Review of the Biology, Ecology, and Management of *Halyomorpha halys* (Hemiptera: Pentatomidae) in China, Japan, and the Republic of Korea

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ABSTRACT Native to China, Japan, Korea, and Taiwan, the brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) was first detected in the United States in the mid-1990s. Since establishing in the United States, this invasive species has caused significant economic losses in agriculture and created major nuisance problems for home and business owners, especially in the mid-Atlantic region. Basic and applied questions on *H. halys* have been addressed in its native range in Asia since the mid-1900s and the research outcomes have been published in at least 216 articles from China, Japan, and the Republic of Korea. In Asia, *H. halys* is described as an occasional or outbreak pest of a number of crops such as apple, pear, persimmon, and soybeans. This species is considered a nuisance pest as well, particularly in Japan. This review summarizes 100 articles primarily translated from Chinese, Japanese, and Korean to English. The content of this review focuses on the biology, ecology, and management of *H. halys* in Asia, with specific emphasis on nomenclature, life history, host range, damage, economic importance, sampling and monitoring tools, and management strategies. This information from the native range of *H. halys* provides greater context and understanding of its biology, ecology, and management in North America.

KEY WORDS brown marmorated stink bug, invasive species, Asia

The brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is an invasive species native to China, Japan, Korea, and Taiwan (Hoebeke and Carter 2003). First discovered in the United States in the mid-1990s in or near Allentown, PA (Hoebeke and Carter 2003), the distribution of *H. halys* has grown steadily and, as of 2013, it had been officially detected in 40 states, the District of Columbia (www.stopbmsb.org), Hamilton, Ontario, Canada (Fogain and Graff 2011), Switzerland (Wermelinger et al. 2008), Liechtenstein (Arnold 2009), Germany (Heckmann 2012), and France (Callot and Brua 2013). Based on climatic data, Zhu et al. (2012) predicted that the eastern, central, and portions of the pacific northwest of the United States are favorable for widespread establishment of *H. halys.* Indeed, this invasive species has emerged as a key pest in tree fruit in the mid-Atlantic region, with damage reported on vegetables, row crops, ornamentals, and potential risks to small fruit and grapes (Leskey et al. 2012). In addition, *H. halys* has become a serious nuisance because of the large numbers of invading adults subsequently overwintering in human-made structures (Hamilton 2009, Inkley 2012).

Basic and applied studies of *Halyomorpha* spp. in Asia have been reported in at least 216 articles from China, Japan, and the Republic of Korea since the mid-1900s (e.g., Sasaki 1905; K. Funayama, personal communication) (Fig. 1; Supp. 1 and 2 [online only] for annotated bibliographies). The number of publications from Asia on *Halyomorpha* spp. has increased rapidly since the 1970s. However, only ≈15% of these publications were written entirely in English, while the rest were entirely in Asian languages or had partial English text (e.g., abstract, tables, figure captions, and references). Consequently, this review encompasses information from a selection of publications from China, Japan, and the Republic of Korea. Of the known publications, 100 articles were selected for inclusion in this review, based on their citation record and breadth of scope. In this review article, we summarized information on *H. halys* published from Asia on the following topics: nomenclature, life history, host range, damage economic importance, sampling and monitoring tools, and management strategies.

Nomenclature

H. halys has had a confusing nomenclatural record, having previously been referred to as *H. mista* or *H.*

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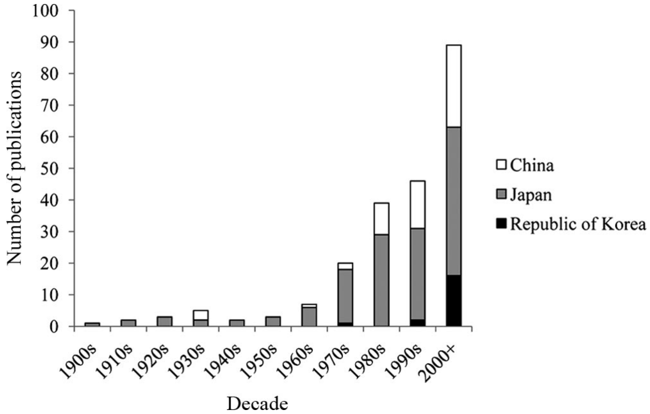

Fig. 1. Number of articles on *Halyomorpha halys* published by decade in China, Japan, and the Republic of Korea.

brevis (synonyms), and *H. picus* (misidentification) (Rider et al. 2002). Ultimately, Josifov and Kerzhner (1978) determined that only one species of *Halyomorpha, H. halys,* is present in eastern China, Japan, and Korea. Therefore, all references to *Halyomorpha* spp. from these locations are considered synonymous with *H. halys* (Rider et al. 2002). In this review article, we followed this nomenclatural verification.

Life History

Studies of the life history and seasonal population dynamics of *H. halys* on economically important crops and in adjacent unmanaged landscapes have generally revealed one or two generations in its native range in Asia. The life history of *H. halys* has been described primarily based on the univoltine populations in the studies reviewed here, although limited phenological information of bivoltine *H. halys* populations is included. We have also incorporated results of studies focused on effects of photoperiod, temperature, and diet on *H. halys* reproduction, development, survivorship, and diapause.

Distribution and Voltinism. In China, one or two generations of *H. halys* are commonly present (Qin 1990, Zhang et al. 1993, Li et al. 1996; as reviewed by Yu and Zhang 2007, Chu et al. 1997), although Hoffman (1931) suggested that four or even six generations may occur in the Kwangtung (Guangdong) province (23° N, 113° E) (Fig. 2). Bivoltine populations in China begin ovipositing in mid- to late May (Wang and Wang 1988, Zhang et al. 1993, Qiu 2007). Following these overwintered adults, first generation adults begin to lay eggs from late June to early July (Qin 1990) or mid- to late-July (Zhang et al. 1993, Qiu 2007), with second generation adults observed between late August (Qiu 2007) and early to mid-September (Qin 1990, Zhang et al. 1993). *H. halys* has not been reported from Xinjiang (42° N, 85° E), Ningxia (37° N, 106° E), Qinghai (35° N, 96° E), or Tibetan (32° N, 89° E) provinces of China (as reviewed by Yu and Zhang 2007). *H. halys* has been found across the Republic of Korea, including the southern island of Jeju (33° 25′ N, 126° 31′ E) and is reported to complete up to two generations in southern portions of the country (Bae et al. 2008, 2009). *H. halys* is also widely distributed across Japan, and tends to be the principal species in cooler regions (Adachi et al. 2007). In Japan, one or two generations have been reported based on anecdotal evidence, as well as laboratory and field studies (Saito et al. 1964, Watanabe et al. 1978, Oda et al. 1980, Yanagi and Hagihara 1980, Kawada and Kitamura 1983a, Fujiie 1985, Katayama et al. 1993, Funayama 2008). Watanabe (1980) suggested that *H. halys* is univoltine and bivoltine in western and eastern Japan, respectively, though no supporting data were presented.

