; Ogata, Y.; Yamamoto, I.; Shimi, K. Stink bug aldehydes. *Agric. Biol. Chem.* **1965**, *29*, 419–427. [[CrossRef](#)]
82. Sugie, H.; Yoshida, M.; Kawasaki, K.; Noguchi, H.; Moriya, S.; Takagi, K.; Fukuda, H.; Fujie, A.; Yamanaka, M.; Ohira, Y.; et al. Identification of the Aggregation Pheromone of the brown-winged green bug, *Plautia stali* Scott (Heteroptera: Pentatomidae). *Appl. Entomol. Zool.* **1996**, *31*, 427–431. [[CrossRef](#)]
83. Millar, J.G. Methyl (2E,4Z,6Z)-deca-2,4,6-trienoate, a thermally unstable, sex-specific compound from the stink bug *Thyanta pallidovirens*. *Tetrahedron Lett.* **1997**, *38*, 7971–7972. [[CrossRef](#)]
84. Fucarino, A.; Millar, J.G.; McElfresh, J.S.; Colazza, S. Chemical and physical signals mediating conspecific and heterospecific aggregation behavior of first instar stink bugs. *J. Chem. Ecol.* **2004**, *30*, 1257–1269. [[CrossRef](#)] [[PubMed](#)]
85. Pal, E.; Allison, J.; Guignard, Q.; Hurley, B.P.; Slippers, B.; Fourie, G. Characterisation of the alarm pheromone of *Bathycyrtus distincta* (Pentatomidae). *J. Chem. Ecol.* **2022**, *48*, 791–801. [[CrossRef](#)]
86. Harris, C.; Abubeker, S.; Yu, M.; Leskey, T.; Zhang, A. Semiochemical production and laboratory behavior response of the brown marmorated stink bug, *Halyomorpha halys*. *PLoS ONE* **2015**, *10*, e0140876. [[CrossRef](#)]
87. Khrimian, A.; Zhang, A.; Weber, D.C.; Ho, H.-Y.; Aldrich, J.R.; Vermillion, K.E.; Siegler, M.A.; Shirali, S.; Guzman, F.; Leskey, T.C. Discovery of the aggregation pheromone of the brown marmorated stink bug (*Halyomorpha halys*) through the creation of stereoisomeric libraries of 1-bisabolen-3-ols. *J. Nat. Prod.* **2014**, *77*, 1708–1717. [[CrossRef](#)]
88. Fraga, D.F.; Parker, J.; Busoli, A.C.; Hamilton, G.C.; Nielsen, A.L.; Rodriguez-Saona, C. Behavioral responses of predaceous minute pirate bugs to tridecane, a volatile emitted by the brown marmorated stink bug. *J. Pest Sci.* **2017**, *90*, 1107–1118. [[CrossRef](#)]
89. Nixon, L.J.; Morrison, W.R.; Rice, K.B.; Brockerhoff, E.G.; Leskey, T.C.; Guzman, F.; Khrimian, A.; Goldson, S.; Rostás, M. Identification of volatiles released by diapausing brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae). *PLoS ONE* **2018**, *13*, e0191223. [[CrossRef](#)] [[PubMed](#)]
90. Zhong, Y.Z.; Zhang, J.P.; Ren, L.L.; Tang, R.; Zhan, H.X.; Chen, G.H.; Zhang, F. Behavioral responses of the egg parasitoid *Trissolcus japonicus* to volatiles from adults of its stink bug host, *Halyomorpha halys*. *J. Pest Sci.* **2017**, *90*, 1097–1105. [[CrossRef](#)]

91. Solomon, D.; Dutcher, D.; Raymond, T. Characterization of *Halyomorpha halys* (brown marmorated stink bug) biogenic volatile organic compound emissions and their role in secondary organic aerosol formation. *J. Air Waste Manag. Assoc.* **2013**, *63*, 1264–1269. [[CrossRef](#)] [[PubMed](#)]
92. Zhong, Y.-Z.; Tang, R.; Zhang, J.-P.; Yang, S.-Y.; Chen, G.-H.; He, K.-L.; Wang, Z.-Y.; Zhang, F. Behavioral Evidence and olfactory reception of a single alarm pheromone component in *Halyomorpha halys*. *Front. Physiol.* **2018**, *9*, 1610. [[CrossRef](#)]
93. Fávoro, C.F.; Zarbin, P.H.G. Identification of (Z)-4- and 1-tridecene in the metathoracic gland secretions of stink bugs employing the GC/FT-IR technique. *J. Chem. Ecol.* **2013**, *39*, 1182–1185. [[CrossRef](#)]
94. Durak, D.; Kalender, Y. Structure and chemical analysis of the metathoracic scent glands of *Carpocoris fuscispinus* (Boheman, 1851) (Heteroptera: Pentatomidae) from Turkey. *Turk. J. Zool.* **2012**, *36*, 526–533. [[CrossRef](#)]
95. Krall, B.S.; Bartelt, R.J.; Lewis, C.J.; Whitman, D.W. Chemical defense in the stink bug *Cosmopepla bimaculata*. *J. Chem. Ecol.* **1999**, *25*, 2477–2494. [[CrossRef](#)]
96. Noge, K.; Prudic, K.L.; Becerra, J.X. Defensive roles of (E)-2-alkenals and related compounds in heteroptera. *J. Chem. Ecol.* **2012**, *38*, 1050–1056. [[CrossRef](#)]
97. Aldrich, J.R.; Hoffmann, M.P.; Kochansky, J.P.; Lusby, W.R.; Eger, J.E.; Payne, J.A. Identification and attractiveness of a major pheromone component for nearctic *Euschistus* spp. stink bugs (Heteroptera: Pentatomidae). *Environ. Entomol.* **1991**, *20*, 477–483. [[CrossRef](#)]
98. Borges, M.; Schmidt, F.G.V.; Sujii, E.R.; Medeiros, M.A.; Mori, K.; Zarbin, P.H.G.; Ferreira, J.T.B. Field responses of stink bugs to the natural and synthetic pheromone of the Neotropical brown stink bug, *Euschistus heros* (Heteroptera: Pentatomidae). *Physiol. Entomol.* **1998**, *23*, 202–207. [[CrossRef](#)]
99. Pareja, M.; Borges, M.; Laumann, R.A.; Moraes, M.C.B. Inter- and intraspecific variation in defensive compounds produced by five neotropical stink bug species (Hemiptera: Pentatomidae). *J. Insect Physiol.* **2007**, *53*, 639–648. [[CrossRef](#)] [[PubMed](#)]
100. Lopes, R.B.; Laumann, R.A.; Blassioli-Moraes, M.C.; Borges, M.; Faria, M. The fungistatic and fungicidal effects of volatiles from metathoracic glands of soybean-attacking stink bugs (Heteroptera: Pentatomidae) on the entomopathogen *Beauveria bassiana*. *J. Invertebr. Pathol.* **2015**, *132*, 77–85. [[CrossRef](#)] [[PubMed](#)]
