Systematic and biological studies on the genus Aphytis Howard (Hymenoptera, Aphelinidae) of Japan Part 2. Biology and mass production

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Systematic and biological studies on the genus *Aphytis* Howard (Hymenoptera, Aphelinidae) of Japan
Part 2. Biology and mass production*

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BIOLOGY

Aphytis diaspidis Howard
(Fig. 1)

Aphytis diaspidis Howard under Japan conditions is usually a unisexual species. It is known to develop on *Aspidiotus perniciosus* Comstock, *Chrysomphalus bifasciculatus* Ferris, *Pseudaulacaspis pentagona* Targioni and *Lepidosaphes* sp. in Japan. This species is a very promising parasite of *Aspidiotus perniciosus* which is the most serious pest of apple and pear trees in Aomori and Yamanashi Prefectures.

Aphytis diaspidis attacks second and third stage female scales, except eggs producing adult scales and second stage prepupal male scales. The scales it attacks for oviposition measure from 0.55–0.72 mm in length by 0.51–0.67 mm in width.

Reproduction is parthenogenetic in this species, only females are produced by this parasite.

The eggs of *Aphytis diaspidis* are deposited under the scale covering either on the upper or lower side of the insect itself, most commonly on the lower side. The adult female parasite moves over the surface of leaves and twigs, palpating scales with its antennae. A through examination is made of the scale by alternately tapping with the antennae from the center of the scale to the periphery. In this way it examines several different scales, sometimes stops abruptly between scales to remain motionless or several seconds or even minutes before continuing its search. Upon reaching the edge of the scale a rapid

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backward movement is made, at the same time turning slightly around so that entire surface is explored by the antennae by backward and forward movements. The parasite selects a particular scale for more through examination and makes several exploratory antennal examinations of the scale. But the parasite does not rarely on the exploration with the antennae, for the ovipositor may be inserted many times without any eggs being deposited. Insertion with the ovipositor may occur with the insect beneath in various conditions, and not frequently it is dead and shriveled up. But exploration by the ovipositor is the final reliance for depositing the egg in the scale.

The ovipositor may be inserted under the scale covering just touching the upper surface of the scale body to deposit egg on the upper surface of the scale body. But generally the ovipositor is inserted through the scale covering just beyond the insect beneath. The parasite is facing away from the scale during oviposition so that the ovipositor is pushed down and backward towards the center of the scale. The parasite raised its abdomen and insert the tip of the ovipositor by a rapid thrust, and slowly penetrate the whole ovipositor inside the scale body. The rapid up and down movement of the ovipositor are accompanied by rotary movement in both clockwise and anti-clockwise direction.

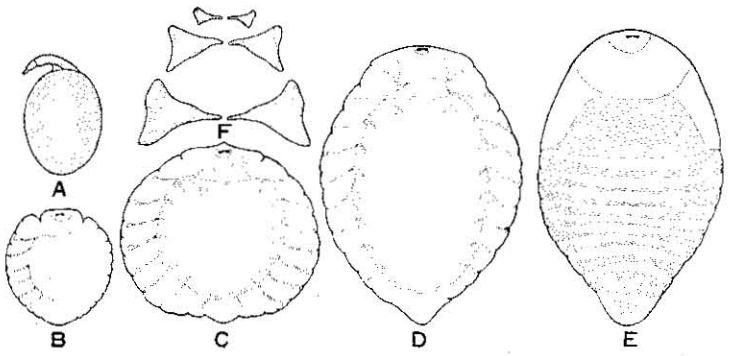

Fig. 1. A, egg; B, newly formed larva with the tracheal system; C, three days old larva with tracheal system; D, full grown larva with tracheal system; E, prepupa; F, mandibles of larvae of *Aphytis diaspidis*.

The actual penetration of the shell is followed by slow deliberate thrusts of the styles into the scale and probing interiorly of the greater part of the soft scale body. Just before the egg is laid, rapid pulsation of the styles ceases, the ovipositor withdrawn from the body, the tip contacts the body wall and an ovoid, somewhat tear-shaped, nearly translucent egg (Fig. 1A) is deposited on the ventral surface

of the scale body. The egg adheres at the point of deposition in the foldings of the scale body.

The deposition of the first egg may be followed by a brief respite, during which time the ovipositor may be partially or completely withdrawn from the scale covering. A second probing action is soon stated, when the parasite deposits more than one eggs in a particular scale by utilizing the same puncture in the scale covering that was used to lay the first egg or it may penetrate its ovipositor through another portion of the scale covering. Generally it deposits 1–6 eggs per scale. A female parasite may deposit 22 eggs or more in its life and it may deposit two to nine eggs per day.

The newly laid egg is yellowish white in colour, ovate in form, measuring 0.11 mm long and 0.09 mm wide. There is a crook-shaped neck or pedicel extending another 0.02 mm (Fig. 1A). The chorion is smooth, with spherical granular bodies showing through with transmitted light.

The first larva is formed inside the egg within three to four days, and the head of the larva is formed at the base of the pedicel, then rotates counter-clockwise to reverse direction. The tracheal system is clearly visible at this time. Six pairs of spiracles are observed in the newly formed larva. The larva in this stage measures 0.12 mm in length and 0.10 mm in width (Fig. 1B). On the third day the larva measures about 0.25 mm in length and 0.18 mm in width (Fig. 1C). The mandibles of the newly formed larva measure 0.01 mm in length (Fig. 1F). On fourth day the larva reaches the size of 0.37 mm in length and 0.44 mm in width. The larva develops very rapidly. The size of the larva on fifth day is 0.69 mm in length and 0.51 mm in width. The full grown larva becomes orange-yellow just the colour of the scale insect. After expelling meconium the larva becomes white in colour. The tracheal system of the full grown larva is shown in Figure 1D. The mandibles are bigger in size (Fig. 1F), measuring 0.02 mm in length. The number of meconia of this species is from 5–12, more than other species, and the size is about 0.18 mm in length and 0.07 mm in width. After expelling meconia the larva turns to prepupa (Fig. 1E). The prepupal period is one day.

The newly developed pupa is nearly translucent, appearing milky white with a slight yellowish tinge. As the development progresses, the body assumes a definite yellowish cast. On the second day the eyes become orange in colour. The pupa becomes dusky in colour on the ventral surface on fourth day. There is a well-defined pigmentation on midthoracic sterna and slightly dusky spotted bands on the sides of the abdomen on fifth day. The late pupal stage, just before its emergence is characterized by a general body colour yellowish-

dusky. The midthoracic sterna, wing pads, appendages and the side of the abdomen attain brownish pigmentation. The eyes are pale greenish with blood red ocelli. The pupal period is generally 7 days in the month of September in room condition.

The average duration of the various stages in the life cycle of *Aphytis diaspidis* observed in the month of September and October in laboratory condition is as follows:

Stages	Number of days
Egg	3–4
Larva	6–7
Prepupa	1
Pupa	6–7
Total	16–19

The parasite is generally emerged by cutting a hole by its mandible in the scale covering. It cuts the hole just above its head by the sharp mandibles. Just after its emergence it may deposit eggs in the scale body.