Overwintering Adults. *H. halys* adults begin moving to overwintering sites in September (Saito et al. 1964, Kobayashi and Kimura 1969, Kawada and Kitamura 1992) (Fig. 3). This activity was reported to increase by mid-October (Qin 1990, Zhang et al. 1993) and to continue into November (Kobayashi and Kimura 1969, Watanabe et al. 1978, Yanagi and Hagihara 1980, Zhang et al. 1993, Funayama 2012b). The majority of *H. halys* become inactive below 9°C (Li et al. 2007). Aggregations of adults are found in dark locations in overwintering sites and, once settled, the individuals are unlikely to leave (Toyama et al. 2011) unless stored nutrients in the fat body are depleted (Funayama 2012b). Toyama et al. (2006) suggested that aggregations were the result of adults responding to tactile and/or olfactory cues, but not visual cues. *H. halys* are commonly found overwintering in human-made structures (Kobayashi and Kimura 1969, Yanagi and Hagihara 1980, Watanabe et al. 1994c, Funayama 2003). Qin (1990) reported that more *H. halys* flew to the west-facing portion of buildings than other cardinal directions. Overwintering adults have also been reported in natural landscapes in litter and tree holes (Qin 1990), under the bark of cedar trees (Ueno and Shoji 1978a), and in dry, high elevation mountain terrain (Wang and Wang 1988).

Survivorship of overwintering *H. halys* has been examined in relation to temperature. Kiritani (2007) cited a report (Plant Protection Division, MAFF 1986)

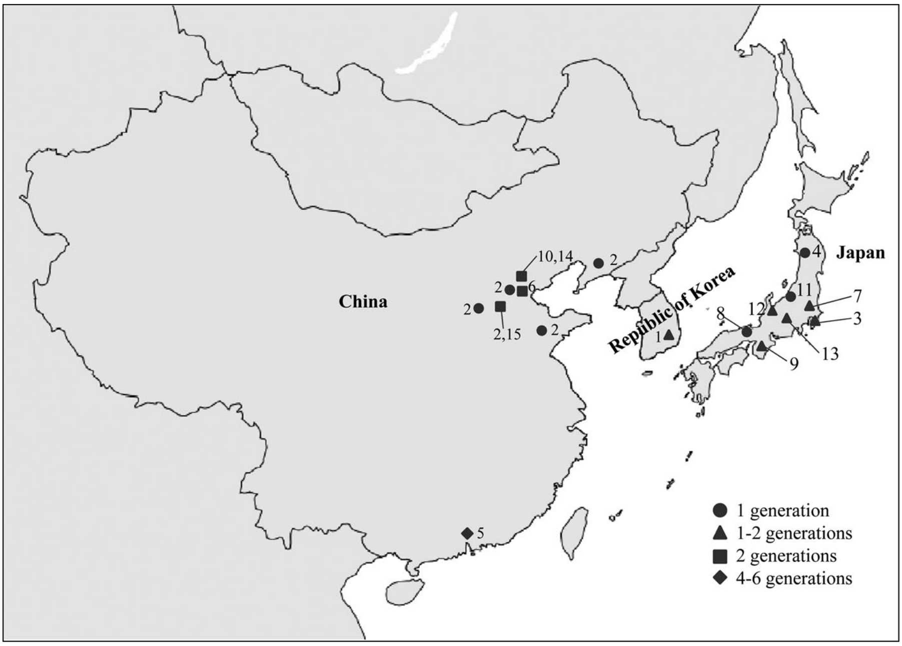

Fig. 2. Number of generations of *Halyomorpha halys* reported in Asia. Numbers in the figure correspond to the following references: [1]Bae et al. 2008; [2]Chu et al. 1997; [3]Fujiie 1985; [4]Funayama 2008; [5]Hoffmann 1931; [6]Hou et al. 2009; [7]Katayama et al. 1993; [8]Kawada and Kitamura 1983a; [9]Oda et al. 1980; [10]Qin 1990; [11]Saito et al. 1964; [12]Watanabe et al. 1978; [13]Yanagi and Hagihara 1980; [14]Yang et al. 2009; [15]Zhang et al. 1993. Map is not to scale.

that related *H. halys* overwintering mortality to mean temperatures in January and February, and concluded that each 1°C rise above 4°C would result in a 13.5% increase in survivorship. Kiritani (2007) also indicated from this report that *H. halys* was more tolerant of low temperatures than *Nezara viridula* (L.); a mean temperature of 4°C was reported to kill up to 81% of *N. viridula* but only 31% of *H. halys.* However, Oda et al. (1982) reported that mortality of overwintering *H. halys* did not appear to be closely linked to low winter temperatures.

Dispersing Adults. The timing of *H. halys* emergence from overwintering sites in the spring and subsequent host use patterns have been described in several studies. *H. halys* adults exit overwintering sites from late March to mid-May (Watanabe et al. 1978, Wang and Wang 1988, Qin 1990, Zhang et al. 1993, Funayama 2012b) when ambient temperatures are >10°C (Qin 1990) (Fig. 3). High temperatures in March and April 2002 resulted in adults exiting overwintering sites about 1 mo earlier than previous years (Ohira 2003; as cited by Kiritani 2007). Exiting an overwintering site is also likely induced by the exhaustion of resources. Funayama (2012b) reported that adults leaving overwintering sites had significantly lower nutritional levels (body weight divided by pronotum width cubed) than those remaining in overwintering sites and lower nutritional levels than those evaluated before entry into overwintering sites.

H. halys adults dispersing from overwintering sites begin to arrive on host plants in April through May (Qin 1990, Kawada and Kitamura 1992, Fujisawa 2001, Funayama 2002a, Qiu 2007, Cai et al. 2008). Some authors reported that adults exiting overwintering sites temporarily use host plants such as Chinese arborvitae (Lee et al. 2009), Chinese milk vetch (Bae et al. 2009), mulberry, elm, willow, and Chinese scholar tree (Wang and Wang 1988) before colonizing cultivated crops. Funayama (2012b) suggested that these transitional hosts may be used as a water source, because some hosts likely do not provide sufficient levels of nutrition to restore depleted resources (Yanagi and Hagihara 1980). *H. halys* adults were reported to begin feeding when temperatures exceeded 17°C, possibly selecting resources using both visual and olfactory cues (Li et al. 2007). Mean longevity of adults has been reported to be 301 d (Zhang et al. 1993) and >365 d (Wang and Wang 1988), with overwintered adults potentially present in the field through mid-July (Qin 1990).

Reproductive Development. Reproductive development of *H. halys* is affected by photoperiod, temperature, and diet. Photoperiod exposure in both the adult (Fujiie 1985) and nymphal stages (Watanabe 1979, Niva and Takeda 2003) affects the reproductive development of adults, although variation in photoperiod during the egg stage does not (Watanabe 1979). Normal ovarian development occurs during photoperiods of ≥14 h (Watanabe et al. 1978, Watanabe 1979, 1980, Yanagi and Hagihara 1980). While some development may occur at 13 or 13.5 h (Watanabe 1979), almost none was reported at ≤12 h (Watanabe 1980, Fujiie 1985). Watanabe (1980) concluded that only photoperiods from late April to mid-