101. Lima, B.S.A.; Martínez, L.C.; Plata-Rueda, A.; Dos Santos, M.H.; De Oliveira, E.E.; Zanoncio, J.C.; Serrão, J.E. Interaction between predatory and phytophagous stink bugs (Heteroptera: Pentatomidae) promoted by secretion of scent glands. *Chemoecology* **2021**, *31*, 209–219. [[CrossRef](#)]
102. Aldrich, J.R.; Rosi, M.C.; Bin, F. Behavioral correlates for minor volatile compounds from stink bugs (Heteroptera: Pentatomidae). *J. Chem. Ecol.* **1995**, *21*, 1907–1920. [[CrossRef](#)] [[PubMed](#)]
103. Marques, F.A.; Wendler, E.P.; Maia, B.H.L.N.S.; Ventura, M.U.; Arruda-Gatti, I.C. Identification of defensive compounds in metathoracic glands of adults of the stink bug *Dichelops melacanthus* (Hemiptera: Pentatomidae). *J. Braz. Chem. Soc.* **2007**, *18*, 1242–1246. [[CrossRef](#)]
104. Yang, C.Y.; Seo, M.H.; Lee, S.C. Male-produced aggregation pheromone of the sloe bug, *Dolycoris baccarum* L. (Hemiptera: Heteroptera: Pentatomidae). *J. Chem. Ecol.* **2019**, *45*, 818–822. [[CrossRef](#)]
105. Durak, D. Morphology and chemical composition of metathoracic scent glands in *Dolycoris baccarum* (Linnaeus, 1758) (Heteroptera: Pentatomidae). *Acta Zool.* **2008**, *89*, 193–199. [[CrossRef](#)]
106. Schildknecht, H.; Holoubek, K.; Weis, K.H.; Krämer, H. Defensive substances of the arthropods, their isolation and identification. *Angew. Chem. Int. Ed.* **1964**, *3*, 73–82. [[CrossRef](#)]
107. Moliterno, A.A.C.; De Melo, D.J.; Zarbin, P.H.G. Identification of zingiberenol and murgantiol as components of the aggregation-sex pheromone of the rice stink bug, *Mormidea v-luteum* (Heteroptera: Pentatomidae). *J. Chem. Ecol.* **2020**, *47*, 1–9. [[CrossRef](#)]
108. Blum, M.S.; Traynham, J.G.; Chidester, J.B.; Boggus, J.D. *n*-Tridecane and *trans*-2-heptenal in scent gland of the rice stink bug *Oebalus pugnax* (F.). *Science* **1960**, *132*, 1480–1481. [[CrossRef](#)]
109. Mori, K.; Tashiro, T.; Yoshimura, T.; Takita, M.; Tabata, J.; Hiradate, S.; Sugie, H. Determination of the absolute configuration of the male aggregation pheromone, 2-methyl-6-(4'-methylenebicyclo[3.1.0]hexyl)hept-2-en-1-ol, of the stink bug *Eysarcoris lewisi* (Distant) as 2*Z*,6*R*,1'*S*,5'*S* by its synthesis. *Tetrahedron Lett.* **2008**, *49*, 354–357. [[CrossRef](#)]
110. Takita, M.; Sugie, H.; Tabata, J.; Ishii, S.; Hiradate, S. Isolation and estimation of the aggregation pheromone from *Eysarcoris lewisi* (Distant) (Heteroptera: Pentatomidae). *Appl. Entomol. Zool.* **2008**, *43*, 11–17. [[CrossRef](#)]
111. Alizadeh, B.H.; Kuwahara, S.; Leal, W.S.; Men, H.-C. Synthesis of the racemate of (Z)-*exo*- α -bergamotenal, a pheromone component of the white-spotted spined bug, *Eysarcoris parvus* Uhler. *Biosci. Biotechnol. Biochem.* **2002**, *66*, 1415–1418. [[CrossRef](#)]
112. Everton, I.J.; Games, D.E.; Staddon, B.W. Composition of scents from *Apodiphys amygdali*. *Ann. Entomol. Soc. Am.* **1974**, *67*, 815–816. [[CrossRef](#)]
113. Blum, M.S. The presence of 2-hexenal in the scent gland of the pentatomid *Brochymena quadripustulata*. *Ann. Entomol. Soc. Am.* **1961**, *54*, 410–412. [[CrossRef](#)]
114. Kou, R.; Tang, D.S.; Chow, Y.S. Alarm pheromone of pentatomid bug, *Erthesina fullo* Thunberg (Hemiptera: Pentatomidae). *J. Chem. Ecol.* **1989**, *15*, 2695–2702. [[CrossRef](#)] [[PubMed](#)]
115. Waterhouse, D.F.; Forss, D.A.; Hackman, R.H. Characteristic odour components of the scent of stink bugs. *J. Insect Physiol.* **1961**, *6*, 113–121. [[CrossRef](#)]
116. Aldrich, J.R.; Numata, H.; Borges, M.; Bin, F.; Waite, G.K.; Lusby, W.R. Artifacts and pheromone blends from *Nezara* spp. and other stink bugs (Heteroptera: Pentatomidae). *Z. Natforsch. C* **1993**, *48*, 73–79. [[CrossRef](#)]

117. McBrien, H.L.; Millar, J.G.; Gottlieb, L.; Chen, X.; Rice, R.E. Male-produced sex attractant pheromone of the green stink bug, *Acrosternum hilare* (Say). *J. Chem. Ecol.* **2001**, *27*, 1821–1839. [[CrossRef](#)]
118. Blassioli-Moraes, M.C.; Laumann, R.A.; Oliveira, M.W.M.; Woodcock, C.M.; Mayon, P.; Hooper, A.; Pickett, J.A.; Birkett, M.A.; Borges, M. Sex pheromone communication in two sympatric neotropical stink bug species *Chinavia ubica* and *Chinavia impicticornis*. *J. Chem. Ecol.* **2012**, *38*, 836–845. [[CrossRef](#)]
119. Aldrich, J.R.; Lusby, W.R.; Marron, B.E.; Nicolaou, K.C.; Hoffmann, M.P.; Wilson, L.T. Pheromone blends of green stink bugs and possible parasitoid selection. *Naturwissenschaften* **1989**, *76*, 173–175. [[CrossRef](#)]
120. Millar, J.G.; McBrien, H.M.; McElfresh, J.S. Field trials of aggregation pheromones for the stink bugs *Chlorochroa uhleri* and *Chlorochroa sayi* (Hemiptera: Pentatomidae). *J. Econ. Entomol.* **2010**, *103*, 1603–1612. [[CrossRef](#)] [[PubMed](#)]
121. Ho, H.-Y.; Millar, J.G. Identification and synthesis of male-produced sex pheromone components of the stink bugs *Chlorochroa ligata* and *Chlorochroa uhleri*. *J. Chem. Ecol.* **2001**, *27*, 2067–2095. [[CrossRef](#)] [[PubMed](#)]
122. Ho, H.Y.; Millar, J.G. Compounds in metathoracic glands of adults and dorsal abdominal glands of nymphs of the stink bugs, *Chlorochroa uhleri*, *C. sayi*, and *C. ligata* (Hemiptera: Pentatomidae). *Zool. Stud.* **2001**, *40*, 193–198.