Hosts and parasite relation: This parasite is an effective parasite of *Aspidiotus perniciosus* scale insect. But it also attacks other diaspidine scales, such as *Chrysomphalus bifasciculatus, Pseudaulacaspis pentagona.* It is observed during the experiment that *Aphytis diaspidis* emerged from the scale, *Aspidiotus perniciosus* can deposit eggs in the scale, *Aonidiella taxus.*

The larva feeds on the body fluids of the scale body. The larva is attached itself on the ventral surface of the scale body. The host body fluids are completely consumed in the larval stages. It takes about 10–12 days to consume the entire body fluids of the scale after the deposition of egg.

Only one adult parasite used to emerge from one scale, though one to six eggs have been observed to deposit in a scale. The adult parasites feed extensively the body juices of the host. This is necessary for continued, sustained eggs production during the life of the female. However it is not necessary for the newly emerged females to host-feed prior to oviposition.

Longevity: The average longevity of adult females of *Aphytis diaspidis* with access to concentrated honey is 19 days. But it can live on concentrated honey upto 47 days in the month in October in room condition.

Parasitism: Though *Aphytis diaspidis* is a parasite of *Chrysomphalus bifasciculatus, Pseudaulacaspis pentagona* and *Aspidiotus perniciosus*, it has been observed that it is not so effective to control all these scale insects except *Aspidiotus perniciosus*, which is partly con-

trolled, about 30 per cent by *Aphytis diaspidis*. The parasites reared from *Aspidiotus perniciosus*, collected in Aomori Perfecture have yielded 71.2 per cent *Aphytis diaspidis* and 28.8 per cent other parasites. So, it is presumed that *Aphytis diaspidis* may control this scale insect pest, if this parasite is produced in large number in the laboratory and released in the scale infested field.

Aphytis japonicus DeBach et Azim

(Fig. 2)

Aphytis japonicus is one of the most important parasites of *Chrysomphalus bifasciculatus* Ferris in Japan. It can be reared from the field collected host material in room condition throughout the year. This species is bisexual. Rearings of field collected host material have yielded about 2 females to one male.

Mating is necessary for continued female production in *Aphytis japonicus*. The newly emerged females mate just after their emergence, if males are available. The parasite is very active inside the glass tube. The male runs after the female very swiftly to catch hold the female. When the male is able to catch hold the female, it sits at the anterior portion of the female, and try to instinct the female by its antennae and mouth. After three to five minutes the male moves backwards towards the abdomen of the female, and bends its abdomen to attach the tip of its own genital organ to the genital organ of the female. The duration of mating is very short, about thirty seconds to one minute. One mating appears to be sufficient for the life time of the female, though subsequent attempts are made by the male to copulate but females do not repond to it.

Virgin females may deposit only male (unfertilized) eggs; mated females may deposit either male or female eggs, depending on whether or not the spermatheca is stimulated to release sperm as an egg is being laid. The more favourable the host scale and the environment during oviposition, the greater will be the proportion of females to males.

The egg of *Aphytis japonicus* is generally deposited on the ventral portion of the scale body which is covered by hard scale covering. The adult female moves over the scales with its antennae in downward position, and suddenly stops over a scale to examine it with its antennae. Sometimes the parasite remains motionless for several seconds or even minutes before continuing its search. Upon selecting a particular scale for more through investigation, the parasite makes several exploratory antennal examinations over the surface of the scale. Satisfied that the scale is suitable for oviposition, the parasite

raises its abdomen, insert the tip of the abdomen by a rapid thrust at the perphery of the scale and slowly penetrate the whole ovipositor inside the scale body. The rapid up and down movement of the styles are accompanied by slower rotary movement in both clockwise and anti-clockwise direction. It is observed that when the penetration is of shorter duration, about one to three minutes the parasite does not deposit any egg inside the scale. It means that the parasite does not rely on the exploration with the antennae only, for the ovipositor may be inserted many times without any egg being deposited. The exploration by the ovipositor is the final reliance for depositing the egg inside the scale. The actual penetration of the scale covering is followed by rather slow, deliberate thrusts of the styles into the scale and the probing interiorly the greater part of the ventral portion of the soft scale body. Just before the egg is laid the rapid pulsation of the styles ceases, the ovipositor withdrawn from the body, the tip contacts the body wall and an ovoid, somewhat tear-shaped, nearly translucent egg is deposited on the ventral surface of the scale body. The eggs adheres at the point of deposition.

The deposition of the first egg may be followed by a brief respite, during which time the tip of the ovipositor may be partially or completely withdrawn from the scale covering. If it deposits the second egg in the same scale it may utilize the same puncture in the scale or may penetrate its ovipositor through the other portion of the scale. The deposition of eggs is limited to second and third instar females, and second instar and prepupal males. It may deposit 1–5 eggs per scale. There is considerable variation between individuals, and very definite differences will occur at different temperatures and humidities, on different host plants.

The newly deposited egg is yellowish white in colour, ovate in form, measuring about 0.11 mm long and 0.06 mm wide. There is a short neck or pedicel extending another 0.02 mm in length. The chorion is smooth, with spherical granular bodies showing through with transmitted light.

The egg develops on the ventral surface of the scale body and the first larva is formed inside the egg-shell. The tracheal system and the spiracles are clearly visible prior to eclosion. The head of the newly formed larva is formed at the base of the neck or pedicel, then the larva rotates counter clockwise to the reverse direction. The size of the newly formed larva is about 0.11 mm long and 00.7 mm wide (Fig. 2A). Six pairs of spiracles are observed in the larva prior to eclosion. On fifth day the larva casts its egg-shell and the pedicel or neck. The mandibles of the larva are about 0.01 mm in length. The larva develops very rapidly in summer. On third day

the larva measures about 0.30 mm long and 0.23 mm wide and white in colour with a slight yellowish tinge, and the digestive tract with food showing a slight pinkish (Fig. 2B). The full grown larva with the food in the digestive tract appears a little greyish. It is very difficult to trace the tracheal system in the full grown larva, but eight pairs of spiracles and the anterior and posterior commissures are observed at 150× magnification by covering the larva with a cover glass (Fig. 2C). Generally the larval period is 6 days in summer, but it took 11-20 days in spring and autumn when the temperature is low. After expelling meconia which is the evacuations of the digestive tract expelling by the larva prior to pre-pupation. These meconia are 5-10 in number and measure about 0.11 mm long and 0.07 mm broad, dark brown or black in colour. The prepupal period is 1–2 days (Fig. 2D).

The newly formed pupa is nearly translucent, appearing milky white with a slight yellowish tinge. As the development progresses, the body assumes a yellow cast, and the eyes become brilliant red. The late pupal stage is characterised by a general colour light yellow, with a pale green eyes and blood red ocelli. The mature pupa is without any black line or pigmentation. The pupal period is 6 days in summer. There is considerable variation in pupal period between individuals, and very definite differences will occur at different temperatures and humidities. The size of the pupa is about 0.67 mm long and 0.30 mm wide.

The average duration of the various stages in the life cycle of *Aphytis japonicus* in the summer in room condition is as follows:

Stages	Number of days
Egg	4–5
Larva	5–6
Prepupa	1–2
Pupa	6–7
Total	16–20

Aphytis japonicus generally deposits one egg in a scale, but it can deposit upto five eggs in a scale. But only one adult is able to develop in a scale. The adult emerges from the scale by cutting a hole just above its head with the help of its mandibles. But sometimes it pushes the scale and emerges through loosened scale. The larva feeds the juices of the soft scale body. The host body fluids are completely consumed in the larval stage. About 30 per cent of the scales are destroyed by this parasite in the field. But the percentage may vary according to the places.