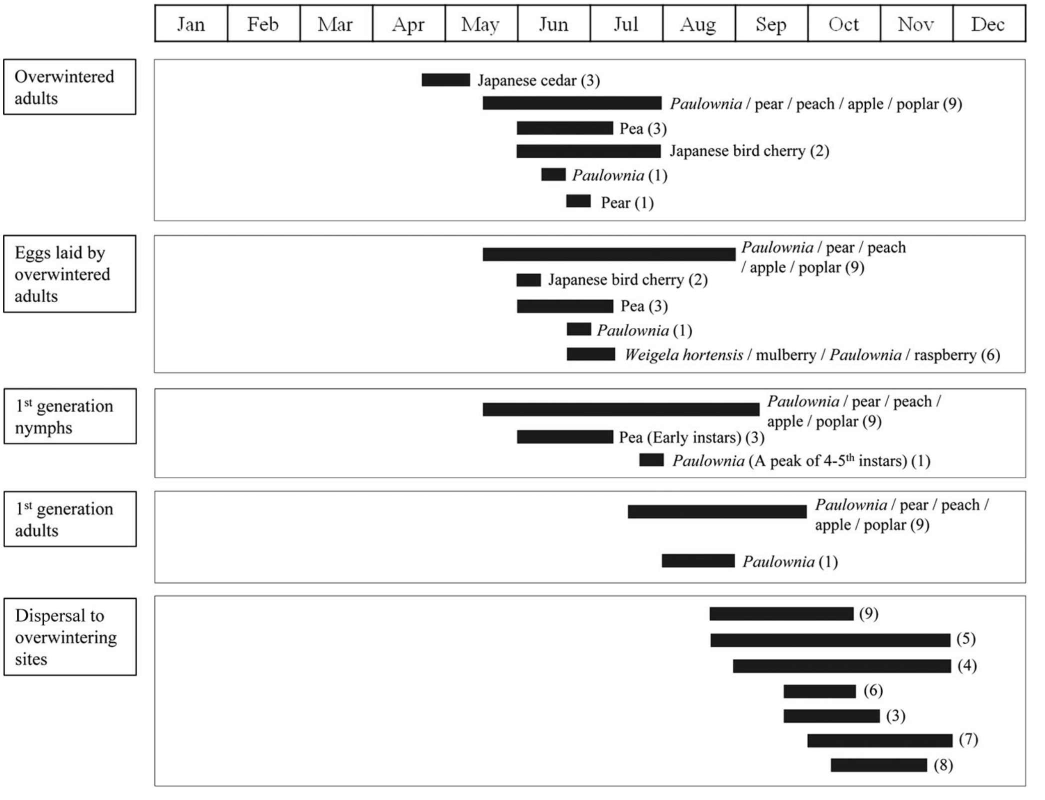

Fig. 3. Seasonal phenology of *Halyomorpha halys* primarily based on univoltine populations reported in Asia. Numbers in the parentheses correspond to the following references: [1]Fujiie 1985; [2]Funayama 2007; [3]Kawada and Kitamura 1992; [4]Kobayashi and Kimura 1969; [5]Qin 1990; [6]Saito et al. 1964; [7]Watanabe et al. 1978; [8]Yanagi and Hagihara 1980; [9]Zhang et al. 1993.

August were suitable for ovarian development in central Japan (i.e., the Toyama prefecture; 36° 41′ N, 137° 12′ E). The minimal temperature at which ovarian development occurred was 16.3°C and 119 degree days (DD) were required to complete development (Watanabe 1980).

Normal ovarian development and egg production can also be affected by diet and may require access to multiple host plants in some cases (Watanabe 1979, Oda et al. 1980, 1981, Yanagi and Hagihara 1980, Funayama 2002a, 2004, 2005, Bae et al. 2009). For example, *H. halys* reared exclusively on a single host of snap bean (Watanabe 1979), mung bean (Bae et al. 2009), or pear (Fujiie 1985) did not produce eggs. Several authors reported that most females reached sexual maturity within 2 wk of emergence to the adult stage (Watanabe 1979, 1980, Yanagi and Hagihara 1980, Kawada and Kitamura 1983b, Qiu 2007, Bae et al. 2009). The ovarian development process has been described and separated into discrete stages (Watanabe et al. 1978, Watanabe 1980, Katayama et al. 1993) with methodology for dissections reported by Watanabe (1980). Niva and Takeda (2002) noted that the red color on the sternum of adults was more common in nondiapausing individuals and may be linked to reproductive maturity.

Mating and Oviposition. Oviposition behavior and fecundity of *H. halys* have been examined in laboratory and field studies. Several studies have described courtship and copulation behavior of *H. halys* (Kawada and Kitamura 1983b, Wang and Wang 1988, Chu et al. 1997, Qiu 2007). Kawada and Kitamura (1983) described mating behavior in detail where multiple copulations were commonly observed. Mating occurs throughout the day (Kawada and Kitamura 1983b) and copulation duration ranges from 5 to 14 min (Saito et al. 1964, Kawada and Kitamura 1983b, Wang and Wang 1988).

Overwintered females begin to deposit eggs in mid- to late May (Wang and Wang 1988, Zhang et al. 1993, Qiu 2007) and from early June through July (Saito et al. 1964, Fujiie 1985, Kawada and Kitamura 1992, Katayama et al. 1993, Funayama 2002a, Funayama 2007). The proportion of females with mature eggs was generally highest from mid- to late July through August (Katayama et al. 1993). Eggs are typically laid in a mass consisting of 28 eggs (e.g., Watanabe et al. 1978, Yanagi and Hagihara 1980, Arakawa et al. 2004, Qiu 2007), deposited on the undersides of leaves (Hoffman 1931, Saito et al. 1964, Funayama 2002a, Yang et al. 2009), and toward the upper and interior tree canopy (Funayama 2002a). Female *H. halys* oviposit throughout their life span if they are held under optimal abiotic conditions with access to high quality food. Egg production was reported to increase if females mated multiple times but then declined with age (Kawada and Kitamura 1983b). In laboratory studies, the oviposition period from emergence until the end of egg laying ranged between 44 (Yanagi and Hagihara 1980) and 104 d (Kawada and Kitamura 1983b). Females oviposited an average of nine (Yanagi and Hagihara 1980) to 16 (Kawada and Kitamura 1983b) times at 4 to 5-d intervals. Substantial variation in the lifetime fecundity of female *H. halys* has been reported (Kawada and Kitamura 1983b, Qin 1990, Chu et al. 1997, Qiu 2007); Yanagi and Hagihara (1980) reported a range of 100–500 eggs with an average of 240 eggs per female.

Egg and Nymphal Development. Developmental periods and/or survivorship of *H. halys* vary with temperature (Oda et al. 1981, Fujiie 1985, Qiu 2007) and diet (Watanabe 1979, Oda et al. 1981, Funayama 2002a, 2005, 2007). Development of eggs and nymphs has been quantified primarily by using individuals reared in laboratory colonies. The colonies were typically provisioned with peanuts, soybeans, and a water source and maintained at ≈25°C, under day lengths ≥14 h (e.g., Saito et al. 1964, Oda et al. 1981, Funayama 2002a, Arakawa et al. 2004, Funayama 2006, Bae et al. 2008), and at least 70% relative humidity (RH) (Watanabe et al. 1978, Qiu 2007).