123. Ho, H.Y.; Millar, J.G. Identification and synthesis of a male-produced sex pheromone from the stink bug *Chlorochroa sayi*. *J. Chem. Ecol.* **2001**, *27*, 1177–1201. [[CrossRef](#)]
124. Aldrich, J.R.; Oliver, J.E.; Lusby, W.R.; Kochansky, J.P.; Lockwood, J.A. Pheromone strains of the Cosmopolitan pest, *Nezara viridula* (Heteroptera: Pentatomidae). *J. Exp. Zool.* **1987**, *244*, 171–175. [[CrossRef](#)]
125. Baker, R.; Borges, M.; Cooke, N.G.; Herbert, R.H. Identification and synthesis of (Z)-(1'S,3'R,4'S)(-)-2-(3',4'-epoxy-4'-methylcyclohexyl)-6-methylhepta-2,5-diene, the sex pheromone of the southern green stinkbug, *Nezara viridula* (L.). *J. Chem. Soc. Chem. Commun.* **1987**, 414–416. [[CrossRef](#)]
126. Brézot, P.; Malosse, C.; Mori, K.; Renou, M. Bisabolene epoxides in sex pheromone in *Nezara viridula* (L.) (Heteroptera: Pentatomidae): Role of *cis* isomer and relation to specificity of pheromone. *J. Chem. Ecol.* **1994**, *20*, 3133–3147. [[CrossRef](#)]
127. Borges, M. Attractant compounds of the southern green stink bug, *Nezara viridula* (L.) (Heteroptera: Pentatomidae). *An. Soc. Entomol. Bras.* **1995**, *24*, 215–225. [[CrossRef](#)]
128. Lancaster, J.; Lehner, B.; Khimian, A.; Muchlinski, A.; Luck, K.; Köllner, T.G.; Weber, D.C.; Gundersen-Rindal, D.E.; Tholl, D. An IDS-Type sesquiterpene synthase produces the pheromone precursor (Z)- α -bisabolene in *Nezara viridula*. *J. Chem. Ecol.* **2019**, *45*, 187–197. [[CrossRef](#)]
129. Aldrich, J.R.; Blum, M.S.; Lloyd, H.A.; Fales, H.M. Pentatomid natural products—Chemistry and morphology of the III-IV dorsal abdominal glands of adults. *J. Chem. Ecol.* **1978**, *4*, 161–172. [[CrossRef](#)]
130. Lockwood, J.A.; Story, R.N. Defensive secretion of the southern green stink bug (Hemiptera: Pentatomidae) as an alarm Pheromone. *An. Soc. Entomol. Soc. Am.* **1987**, *80*, 686–691. [[CrossRef](#)]
131. Gilby, A.R.; Waterhouse, D.F. The composition of the scent of the green vegetable bug, *Nezara viridula*. *Proc. R. Soc. B* **1965**, *162*, 105–120. [[CrossRef](#)]
132. Pavis, C.; Malosse, C.; Ducrot, P.H.; Descoins, C. Dorsal abdominal glands in nymphs of southern green stink bug, *Nezara viridula* (L.) (heteroptera: Pentatomidae): Chemistry of secretions of five instars and role of (E)-4-oxo-2-decenal, compound specific to first instars. *J. Chem. Ecol.* **1994**, *20*, 2213–2227. [[CrossRef](#)]
133. Ishiwatari, T. Studies on the scent of stink bugs (Hemiptera: Pentatomidae): I. Alarm pheromone activity. *Appl. Entomol. Zool.* **1974**, *9*, 153–158. [[CrossRef](#)]
134. Fávaro, C.F.; Soldi, R.A.; Ando, T.; Aldrich, J.R.; Zarbin, P.H. (6R,10S)-Pallantione: The first ketone identified as sex pheromone in stink bugs. *Org. Lett.* **2013**, *15*, 1822–1825. [[CrossRef](#)] [[PubMed](#)]
135. Fávaro, C.F.; Rodrigues, M.A.C.D.M.; Aldrich, J.R.; Zarbin, P.H.G. Identification of semiochemicals in adults and nymphs of the stink bug *Pallantia macunaima* Grazia (Hemiptera: Pentatomidae). *J. Braz. Chem. Soc.* **2011**, *22*, 58–64. [[CrossRef](#)]
136. Fávaro, C.F.; Millar, J.G.; Zarbin, P.H.G. Identification and synthesis of the male-produced sex pheromone of the stink bug, *Pellaea stictica*. *J. Chem. Ecol.* **2015**, *41*, 859–868. [[CrossRef](#)]
137. Gomes, C.M.B.; Souza, J.P.A.; Millar, J.G.; Zarbin, P.H.G. Determination of the absolute configuration of the male-produced sex pheromone of the stink bug *Pellaea stictica*, (2R,4R,8R)-2,4,8,13-tetramethyltetradecan-1-ol by stereoselective synthesis coupled with enantiomeric resolution. *J. Chem. Ecol.* **2022**, *48*, 502–517. [[CrossRef](#)]
138. Durak, D.; Kalender, Y. Scanning electron microscopic and chemical study of the metathoracic scent glands system of *Rhaphigaster nebulosa* (Poda, 1761) (Heteroptera: Pentatomidae). *J. Entomol. Res.* **2009**, *11*, 21–29.
139. Borges, M.; Millar, J.G.; Laumann, R.A.; Moraes, M.C.B. A male-produced sex pheromone from the neotropical redbanded stink bug, *Piezodorus guildinii* (W.). *J. Chem. Ecol.* **2007**, *33*, 1235–1248. [[CrossRef](#)]
140. Zarbin, P.H.G.; Borges, M.; Dos Santos, A.A.; De Oliveira, A.R.M.; Simonelli, F.; Marques, F.D.A. Alarm pheromone system of stink bug *Piezodorus guildinii* (Heteroptera: Pentatomidae). *J. Braz. Chem. Soc.* **2000**, *11*, 424–428. [[CrossRef](#)]
141. Gilchrist, T.L.; Stansfield, F.; Cloudsley-Thompson, J.L. The odoriferous principle of *Piezodorus teretipes* (Stål) (Hemiptera: Pentatomoidea). *Proc. R. Entomol. Soc. Lond.* **1966**, *41*, 55–56. [[CrossRef](#)]
142. Oliver, J.E. A male-produced pheromone of the spined citrus bug. *Tetrahedron Lett.* **1992**, *33*, 891–894. [[CrossRef](#)]
143. James, D.G.; Heffer, R.; Amaike, M. Field attraction of *Biprorulus bibax* Breddin (Hemiptera: Pentatomidae) to synthetic aggregation pheromone and (E)-2-hexenal, a pentatomid defense chemical. *J. Chem. Ecol.* **1996**, *22*, 1697–1708. [[CrossRef](#)]

144. James, D.G.; Mori, K.; Aldrich, J.R.; Oliver, J.E. Flight-mediated attraction of *Biprorulus bibax* breddin (Hemiptera: Pentatomidae) to natural and synthetic aggregation pheromone. *J. Chem. Ecol.* **1994**, *20*, 71–80. [[CrossRef](#)]
145. Mori, K.; Amaike, M.; Oliver, J.E. Synthesis and absolute configuration of the hemiacetal pheromone of the spined citrus bug *Biprorulus bibax*. *Liebigs Ann. Chem.* **1992**, *1992*, 1185–1190. [[CrossRef](#)]
146. Mori, K.; Amaike, M.; Watanabe, H. New synthesis and revision of the absolute configuration of the hemiacetal pheromone of the spined citrus bug *Biprorulus bibax*. *Liebigs Ann. Chem.* **1993**, *1993*, 1287–1294. [[CrossRef](#)]
147. Macleod, J.K.; Howe, I.; Cable, J.; Blake, J.D.; Baker, J.T.; Smith, D. Volatile scent gland components of some tropical Hemiptera. *J. Insect Physiol.* **1975**, *21*, 1219–1224. [[CrossRef](#)]
148. Smith, R.M. The defensive secretion of *Vitellus insularis* (Heteroptera: Pentatomidae). *N. Z. J. Zool.* **1974**, *1*, 375–376. [[CrossRef](#)]
149. Arif, M.A.; Guarino, S.; Colazza, S.; Peri, E. The role of (*E*)-2-octenyl acetate as a pheromone of *Bagrada hilaris* (Burmeister): Laboratory and field evaluation. *Insects* **2020**, *11*, 109. [[CrossRef](#)] [[PubMed](#)]
150. Guarino, S.; De Pasquale, C.; Peri, E.; Alonzo, G.; Colazza, S. Role of volatile and contact pheromones in the mating behaviour of *Bagrada hilaris* (Heteroptera: Pentatomidae). *Eur. J. Entomol.* **2008**, *105*, 613–617. [[CrossRef](#)]