The longevity of this parasite on concentrated honey in room

condition is better in autumn than in summer. The average longevity in summer is 15.13 days, maximum 30 days and in autumn on an average 30.5 days, maximum 49 days, minimum 9 days.

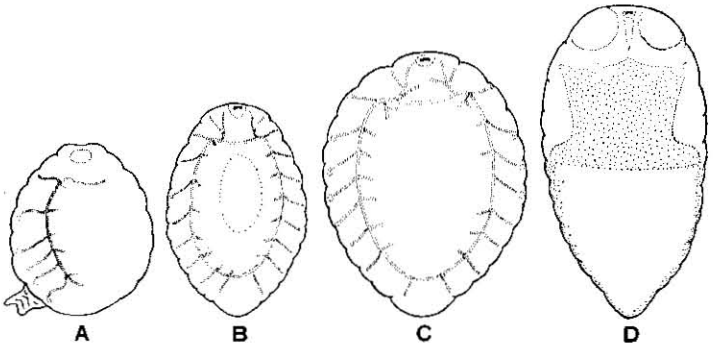

Fig. 2. A, newly formed larva; with tracheal system; B, three days old larva with tracheal system; B, full grown larva with tracheal system; D, prepupa of *Aphytis japonicus*.

The females are greater in number than males. Rearings of the field collected host material have yielded about 2 females to 1 male. Sometimes the larva and pupa of this parasite are observed in most of the male scale. This may be due to this that most of the female scales are occupied by other parasites or may be in egg producing stage. *Aphytis japonicus* can deposit eggs in both male and female scales. So, when the female scales are occupied by other parasites it deposits eggs in the male scales. There is no secondary parasite of this parasite, but *Marietta carnesi* Howard deposits eggs on the larva and pupa of *Comperiella bifasciata* Howard which is also the primary parasite of *Chrysomphalus bifasciculatus* Ferris.

Aphytis yasumatsui Azim

(Fig. 3)

Aphytis yasumatsui is another important primary parasite of *Chrysomphalus bifasciculatus* Ferris. But this parasite is reared from the scales infested on *Illicium religiosum* Sieb. et Zucc. It is very interesting to note that the scales collected from *Illicium religiosum* have yielded *Aphytis yasumatsui, Casca chinensis* in greater numbers, but only few specimens of *Comperiella bifasciata* have yielded from these scales; whereas *Comperiella bifasciata* has been reared in greater numbers from the same host infested on *Euonymus japonica* Thunberg and *Aspidistra eltior* Blume. The scales collected from *Euonymus japonica* and *Aspidistra elatior* have not yielded any *Aphytis yasu-*

matsui. It is presumed that host plants is another important factor for the parasites to deposit eggs and to develop in it.

This parasite is very active after its emergence and mating takes place immediately, if male is available. Mating is essential for continued female production in *Aphytis yasumatsui*. The male runs very swiftly after female, and when it is able to catch hold the female, it sits on the head portion of the female. Then the male tries to instinct the female with the antennae and mouth. After few minutes it moves towards the abdomen of the female, bends its abdomen and inserts the tip of its organ to the genital organ of the female. The duration of mating is very short, about one to two minutes. One mating appears to be sufficient for the life time of the female, in fact, preliminary evidence indicates that subsequent attempts in copulation by males may be refused by the female. Virgin females deposit only male (unfertilized) eggs; mated females may deposit either male or female eggs. The more favourable the host scale and the environment during oviposition, the greater will be the proportion of females to males.

Aphytis yasumatsui attacks second and third instar female scales and second instar and prepupal males. The eggs are generally deposited on the ventral surface of the scale body which is covered by hard scale covering. The adult female parasite moves rapidly on the scales with its antennae downward direction. Sometimes it stops abruptly between scales to remain motionless for several seconds or minutes. It taps several scales with the help of its antennae. It is observed that the parasite takes a complete turn over the surface of the scale covering to examine the other sides of the scale. When the parasite is satisfied that the scale is suitable for oviposition, a site is chosen for the penetration or drilling the hard dorsal surface or near the margin of the scale covering. Generally it prefers periphery of the scale covering, because it is easier to penetrate due to thinness. It raises its abdomen, inserts the tip of the ovipositor by a rapid thrust, and slowly penetrates the whole ovipositor inside the scale body. The rapid up-and-down movements of the styles are accompanied by slower rotary movement in both clockwise and anti-clockwise direction. The actual penetration of the scale covering is followed by rather slow, deliberate thrusts of the styles into the scale and probing interiorly the greater part of the ventral portion of the soft scale body. Just before the egg is laid, rapid pulsation of the styles ceases, the ovipositor withdrawn from the scale body, the tip contacts the body wall and an ovoid, somewhat tear-shaped, nearly translucent egg is deposited on the ventral surface of the scale body. The egg adheres at the point of deposition. Occasionally the ovipositor may be inserted

many times without any eggs being deposited, so it is presumed that the parasite does not rely alone on the exploration with the antennae. The exploration by the ovipositor is the final reliance for placing of the egg.

The deposition of the first egg may be followed by brief respite, during which time the tip of the ovipositor may be partially or completely withdrawn from the scale covering. The second probing action may be started soon by utilizing the same puncture in the scale covering that was used to deposit the first egg, if the parasite deposits more than one egg in the same scale. Generally it deposits one egg in a scale. It deposits 3 to 5 eggs in a day. It may vary according to the temperatures and humidities. The newly deposited egg is yellowish white in colour, ovate in form, measures about 0.11 mm long and 0.08 mm wide. There is a small neck or pedicel, projecting from the narrower end of the egg (Fig. 3A). The chorion is smooth, with spherical granular bodies showing through with transmitted light.

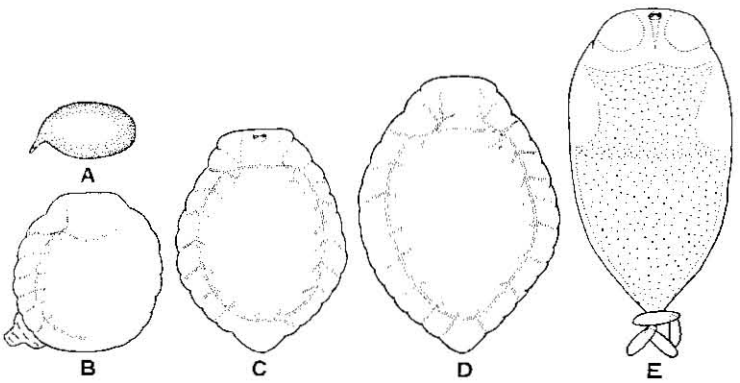

Fig. 3. A, deposited egg of *Aphytis yasumatsui*; B, newly formed larva with tracheal system; C, three days old larva with tracheal system; D, full grown larva with tracheal system; E, prepupa accompanying with dark-brown or black torpedo-like bodies, meconia of *Aphytis yasumatsui*.

The first larva is formed inside the egg-shell with the head at the base of the pedicel or neck after 4 days. The tracheal system can be traceable prior to eclosion. Six pairs of spiracles are clearly evident at 600× magnification in the newly formed larva (Fig. 3B). After 5 days the larva casts its egg-shell and the neck. The size of the newly formed larva is just the size of the egg. The colour is yellowish white. As the development progresses the larva becomes glassy white, with the food in the digestive tract showing distinctly yellow. The full grown larva is also glassy white, but the digestive

tract becomes greyish black. It may be the colour of the meconia which will be expelled prior to prepupation from the digestive tract. The full grown larva measures about 0.46 mm long and 0.41 mm wide. Eight pairs of spiracles with anterior and posterior commissures are evident in this stage (Fig. 3D). Three days old larva with tracheal system is in Figure 3C. The larval period is 5–6 day in summer.