Egg development typically occurs in 5–6 d (Watanabe 1979, Yanagi and Hagihara 1980, Oda et al. 1981, Kawada and Kitamura 1983b, Chu et al. 1997). Funayama (2002a) suggested that egg eclosion was nearly 100% in the field. First instars, and to some extent second instars, remain aggregated on or near the hatched eggs before dispersing to seek food (Saito et al. 1964, Wang and Wang 1988, Qin 1990, Chu et al. 1997), whereas later instars do not exhibit this behavior (Kawada and Kitamura 1992). Variation in photoperiod exposure during the nymphal stages affected pigmentation, body size, feeding frequency, developmental rate, and lipid accumulation in laboratory study (Niva and Takeda 2003). Nymphal developmental rate increased as photoperiod decreased (Niva and Takeda 2003). In the laboratory, the duration of development from egg through five instars averaged between 44 and 52 d (Saito et al. 1964, Kobayashi 1967, Watanabe et al. 1978, Yanagi and Hagihara 1980, Oda et al. 1981, Fujiie 1985, Chu et al. 1997, Qiu 2007). Summer generation adults have been first detected in mid-July (Fujisawa 2001), but more commonly in August (Fujiie 1985, Funayama 2002a, Funayama 2007) (Fig. 3). Critical temperature thresholds and DD required for completion of *H. halys* development are summarized in Table 1.

Reproductive Diapause. Ovarian degeneration and reproductive diapause begins in early to mid-August (Saito et al. 1964, Watanabe 1980, Yanagi and Hagihara 1980, Fujiie 1985, Katayama et al. 1993, Funayama 2002a). Saito et al. (1964) found that some females collected from *Paulownia* spp. at the end of July oviposited, but those collected on 20 August did not. Niva and Takeda (2003) suggested that decreasing photoperiod suppresses reproductive activity of adults, and these are the adults that ultimately move to overwintering sites. Reproductive diapause has been characterized by the presence of undeveloped oocytes in females and an unapparent ectodermal sac in males (Niva and Takeda 2003). Diapause induction in adults is influenced by short-day conditions (Watanabe 1980, Fujiie 1985, Niva and Takeda 2003, Toyama et al. 2006, 2011) and low temperatures (Watanabe 1980) in the nymphal and adult stages (Niva and Takeda 2003).

Table 1. Minimum temperature thresholds and total degree days required for *Halyomorpha halys* development reported in Asia

Minimum temp. (°C)	Degree days	Reference
11.0	630	Fujiie 1985[a]
11.7	580	Cited by Kiritani 2007
11.9	648	Cited by Kiritani 2007
12.1	649	Cited by Kiritani 2007
12.1	598	Cited by Yanagi and Hagihara 1980
12.9	625	Watanabe 1980
13.9	471	Yanagi and Hagihara 1980

[a] Also suggested a max temperature threshold for development of 30°C.

Host Range

H. halys is a polyphagous pest in its native range (Oda et al. 1980, Yanagi and Hagihara 1980, Kawada and Kitamura 1983a, 1992, Kang et al. 2003, Funayama 2004, Yu and Zhang 2007). In China, it has been reported to feed on 45 hosts, including economically important crops (Yu and Zhang 2007), with a majority of these in the subclasses Rosidae and Asteridae. In Japan, adult and nymphal *H. halys* use plants from 21 families and >49 species (Kawada and Kitamura 1983a, Tsutsumi 2001; as reviewed by Funayama 2007, 2012a,b). Collectively, a total of 106 host plants in 45 families have been reported in 45 Asian publications, with many from Fabaceae and Rosaceae (Table 2).

Although *H. halys* feed on a wide range of plants and often disperse among them during the season (Wang and Wang 1988, Fujisawa 2001), hosts vary in suitability and acceptability (Hoffmann 1931, Oda et al. 1980, Funayama 2002a, 2004, Yu and Zhang 2007, Bae et al. 2009). Zhang et al. (1993) reported the relative abundance of *H. halys* nymphs on *Paulownia* spp., pear, peach, apple, and poplar from May through August; population density decreased on *Paulownia* spp. and peach, increased on pear, but varied only slightly on apple and poplar over time. Oda et al. (1980) separated hosts of *H. halys* into two categories: breeding and food plants. Breeding plants were defined as those on which adults, nymphs and eggs were observed, whereas food plants were those on which only adults were observed feeding (Table 2). In addition, Funayama (2002a, 2004) suggested that multiple host plants are needed for normal *H. halys* development. For example, when other hosts were unavailable, adult survival and sexual maturation were aided by feeding

Table 2. Host plants of *Halyomorpha halys* reported in Asia

Family	Common name	Scientific name[a]	Reference
Aceraceae	Maple		23
Actinidiaceae	Chinese gooseberry	*Actinidia deliciosa* C. F. Liang & A. R. Ferguson	5, 31[d]
Adoxaceae	Red elderberry[c]		32
	Viburnum[b,c]		32, 43
Amaranthaceae	Beet	*Beta vulgaris* L.	35, 44[d]
	Feather cockscomb		19, 28
Anacardiaceae	Staghorn sumac	*Rhus typhina* L.	44
Asparagaceae	Asparagus		11
Asteraceae	Argyi wormwood	*Artemisia argyi* H. Lév. & Vaniot	44
	Burdock		27[d], 28[d]
	Mums	*Dendranthema morifolium* L.	44
	Sunflower[c]	*Helianthus annuus* L.	32, 44
Balsaminaceae	Rose balsam[b,c]		32
Basellaceae	T'ang ts'oi	*Basella rubra* L.	19
Betulaceae	Alder		28[d]
	Birch		23
Bignoniaceae	Catalpa[b,c]		32, 43
Brassicaceae	Rape		23, 35
Cannabaceae	Hop	*Humulus scandens* (Loureiro) Merrill	44
Caprifoliaceae	Japanese weigela	*Weigela hortensis* (Sieb. Et Zucc.) K. Koch	28[d], 36
Celastraceae	Japanese spindle	*Euonymus japonicus* Thunb.	43, 44
Cucurbitaceae	Cucumber		11, 23
Cupressaceae	Hinoki cypress[b,c]		10, 23[d], 32
	Oriental arborvitae	*Platycladus orientalis* (L.) Franco	20, 30, 34, 44
Ebenaceae	Persimmon[c]	*Diospyros* spp.	7, 21[d], 23, 24, 25[d], 27[d], 28[d], 29, 30, 32, 33, 44[d]
Euphorbiaceae	Tapioca		23[d]
	Tung		35
Fabaceae	Acacia		20, 34
	Azuki bean		23[d], 28[d]
	Black locust	*Robinia pseudoacacia* L.	44[d]
	Chinese long bean	*Vigna sesquipedalis* L.	19
	Chinese milk vetch		3
	Chinese wisteria	*Wisteria sinensis* (Sims) DC.	44
	Clover		43
	Cowpea		23[d], 28[d]
	Hairy vetch		3
	Kidney bean[b,c]		23, 25[d], 32
	Kudzu	*Pueraria montana* var. *lobata* (Willd.) Maesen and S. Almeida	39, 42
	Lima bean	*Phaseolus lunatus* L.	19, 44[d]
	Pea		11, 23, 25
	Soybean[b,c]	*Glycine max* L.	1, 2, 3, 11, 21[d], 23[d], 25[d], 27[d], 28[d], 32, 37, 43, 44[d]
	String bean		28[d], 42
	Weeping scholar tree	*Sophora japonica* L. forma *pendula* Zabel	20, 35, 44
Fagaceae	Chestnut[c]		32
Lamiaceae	Chinese chaste tree	*Vitex negundo* L.	44
	Harlequin glorybower	*Clerodendrum trichotomum* Thunb.	23[d], 28[d], 42, 43
Lardizabalaceae	Chocolate vine	*Akebia* spp.	42
Lauraceae	Camphortree	*Cinnamomum camphora* (L.) J. Presl	44[d]
Lythraceae	Pomegranate	*Punica granatum* L.	35, 44[d]
Malvaceae	Chinese hibiscus	*Hibiscus rosa-sinensis* L.	19
	Chinese parasol tree	*Firmiana platanifolia* (L. f.) Schott & Endl.	44[d]
	Common mallow[b,c]		32
	Hollyhock[b,c]		32, 44
	Upland cotton	*Gossypium hirsutum* L.	44[d]
Marantaceae	Arrowroot		25[d]
Moraceae	Fig		27[d], 28[d], 35, 44[d]
	Mulberry[c]		16, 27[d], 28[d], 32, 36, 43
Myricaceae	Wax myrtle[c]		32
Oleaceae	Chinese ash	*Fraxinus chinensis* Roxb.	35
	Lilac	*Syringa* spp.	44[d]
	Wild olive	*Olea oleaster* Hoffmanns. & Link	42
Orchidaceae	Orchid	*Brassia* spp.	44[d]
Paulowniaceae	Empress tree[b,c]	*Paulownia* spp.	4, 9, 16, 23, 25[d], 28[d], 32, 35, 36, 44[d], 45
Pinaceae	Cedar[b,c]		15[d], 17, 23, 25, 32, 43
	Pine		43
Poaceae	Common millet	*Panicum miliaceum* L.	26
	Corn	*Zea mays* L.	23[d], 25[d], 44
	Pearl millet	*Setaria italica* L.	26
	Sorghum	*Sorghum bicolor* L.	26
	Sweet corn		11

