Importance of apple fruits as food for the brown-marmorated stink bug, *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae)

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**Abstract**

The nutritional status and ovarian development of *Halyomorpha halys* adults collected in an apple orchard and in coppiced trees were investigated in 2000 and 2001, and those of adults reared on apple trees with fruits were investigated in 2002. Adults were observed earlier in the apple orchard than in the coppices; adults immigrated into the apple orchard in May of each year. Female adults had developed ovaries and produced mature eggs. Adults were seldom observed in the orchard after early June, when many adults were observed in the coppices. However, many adults were observed in the apple orchard from mid-July to early August in 2001; the nutritional status of these adults was inferior to that of adults collected in the coppices, and many of the females had undeveloped ovaries. The nutritional status and the number of deposited eggs of the adults reared on apple trees with fruits were significantly inferior to those of adults reared on peanuts and soybeans, foods which were similarly suitable as mature fruit of Japanese flowering cherry. These results suggest that apple fruit is not as good a food for *H. halys* adults as other plants, but apple is satisfactory when more suitable foods are in short supply.

**Key words:** *Halyomorpha halys*; apple; ovarian development; nutritional level

**INTRODUCTION**

More than 40 species of bugs are regarded as fruit-spotting bugs in Japan (Kawamura, 1993). Generally, fruits of cultivated species are unsuitable food for these stink bugs: neither their eggs nor their nymphs are found on fruit trees (Oda et al., 1980; Yamada and Miyahara, 1980; Shiga and Moriya, 1984). On the other hand, the brown-marmorated stink bug, *Halyomorpha halys* (Stål), can develop successfully to adulthood by feeding solely on fresh apple fruits (Funayama, 2002a). This finding indicates that apple could be a host plant of *H. halys*.

The life history of *H. halys* has been reported as follows: adults invade houses and sheds in autumn, pass the winter there, and emerge again in early spring (Watanabe et al., 1994). Adults migrate seasonally among fruiting plants like Japanese flowering cherry, mulberry, pea and kidney bean (Yanagi and Hagihara, 1980; Kawada and Kitamura, 1983), although adults are found on *Paulownia tomentosa* Steudel regardless of fruiting (Fujiiie, 1985). Generally, the fruiting periods of these host plants are short. In contrast, apples continuously bear fruit from May to November, much longer than other food plants (Umeya, 1976). However, *H. halys* adults are not always found in apple orchards throughout the fruiting period, though they sometimes raid orchards to suck on fruits.

Fruit damage by *H. halys* has recently increased in apple orchards in Akita Prefecture, Japan (Funayama, 2003). At present, *H. halys* is controlled in apple orchards only by chemical spraying. However, few insecticides last long enough (Funayama, 2002b). Therefore, it is essential to understand why *H. halys* moves into apple orchards to achieve effective control.

This study was undertaken to determine whether apple fruits are a suitable food resource for survival and sexual maturation of *H. halys* adults. These results will help to clarify the role of apple fruits in the life history of *H. halys*.

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MATERIALS AND METHODS

Nutritional status and ovarian development of field-collected *H. halys* adults. The seasonal changes of the nutritional status and the ovarian development of *H. halys* adults were compared between those collected in an apple orchard and in coppiced trees in 2000 and 2001 as follows: adults were collected in an insect net (50 cm diameter, 4.5 m length) by sweeping at intervals of about 7-d from May to early August. The pronotum widths (mm) were measured with an electronic caliper and the live body weights (mg) were measured with an electronic balance. An index of nutritional level was calculated as follows (Kondoh, 1968):

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\text{Nutritional level} = \frac{\text{live weight (mg)}}{\text{pronotum width (mm)}^3}
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Female adults were dissected and their ovaries were observed; then the development of the ovaries was graded according to Noda and Ishii (1981) as follows: I, ovaries are undeveloped; II, mature eggs are not observed, but oogenesis is obvious; and III, mature eggs are observed.

The apple orchard (about 40 a) in which *H. halys* adults were collected was located in a ravine in the town of Inakawa, in southern Akita Prefecture, Japan. In this orchard, 38 apple trees grow (cultivars ‘Fuji’ and ‘Orin’; tree height, about 4 m; tree age, about 40 years). The coppices in which *H. halys* adults were collected were also located in southern Akita Prefecture. The host plants were five Japanese flowering cherry trees, Prunus sp. probably *P. apetala* (Siebold et Zucc.) Franch. et Sav. var. *pliosa* (Koidz.) Wilson, in the town of Hiraka in 2000 and 2001; five Japanese bird cherry trees, *Prunus grayana* Maxim., in Hiraka; three mulberry trees, *Morus* sp., and five paulownia trees in the town of Inakawa in 2001.