After five days the larva enters prepupal stage. The prepupa always accompanies with five to ten black or brown torpedo-like bodies, measure about 0.13 mm long and 0.05 mm wide (meconia) which are evacuations of the digestive tract, expelling by the larva prior to prepupation (Fig. 3E). The prepupa is glassy white in colour, measures about 0.60 mm long and 0.27 mm wide. Generally the prepupal period is 1 day, but sometimes it is $1\frac{1}{2}$ days. There is a considerable variation between individuals, and very definite differences will occur at different temperatures and humidities.

The newly formed pupa is nearly translucent, appearing milky white with a slight yellowish tinge. As the development progresses, the body assumes a definite yellow cast, and the eyes become brilliant red. The pupa just before emergence becomes dusky, there is a brownish pigmentation on midthoracic sterna, and head, wing pads and appendages slightly brown. Sometimes the anterior portion of the abdomen is slightly brownish. The size of the pupa is about 0.69 mm long and 0.32 mm wide. The pupal period is 5 to 6 days in summer.

The average duration of the various stages in the life cycle of *Aphytis yasumatsui* in summer (30°C) is as follows:

Stages	Number of days
Eggs	4–5
Larva	5–6
Prepupa	1–$1\frac{1}{2}$
Pupa	5–6
Total	15–$18\frac{1}{2}$

The parasite cuts a hole just above its head in the scale covering with the help of its mandibles and exit through this hole. When more than one parasite completes development in a single scale, all adults usually emerge through the same exit hole made by the first individual, although more than one holes are observed in several occasions.

Aphytis yasumatsui has proved to be a promising parasite of *Chrysomphalus bifasciculatus* Ferris. This parasite was reared from the field collected material throughout the year. It has been able to control the scale insects, *Chrysomphalus bifasciculatus* about 36 to 40

per cent in the field. It attacks both male and female scales in the field and laboratory, but prefers female scales (about 69 percent female scales).

The larva feeds on the body fluids of the scale body. The host body fluids are completely consumed in the larval stages. Generally one adult emerges from one scale, but two pupae are observed in the third instar scales in several occasions. This parasite is dominant in character and disperse widely and rapidly due its all the year around oviposition behavior. The parasites reared from the scales, *Chrysomphalus bifasciculatus* infested on *Illicium religiosum* collected at Yamato-cho, Hakozaki, Fukuoka, in 1961 have yielded 75.8 per cent *Casca chinensis* Howard and 16.4 per cent *Aphytis yasumatsui*, rest other secondary parasites. But in 1962, the parasites reared from the same host scale and same host plant have yielded 9.13 per cent *Aphytis yasumatsui* and 8.7 per cent *Casca chinensis*.

The parasites reared from this scale infested on *Illicium religiosum* Sieb. et Zucc. collected at Gofuku-machi, Fukuoka have yielded 8.23 per cent *Aphytis yasumatsui*, 15.5 per cent *Casca chinensis* and 2.2 per cent *Prospaltella* sp. From this result, it is presumed that this parasite is effective to control this pest of scale insects.

The average longevity of this parasite on concentrated honey is about 20 days. But it can live more than two months in autumn and winter (11°C temperature). The parasite, *Aphytis yasumatsui* emerged on October, 1961 was alive on concentrated honey up to December 31, 1961.

Aphytis debachi Azim

(Fig. 4)

Aphytis debachi is the primary parasite of *Parlatoria* sp. infested on *Camellia japonica* Linnaeus. *Parlatoria* scale is a serious pest of cultivated plants of Japan and other parts of the world. In some place the infestation is so heavy that it is problem to control this pest. But *Aphytis debachi* is an effective parasite of this scale insect pest, and this pest is partly controlled by this parasite in the field.

This species attacks second and third stage females and second stage and prepupal male scales.

Reproduction is arrhenotokous in this species, as in other species of the genus *Aphytis* Howard. Unfertilized eggs, either from virgin or mated females, give rise to males only; fertilized eggs give females. Mated females may deposit either fertilized or unfertilized eggs, thus producing both females and males. Unmated females produce male progeny.

Mating is necessary for continued female production in *Aphytis*

debachi. Normally mating occurs just after the emergence of both female and male. The male takes the initiative for mating. It runs after the females. When the male is able to catch hold a virgin female, it sits on the head of the female try to instinct the female for mating with the help of its antennae and mouth. After a few minutes the male moves towards the abdomen of the female, bends its abdomen and inserts the tip of its organ to the genital organ of the female. It takes about 1 minute to complete the mating. One mating appears to be sufficient for the life time of the female. The male attempts to copulate again, but the female refuses to accept the male for copulation.

The eggs of *Aphytis debachi* are generally deposited on the ventral surface of the scale body. The adult female parasite moves rapidly on the scales with its antennae in downward direction, to examine the scales with its antennae. Sometimes it stops abruptly between scales or on a scale, to remain motionless for several seconds or minutes. Upon selecting a particular scale for more through investigation, the parasite makes several exploratory antennal examination on the surface of the scale. When the parasite is satisfied of antennal examination that the scale is suitable for oviposition, a site is chosen for the penetration or drilling, the hard surface of the scale covering. The parasite is facing away from the scale during insertion of the ovipositor, so that the ovipositor can be pushed down on the ventral surface of the scale. At the time of drilling, it raises its abdomen and inserts the tip of the ovipositor by a rapid thrust and slowly penetrate the whole ovipositor inside the scale body. The rapid up-and-down movements of the styles are accompanied by slower rotary movement in both clockwise and counter clockwise direction. The actual penetration of the scale covering is followed by rather slow deliberate thrusts of the styles into the scale and probing interiorly the greater part of the ventral surface of the scale body.

The ovipositor may be inserted many times by the parasite without depositing any eggs in the scale. This may be due to this that the parasite does not rely alone on the exploration with the antennae. So, the parasite inserts its ovipositor many times in the scale body to be sure that whether the scale body is suitable for oviposition or not. Just before the eggs is deposited, rapid pulsation of the styles are ceases, the ovipositor is withdrawn from the body of the scale, the tip contacts the body wall and an ovoid, somewhat tear-shaped, nearly translucent egg is deposited on the ventral surface of the scale body. The egg adheres at the point of deposition.

Generally one egg is deposited in a scale. But sometimes more than one egg is observed in a scale. Once the ovipositor is inserted

inside the scale the parasite is not disturbed, if the scale infested leaf is taken out from the tube. It may utilize the same puncture used by the parasite to deposit the first egg for the deposition of the second egg. The second probing action in the same scale is very slow and with great care so that the egg deposited before may not be spoiled.

The newly deposited egg is yellowish white in colour, ovate in shape, measures about 0.10 mm long and 0.06 mm wide. The ovarian egg of this parasite is about 0.13 mm long and 0.04 mm wide. There is a short neck or pedicel at the narrower end of the deposited egg. The chorion of deposited egg is smooth, with spherical granular bodies showing through with transmitted light. The incubation period is about 5 days.