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Table 2. Continued

Family	Common name	Scientific name[a]	Reference
	Wheat		23[d], 25[d], 44[d]
Polygonaceae	Mile-a-minute weed	*Polygonum perfoliatum* L.	8
Rhamnaceae	Jujube	*Ziziphus jujube* (L.) H. Karst.	44
Rosaceae	Apple	*Malus domestica* Borkh.	10, 12, 13, 14, 16, 23[d], 25[d], 27[d], 28[d], 35, 43, 44[d], 45
	Apricot	*Prunus armeniaca* L.	20, 44[d]
	Cambridge cherry	*Prunus pseudocerasus* L.	44[d]
	Cherry[c]	*Prunus* spp.	10, 16, 23, 25[d], 27[d], 28[d], 32, 41, 43
	Chinese hawthorn	*Crataegus pinnatifida* Bunge	35, 44[d]
	Green plum[c]		32
	Japanese bird cherry		16, 18
	Loquat[c]		22[d], 32
	Peach[c]	*Prunus* spp.	10, 23[d], 25[d], 27[d], 28[d], 32, 33, 34, 35, 43, 45
	Pear[c]	*Pyrus* spp.	9, 10, 22[d], 23[d], 25[d], 32, 34, 35, 40, 44[d], 45
	Plum[c]		23[d], 27[d], 28[d], 32, 43, 44[d]
	Quince	*Chaenomeles speciosa* (Sweet) Nak.	35
	Raspberry		28[d], 36
	Strawberry		11, 28[d]
Rutaceae	Citrus		23[d], 25[d], 33
	Mandarin orange[c]		21[d], 28[d], 32, 44[d]
	Orange		27[d]
	Yuzu		6
Salicaceae	Chinese white poplar	*Populus tomentosa* Carriere	44[d], 45
Simaroubaceae	Tree of heaven	*Ailanthus* spp.	20, 35
Solanaceae	Bell pepper		11
	Black nightshade	*Solanum nigrum* L.	19, 28[d], 44
	Eggplant		11
	Jasmine tobacco	*Nicotiana alata* Link & Otto	44[d]
	Tomato[c]		32
	Wolfberry	*Lycium barbarum* L.	44[d]
Taxaceae	Japanese yew		43
Theaceae	Chinese tea	*Camellia sinensis* (L.) Kuntze	38[d], 44i[d]
	Oil-seed camellia	*Camellia oleifera* C. Abel	44[d]
Ulmaceae	Japanese zelkova	*Zelkova* spp.	42
	Elm	*Ulmus pumila* L.	34, 44[d]
Vitaceae	Bushkiller	*Cayratia japonica* (Thunb.) Gagnep.	44
	Grape		23[d], 25[d], 27[d], 28[d], 33, 44[d]

[a] Scientific name was included only when mentioned in original paper.
[b] Breeding plant and [c] food plant defined by Oda et al. 1980 (see the text for the definition).
[d] Cited by: [1]Bae et al. 2007; [2]Bae et al. 2008; [3]Bae et al. 2009; [4]Bak et al. 1993; [5]Cai et al. 2008; [6]Choi et al. 2000; [7]Chung et al. 1995; [8]Ding et al. 2004; [9]Fujiie 1985; [10]Fujisawa 2001; [11]Fukuoka et al. 2002; [12]Funayama 1996; [13]Funayama 2002a; [14]Funayama 2002b; [15]Funayama 2003; [16]Funayama 2004; [17]Funayama 2005; [18]Funayama 2007; [19]Hoffman 1931; [20]Hou et al. 2009; [21]Kang et al. 2003; [22]Katase et al. 2005; [23]Kawada and Kitamura 1983a; [24]Kawada and Kitamura 1983b; [25]Kawada and Kitamura 1992; [26]Kim et al. 2010; [27]Kobayashi 1967; [28]Kobayashi and Kimura 1969; [29]Lee et al. 2002; [30]Lee et al. 2009; [31]Li et al. 2007; [32]Oda et al. 1980; [33]Ohira 2003; [34]Qin 1990; [35]Qiu 2007; [36]Saito et al. 1964; [37]Son et al. 2000; [38]Song et al. 2008; [39]Sun et al. 2006; [40]Wang and Wang 1988; [41]Watanabe 1996; [42]Watanabe et al. 1978; [43]Yanagi and Hagihara 1980; [44]Yu and Zhang 2007; [45]Zhang et al. 1993.

on apple fruit during the early spring. However, the development and fitness of nymphs that fed only on apple was inferior (e.g., distended air sacs and poorly developed fat body) compared with individuals that fed on multiple hosts (Funayama 2002a).

Damage and Economic Importance

H. halys causes significant damage to many economically important crops in Asia including apple, pear, peach, persimmon and soybean, although actual monetary losses in those crops are not well documented in the published literature. In Japan, outbreak populations of *H. halys* on apple (e.g., Oda et al. 1980, Yanagi and Hagihara 1980, Funayama 2003, Ohira 2003), pear, plum, satsuma mandarin, and grape (Oda et al. 1980) have been reported, with damage characteristics and levels varying among crops. The timing of *H. halys* feeding and crop cultivars were identified as major factors affecting injury expression and severity (Ueno and Shoji 1978b, Wang and Wang 1988, Qin 1990, Chung et al. 1995, Funayama 1996, Fujisawa 2001, Lee et al. 2009). The following is a summary of the appearance and severity of feeding injury by *H. halys* to susceptible fruit in Asia.

