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Life cycle of the soybean aphid *Aphis glycines* Matsumura, in Japan

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The soybean aphid *Aphis glycines* MATSUMURA is the main sap-sucking pest on soybeans *Glycine max*. In Japan, it is distributed from Hokkaido to Kyushu (Sakai, 1949); abroad, it is found in Korea, China, Taiwan, Thailand, Malay (Paik, 1965), the Phillipines (Takahashi, 1966), and India (Raychaudhuri et al., 1980). In addition to soybeans, wild *Glycine* species are known to be a secondary host.

Matsumura reported this aphid species on soybean (1917a) and in the same year recorded that its eggs over-wintered on plants belonging to the wild pea family (1917b). Shindo (1928, 1932) originally identified *Kitsunenomago* *Justicia procumbens* and purplish amaranth *Amaranthus blitum* as primary hosts, but later retracted and reported that the eggs over-winter in the roots of the Japanese chaff flower *Acyranthes japonica* (1941). However, Sakai (1949, 1950a, b) showed in greenhouse studies that this aphid does not over-winter in the chaff flower, and concluded that the species found on chaff flower was actually *Aphis justiciae* SHINJI which Shindo (1928) considered to be the same as *Aphis glycines*.

While the controversy in Japan about the primary host remained unresolved, in China it was reported by Wang *et al.* (1962) that the eggs over-wintered in the Dahurian buckthorn *Rhamnus davurica* of the buckthorn family. Zhang and Zhong (1982) subsequently established that several of the 15 species in the genus *Rhamnus* found in China were primary hosts. In the reports from China, only the body color and the number of secondary sensilla of the third antennal segment of gynopara were reported, and no mention was made of the morphs on the primary host. Since 1981, our field surveys and greenhouse studies have focused on the life cycle and morphs on primary hosts in the genus *Rhamnus*, the results of which are reported here.

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SURVEY AND EXPERIMENT METHODS

1. Field surveys

Based on the information from China, we surveyed the occurrence of soybean aphids primarily on Japanese buckthorn *Rhamnus japonica* and Dahurian buckthorn, both in the family *Rhamnaceae*. The surveys were conducted from 1981 to 1990 in Tochigi and Nagano prefectures.

In addition, occasional surveys of Isonoki *R. crenata* in the genus *Rhamnus*, and *Rhamnella franguloides*, *Ziyhus jujuba* var. *inermis*, *Berchemia racemosa*, Japanese raisin tree *Hovenia dulcis* in the family *Rhamnaceae* were conducted.

In 1982 and 1983, we investigated the timing of the arrival of *A. glycine* spring migrants on soybeans and wild *Glycine* species and the appearance of gynoparae and male in Tochigi prefecture. Because of the difficulty in distinguishing viviparous and oviparous winged female morphs in the field, specimens were collected and inoculated onto buckthorn in the laboratory, and classified by the presence or absence of egg-laying.

Some of the specimens from the surveys were retained, prepared, and measurements of the different morphs were made.

2. Laboratory experiments

We conducted a host-transfer experiment in which gynoparae collected in the fall from soybeans were inoculated onto buckthorn or Dahurian buckthorn, and the spring-migrants that emerged were *reinoculated* onto soybeans. In addition, we investigated the succession of generations on buckthorn, starting from over-wintering eggs. These experiments were conducted in a breeding chamber having good ventilation and no temperature difference with the outside.

Some of the specimens from these studies were retained, prepared, and measurements were made.

RESULTS

1. Field Surveys

1) Spring

Despite the numerous surveys conducted in 1981 to 1982, not a single *A. glycines* specimen was observed. In the surveys of Tochigi prefecture between March and June of 1983, 6 of 273 buckthorn trees (3 in Shikanuma city, 3 in Utsunomiya city) were confirmed to be infested by *A. glycines*. A colony of 3 fundatrix adults, 1 fundatrix nymph, and 37 second-generation nymphs was observed on one tree in Shikanuma city, surveyed on April 18th. Colonies on all trees disappeared in late May following the appearance and migration of numerous winged aphids. Similarly, in the five colonies found on April 28th, 1990, many winged aphids were already present. By late May, all of the aphids were winged, and the colony disappeared thereafter.