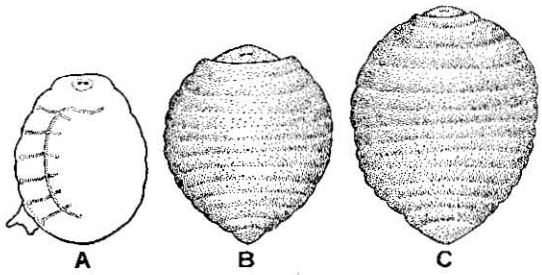

Fig. 4. A, newly formed larva with tracheal system; B, three days old larva; C, full grown larva of *Aphytis debachi*.

The first larva is formed inside the egg, and the head is situated at the base of the pedicel of the egg. Then the larva rotates to the riverse direction within a few hours. The tracheal system is evident in the newly formed larva prior to eclosion at 600× magnification. Six pairs of spiracles are visible in the newly formed larva (Fig. 4A). The larva casts the egg-shell and pedicel within a few hours. The colour of the larva is white with a slight yellowish tinge. On the second day the larva measures about 0.10 mm long and 0.16 mm wide. As the development progresses, the body of the larva assumes a slight yellowish colour with the food in the digestive tract. On the third day the larva reaches the size of 0.20 mm long and 0.23 mm wide. The full grown larva is a little greyish black due to the black substance (meconia) in a digestive tract, and measures about 0.48 mm long and 0.27 mm wide (Fig. 4C). On the sixth day the larva expelles black or dark-brown torpedo-shaped like bodies which are six to twelve in numbers (meconia) and evacuation from the digestive tract. After expelling meconia, the larva enters prepupal stage. The prepupal period is 1 day. The prepupa measures about 0.53 mm long and 0.28 mm wide.

The newly formed pupa is nearly translucent, appearing milky

white with a slight yellowish tinge. As the development progresses, the body of the pupa assumes a definite yellow cast, and the eyes become brilliant red. The late pupal stage is characterised by a general body colour of yellow, with a slight brownish pigmentation on midthoracic sterna. The eyes are pale green with blood red ocelli. The pupal period is 6 days in summer in room condition.

The average duration of the various stages in the life cycle of *Aphytis debachi* observed in summer in room condition is as follows:

Stages	Number of days
Egg	5-6
Larva	6-7
Prepupa	1-1½
Pupa	6-7
Total	18-21½

The emergence of the adult parasite is generally accomplished by cutting a hole in the scale covering, with the help of its mandibles.

The average longevity of this parasite is about 13 days on concentrated honey. There is considerable variation according to the temperatures and humidities.

This is the only parasite reared from the *Parlatoria* scales, collected at Hakozaki, Fukuoka on *Camellia japonica* Linnaeus, except few specimens of *Prospaltella* sp. The percentage of this parasite reared from field collected materials is about 89.6 per cent. The entire body fluids of the scales are consumed in the larval stages. The infestation is so heavy that this parasite has been able to control 20 to 30 per cent of the scales.

The life history of the Aphelinid parasites *Aphytis fuscipennis* Howard, *Aphytis citrinus* Compere and *Aphytis fisheri* DeBach are broadly similar to other species of the genus. The general biology and habits of *Aphytis fuscipennis* are similar to those of *diaspidis* and described by Smith (1897) and Quayle (1911).

Aphytis citrinus and *Aphytis fisheri* are the parasites of *Aonidiella aurantii* Maskell. *Aphytis citrinus* is also the parasite of *Aonidiella citrina* Coquillett. These two species are biparental, mating, oviposition behavior and life cycle are broadly similar to *Aphytis japonicus*. But the pupal pigmentation of *Aphytis citrinus* is different from *Aphytis japonicus* and *Aphytis fisheri*. The pupa of *Aphytis citrinus* is weak *lingnanensis* type (midthoracic sterna and abdomen with light brownish pigmentation). The pupa of *Aphytis fisheri* has no black lines or furcae whatsoever on the body; thoracic sterna, abdominal sterna and head yellowish; wing pads and appendages may vary from yellow to yellow-brown; dorsal surface yellow.

Effect of temperature: Temperature plays a great role in the development and longevity of the parasites. In summer, when the temperature is about 25–30 degree centigrades, the life cycle of *Aphytis* species are ranging from 15 to 22 days. But in water, when the temperature is about 5–10 degree centigrades, the life cycle of *Aphytis* species are ranging from 45 to 60 days. So is the case with the longevity of this species, in summer the average longevity of this species is about 15 to 20 days, but in winter (5–10°C) the species of this group can live on concentrated honey for more than two months. For example, *Aphytis yasumatsui* emerged on October 19, 1961 was alive on concentrated honey in room condition upto January 5, 1962.

The development of pupa varies according to the temperature. For example, The pupal period of *Aphytis cylindratus* was 28 days in February (8–12°C), 24 days in March (10–15°C), 13–15 days in April (18–22°C). The pupal period of *Aphytis yasumatsui* was 15 days in the month of April. The larvae of *Aphytis japonicus* could not develop at 5–8 degree centigrade. The species of *Aphytis* group is very active at 26 to 28 degree temperature.

MASS PROPAGATION OF *Aphytis* SPECIES

The mass production of beneficial insects becomes desirable when the pest is not controlled completely by the parasites unaided. The failure of the parasites to control their hosts comes about through faulty synchronization of host and parasite populations. If the parasites are produced in large numbers in the laboratory and release them in the scale infested field, then there is every possibility to control the pest effectively. Because the natural population of the parasites in the field may not been able to destroy all the scales of the heavily infested field. So, it is necessary to increase the parasite populations in the field by adding more parasites which will be possible by mass producing the parasites in the laboratory. The parasites can be produced in large numbers, if the host scale can be produced in large numbers on artificial host plants. But it was observed by Flanders (1947) that the red scale, *Aonidiella aurantii* Maskell developed and reproduced in a normal manner on smooth-skinned White Rose potato tubers. DeBach and White (1960) produced red scale, *Aonidiella aurantii* on host plant, banana squash, *Cucurbita maxima* for the mass production of *Aphytis lingnanensis*.

The author has studied the mass production of *Pseudaonidia duplex* Cockerell, *Aspidiotus perniciosus* Comstock, *Chrysomphalus bifasciculatus* Ferris, and *Pseudaulacaspis pentagona* Targioni and their parasites of the genus *Aphytis* Howard which are presented in this

paper.

MATERIALS AND METHOD

The host plants: Hosts tested included the pink and green squash, *Cucurbita moschata* Duch. var. *melonaeformis* Makino and *Cucurbita pepo* Linnaeus, commercial potato tubers. Among them squash of pink colour, *Cucurbita moschata* var. *melonaeformis* Makino is found to be the best for the mass production of the scale insects. Squash has greater surface area, easy to store for about a year, less costly in the season, free from insectary pest except mites, better length of life and easy to handle it than others.