151. Aldrich, J.R.; Avery, J.W.; Lee, C.-J.; Graf, J.C.; Harrison, D.J.; Bin, F. Semiochemistry of cabbage bugs (Heteroptera: Pentatomidae: *Eurydema* and *Murgantia*). *J. Entomol. Sci.* **1996**, *31*, 172–182. [[CrossRef](#)]
152. Ishiwatari, T. Studies on the scent of stink bugs (Hemiptera: Pentatomidae): II. Aggregation heromone activity. *Appl. Entomol. Zool.* **1976**, *11*, 38–44. [[CrossRef](#)]
153. Khrimian, A.; Shirali, S.; Vermillion, K.E.; Siegler, M.A.; Guzman, F.; Chauhan, K.; Aldrich, J.R.; Weber, D.C. Determination of the stereochemistry of the aggregation pheromone of harlequin bug, *Murgantia histrionica*. *J. Chem. Ecol.* **2014**, *40*, 1260–1268. [[CrossRef](#)]
154. Zahn, D.K.; Moreira, J.A.; Millar, J.G. Identification, synthesis, and bioassay of a male-specific aggregation pheromone from the harlequin bug, *Murgantia histrionica*. *J. Chem. Ecol.* **2008**, *34*, 238–251. [[CrossRef](#)]
155. Lancaster, J.; Khrimian, A.; Young, S.; Lehner, B.; Luck, K.; Wallingford, A.; Ghosh, S.K.B.; Zerbe, P.; Muchlinski, A.; Marek, P.E.; et al. De novo formation of an aggregation pheromone precursor by an isoprenyl diphosphate synthase-related terpene synthase in the harlequin bug. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, E8634–E8641. [[CrossRef](#)]
156. Durak, D.; Kalender, Y. Fine structure and chemical analysis of the metathoracic scent gland secretion in *Graphosoma lineatum* (Linnaeus, 1758) (Heteroptera, Pentatomidae). *C. R. Biol.* **2009**, *332*, 34–42. [[CrossRef](#)]
157. Šanda, M.; Žáček, P.; Streinz, L.; Dračinský, M.; Koutek, B. Profiling and characterization of volatile secretions from the European stink bug *Graphosoma lineatum* (Heteroptera: Pentatomidae) by two-dimensional gas chromatography/time-of-flight mass spectrometry. *J. Chromatogr. B* **2012**, *881–882*, 69–75. [[CrossRef](#)] [[PubMed](#)]
158. Durak, D.; Kalender, Y. Fine structure and chemical analysis of the metathoracic scent glands *Graphosoma semipunctatum* (Fabricius, 1775) (Heteroptera, Pentatomidae). *J. Appl. Biol. Sci.* **2007**, *1*, 43–50.
159. Endo, N.; Yasuda, T.; Wada, T.; Muto, S.E.; Sasaki, R. Age-related and individual variation in male *Piezodorus hybneri* (Heteroptera: Pentatomidae) pheromones. *Psyche* **2012**, *2012*, 608572. [[CrossRef](#)]
160. Miklas, N.; Renou, M.; Malosse, I.; Malosse, C. Repeatability of pheromone blend composition in individual males of the Southern green stink bug, *Nezara viridula*. *J. Chem. Ecol.* **2000**, *26*, 2473–2485. [[CrossRef](#)]
161. Moraes, M.C.B.; Borges, M.; Pareja, M.; Vieira, H.G.; De Souza Sereno, F.T.P.; Laumann, R.A. Food and humidity affect sex pheromone ratios in the stink bug, *Euschistus heros*. *Physiol. Entomol.* **2008**, *33*, 43–50. [[CrossRef](#)]
162. Ryan, M.A.; Moore, C.J.; Walter, G.H. Individual variation in pheromone composition in *Nezara viridula* (Heteroptera: Pentatomidae): How valid is the basis for designating “pheromone strains”? *Comp. Biochem. Physiol. B Biochem. Mol. Biol.* **1995**, *111*, 189–193. [[CrossRef](#)]
163. Cullen, E.M.; Zalom, F.G. Relationship between *Euschistus conspersus* (Hem., Pentatomidae) pheromone trap catch and canopy samples in processing tomatoes. *J. Appl. Entomol.* **2005**, *129*, 505–514. [[CrossRef](#)]
164. Zapponi, L.; Nieri, R.; Zaffaroni-Caorsi, V.; Pugno, N.M.; Mazzoni, V. Vibrational calling signals improve the efficacy of pheromone traps to capture the brown marmorated stink bug. *J. Pest Sci.* **2023**, *96*, 587–597. [[CrossRef](#)]
165. Mazzoni, V.; Polajnar, J.; Baldini, M.; Rossi Stacconi, M.V.; Anfora, G.; Guidetti, R.; Maistrello, L. Use of substrate-borne vibrational signals to attract the brown marmorated stink bug, *Halyomorpha halys*. *J. Pest Sci.* **2017**, *90*, 1219–1229. [[CrossRef](#)]
166. Aldrich, J. Chemical ecology of the Heteroptera. *Ann. Rev. Entomol.* **1988**, *33*, 211–238. [[CrossRef](#)]
167. Ho, H.Y.; Kou, R.; Tseng, H.K. Semiochemicals from the predatory stink bug *Eocanthecona furcellata* (Wolff): Components of metathoracic gland, dorsal abdominal gland, and sternal gland secretions. *J. Chem. Ecol.* **2003**, *29*, 2101–2114. [[CrossRef](#)] [[PubMed](#)]
168. Pavis, C. Les sécrétions exocrines des hétéroptères point bibliographique. *Agronomie* **1987**, *7*, 547–561. [[CrossRef](#)]
169. Staddon, B.W. The Scent Glands of Heteroptera. In *Advances in Insect Physiology*; Treherne, J.E., Berridge, M.J., Wigglesworth, V.B., Eds.; Academic Press: Cambridge, MA, USA, 1989; Volume 14, pp. 351–418.
170. Kment, P.; Vilímová, J. Thoracic scent efferent system of Pentatomoidea (Hemiptera: Heteroptera): A review of terminology. *Zootaxa* **2010**, *2706*, 1–77. [[CrossRef](#)]
171. Lewis, W.J.; Martin, W.R. Semiochemicals for use with parasitoids: Status and future. *J. Chem. Ecol.* **1990**, *16*, 3067–3089. [[CrossRef](#)] [[PubMed](#)]
172. Powell, W.; Pickett, J.A. Manipulation of parasitoids for aphid pest management: Progress and prospects. *Pest Manag. Sci.* **2003**, *59*, 149–155. [[CrossRef](#)] [[PubMed](#)]

173. Colazza, S.; Salerno, G.; Wajnberg, E. Volatile and contact chemicals released by *Nezara viridula* (Heteroptera: Pentatomidae) have a kairomonal effect on the egg parasitoid *Trissolcus basalus* (Hymenoptera: Scelionidae). *Biol. Control* **1999**, *16*, 310–317. [CrossRef]
174. Laumann, R.A.; Aquino, M.F.S.; Moraes, M.C.B.; Pareja, M.; Borges, M. Response of the egg parasitoids *Trissolcus basalus* and *Telenomus podisi* to compounds from defensive secretions of stink bugs. *J. Chem. Ecol.* **2009**, *35*, 8–19. [CrossRef] [PubMed]
175. Vieira, C.R.; Blassioli-Moraes, M.C.; Borges, M.; Pires, C.S.S.; Sujii, E.R.; Laumann, R.A. Field evaluation of (*E*)-2-hexenal efficacy for behavioral manipulation of egg parasitoids in soybean. *BioControl* **2014**, *59*, 525–537. [CrossRef]
176. Mattiacci, L.; Vinson, S.B.; Williams, H.J.; Aldrich, J.R.; Bin, F. A long-range attractant kairomone for egg parasitoid *Trissolcus basalus*, isolated from defensive secretion of its host, *Nezara viridula*. *J. Chem. Ecol.* **1993**, *19*, 1167–1181. [CrossRef]
177. Aldrich, J.R.; Khimian, A.; Camp, M.J. Methyl 2,4,6-decatrienoates attract stink bugs and tachinid parasitoids. *J. Chem. Ecol.* **2007**, *33*, 801–815. [CrossRef]
178. Aldrich, J.R.; Barros, T.M. Chemical attraction of male crab spiders (Araneae, Thomisidae) and kleptoparasitic flies (Diptera, Milichiidae and Chloropidae). *J. Arachnol.* **1995**, *23*, 212–214.