Apple. The appearance of external *H. halys* injury on apple includes black spots, dimpling or depressions, and internally as brown lines or flesh (Ueno and Shoji 1978b, Fujisawa 2001). Zhang et al. (2007) reported that more apples were injured and with greater severity on the periphery of orchard blocks. The early maturing variety, 'Sansa,' was reported to be more susceptible to stink bug damage than other cultivars, including 'Hokuto,' 'Mutsu,' 'Jonagold,' 'Fuji,' 'Jonathan,' and 'Orin' (Fujisawa 2001, Funayama 2002b). By contrast, Zhang et al. (2007) reported that fruit injury levels were similar among early ('White Mulberry'), mid- ('Ya Taka'), and late

('Fuji') season varieties with 23–31% injury rates reported. Vulnerability to *H. halys* injury varied during the fruiting period, such that severe injury was more clearly expressed when feeding coincided with periods of rapid fruit growth (Funayama 1996). Moreover, injury inflicted very close to harvest was not as easily detected on the fruit surface, but may still have led to brown flesh (Fujisawa 2001). Early season feeding caused fruit abscission on 'Orin', but none was recorded thereafter (Fujisawa 2001).

Pear. Pear susceptibility to *H. halys* feeding injury varies throughout the growing season (Wang and Wang 1988, Qin 1990, Chu et al. 1997). Fruit injured in July developed green depressions with corked flesh; those injured a month later did not develop external symptoms, although the quality was still affected internally (Qin 1990). Wang and Wang (1988) suggested that *H. halys* feeding on fruit with <3-cm diameter severely affected fruit development and caused deformity. Variability in injury levels on pear has been reported, ranging from 10 to 80% (Wang and Wang 1988, Qin 1990, Zhang et al. 1993, Chu et al. 1997, Ming et al. 2001; as reviewed by Yang et al. 2009), with substantial increases between June and July (Chu et al. 1997).

Peach. Damage is first observed in early May on young peach fruit (Ohira 2003). Qin (1990) caged *H. halys* on peaches to characterize injury symptoms: fruit exposed to *H. halys* before mid-May were deformed and showed gummosis, but after mid-May expressed depressed brown spots in addition to gummosis. Qin (1990) reported that all injury symptoms severely affected marketability of peaches. Furthermore, Ueno and Shoji (1978b) reported fruit abscission when *H. halys* were caged on fruit in May, but only deformity in June. *H. halys* injury to peach has been reported to range from 50 to 70% when orchards were not properly managed (Qin 1990). Feeding duration on peach was reported to last from 3 to 51 min per insect (Li et al. 2007).

Persimmon. *H. halys* is a key stink bug pest on persimmon (Chung et al. 1995, Lee et al. 2009, Son et al. 2009). Fruit injured by *H. halys* developed round softened spots, especially around the top of the fruit, which could subsequently result in fruit abscission (Lee et al. 2009). Fruit abscission from *H. halys* feeding was generally greatest in July, but the rate of abscission declined after August, and very few fruit dropped in October (Chung et al. 1995, Lee et al. 2009). Chung et al. (1995) reported 23–44% fruit injury levels by stink bugs near harvest in commercial orchards. Damage to persimmons by *H. halys* can be severe even in low density populations; a single adult caged with 9–14 fruit resulted in 56, 43, and 21% injured fruit in July, August, and September, respectively (Lee et al. 2009).

Other Crops. Crop damage by *H. halys* has been reported in other tree and vegetable crops in Asia. In the Republic of Korea, the density of stink bugs, including *H. halys*, has increased on soybean since 2000 (Bae et al. 2008). *H. halys* first attacks the stems and leaves of young plants, then feeds on seedpods and seeds (Son et al. 2000, Paik et al. 2007). Kawamoto et al. (1987) reported a mean feeding duration on soybean from 1.7 to 2.6 h.

Fukuoka et al. (2002) reported damage to and injury levels of 90% on cucumber, saya pea, and eggplant, 70% on sweet corn, 60% on asparagus and edamame bean, 8% on pepper, and 80% on strawberry. *H. halys* damage was also reported on jujube (Song and Wang 1993; as reviewed by Yu and Zhang 2007), cherry (Ueno and Shoji 1978b, Watanabe 1996), and tea (*Camellia sinensis* L.) (Song et al. 2008). *H. halys* can also transmit the phytoplasma responsible for *Paulownia* witches' broom disease (e.g., Shiozawa 1986; as reviewed by Hiruki 1999, Bak et al. 1993).

Nuisance Problem. In addition to its agricultural significance, *H. halys* is an important nuisance pest when it overwinters inside human-made structures (Kobayashi and Kimura 1969, Yanagi and Hagihara 1980, Watanabe et al. 1994c, Funayama 2003). Kobayashi and Kimura (1969) conducted questionnaire-based surveys in northern Japan and reported widespread nuisance problems by stink bugs, with *H. halys* as the dominant species. Adult *H. halys* were found overwintering in closets, clothing, mattresses, sacks, and wood piles, under roofs and in wood paneling (Kobayashi and Kimura 1969).

Sampling and Monitoring Tools

Researchers in Asia continue to search for effective monitoring tools for foraging and overwintering populations of *H. halys.* For foraging field populations, several trap types with attractants are commonly used to monitor activity and relative densities of this insect. For overwintering populations, passive traps mimicking potential overwintering structures have been deployed in and around known human-made overwintering sites to estimate the size of overwintering *H. halys* populations.

Field Populations. *Light traps.* Emergence patterns, relative population density, and seasonal phenology of adult *H. halys* have been investigated using light traps (Saito et al. 1964, Oda et al. 1980, Fujiie 1985, Moriya et al. 1987, Katayama et al. 1993, Chung et al. 1995, Yanase 1997, Choi et al. 2000, Fujisawa 2001, Tada et al. 2001a,b, Fukuoka et al. 2002, Lee et al. 2002, Funayama 2003, Ohira 2003). Traps were typically operated from dusk to dawn (Moriya et al. 1987, Katayama et al. 1993, Chung et al. 1995, Funayama 2003). Cai et al. (2008) used a frequency trembler pest-killing lamp trap positioned 1.5 m above the ground as a monitoring tool in an organic apple orchard. Katayama et al. (1993) also used light traps to monitor pentatomid bugs, including *H. halys,* in a research orchard over 15 yr. The traps were hung 1.5 m above the ground in an orchard and the collection device beneath was a 46-cm diameter funnel leading into a plastic container with a DVDP (2,2-dichlorovinyl dimethyl phosphate) kill strip.

H. halys captures in light traps vary throughout the season (Fujiie 1985, Moriya et al. 1987, Fujisawa 2001, Fukuoka et al. 2002). Fujisawa (2001) reported that captures were high in the summer when night temperatures were warm compared with night temperatures in spring and autumn, but no specific details were provided. In Japan, peak captures of adult *H. halys* typically occur between mid-July and early August (Saito et al. 1964, Fujiie 1985, Moriya et al. 1987, Katayama et al. 1993, Fujisawa 2001, Fukuoka et al. 2002, Funayama 2003, Ohira 2003), with some reports of an additional peak in June when overwintering populations are large (Fujiie 1985, Katayama et al. 1993).