With the exception of a single tree (exceptionally tall 1.5m), all trees colonized were short (53~62cm), young, and had young, vigorous shoots. *A. glycine* specimens were found exclusively on the underside or leaf stem of new leaves near the tip of shoots, or young twigs near the growing tip. In the two colonies with the greatest number of aphids, the aphids caused the leaf to curl towards the underside and to shrink, creating a false-gall. No *A. glycines* were observed on the 16 Dahurian buckthorn, 51 *R. crenata*, 2 *R. franguloides*, 3 *Z. jujuba* var. *inermis*, and 1 *H. dulcis* surveyed in Tochigi prefecture.

However, on May 12th, 1985, a colony of 4 fundatrix adults, 5 second-generation apterous fundatrigenia, and numerous nymphs was found on 1 Dahurian buckthorn in Komuro city, Nagano prefecture. Furthermore on May 17th, 1988, 4 colonies in Komuro city and 2 colonies in Tobu village, also in Nagano prefecture, were confirmed on the same plant species. The colonized trees were similarly short, around 50cm tall; although the location of the aphids was the same as that on buckthorn, aphids were also observed on the stalk of flowers in bloom.

2) Fall

(1) Buckthorn

In the 1983 survey, the migration to buckthorn began around October 20th, and was observed from late October to early November. In that year, of the 65 trees surveyed, 17 were colonized by a total of 51 aphids. Among the trees surveyed, 15 trees were shorter than 70cm, 3 of which had 4 aphids migrating to them. All of the gynoparae which migrated to the buckthorns alit on the underside of leaves, and bore nymphs while feeding on the sap. On the other hand, male aphids were observed migrating in November; six aphids were observed on 5 of the trees surveyed. No males were observed on short trees. Five of the 6 males were found on trees on which gynoparae were also present. Four of the 5 were found on leaves that also had colonies of gynoparae and oviparae.

Of the colonies found on buckthorn originating from the 51 gynoparae, 42 disappeared when the colonized leaves fell off, 8 disappeared for other reasons, leaving only 1 colony in which the egg-laying adult females could be found. However, even this leaf fell and it was not possible to confirm egg-laying.

(2) Dahurian buckthorn

In the 1982 survey, the arrival of *A. glycine* gynoparae on the 3 trees in Utsunomiya city started October 20th, and adult oviparae were observed from November 11th to 22nd. The arrival of males was confirmed on November 11th, and on the same day mating with ovipara was observed.

In the 1983 Nagano prefecture survey, 42 Dahurian buckthorn trees were found, of which 23 had a total of 135 *A. glycinis* colonies. The majority of colonies consisted of nymphs of both gynoparae and oviparae; in some colonies, adult oviparae and males, some in the act of mating, were observed.

(3) Other plants in the *Rhamnaceae* family

On November 1st 1983, 4 *A. glycine* gynoparae were found on 2 of 9 *R. crenata* trees surveyed in Utsunomiya city. Of these specimens, 2 had borne 7 and 4 ovipara nymphs, respectively; the whereabouts of these became unknown by November 4th. It was not possible to confirm the arrival of *A. glycine* on *R. franguloides*, *Z. jujuba*, *B. racemosa*, or *H. dulcis*. When gynoparae were inoculated onto these tree species, nymphs were produced; however, no oviparae matured into adults.

(3) Soybean and wild Glycine species [*Glycine max* (L.) Merr. subsp. *soja* (Sieb. et Zucc.) Ohashi]

Despite the low level of migration to soybean observed in Utsunomiya City around May 10th, when transplanting occurs, we were able to confirm 2 specimens on May 9th, 1982, and 1 specimen on May 11th, 1983. Although in both years only 6 specimens were confirmed in mid-May, by mid-June the number of winged females was increasing, along with migration to uncolonized soybeans.