179. Eisner, T.; Eisner, M.; Deyrup, M. Chemical attraction of kleptoparasitic flies to heteropteran insects caught by orb-weaving spiders. *Proc. Natl. Acad. Sci. USA* **1991**, *88*, 8194–8197. [CrossRef]
180. Colazza, S.; Cusumano, A.; Lo Giudice, D.; Peri, E. Chemo-orientation responses in hymenopteran parasitoids induced by substrate-borne semiochemicals. *BioControl* **2014**, *59*, 1–17. [CrossRef]
181. Moraes, M.C.B.; Pareja, M.; Laumann, R.A.; Hoffmann-Campo, C.B.; Borges, M. Response of the parasitoid *Telenomus podisi* to induced volatiles from soybean damaged by stink bug herbivory and oviposition. *J. Plant Interact.* **2008**, *3*, 111–118. [CrossRef]
182. Conti, E.; Salerno, G.; Bin, F.; Williams, H.J.; Vinson, S.B. Chemical cues from *Murgantia histrionica* eliciting host location and recognition in the egg parasitoid *Trissolcus brochymenae*. *J. Chem. Ecol.* **2003**, *29*, 115–130. [CrossRef]
183. Silva, C.C.; Moraes, M.C.B.; Laumann, R.A.; Borges, M. Sensory response of the egg parasitoid *Telenomus podisi* to stimuli from the bug *Euschistus heros*. *Pesqui. Agropecu. Bras.* **2006**, *41*, 1093–1098. [CrossRef]
184. Borges, M.; Colazza, S.; Ramirez-Lucas, P.; Chauhan, K.R.; Moraes, M.C.B.; Richard Aldrich, J. Kairomonal effect of walking traces from *Euschistus heros* (Heteroptera: Pentatomidae) on two strains of *Telenomus podisi* (Hymenoptera: Scelionidae). *Physiol. Entomol.* **2003**, *28*, 349–355. [CrossRef]
185. Boyle, S.M.; Weber, D.C.; Hough-Goldstein, J.; Hoelmer, K.A. Host kairomones influence searching behavior of *Trissolcus japonicus* (Hymenoptera: Scelionidae), a parasitoid of *Halyomorpha halys* (Heteroptera: Pentatomidae). *Environ. Entomol.* **2020**, *49*, 15–20. [CrossRef] [PubMed]
186. de Aquino, M.F.S.; Dias, A.M.; Borges, M.; Moraes, M.C.B.; Laumann, R.A. Influence of visual cues on host-searching and learning behaviour of the egg parasitoids *Telenomus podisi* and *Trissolcus basalus*. *Entomol. Exp. Appl.* **2012**, *145*, 162–174. [CrossRef]
187. Pålsson, J.; Porcel, M.; Dekker, T.; Tasin, M. Attract, reward and disrupt: Responses of pests and natural enemies to combinations of habitat manipulation and semiochemicals in organic apple. *J. Pest Sci.* **2022**, *95*, 619–631. [CrossRef]
188. Simpson, M.; Gurr, G.M.; Simmons, A.T.; Wratten, S.D.; James, D.G.; Leeson, G.; Nicol, H.I.; Orre-Gordon, G.U.S. Attract and reward: Combining chemical ecology and habitat manipulation to enhance biological control in field crops. *J. Appl. Ecol.* **2011**, *48*, 580–590. [CrossRef]
189. Fountain, M.T.; Deakin, G.; Farman, D.; Hall, D.; Jay, C.; Shaw, B.; Walker, A. An effective ‘push–pull’ control strategy for European tarnished plant bug, *Lygus rugulipennis* (Heteroptera: Miridae), in strawberry using synthetic semiochemicals. *Pest Manag. Sci.* **2021**, *77*, 2747–2755. [CrossRef] [PubMed]
190. Niu, Y.; Han, S.; Wu, Z.; Pan, C.; Wang, M.; Tang, Y.; Zhang, Q.-H.; Tan, G.; Han, B. A push–pull strategy for controlling the tea green leafhopper (*Empoasca flavescens* F.) using semiochemicals from *Tagetes erecta* and *Flemingia macrophylla*. *Pest Manag. Sci.* **2022**, *78*, 2161–2172. [CrossRef]
191. Zhang, Z.; Sun, X.; Luo, Z.; Gao, Y.; Chen, Z. The manipulation mechanism of “push–pull” habitat management strategy and advances in its application. *Acta Ecol. Sin.* **2013**, *33*, 94–101. [CrossRef]
192. Wertheim, B.; Van Baalen, E.J.A.; Dicke, M.; Vet, L.E.M. Pheromone-mediated aggregation in nonsocial arthropods: An evolutionary ecological perspective. *Ann. Rev. Entomol.* **2005**, *50*, 321–346. [CrossRef]
193. Toyama, M.; Ihara, F.; Yaginuma, K. Formation of aggregations in adults of the brown marmorated stink bug, *Halyomorpha halys* (Stal) (Heteroptera: Pentatomidae): The role of antennae in short-range locations. *Appl. Entomol. Zool.* **2006**, *41*, 309–315. [CrossRef]
194. Bedoya, C.L.; Brockerhoff, E.G.; Hayes, M.; Leskey, T.C.; Morrison, W.R.; Rice, K.B.; Nelson, X.J. Brown marmorated stink bug overwintering aggregations are not regulated through vibrational signals during autumn dispersal. *R. Soc. Open Sci.* **2020**, *7*, 201371. [CrossRef] [PubMed]
195. El-Sayed, A.M. The Pherobase: Database of Pheromones and Semiochemicals. 2019. Available online: <https://www.pherobase.com/database/family/family-Pentatomidae.php> (accessed on 5 January 2023).