Cross-attractant pheromone traps. The male-produced aggregation pheromone (methyl (*E,E,Z*)-2,4,6-decatrienoate) of the brown-winged green bug, *Plautia stali* Scott (Sugie et al. 1996) is commonly used to attract *H. halys* to traps (e.g., Fujisawa 2001, Tada et al. 2001a,b, Lee et al. 2002, Adachi et al. 2007, Park et al. 2010). Fujisawa (2001) and Funayama (2008) proposed that the mechanism of *H. halys* cross-attraction to the *P. stali* pheromone is in response to searching for food sources. Capture of adult *H. halys* in traps baited with the *P. stali* pheromone occurs primarily between July and September (Tada et al. 2001a,b, Funayama 2003, 2008, Ohira 2003), but in an outbreak year, captures have been recorded season-long, starting in May (Funayama 2008). Captures were not significantly different among traps using polyethylene vials, tubes, or rubber septa as lure dispensers (Park et al. 2010). Bae et al. (2012) demonstrated that traps baited with male *H. halys* were attractive to both sexes of the species.

Other monitoring methods. Relative population density has been measured using visual observation, sweep nets, and beat sampling (Kawada and Kitamura 1983a, Choi et al. 2000, Son et al. 2000, Bae et al. 2007, Paik et al. 2007, Kim et al. 2010). Bae et al. (2007) found beat sampling most effective in soybean fields, because of the dropping behavior of disturbed *H. halys.* Hoffman (1931) suggested that adults were more easily captured in the morning or during rainy days when using these sampling methods. High levels of cedar and cypress cone production (Oda et al. 1982, Fukuoka et al. 2002) and pollen production (Ohira 2003) in a given year have been linked to increases in *H. halys* density in the following year, providing an alternative tool to predict the size of *H. halys* populations.

Overwintering Populations. *Box and slit traps.* Apple boxes packed with straw (Funayama 2003), scraps of paper (Yanagi and Hagihara 1980, Oda et al. 1982), and straw mats (Oda et al. 1982) placed in, on or near known human-made overwintering sites have been shown to provide suitable harborage for adult *H. halys.* Boxes with straw were used to monitor relative adult densities in overwintering sites annually for 3 yr and to predict the potential threat to cultivated crops in the following season (Funayama 2003). Similarly, Watanabe et al. (1994c) positioned three-layered, wooden veneer slit traps on the roof and under the eaves of buildings known to have overwintering aggregations of adult *H. halys.* More *H. halys* were recovered from brown and white slit traps placed under the eaves than those placed on the roof or those painted black (Watanabe et al. 1994c).

Management Strategies

Management programs for *H. halys* in cultivated crops in Asia have relied primarily on repeated insecticide sprays. In general, pyrethroids and neonicotinoids are recommended for control. Recently, more researchers have explored the natural enemy complex of *H. halys* in Asia, and several studies have indicated that species in the genus *Trissolcus* are promising candidates for management of *H. halys.* Only limited information is available for cultural management tools practiced in Asia.

Chemical Control. Several laboratory and semifield studies have evaluated insecticide efficacy against *H. halys* for commercial (Saito et al. 1964, Qin 1990, Chung et al. 1995, Son et al. 2000, Fujisawa 2001, Funayama 2002c, Bae et al. 2008, Funayama 2012a) and domestic (Watanabe et al. 1992, 1994a,d; as reviewed by Watanabe et al. 1994b) use. The efficacy of active ingredients tested against *H. halys* is summarized in Table 3. Saito et al. (1964) performed some of the earliest insecticide tests against *H. halys,* evaluating DDT, diazinon, dichlorvos, dieldrin, fenitrothion, and lindane in both continuous and interval exposures. These materials provided 100% control of *H. halys* adults under continuous exposure or following ≥5 min of a single exposure. However, the mortality rate decreased with shortened periods of exposure. In general, pyrethroids and neonicotinoids (Zhang et al. 1993, Tsutsumi 2003; K. Funayama, personal communication), such as bifenthrin and dinotefuran (Funayama 2012a) are recommended for control of *H. halys* in commercial management programs, especially when overwintering adult populations are high (Tsutsumi 2003; K. Funayama, personal communication). Son et al. (2000) reported that carbaryl, fenitrothion, and triazophos effectively controlled *H. halys* in soybean fields, with >90% decrease in pest density. Thus far, no resistance to insecticides has been detected (Son et al. 2000, Bae et al. 2008).

Several factors have been suggested to improve insecticide efficacy against *H. halys.* Because of the escapism behavior of *H. halys* when disturbed, particularly at high temperatures (Li et al. 2007), timing of insecticide applications were recommended early in the morning when bugs were less active (Bae et al. 2008). Furthermore, Li et al. (2007) suggested using the natural dropping behavior as a tool for management, by beating trees and then spraying the ground when the bugs drop. Others have suggested targeting insecticide treatments against overwintered adults and nymphal populations (Wang and Wang 1988, Qin 1990, Chu et al. 1997, Son et al. 2000), and spraying into wooded habitats adjacent to cropland (Qin 1990).

Biological Control. The parasitoids, predators, and entomopathogens that have been reported as potential biological control agents of *H. halys* are sum-

Table 3. Effectiveness of insecticides against *Halyomorpha halys* reported in Asia

Insecticide class	Active ingredient	Efficacy against *H. halys*[a]		
		Excellent[b]	Good[c]	Poor[d]
Carbamates	Alanycarb	X[f,k]		X[h,i]
	Carbaryl	X[g,i,j,k]		X[h]
	Thiodicarb			X[k]
Organophosphates	Chlorpyrifos	X[g,h]		X[j,k]
	Cyanophos	X[g,h,i,j]		
	Diazinon	X[g,h,k,m]		X[i,j]
	Dichlorvos	X[k,l,m]		
	Dimethoate	X[l]		
	Fenitrothion	X[g,h,j,k,l,m]	X[e,j]	
	Fenthion		X[e]	
	Methidathion	X[g,h,j]	X[i]	
	Omethoate	X[l]		
	Phenthoate	X[f,k]		X[e]
	Prothiophos	X[g,h]	X[k]	
Organochlorines	DDT	X[m]		
	Dieldrin	X[m]		
	Lindane	X[m]		
Pyrethroids	Acrinathrin			X[g,h]
	Bifenthrin	X[g,i,j,k]		X[h]
	β-Cyfluthrin	X[k]		X[g,h]
	Cyhalothrin		X[g]	X[h,k]
	Cypermethrin	X[g,k]		X[h]
	Deltamethrin	X[e]		
	Etofenprox	X[f]	X[e]	
	Fenpropathrin	X[k]		
	Fenvalerate	X[g,l]		X[h]
	Flucythrinate			X[g,h,k]
	Fluvalinate			X[g,h,k]
	Halfenprox		X[g]	X[h]
	Permethrin	X[g,k]		X[h]
	Silafluofen	X[g]		X[h]
	Tralomethrin		X[k]	X[g,h]
Neonicotinoids	Acetamiprid	X[g,k]	X[i]	X[h,j]
	Clothianidin	X[e,i]		X[j]
	Dinotefuran	X[i]		X[j]
	Imidacloprid	X[g,k]	X[i]	X[h,j]
	Thiamethoxam	X[i]	X[j]	
Phenylpyrazoles	Fipronil	X[e]		
Combinations	Dichlorvos + Diazinon	X[m]		
	Dichlorvos + Lindane	X[m]		
	Fenvalerate + Fenitrothion	X[g,h,k]		
	Fenvalerate + Malathion	X[l]		
Other agents	Kerosene	X[m]		