Collection and transfering of crawlers: Two methods are adopted to transfer the crawlers on the host plants: 1. The contact method, which involves the temporary placement of the mother infested squash or potato on the fresh host plants so that the crawlers can move from one to the other or dropping from the former when they are unable to maintain foothold, because of crowding. If the squash or potato is illuminated by electric light, almost all the crawlers move to the lighted portion of the squash or potato. 2. Shadow-light method, which is made by placing a fluorescent tube light about one feet long, in a box with upper and lower platforms, a rectangular hole is made in the middle of the upper platform, through which the sources of light from the fluorescent tube can pass to the lower platform; a rectangular card board is attached to the whole, so that only the middle portion of the lower platform can be illuminated. The mother infested squash or potato is placed on a hard white paper in the shadowed portion of the platform. The crawlers are attracted to the lighted portion, on the lower platform and assembled there. The crawlers which are collected on the paper can be transfered to the fresh squash or potato by taking out the paper with crawlers and dislodge them on the squash or other host plants by folding the paper over the host plants and rapping the folded roll of the paper with the help of a pencil or camels' hair brush handle. The folding of the paper may be done by inserting the corners of the paper in one hand with the fingers and the other hand can be used for rapping. The dislodged crawlers will drop down on the host plants.

The shadow-light method is found to be efficient because by this method a large number of crawlers can be collected on the paper and spread them on new host plants. It is better to transfer the crawlers on the new host plants after 12 or 24 hours, because if the crawlers are kept in the box for a long time, the crawlers may die due to the heat of the light.

THE HOST SCALE

Development of *Pseudaonidia duplex* Cockerell: This scale develops continuously generation after generation in the field and laboratory. This scale is ovoviviparous, the young nymphs or crawlers remaining under the parental scale cover for a few hours and then emerging to search for a suitable feeding position. The crawlers which are collected by shadowlight method, distributed on the surface of the squash and are given several minutes to scatter and spread on the squash. A source of light (ordinary electric light) encourages their spreading. The squash is then rotated and distributed the crawlers over the uninfested portion of the squash. In this way, the squash has been rotated completely and infested. After the surface of the squash has been completely infested with crawlers, the squash is then kept in a dark place for a day or two in order to permit the crawlers to settle on the surface of the squash uniformly without the disturbance of the outer source of light.

Upon settling the crawler draws its legs and antennae beneath the body and in a few hours white cottony secretion appears over the body. The cottony threads envelop the entire insect and extend down over its sides to the surface where it is becoming fixed within a few hours or day. When the insect is fixed on the squash, the squash is transfered to a rearing box.

As the development progresses the scale reaches the size of 0.28 mm by 0.24 mm after a day, and completely covered with the wax. This stage is considered to be the 'White cap' stage. After a few days (about 3 days) the cap settles down around a center, and a thin yellowish grey ring is formed around the central nipple. The scale begins to increase in size and spreads its outer margin. In four to five days the cottony effect of the scale is lost and the covering becomes yellowish brown, and the diameter of the scale is about 0.37 mm. The time required for completion of the first instar is about 12 to 18 days in summer. With the increased size of the insect after the first molt, the covering is extended farther and farther beyond the cast skin when the second exuvia is incorporated into the covering and is about twice the size of the first exuvia, both forming concentric circles. The diameter of the first instar is about 0.6 mm and that of second instar is about 1.2 mm. The length of the second instar is about 10 to 15 days in summer.

After completing the second molt the insect again extends its covering until there is a wide grey margin of the covering extending beyond the insect body. After 44 days the covering of the scale insect reaches the diameter of about 2 mm. This stage or period is known as grey adult. During this time fertilization occurs and soon after

the insect enters the young producing period. The insect can live in this stage for a long time if the fertilization does not occur. After being matured and fertilized it begins to produce the young nymphs or crawlers. It takes about 52 days in summer from one to another nymphal stages. The size of the matured female is about 2.6 mm in diameter.

The sexes are not distinguishable in the first instar. After the first molt, the male becomes elongate. As the larva attains the end of the second instar larva, purple eyes spots are formed and these are retained through all the succeeding immature stages, eventually becoming eyes in the winged adult. After the second molt the male enters the prepupal stage. By the time the growth of this stage completed, the outline of the antennae and wings can be seen. The colour is bright yellow to yellowish brown. The fourth and last molt brings the male to adult stage. The adult is a delicate, two winged insect,

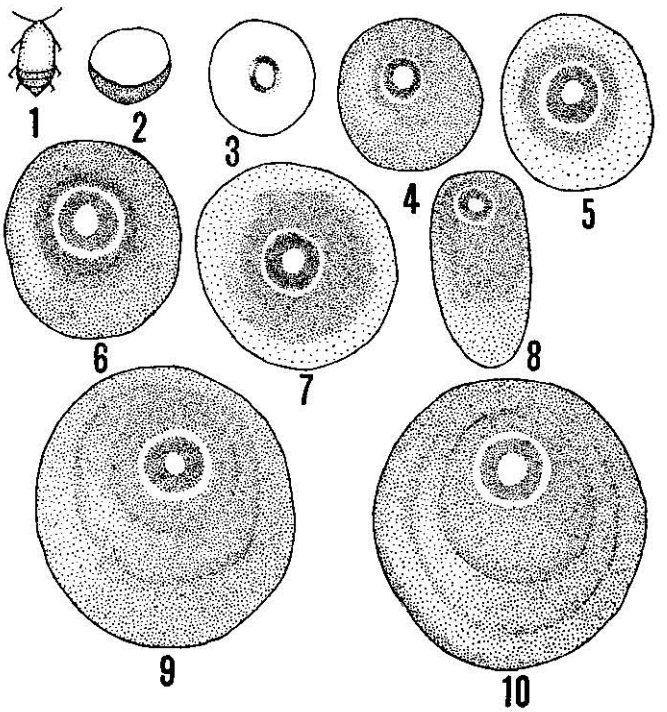

Fig. 5. Developmental stages of *Pseudaonidia duplex* Cockerell.
(1) crawlers, (2) white cap, (3) nipple stage, (4) first molt, (5) second stage, (6) third stage, (7) third stage gravid female, (8) scale covering under which the male transforms prepupa, pupa and adult.

reddish brown in colour.

Parasite production: The adult female of *Aphytis cylindratus* Compere is introduced on the scale developed on squash. This parasite can deposit eggs in the second and third instar female scale (including eggs producing scale), second instar and prepupal male scale. It prefers third instar scales. The parasite is introduced on 42 days old scales developed on squash on August 11, 1962 and taken out on August 12, 1962. Two females have emerged on August 29, and two females on August 30, 1962. It takes 17 to 18 days to develop on the scale developed on squash. It has been observed that this parasite can produce 32 progeny within two months. A single female has been produced 219 progeny in four and half months. This result is due to the polyparasitism habit of this parasite. One of the squash is about to be spoiled due to attack of fungus, the scales of this squash are dissected under the binocular microscope, and observed that 86.6 per cent scales are infested with more than one pupa. Two to five pupae are observed per scale, and the parasite can be produced throughout the year in the laboratory. A ratio, as great as 6 females to 1 male may be obtained with *Aphytis cylindratus* reared on *Pseudaonidia duplex* on squash. This scale, *Pseudaonidia duplex*, can also be produced on a large number on the wild host plant, *Solidago serotina* Ait. in summer. But it becomes dry in winter.