196. Rebholz, Z.; Lancaster, J.; Larose, H.; Khimian, A.; Luck, K.; Sparks, M.E.; Gendreau, K.L.; Shewade, L.; Köllner, T.G.; Weber, D.C.; et al. Ancient origin and conserved gene function in terpene pheromone and defense evolution of stink bugs and hemipteran insects. *Insect Biochem. Mol. Biol.* **2023**, *152*, 103879. [CrossRef]
197. Weber, D.C.; Leskey, T.C.; Walsh, G.C.; Khimian, A. Synergy of aggregation pheromone with methyl (*E,E,Z*)-2,4,6-decatrienoate in attraction of *Halyomorpha halys* (Hemiptera: Pentatomidae). *J. Econ. Entomol.* **2014**, *107*, 1061–1068. [CrossRef] [PubMed]

198. Morrison, W.R.; Milonas, P.; Kapantaidaki, D.E.; Cesari, M.; Di Bella, E.; Guidetti, R.; Haye, T.; Maistrello, L.; Moraglio, S.T.; Piemontese, L.; et al. Attraction of *Halyomorpha halys* (Hemiptera: Pentatomidae) haplotypes in North America and Europe to baited traps. *Sci. Rep.* **2017**, *7*, 16941. [[CrossRef](#)]
199. Leskey, T.C.; Agnello, A.; Bergh, J.C.; Dively, G.P.; Hamilton, G.C.; Jentsch, P.; Khrimian, A.; Krawczyk, G.; Kuhar, T.P.; Lee, D.H.; et al. Attraction of the invasive *Halyomorpha halys* (Hemiptera: Pentatomidae) to traps baited with semiochemical stimuli across the United States. *J. Econ. Entomol.* **2015**, *44*, 746–756. [[CrossRef](#)]
200. Hogmire, H.W.; Leskey, T.C. An Improved trap for monitoring stink bugs (Heteroptera: Pentatomidae) in apple and peach orchards. *J. Entomol. Sci.* **2006**, *41*, 9–21. [[CrossRef](#)]
201. Leskey, T.C.; Hogmire, H.W. Monitoring stink bugs (Hemiptera: Pentatomidae) in Mid-Atlantic apple and peach orchards. *J. Econ. Entomol.* **2005**, *98*, 143–153. [[CrossRef](#)]
202. Cullen, E.M.; Zalom, F.G. Phenology-based field monitoring for consperse stink bug (Hemiptera: Pentatomidae) in processing tomatoes. *Environ. Entomol.* **2000**, *29*, 560–567. [[CrossRef](#)]
203. Krupke, C.H.; Brunner, J.F.; Doerr, M.D.; Kahn, A.D. Field attraction of the stink bug *Euschistus conspersus* (Hemiptera: Pentatomidae) to synthetic pheromone-baited host plants. *J. Econ. Entomol.* **2001**, *94*, 1500–1505. [[CrossRef](#)]
204. Yamanaka, T.; Teshiba, M.; Tuda, M.; Tsutsumi, T. Possible use of synthetic aggregation pheromones to control stinkbug *Plautia stali* in kaki persimmon orchards. *Agric. For. Entomol.* **2011**, *13*, 321–331. [[CrossRef](#)]
205. Morrison, W.R.; Cullum, J.P.; Leskey, T.C. Evaluation of trap designs and deployment strategies for capturing *Halyomorpha halys* (Hemiptera: Pentatomidae). *J. Econ. Entomol.* **2015**, *108*, 1683–1692. [[CrossRef](#)]
206. Morrison, W.R.; Lee, D.-H.; Short, B.D.; Khrimian, A.; Leskey, T.C. Establishing the behavioral basis for an attract-and-kill strategy to manage the invasive *Halyomorpha halys* in apple orchards. *J. Pest Sci.* **2016**, *89*, 81–96. [[CrossRef](#)]
207. Morrison, W.R.; Blaauw, B.R.; Short, B.D.; Nielsen, A.L.; Bergh, J.C.; Krawczyk, G.; Park, Y.-L.; Butler, B.; Khrimian, A.; Leskey, T.C. Successful management of *Halyomorpha halys* (Hemiptera: Pentatomidae) in commercial apple orchards with an attract-and-kill strategy. *Pest Manag. Sci.* **2019**, *75*, 104–114. [[CrossRef](#)] [[PubMed](#)]
208. Kikuchi, Y. Endosymbiotic bacteria in insects: Their diversity and culturability. *Microbes Environ.* **2009**, *24*, 195–204. [[CrossRef](#)] [[PubMed](#)]
209. Ishikawa, H. Insect symbiosis: An introduction. In *Insect Symbiosis*; Bourtzis, K., Miller, T.A., Eds.; CRC Press: Boca Raton, FL, USA, 2003; pp. 1–16.
210. Engel, P.; Moran, N.A. The gut microbiota of insects—Diversity in structure and function. *FEMS Microbiol. Rev.* **2013**, *37*, 699–735. [[CrossRef](#)] [[PubMed](#)]
211. Su, Q.; Zhou, X.; Zhang, Y. Symbiont-mediated functions in insect hosts. *Commun. Integr. Biol.* **2013**, *6*, e23804. [[CrossRef](#)] [[PubMed](#)]
212. Douglas, A.E. Phloem-sap feeding by animals: Problems and solutions. *J. Exp. Bot.* **2006**, *57*, 747–754. [[CrossRef](#)]
213. Sudakaran, S.; Kost, C.; Kaltenpoth, M. Symbiont acquisition and replacement as a source of ecological innovation. *Trends Microbiol.* **2017**, *25*, 375–390. [[CrossRef](#)] [[PubMed](#)]
214. Bansal, R.; Michel, A.P.; Sabree, Z.L. The crypt-dwelling primary bacterial symbiont of the polyphagous pentatomid pest *Halyomorpha halys* (Hemiptera: Pentatomidae). *Environ. Entomol.* **2014**, *43*, 617–625. [[CrossRef](#)] [[PubMed](#)]
215. Kashkouli, M.; Fathipour, Y.; Mehrabadi, M. Habitat visualization, acquisition features and necessity of the gammaproteobacterial symbiont of pistachio stink bug, *Acrosternum heegeri* (Hem.: Pentatomidae). *Bull. Entomol. Res.* **2020**, *110*, 22–33. [[CrossRef](#)]
216. Kikuchi, Y.; Fukatsu, T. Diversity of Wolbachia endosymbionts in Heteropteran bugs. *Appl. Environ. Microbiol.* **2003**, *69*, 6082–6090. [[CrossRef](#)]
217. Duron, O.; Noël, V. A wide diversity of *Pantoea* lineages are engaged in mutualistic symbiosis and cospeciation processes with stink bugs. *Environ. Microbiol. Rep.* **2016**, *8*, 715–727. [[CrossRef](#)]
218. Kenyon, L.J.; Meulia, T.; Sabree, Z.L. Habitat visualization and genomic analysis of “*Candidatus Pantoea carbekii*” the primary symbiont of the brown marmorated stink bug. *Genome Biol. Evol.* **2015**, *7*, 620–635. [[CrossRef](#)]
219. Otero-Bravo, A.; Goffredi, S.; Sabree, Z.L. Cladogenesis and genomic streamlining in extracellular endosymbionts of tropical stink bugs. *Genome Biol. Evol.* **2018**, *10*, 680–693. [[CrossRef](#)]
220. Medina, V.; Sardoy, P.M.; Soria, M.; Vay, C.A.; Gutkind, G.O.; Zavala, J.A. Characterized non-transient microbiota from stinkbug (*Nezara viridula*) midgut deactivates soybean chemical defenses. *PLoS ONE* **2018**, *13*, e0200161. [[CrossRef](#)]
221. Hosokawa, T.; Kikuchi, Y.; Nikoh, N.; Shimada, M.; Fukatsu, T. Strict host-symbiont cospeciation and reductive genome evolution in insect gut bacteria. *PLoS Biol.* **2006**, *4*, e337. [[CrossRef](#)]
222. Nikoh, N.; Hosokawa, T.; Oshima, K.; Hattori, M.; Fukatsu, T. Reductive evolution of bacterial genome in insect gut environment. *Genome Biol. Evol.* **2011**, *3*, 702–714. [[CrossRef](#)] [[PubMed](#)]
223. Geerinck, M.W.J.; Van Hee, S.; Gloder, G.; Crauwels, S.; Colazza, S.; Jacquemyn, H.; Cusumano, A.; Lievens, B. Diversity and composition of the microbiome associated with eggs of the Southern green stinkbug, *Nezara viridula* (Hemiptera: Pentatomidae). *Microbiologyopen* **2022**, *11*, e1337. [[CrossRef](#)] [[PubMed](#)]
224. Oishi, S.; Moriyama, M.; Koga, R.; Fukatsu, T. Morphogenesis and development of midgut symbiotic organ of the stinkbug *Plautia stali* (Hemiptera: Pentatomidae). *Zool. Lett.* **2019**, *5*, 16. [[CrossRef](#)] [[PubMed](#)]