On the wild *Glycine* species, which begin to germinate in late-April, colonization was confirmed starting July 10th in 1982, and July 6th in 1983. These soybean and wild *Glycine* plants continued to be infested until fall.

As to the appearance of the sexual generations, in the case of soybeans in 1983, gynoparae appeared between October 12th and November 10th, with the greatest number between October 17th and 31st. Males appeared later than gynoparae, between October 26th and November 10th.

2. Laboratory Experiments

Gynoparae collected from soybeans in the fall produced oviparae on buckthorn and Dahurian buckthorn. These juveniles matured normally into adults. Spring migrants from the buckthorn and Dahurian buckthorn produced progeny on soybeans. These nymphs matured normally into adults, which produced a subsequent generation. On March 13th, the nymphs emerged from eggs which had over-wintered in buckthorn, and matured into adults by mid-April. By June 11th, we succeeded in propagating up to the fifth generation. The spring-migrants were born from the generation arising from the fundatrix, and in the fifth generation comprised 100% of the population, bringing an end to the infestation.

3. Morphology of the fundatrix, fundatrigenia, gynopara, ovipara, and males (Table 1)

(1) Fundatrix (fig. 1-1)

Immediately after emergence from eggs, the nymphs were a dark green similar to that of the cotton aphid fundatrix, which also infests buckthorn; but as they matured, they became increasingly lighter in color, ending in a green color, which was distinct from that of adult cotton aphid fundatrix. Dimensions of body parts are presented in table 1. The antennae had 5 segments, with no observable annuli in the third segment; the flagella were short, approximately 1.35 times the length of the scape. There were 1.6 setae on the third segment, less than the 3.3 setae of the cotton aphid fundatrix. The legs were short; the average length of the hind-leg tibia was 0.62mm, approximately 1/3 the body length. While all other morphs had 4 total setae on the front of the head, two in the middle and two on the sides, the fundatrix had only two in the middle. The abdomen was longer than that of the cotton aphid, and had 9.8 setae as opposed to 7.6.

(2) Apterous fundatrigenia (fig. 1-2)

The living apterous fundatrigenia were yellow to green. The antennae had six segments; the flagella were approximately 2.45 the length of the scape. The hind-leg tibia length was on average 0.78mm, which is approximately 0.42 times the body length.

(3) Alate fundatrigenia – spring migrant (fig. 1-3)

The color of the living alate fundatrigenia was the same as the wingless morph. The antennae had 6 segments; the flagella were approximately 2.367 times the length of the scape. The hind-leg tibia length was on average 0.87mm, which is approximately 0.49 times the body length.

(4) gynopara (fig. 1-6)

The living gynoparae were yellowish green. The antennae had 6 segments. The basal area of the third segment was pale and differed from that of the cotton aphid, which was entirely brown. The flagella were roughly 2.67 times the length of the scape. Whereas the cotton aphid had 10.0 sensilla pores on the third antennal segment, 4.0 on the fourth, and 0.1 on the fifth, *A. glycines* has somewhat fewer pores with 9.4 on the third segment, 0.7 on the fourth, and none on the fifth. The legs were long, and the tibia of the hind leg was on average 1.02mm, which is approximately 0.51 times the body length.