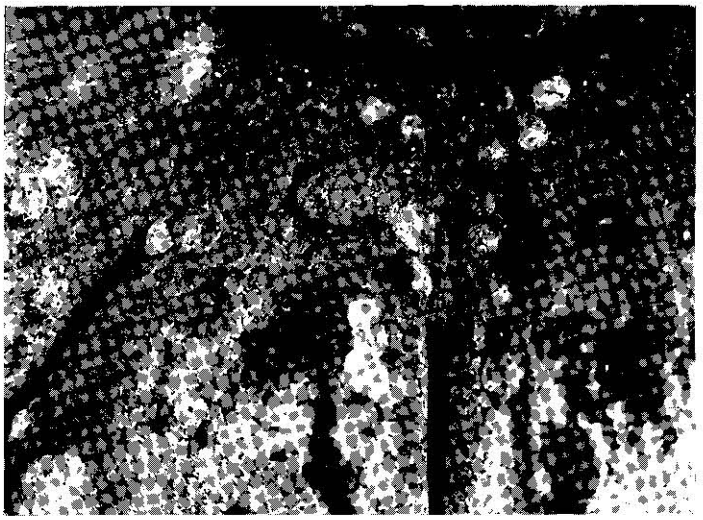

Fig. 6. Scales "*Pseudaonidia duplex* Cockerell" developed on the squash.

Development of *Pseudaulacaspis pentagona* Targioni: Squash is the most suitable host plant than other host plants for the mass-culture

of this scales. It can be reared throughout the year on squash in laboratory conditions. The density of this scale on the squash may be about 25 to 30 per Sq. Cm. (Fig. 8).

The crawlers of this scales are collected by the 'shadow-light' technique and distributed over the surface of the squash, and are given several minutes to scatter and spread on the squash. The squash is then rotated and distributed the crawlers over the uninfested portion of the squash. When the surface of the squash has been completely covered with crawlers, it is placed in a dark place for a day or more in order to permit the crawlers to settle on the surface of the squash uniformly without the disturbance of the outer source of light.

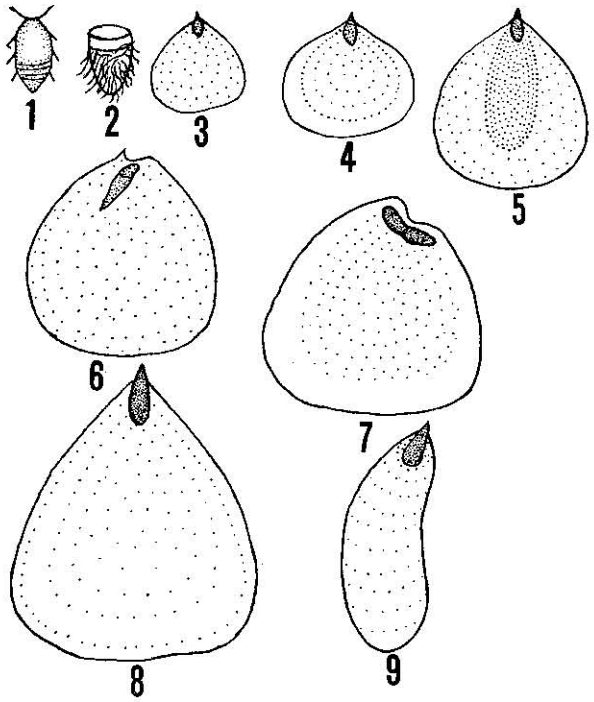

Fig. 7. Developmental stages of *Pseudaulacaspis pentagona* Targioni. (1) crawler, (2) white cap, (3) first stage, (4 & 5) second stage, (6) second molt, (7) third stage, (8) third stage gravid female, (9) scale covering under which the male transforms prepupa, pupa and adult.

The crawler inserts its mouth parts on the surface of the squash and draws its legs and antennae beneath its body and settles on it. After a few hours wax-like threads appear on the body of the crawler. Once the scale settles, it remains fixed in position through its life,

except the winged males which emerges from beneath its covering. After three days the scale reaches the size of 0.32 mm by 0.24 mm.

Fig. 8. Scales "*Pseudaulacasps pentagona* Targioni" developed on the surface of the squash.

After five days the scale is completely covered with white wax and measures about 0.44 mm by 0.32 mm. Just before molting, the mid-dorsal part of the scale becomes orange yellow and the margin is white in colour. The time required for the completion of the first instar is about 13 to 15 days in summer. After the first molt the covering of the scale is extended farther and farther beyond the cast

skin when the second exuvia incorporated into the covering and bigger in size. The length of second instar is about 11 days in summer. Just before second molt the scale becomes completely white and the colour of the nipple is orange grey, and the size of the scale is about 1.52 mm by 1.48 mm. After the second molt the scale again extends its covering and becomes adult female. During this time fertilization occurs and soon thereafter the insect enters in the young producing period. The insect can live in this stage for a long time if the fertilization does not occur. The gravid female is completely white with the nipple at the anterior portion is brown, and the size is about 2.00 mm by 1.92 mm.

The sexes are not distinguishable in the first instar. After the first molt the male becomes elongate and assumes the size of 1.04 mm by 0.36 mm. After the second molt the male enters the prepupal stage. By the time the growth of this stage completed, the outline of the antennae and wings can be seen. After the third molt the male enters the pupal stage. In this stage it has the general shape of the adult, and outline of antennae, wings, styles and legs are evident. The fourth and last molt brings the male to adult stage.

This scale takes about 40 to 60 days from one to another nymphal stages on the squash. The nymphs or crawlers which are distributed on the squash on July 15, 1962 become adult female on August 14, 1962 and the new second generation nymphs or crawlers are started to emerge on August 24, 1962. The experiment is carried out in room condition at 25 to 30 degree centigrade temperature.

Aphytis diaspidis may be reared on these scales developed on squash. The life cycle of this parasite reared on this scale on squash is about 18 to 22 days. Only females parasites are reared from these scales on squash. This parasite can oviposit on both female and male scale, but third instar female scales are suitable for the mass propagation of this parasite.

Development of *Aspidiotus perniciosus* Comstock: This scale is the most serious pest of apple and pear in Aomori Prefecture of Japan. Squash is suitable for the mass propagation of this scale.

Crawlers collected by the "shadow-light" technique are spread over the upper surface of the squash and are given several minutes to scatter and spread on it. A source of light encourages their spreading. The squash is then rotated and distributed the crawlers over the uninfested portion of the squash. When the squash is completely covered with crawlers, it is removed to a dark place for a day or more in order to permit the crawlers to settle on the surface of the squash uniformly without the disturbance of the outer source of light. After the crawlers are settled on the squash, it is transfered to a

rearing box.

Aspidiotus perniciosus scale develops continuously generation after genearation in the laboratory and field. After hatching the young nymphs or crawlers remain under the parental scale cover for a few hours and then come out from it, and moves over the surface of the squash. This is the best time for the collection of crawlers by "shadow-light" method or by contact method.

The crawlers settle on the squash by inserting the mouth parts on the squash and draw the legs and antennae under the body. After a few hours the wax-like threads of the scale appear on the body of the scale, as they are being secreted, the body is slowly rotated, until it is turned completely around, and then the movement is retraced. Once the scale settles, it remains fixed in the position through its life, except the winged male which emerges from beneath its covering. After a couple of days, the nymph is completely covered with the wax, and it is considered to be the "White cap" stage. At this stage the covering is round and sides are vertical. After a few days the cap settles down around a center, and a thin grey ring is formed around the central nipple. The scale begins to increase in size and spreads out its margin. After three days the size of the scale is about 0.28 mm in diameter. In a week or more the cottony effect of the scale is lost and the covering becomes a compacted film. The time required for completion of the first instar is about 10 to 15 days in August, 1962. On 7th day the size of the scale is about 0.42 mm in diameter. With the increased size of the insect after the first molt the covering is extended farther and farther beyond the cast skin when the second exuvia is incorporated into the covering and is about twice the size of the first exuvia, both forming concentric circles. The diameter of the first instar scale is about 0.40 mm. The length of the second instar scale is about 12 to 16 days in summer, and measures about 0.96 mm in diameter.