225. Hosokawa, T.; Kikuchi, Y.; Shimada, M.; Fukatsu, T. Symbiont acquisition alters behaviour of stinkbug nymphs. *Biol. Lett.* **2008**, *4*, 45–48. [[CrossRef](#)] [[PubMed](#)]

226. Glasgow, H. The gastric caeca and the caecal bacteria of the Heteroptera. *Biol. Bull.* **1914**, *16*, 101–171. [[CrossRef](#)]
227. Hayashi, T.; Hosokawa, T.; Meng, X.Y.; Koga, R.; Fukatsu, T. Female-specific specialization of a posterior end region of the midgut symbiotic organ in *Plautia splendens* and allied stinkbugs. *Appl. Environ. Microbiol.* **2015**, *81*, 2603–2611. [[CrossRef](#)]
228. Hosokawa, T.; Ishii, Y.; Nikoh, N.; Fujie, M.; Satoh, N.; Fukatsu, T. Obligate bacterial mutualists evolving from environmental bacteria in natural insect populations. *Nat. Microbiol.* **2016**, *1*, 15011. [[CrossRef](#)]
229. Tada, A.; Kikuchi, Y.; Hosokawa, T.; Musolin, D.L.; Fujisaki, K.; Fukatsu, T. Obligate association with gut bacterial symbiont in Japanese populations of the southern green stinkbug *Nezara viridula* (Heteroptera: Pentatomidae). *Appl. Entomol. Zool.* **2011**, *46*, 483–488. [[CrossRef](#)]
230. Gonella, E.; Orrù, B.; Alma, A. Egg masses treatment with micronutrient fertilizers has a suppressive effect on newly-emerged nymphs of the brown marmorated stink bug *Halyomorpha halys*. *Entomol. Gen.* **2019**, *39*, 231–238. [[CrossRef](#)]
231. Mathews, C.R.; Barry, S. Compost tea reduces egg hatch and early stage nymphal development of *Halyomorpha halys* (Hemiptera: Pentatomidae). *Fla. Entomol.* **2014**, *97*, 1726–1732. [[CrossRef](#)]
232. Prokopy, R.J.; Owens, E.D. Visual detection of plants by herbivorous insects. *Ann. Rev. Entomol.* **1983**, *28*, 337–364. [[CrossRef](#)]
233. Tillman, P.G.; Cottrell, T.E. Use of pheromones for monitoring phytophagous stink bugs (Hemiptera: Pentatomidae). In *Stink Bugs: Biorational Control Based on Communication Processes*; Čokl, A., Borges, M., Eds.; CRC Press: Boca Raton, FL, USA, 2017; pp. 210–225.
234. Leskey, T.C.; Wright, S.E.; Short, B.D.; Khrimian, A. Development of behaviorally-based monitoring tools for the brown marmorated stink bug (Heteroptera: Pentatomidae) in commercial tree fruit orchards. *J. Entomol. Sci.* **2012**, *47*, 76–85. [[CrossRef](#)]
235. Joseph, S.V. Effect of trap color on captures of bagrada bug, *Bagrada hilaris* (Hemiptera: Pentatomidae). *J. Entomol. Sci.* **2014**, *49*, 318–321. [[CrossRef](#)]
236. DiMeglio, A.S.; Kuhar, T.P.; Weber, D.C. Color preference of harlequin bug (Heteroptera: Pentatomidae). *J. Econ. Entomol.* **2017**, *110*, 2275–2277. [[CrossRef](#)] [[PubMed](#)]
237. Duehl, A.J.; Cohnstaedt, L.W.; Arbogast, R.T.; Teal, P.E.A. Evaluating light attraction to increase trap efficiency for *Tribolium castaneum* (Coleoptera: Tenebrionidae). *J. Econ. Entomol.* **2011**, *104*, 1430–1435. [[CrossRef](#)] [[PubMed](#)]
238. Kim, M.-G.; Yang, J.-Y.; Lee, H.-S. Phototactic behavior: Repellent effects of cigarette beetle, *Lasioderma serricorne* (Coleoptera: Anobiidae), to light-emitting diodes. *J. Korean Soc. Appl. Biol. Chem.* **2013**, *56*, 331–333. [[CrossRef](#)]
239. Kim, K.N.; Huang, Q.Y.; Lei, C.L. Advances in insect phototaxis and application to pest management: A review. *Pest Manag. Sci.* **2019**, *75*, 3135–3143. [[CrossRef](#)]
240. Shimoda, M.; Honda, K.-I. Insect reactions to light and its applications to pest management. *Appl. Entomol. Zool.* **2013**, *48*, 413–421. [[CrossRef](#)]
241. Nielsen, A.L.; Holmstrom, K.; Hamilton, G.C.; Cambridge, J.; Ingerson-Mahar, J. Use of black light traps to monitor the abundance, spread, and flight behavior of *Halyomorpha halys* (Hemiptera: Pentatomidae). *J. Econ. Entomol.* **2013**, *106*, 1495–1502. [[CrossRef](#)]
242. Antignus, Y. Manipulation of wavelength-dependent behaviour of insects: An IPM tool to impede insects and restrict epidemics of insect-borne viruses. *Virus Res.* **2000**, *71*, 213–220. [[CrossRef](#)] [[PubMed](#)]
243. Coombe, P.E. Wavelength specific behaviour of the whitefly *Trialewodes vaporariorum* (Homoptera: Aleyrodidae). *J. Comp. Physiol.* **1981**, *144*, 83–90. [[CrossRef](#)]
244. Hardie, J. Spectral specificity for targeted flight in the black bean aphid, *Aphis fabae*. *J. Insect Physiol.* **1989**, *35*, 619–626. [[CrossRef](#)]
245. Cambridge, J.E.; Francoeur, L.; Hamilton, G.C. Brown marmorated stink bug (Hemiptera: Pentatomidae) attraction to various light stimuli. *Fla. Entomol.* **2017**, *100*, 583–588. [[CrossRef](#)]
246. Leskey, T.C.; Lee, D.-H.; Glenn, D.M.; Morrison, W.R. Behavioral responses of the invasive *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) to light-based stimuli in the laboratory and field. *J. Insect Behav.* **2015**, *28*, 674–692. [[CrossRef](#)]
247. Bergmann, P.; Richter, S.; Glöckner, N.; Betz, O. Morphology of hindwing veins in the shield bug *Graphosoma italicum* (Heteroptera: Pentatomidae). *Arthropod Struct. Dev.* **2018**, *47*, 375–390. [[CrossRef](#)]
248. Lee, D.H.; Leskey, T.C. Flight behavior of foraging and overwintering brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae). *Bull. Entomol. Res.* **2015**, *105*, 566–573. [[CrossRef](#)]
249. Wiman, N.G.; Walton, V.M.; Shearer, P.W.; Rondon, S.I.; Lee, J.C. Factors affecting flight capacity of brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae). *J. Pest Sci.* **2015**, *88*, 37–47. [[CrossRef](#)]
250. Minter, M.; Pearson, A.; Lim, K.S.; Wilson, K.; Chapman, J.W.; Jones, C.M. The tethered flight technique as a tool for studying life-history strategies associated with migration in insects. *Ecol. Entomol.* **2018**, *43*, 397–411. [[CrossRef](#)]
251. Naranjo, S.E. Assessing insect flight behavior in the laboratory: A primer on flight mill methodology and what can be learned. *Ann. Entomol. Soc. Am.* **2019**, *112*, 182–199. [[CrossRef](#)]
252. Aita, R.C.; Kees, A.M.; Aukema, B.H.; Hutchison, W.D.; Koch, R.L. Effects of starvation, age, and mating status on flight capacity of laboratory-reared brown marmorated stink bug (Hemiptera: Pentatomidae). *Environ. Entomol.* **2021**, *50*, 532–540. [[CrossRef](#)]
253. Babu, A.; Del Pozo-Valdivia, A.I.; Reising, D.D. Baseline flight potential of *Euschistus servus* (Hemiptera: Pentatomidae) and its implications on local dispersal. *Environ. Entomol.* **2020**, *49*, 699–708. [[CrossRef](#)]
254. Ali, S.; Ullah, M.I.; Sajjad, A.; Shakeel, Q.; Hussain, A. Environmental and health effects of pesticide residues. In *Sustainable Agriculture Reviews*; Springer: Cham, Switzerland, 2021; Volume 48, pp. 311–336.