Nutritional status and number of deposited eggs by *H. halys* adults reared on apple trees with fruit under semi-field conditions. The seasonal changes of the nutritional status and the number of deposited eggs of *H. halys* adults were compared between bugs reared on apple trees with fruit and those fed peanuts and soybeans under semi-field conditions. This experiment was performed in an apple orchard (cultivar ‘Fuji’; tree height, about 3.5 m; tree age, 7 years) at the Akita Fruit Tree Experiment Station, Hiraka town, Akita Prefecture, Japan, in 2002. *H. halys* adults were collected from a house in the village of Sannai, in southern Akita Prefecture, on 1 April and kept in a refrigerator at 5°C; the pronotum widths (mm) were measured with an electronic caliper just before use in the experiment. On 24 April, 1 female and 1 male were put in each of 30 transparent polypropylene bags (25 cm×25 cm, with holes of 1 mm diameter all around). The bags were placed over a cluster of leaves and either fruit or flowers and were bound with polyethylene tape. On the same day, other adults (one female and one male) were put into 20 glass Petri dishes (2 cm height, 9 cm diameter) with fresh peanuts, dry soybeans, and damp absorbent cotton. The dishes were then put into a stainless steel cage (30 cm×30 cm×30 cm), and the cage was put in the field in shade under the apple trees. Bags and dishes were examined at 4-d intervals, and the numbers of live and dead adults and deposited eggs were counted; the live body weights (mg) of survivors were measured with an electronic balance and the index of the nutritional level was calculated. This investigation was continued until mid-October. Peanuts and soybeans were replaced with new ones before rotting. Water was added to the cotton at 4-d intervals. Moreover, mean air temperature was measured daily in the field. The number of deposited eggs and the survival periods were compared by a *t*-test between adults reared on apple trees with fruit and those reared on peanuts and soybeans.

The number of eggs deposited by *H. halys* adults was compared between those given mature fruits of Japanese flowering cherry and those given fresh peanuts and dry soybeans in 2003. *H. halys* adults were collected from a house in the town of Inakawa, southern Akita Prefecture, on 1 April 2003 and kept in a refrigerator at 5°C. On 26 May, adults (1 female and 1 male) were put into 10 glass Petri dishes with mature fruits of Japanese flowering cherry and damp absorbent cotton. Fresh peanuts and dry soybeans were similarly provided. The dishes were put into an incubator (25°C, 16L–8D). Dishes were examined at 2-d intervals and the numbers of deposited eggs were counted. This investigation was continued until 7 July when almost all mature fruits of Japanese flowering cherry had fallen. The cherries were replaced with new ones at 7-d intervals. Fresh peanuts and dry soybeans were replaced with new ones before
rotting could occur. Water was added to the cotton at 4-d intervals. The number of eggs deposited by adults was compared between treatments by a t-test.

RESULTS
Nutritional status and ovarian development of field-collected H. halys adults
Figure 1 shows the seasonal changes of the nutritional level and the ovarian development level of H. halys adults collected in an apple orchard and Japanese flowering cherries in Akita Prefecture in 2000. Females were observed in the apple orchard from mid-May to late May and males were observed in late May. The nutritional level of the females increased in late May. Most adults developed ovaries or had mature eggs from mid-May to late May. The ovarian development of the females collected in mid-July varied, but a considerable portion of them had undeveloped ovaries. The nutritional level of the males reached a peak in mid-May and decreased afterward. Adults were observed on mulberry from late May to late June. The nutritional level of the females varied suddenly in late-May. Most of them had developed ovaries or mature eggs. The nutritional level of the males remained nearly constant.

Figure 2 shows seasonal changes of the nutritional level and the ovarian development level of H. halys adults collected in an apple orchard and in coppices in 2001. The adults were observed in the apple orchard in May and from mid-July to early August. The nutritional level of the females increased from mid-May. Most females developed ovaries or had mature eggs from mid-May to late May. The ovarian development of the females collected in mid-July varied, but a considerable portion of them had undeveloped ovaries. The nutritional level of the males reached a peak in mid-May and decreased afterward. Adults were observed on Japanese flowering cherry from early May to late June. The nutritional level of females increased suddenly in late-May. Most of them had developed ovaries or mature eggs. The nutritional level of the males remained nearly constant until mid-June. Adults were observed on mulberry from late May to late June. The nutritional level of the females and males was almost constant. All of the females had mature eggs or developed ovaries. Adults were observed on Japanese bird cherry from early June to late July. The nutritional level of the females decreased from late June to early July, and increased again afterward. Most of the females had mature eggs or developed ovaries. Adults were observed on paulownia from late May...
to early August. The nutritional level of females and males remained nearly constant. Most of the females had mature eggs or developed ovaries, but some individuals had undeveloped ovaries, especially from mid-July to late July.