[a] X = Efficacy classification of insecticide materials; concentration of insecticide is not considered in the classification.
[b] Excellent refers to 90–100% mortality or $LC_{50} < 10$ ppm.
[c] Good refers to 70–89% mortality or $LC_{50} = 11–30$ ppm.
[d] Poor refers to < 70% mortality or $LC_{50} > 30$ ppm.
[e] Adult sprayed with insecticide in plastic cylinder in laboratory (Bae et al. 2008).
[f] Adult bagged on insecticide-treated persimmon trees for 24 h (Chung et al. 1995).
[g] Adult dipped in insecticide solution for 15 s in laboratory (Fujisawa 2001).
[h] Adult exposed to filter paper dipped in insecticide solution for 15 s and air dried in laboratory (Fujisawa 2001).
[i] Adult bagged on insecticide-treated apple trees in late Aug. (Fujisawa 2001).
[j] Adult bagged on insecticide-treated apple trees in late Sept. (Fujisawa 2001).
[k] Adult dipped in insecticide solution for 10 s in laboratory (Funayama 2002c).
[l] Nymph bagged on insecticide-treated pear trees in June (Qin 1990).
[m] Adult sprayed with insecticide on filter paper in laboratory (Saito et al. 1964).

marized in Table 4. Parasitoids in the genus *Trissolcus* are considered the most specialized and effective parasitoids of *H. halys* (Arakawa and Namura 2002, Arakawa et al. 2004, Qiu 2007, Yang et al. 2009). *T. halyomorphae* was identified as the predominant parasitic wasp in Beijing, China (Yang et al. 2009) with over 10 generations per year (Qiu 2007), while *T. mitsukurii* was the key parasitoid in Japan, with 14–15 generations per year (Arakawa and Namura 2002, Arakawa et al. 2004). Arakawa et al. (2004) reported that *T. mitsukurii* longevity, body size, and egg production increased after 7 d when reared on *H. halys* compared with *N. viridula* or *P. stali*. Interspecific competition between *Anastatus* sp. and *T. halyomorphae* has been reported, but with no reduction in total parasitism (Qiu 2007). *H. halys* was significantly less sensitive to infection by the entomopathogenic fungus, *Metarhizum anisopliate* strain FRM515, than either *P. stali* or *Glaucias subpunctatus* Walker (Ihara et al. 2008).

Table 4. List of potential biological control agents against *Halyomorpha halys* identified in Asia

Agent	Family	Host stage affected	Max % parasitism	Country	Reference
Parasitoid					
Acroclisoides sp.	Pteromalidae	Egg		China	8
Anastatus sp.	Eupelmidae	Egg	77.2	China	3
Anastatus gastropachae Ashmead	Eupelmidae	Egg		Japan	1, 4
Bogosia sp.	Tachinidae	Egg		Japan	4
Ooencyrtus nezarae Ishii	Encyrtidae	Egg		Japan	1, 4
Ooencyrtus sp.	Encyrtidae	Egg		China	8
Telenomus nigripedius Nakagawa	Scelionidae	Egg		Korea	5
Telenomus mitsukurii (Ashmead)[a]	Scelionidae	Egg	84.7	China	2
Telenomus sp.	Scelionidae	Egg		China	8, 11
Trissolcus mitsukurii (Ashmead)	Scelionidae	Egg		Japan, China	1
Trissolcus itoi Ryu [basionym]	Scelionidae	Egg		Japan	1
Trissolcus plautiae (Watanabe)	Scelionidae	Egg		Japan	4
Trissolcus flavipes Thomson	Scelionidae	Egg	63.3	China	8[b], 13
Trissolcus halyomorphae Yang	Scelionidae	Egg	70	China	8, 12
Predator					
Arma chinensis (Fallou)	Pentatomidae	Egg and adult		China	8
Astochia virgatipes Coquillett	Asilidae	Unknown		China	8[b]
Isyndus obscurus (Dallas)	Reduviidae	Nymph and adult		Japan	4, 7
Misumena tricuspidata (F.)	Thomisidae	Egg and adult		China	8
Nyctereutes procyonoides Gray	Canidae	Adult		East Asia	9
Orius sp.	Anthocoridae	Egg		China	8
Entomopathogen					
Ophiocordyceps nutans (Pat.) G.H. Sung, J.M. Sung, Hywel-Jones & Spatafora		Nymph and adult		Japan	10
Plautia stali intestine virus (PSIV)		Nymph and adult		Japan	6

[1]Arakawa and Namura 2002; [2]Chu et al. 1997; [3]Hou et al. 2009; [4]Kawada and Kitamura 1992; [5]Lim et al. 2007; [6]Nakashima et al. 1998; [7]Oda et al. 1982; [8]Qiu 2007; [9]Sasaki and Kawabata 1994; [10]Sasaki et al. 2012; [11]Wang and Wang 1988; [12]Yang et al. 2009; [13]Zhang et al. 1993.
[a] Reported by Yang et al. (2009) to be *Trissolcus mitsukurii*.
[b] Cited by.

Cultural Control. Although specific methods for cultural control of *H. halys* have not been widely practiced in Asia, some authors have suggested mechanical removal of eggs and nymphs from crops (Hoffman 1931, Qin 1990, Cai et al. 2008), destruction of nearby alternate hosts (Hoffman 1931), construction of overwintering traps (Qin 1990), and bagging fruit (Yu and Zhang 2007, Zhang et al. 2007) as potential control techniques. However, Li et al. (2007) stated that fruit bags did not prevent injury in their studies.

Two studies have discussed the use of trap cropping for control of *H. halys*. Osakabe and Honda (2002) examined the effects of using early maturing soybeans as a trap crop to protect mid- and late maturing varieties. More *H. halys* were observed on the early maturing soybeans than the later varieties and populations did not increase in later varieties upon harvest of the early crop. Similarly, Cai et al. (2008) suggested planting sour jujube trees around orchards as a trap crop, but this method was not attempted.

Conclusions

H. halys is a common stink bug species in China, Japan, and the Republic of Korea, capable of causing economic damage in many crops including apple, pear, peach, and persimmon. As predicted based on climate conditions of the United States, this invasive species has steadily expanded its distribution in the United States (Zhu et al. 2012) and emerged as a pest in tree fruit, vegetables, row crops, and ornamentals, especially in the mid-Atlantic region (Leskey et al. 2012). *H. halys* is polyphagous with ≈100 host plant species reported in Asia, and many of which are also present in the United States. In addition, *H. halys* adults have become a serious nuisance by overwintering in large aggregations in human-made structures.

In Asia, temperature, photoperiod, and diet were reported to directly influence *H. halys* reproduction, development, and diapause. *H. halys* populations were generally univoltine or bivoltine throughout China, Japan, and the Republic of Korea. Overwintered adults typically begin to move to host plants in April and May and thereafter reproduce. Summer generations feed on multiple hosts through September and then seek out overwintering sites from September to November. The phenological information in the native range of *H. halys* may serve as baseline knowledge for researchers to develop and enhance monitoring and management programs for *H. halys* in invaded regions.

In diverse crop systems in China, Japan, and the Republic of Korea, traps equipped with mercury lamps or the *P. stali* aggregation pheromone are widely used to monitor *H. halys* populations. Management programs for *H. halys* in agriculture in Asia rely mainly on repeated insecticide sprays of pyrethroids and neonicotinoids. Recently, there have been more attempts to develop biological control programs for *H. halys*, and parasitoids in the genus *Trissolcus* have been suggested as promising candidates. Further research is warranted to evaluate the potential of these parasitoids for use in classical biological control against *H. halys* in invaded regions.

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