255. Le Goff, G.; Giraudo, M. Effects of pesticides on the environment and insecticide resistance. In *Olfactory Concepts of Insect Control—Alternative to Insecticides*; Springer International Publishing: Berlin/Heidelberg, Germany, 2019; pp. 51–78.

256. Lowenstein, D.M.; Andrews, H.; Mugica, A.; Wiman, N.G. Sensitivity of the egg parasitoid *Trissolcus japonicus* (Hymenoptera: Scelionidae) to field and laboratory-applied insecticide residue. *J. Econ. Entomol.* **2019**, *112*, 2077–2084. [[CrossRef](#)]
257. Guedes, R.N.C.; Smaghe, G.; Stark, J.D.; Desneux, N. Pesticide-induced stress in arthropod pests for optimized integrated pest management programs. *Annu. Rev. Entomol.* **2016**, *61*, 43–62. [[CrossRef](#)]
258. Hill, M.P.; Macfadyen, S.; Nash, M.A. Broad spectrum pesticide application alters natural enemy communities and may facilitate secondary pest outbreaks. *PeerJ* **2017**, *5*, e4179. [[CrossRef](#)]
259. Brzozowski, L.; Mazourek, M. A sustainable agricultural future relies on the transition to organic agroecological pest management. *Sustainability* **2018**, *10*, 2023. [[CrossRef](#)]
260. Sparks, M.E.; Shelby, K.S.; Kuhar, D.; Gundersen-Rindal, D.E. Transcriptome of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae). *PLoS ONE* **2014**, *9*, e111646. [[CrossRef](#)] [[PubMed](#)]
261. Sun, D.; Huang, Y.; Qin, Z.; Zhan, H.; Zhang, J.; Liu, Y.; Yang, S. Identification of candidate olfactory genes in the antennal transcriptome of the stink bug *Halyomorpha halys*. *Front. Physiol.* **2020**, *11*, 876. [[CrossRef](#)] [[PubMed](#)]
262. Cagliari, D.; Dias, N.P.; Dos Santos, E.Á.; Rickes, L.N.; Kremer, F.S.; Farias, J.R.; Lenz, G.; Galdeano, D.M.; Garcia, F.R.M.; Smaghe, G.; et al. First transcriptome of the Neotropical pest *Euschistus heros* (Hemiptera: Pentatomidae) with dissection of its siRNA machinery. *Sci. Rep.* **2020**, *10*, 4856. [[CrossRef](#)]
263. King, R.; Buer, B.; Davies, T.G.E.; Ganko, E.; Guest, M.; Hassani-Pak, K.; Hughes, D.; Raming, K.; Rawlings, C.; Williamson, M.; et al. The complete genome assemblies of 19 insect pests of worldwide importance to agriculture. *Pestic. Biochem. Phys.* **2023**, *191*, 105339. [[CrossRef](#)] [[PubMed](#)]
264. Leal, W.S. Reverse chemical ecology at the service of conservation biology. *Proc. Nat. Acad. Sci. USA* **2017**, *114*, 12094–12096. [[CrossRef](#)] [[PubMed](#)]
265. Pickett, J.A. Chemical ecology in the post genomics era. *J. Chem. Ecol.* **2014**, *40*, 319. [[CrossRef](#)] [[PubMed](#)]
266. Cagliari, D.; Smaghe, G.; Zotti, M.; Taning, C.N.T. RNAi and CRISPR/Cas9 as functional genomics tools in the neotropical stink bug, *Euschistus heros*. *Insects* **2020**, *11*, 838. [[CrossRef](#)]
267. Singh, S.; Rahangdale, S.; Pandita, S.; Saxena, G.; Upadhyay, S.K.; Mishra, G.; Verma, P.C. CRISPR/Cas9 for insect pests management: A comprehensive review of advances and applications. *Agriculture* **2022**, *12*, 1896. [[CrossRef](#)]
268. Henderson, W.G.; Khalilian, A.; Han, Y.J.; Greene, J.K.; Degenhardt, D.C. Detecting stink bugs/damage in cotton utilizing a portable electronic nose. *Comput. Electron. Agric.* **2010**, *70*, 157–162. [[CrossRef](#)]
269. Lampson, B.D.; Khalilian, A.; Greene, J.K.; Han, Y.J.; Degenhardt, D.C. Development of a portable electronic nose for detection of cotton damaged by *Nezara viridula* (Hemiptera: Pentatomidae). *J. Insects* **2014**, *2014*, 297219. [[CrossRef](#)]
270. Martinazzo, J.; Moraes, M.C.B.; Steffens, J.; Steffens, C. Application of gas nanosensor for detection pheromone and its interferents compounds in vivo *Euschistus heros* (F.) stink bugs insects. *Sens. Actuat. A Phys.* **2022**, *345*, 113804. [[CrossRef](#)]
271. Reddy, G.V.P.; Guerrero, A. Interactions of insect pheromones and plant semiochemicals. *Trends Plant Sci.* **2004**, *9*, 253–261. [[CrossRef](#)]
272. Thrift, E.M.; Herlihy, M.V.; Wallingford, A.K.; Weber, D.C. Fooling the Harlequin Bug (Hemiptera: Pentatomidae) using synthetic volatiles to alter host plant choice. *Environ. Entomol.* **2018**, *47*, 432–439. [[CrossRef](#)]
273. Guignard, Q.; Allison, J.D.; Slippers, B. The evolution of insect visual opsin genes with specific consideration of the influence of ocelli and life history traits. *BMC Ecol. Evol.* **2022**, *22*, 2. [[CrossRef](#)] [[PubMed](#)]
274. Xu, P.; Lu, B.; Chao, J.; Holdbrook, R.; Liang, G.; Lu, Y. The evolution of opsin genes in five species of mirid bugs: Duplication of long-wavelength opsins and loss of blue-sensitive opsins. *BMC Ecol. Evol.* **2021**, *21*, 66. [[CrossRef](#)] [[PubMed](#)]

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.