The body is flexible between molts, being not distended by the body fluids, and the scale covering separates from the insect itself. After completing the second molt the insect again extends its covering separates from the insect itself. After completing the second molt the insect again extends its covering until there is a wide grey margin of the covering extending beyond the insect body. This stage or period is known as grey adult. During this time the fertilization occurs and soon thereafter the insect enters the young producing period, and its covering again becomes intimately associated with the insect and can not be readily separated from one another. The insect can live in this stage for a long time if the fertilization does not occur. After being matured and fertilized it begins to produce the young nymphs

or crawlers. The size of the matured female is about 1.70 mm in diameter.

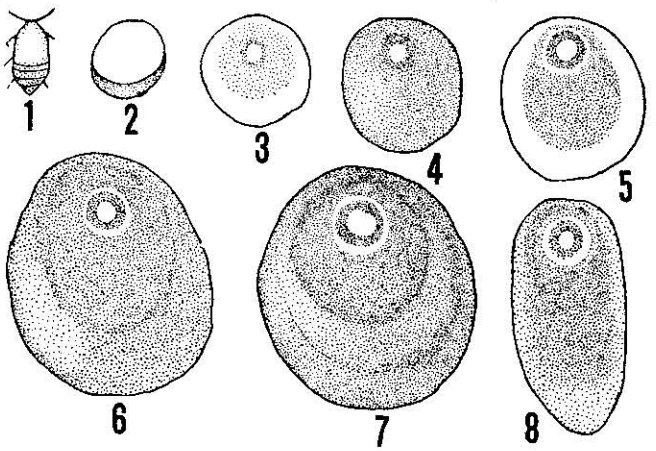

Fig. 9. Developmental stages of *Aspidiotus perniciosus* Comstock. (1) crawler, (2) white cap stage, (3) nipple stage, (4) first molt, (5 & 6) second stage, (7 & 9) third stage, (10) third stage gravid female, (8) scale covering under which the male transforms prepupa, pupa and adult.

The sexes are not distinguishable in the first instar. After the first molt the male becomes elongate. As the growth continues, the scale covering of the male becomes more convex than the female. After the second molt the male enters the prepupal stage. When the growth of this stage is completed, the outline of the antennae and wings can be seen. The male enters the pupal stage after the third molt. The male in this stage is two times longer than wide. In pupal stage the male has the general shape of the adult, and outline of antennae, wings, legs and styles are clearly visible. The fourth and last molt brings the male to adult stage.

This scale can be reared on squash in large numbers within 40 to 50 days in summer. The nymphs of this scale are distributed on squash on July 8, 1962, first molt is observed on July 20, second molt on August 4, and the nymphs are begun to emerge on August 18, 1962. The development of this scale is observed in room condition at 25 to 30 degree centigrade temperature.

Aphytis diaspidis may be produced on this scale for mass propagation.

The mass propagation of the *Aphytis* species on the scales developed on squash or potato have been the usual method to control the menace of diaspidine scale pest in different parts of the world.

Flanders (1651) was successfully produced *Aphytis chrysomphali* in large numbers on the scales, *Aonidiella aurantii* developed on White Rose potato tubers for the control of this scale pest. DeBach and White (1960) reported that *Aphytis lingnanensis* can be reared in abundance on oleander scale, *Aspidiotus hederae* Maskell on banana squash, *Cucurbita maxima* for the control of red scale, and *Aphytis lingnanensis* has proved to be the most effective parasite of red scale than its closest competitor and near relative, *Aphytis chrysomphali*. A ratio as great as 9 females to 1 male may be obtained with *Aphytis lingnanensis* reared on oleander scale on banana squash. In the propagating *Aphytis* spp., efficiency in parasitization involves the introduction of host populations into a parasite population (Flanders, 1949). In this paper the author has discussed the ways and means for the mass propagation of the *Aphytis* spp., of Japan.

SUMMARY

Taxonomy of the *Aphytis* spp. of Japan including two new species, *Aphytis yasumatsui* and *Aphytis debachi* is discussed in this paper, specially their number of crenulae on the posterior margin of the propodeum, number of nodules along the submarginal vein, and setae on the mesoscutum and at the delta basad of the speculum of the forewings. These species are very small in size about 1 mm in body length. The general colour of the body is yellow, except *diaspidis* which is dusky and sides of the abdomen with brownish bands. Generally the ovipositor of this genus is exerted. Generally the forewings are without any infuscation of clouds, except some species. *Aphytis diaspidis* is the only species whose forewings are clearly infuscated beneath the stigma and at the junction of the marginal and submarginal veins, the wings of *Aphytis chrysomphali* is with a faint dark cloud beneath the stigma and a more distinct cloud more or less across the disc beneath the union of the marginal and submarginal veins; the forewings of *Aphytis debachi* is slightly infuscated beneath the junction of marginal and submarginal veins. Setae are also present on the head of all the species of this genus.

The biology of the genus *Aphytis* Howard is broadly same in all the species. The duration of the various stages in the life cycle varies according to the temperatures and humidities. Generally the life cycle of these species is about 15 to 18 days, incubation period is 3 to 5 days, larval period is 5 to 10 days, prepupal period is 1 to $1\frac{1}{2}$ days, and the pupal period is 5 to 10 days.

The oviposition behavior is almost same in all the species. Generally they deposit eggs on the ventral surface of the scale body which

is covered by scale covering. But *Aphytis cylindratus* deposits egg on the dorsal surface of the scale body, just under the scale covering. The first larva is formed inside the egg, and the tracheal system is clearly visible prior to eclosion. The colour of the larva is generally white, with a slight yellowish tinge in the middle. The mandibles of the newly formed larva measures about 0.01 mm in length and that of full grown larva are about 0.02 mm in length. The prepupa is always accompanying with six to ten or twelve black or dark brown torpedo-like bodies which are evacuations from the digestive tract and are expelled by the larva prior to prepupation. These bodies (meconia) are observed under the scale covering even after the emergence of the parasite.

The pupae are generally yellow in colour, but in some species the pupae are pigmented on midthoracic sterna, wing pads, antennae and appendages. The pupal pigmentation is now the most important factor to study the taxonomy of this genus, and this is clearly discussed in this paper.

Mass propagation of the parasites and their host are essential for the control of the scale pest. Squash, potato and cucumber are used for the mass-culture of the host scales, but the squash is found to be the most suitable for the mass-culture of the host scales. It is easy to handle and has better length of life. The mass propagation of *Pseudaonidia duplex*, *Chrysomphalus bifasciculatus*, *Aspidiotus perniciosus* and *Pseudaulacaspis pentagona* and their parasites of *Aphytis* genus are studied. The parasites are successfully produced on their host scales developed and reproduced on squash. It takes about 40 to 60 days to produce the host scales on squash. The parasites are reared from the respective host scales on squash, and they take 15 to 20 days to emerge after the deposition of the eggs.

These parasites are economically too important for the control of scale insect pests of economic plants. So far as known these parasites are the most important primary parasites of diaspidine scales. It is not yet known that there is any second parasites of these *Aphytis* species. These parasites are more effective than other Encyrtid and Aphelinid parasites due to short life cycle and can be produced throughout the year.

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