(5) ovipara (fig. 1-8,9)

Immediately after birth, the ovipara nymphs were yellow-green in color, but as they matured their abdomens became green, while the rest of their bodies became a dark green. Whereas the oviparae of the cotton aphid all had 5-segmented antennae, *A. glycine* were found to have either 5 or 6-segmented antennae; on the 5-segmented antennae, annuli were found on the 3rd segment. The flagella were approximately 2.09 times the length of the scape; for the cotton aphid, 2.28. The tibia of the hind legs were enlarged and had on average 96 false sensilla pores¹, as compared to 126 on the cotton aphid; the average length of the tibia was approximately 0.5mm, and there was a black patch in the middle section. The arrangement of setae was 3:2:2, different from that of other morphs (3:3:2). There were a high number of setae on the genital segment (22~37); this was quite distinct from the number on the other morphs, where there were 2 to 6 at the anterior end and 6 to 13 on the posterior end for a total of less than 20. The lateral spurs on other morphs are found on the 1st and 7th segments, but on oviparae none were found on the 7th segment. The abdomen was longer than that of the cotton aphid and had more setae than the 6.8 found on the cotton aphid.

(6) male (fig. 1-7)

The living male was yellow-green, possessed wings, and had pincers and a penis on the terminus of the abdomen. The antennae had 6 segments; the 3rd segment was pale, as opposed to the brown of the cotton aphid. The length of the flagella was 2.72 times that of the scape. While the cotton aphid antennae had 33.1 sensilla pores on the 3rd segment, 22.5 on the 4th, and 12.9 on the fifth, *A. glycines* males had somewhat fewer with 26.9 on the 3rd, 23.4 on the 4th, and 11.4 on the 5th. The tibia was approximately 0.85mm, which is roughly 0.51 times the body length. Although most specimens possessed cornicles on the 1st and 7th segments, some specimens had none.

DISCUSSION

The field surveys and lab experiments established that the primary hosts for the soybean aphid in Japan are buckthorn and Dahurian buckthorn of the buckthorn family. Although the timing of infestation on Dahurian buckthorn was similar to what was

¹'false sensilla pores' is a direct translation from the Japanese term

reported in China, the emergence of the fundatrix was earlier by approximately 1 month and the migration of the gynoparae was later by more than a month.

The number of colonies discovered on buckthorn and Dahurian buckthorn in the spring was extremely low.

It is speculated that the reason for the low numbers of aphids on the primary hosts is a lack of synchronization with plant maturation; the buckthorn trees surveyed, most of which were in Tochigi prefecture, had mostly defoliated by early-November when the oviparae matured into adults, and only a few of the oviparae were able to lay their eggs. In other words, it is thought that egg-laying is performed only by those insects which have matured before leaf-drop and moved to the twigs or those that have fallen with the leaves but are able to return to the twigs.

The hatching of eggs that have over-wintered beginning in mid-April of the following spring is adequately synchronized with the germination of buckthorns, which begins in late-March.

On the other hand, the Dahurian buckthorns in Tochigi prefecture lose their leaves later than the buckthorns and are well synchronized with the maturation of the oviparae; however, germination occurs later in early-April, and is not at all synchronized with fundatrix emergence, and consequently no development of the fundatrix nymphs was observed. In contrast, in Komuro, Kariuzawa, Miyota, and Tobu village in Nagano prefecture, which have a cooler climate, Dahurian buckthorn germination and fundatrix emergence coincide, and it was possible to confirm infestation by *A. glycine*.

As described above, it is thought that depending on the region, the soybean aphid uses either buckthorn or Dahurian buckthorn, or both, as its primary host and thereby completes its life-cycle. Combining this information with Sakai's data (1950a), it is estimated that approximately 21 generations are completed per year in the Hirano area of the Kanto region. In China, it is believed that the spring-migrants appear in the first generation after the fundatrix, but it became clear that in Japan they appeared over the first 4 generations.

SUMMARY

1) We clarified that in Japan the soybean aphid uses buckthorn and Dahurian buckthorn, both of the family *Rhamnaceae* family, as primary hosts.

2) We considered the temporal relationship of the soybean aphid life cycle and defoliation as well as germination of the primary hosts.

3) We described the fundatrix, fundatrigenia, oviparae, and males of the species, which had not been done previously, and the gynoparae, which had only been partially reported, of *A. glycines* in comparison to the cotton aphid.

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