*H. halys* adults were observed earlier in the apple orchard than in coppices in both years. Adults were seldom observed in the apple orchard from early June to early July, when many adults were observed in the coppices. Most of the adult females collected from the coppiced trees tended to have mature eggs or developed ovaries, and more adult females with undeveloped ovaries were collected from the apple orchard than from the coppiced trees.

**Nutritional status and number of eggs deposited by *H. halys* adults reared on apple trees with fruit under semi-field conditions**

Figure 3 shows the seasonal changes in nutri-
The nutritional level of females reared on apple increased from late May (about 14-d after petal fall; fruit width about 15 mm), peaked in mid-June, decreased gradually until mid-August, and increased again in late August. Mean air temperature in the field exceeded 16.3°C, which is the threshold temperature for ovarian development of *Halyomorpha halys* (Watanabe, 1980), from late May. Eggs were laid from mid-June to late August. The nutritional level of males reared on apple was moderate until mid-August, but increased in late August. The nutritional level of adults reared on apple was considerably lower than that of adults reared on peanuts and soybeans. In addition, the number of eggs deposited by females (mean±SE) reared on apple was 47.0±33.7, which was significantly less than that by adults fed peanuts and soybeans (146.7±

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Fig. 3. Seasonal changes in the mean air temperature (per 4-d) (A) measured in the field, survival rate (B), average nutritional level (C), and average fertility (D) of overwintered adults of *Halyomorpha halys* reared on apple trees with fruit (female ♂; male ▲) and those reared on fresh peanuts and dry soybeans (female ○; male △) in 2002.
Fruits of cultivated species are on unsuitable food for Plautia crosota stali Scott (Oda et al., 1980; Yamada and Miyahara, 1980; Shiga and Moriya, 1984). Therefore, it has remained unclear why many P. c. stali adults sometimes immigrate into orchards. Recently, Moriya (1995) clarified that P. c. stali adults laid eggs when given mature apple and pear seeds; that study concluded that the adults immigrate into the orchard to feed on seeds. In this study, on the other hand, H. halys adults reared on apple trees with fruits laid eggs and some adults survived until autumn (Fig. 3). This implies that H. halys might immigrate into the apple orchard to feed on fruits. However, the nutritional level of, and number of eggs deposited by adults fed apple are inferior to those of adults fed peanuts and soybeans, foods which were similarly suitable as mature fruit of Japanese flowering cherry (Fig. 3). These results suggest that apple fruits are not good food for H. halys adults. This raises the following question: why do many H. halys adults immigrate into apple orchards?

H. halys adults were observed earlier in the apple orchard than in the coppices; the adults immigrated into the apple orchard in May each year and many females developed ovaries (Figs. 1, 2). The threshold temperature for ovarian development of H. halys is 16.3°C (Watanabe, 1980), and the mean air temperature in Akita Prefecture commonly exceeds this level from about mid-May to late May. Thus, it appears that H. halys adults require suitable food for sexual maturation from this time. However, suitable food plants for H. halys adults are uncommon in early spring (April–May) (Kawasawa and Kawamura, 1975; Yanagi and Hagihara, 1980; Kawada and Kitamura, 1983). These observations suggest that feeding on apple fruits aids survival and sexual maturation of the adults in early spring. This indicates that apple fruits are important for some H. halys adults, at least in the early spring. In support of this, damage to apple fruits by stink bugs has been observed during spring (May–June) (Hasegawa and Umeya, 1974).

H. halys adults were seldom found in the apple orchard from June to early July each year (Figs. 1, 2) and many adults were observed on food plants in coppices in June; most of those females had mature eggs or developed ovaries (Figs. 1, 2). This may indicate that H. halys adults migrate to more suitable food sources outside the apple orchard every year. However, many adults immigrated again into the apple orchard from mid-July to early August in 2001 (Fig. 2), when an outbreak of H. halys adults occurred in Akita Prefecture (Funayama, 2003). The nutritional status of the males was inferior to those collected in the coppices, and many females had undeveloped ovaries (Fig. 2). This observation suggests that H. halys adults immigrated into the apple orchard to feed because they were starving. These facts indicate that apple fruit are important for H. halys adults when more suitable foods are in short supply. However, it is not clear whether the adults immigrate into apple orchards in summer every year. Detailed investigation of the life history of H. halys is necessary to clarify this aspect.

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REFERENCES


