Development of New Insecticide "Robinhood"

Sumitomo Chemical Co., Ltd.
Health & Crop Sciences Research Laboratory
Takashi SATO
AgroSolutions Division-Japan
Naoki SATO

"Robinhood" is a novel insecticide developed to control the wood boring insects which inhabit tree trunks and branches, by spray-injection of the pesticide from the entrance of the pest tunnel to beat them directly. This product contains fenpropathrin, a broad spectrum insecticide, 0.02% as an active ingredient and it has a compact product form so that it can be sprayed easily on the damage points situated at complex structures of living trees.

"Robinhood" was launched in June 2016 and it has shown good efficacy for a wide range of wood boring insects, including serious pests such as *Cossus insularis* and *Anoplophora chinensis malasiaca* in domestic orchards.

The developmental history and insecticidal properties of "Robinhood" are described in this report.

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Introduction

Synthetic pyrethroids, which were developed by modifying the lead chemical structure of pyrethrins, have broad spectrum and fast acting features against insects, and this chemical group has been used for many years in agricultural and/or environmental health fields. Sumitomo Chemical Co., Ltd. developed four active ingredients in this group for domestic agricultural use, namely fenvalerate (VEGIHON® EC and HAKUSAP® WP, etc.), permethrin (ADION® EC, WP and FL), cypermethrin (AGROTHRIN® EC and WP), and fenpropathrin (RODY® EC and WP), and they contribute to stable yields for agricultural products. Fenpropathrin has been originally developed by Sumitomo Chemical Co., Ltd., and it has unique properties which are effective against agricultural insect pests and adult mites[1]. The product is widely used throughout the world, mainly for the control of mites and Lepidopteran and Hemipteran pests in orchards.

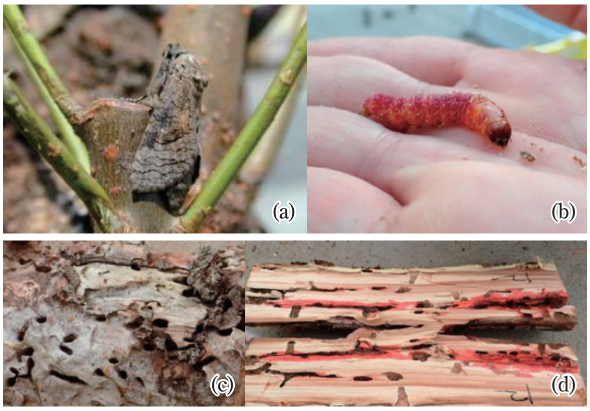
"Robinhood" (S-1675 aerosol) is an aerosolized product including an active ingredient of 0.02% fenpropathrin, and the product was developed based on the concept of inserting a nozzle into the tunnels of wood boring insects in tree trunks and delivering the active ingredient to their habitat directly to reduce damage to the trees. A feature of the product is the ability to obtain good control effects on varieties of wood boring insects with simple and effective treatment. The product was registered as an agricultural chemical for apples and pears on March 2, 2016 (**Fig. 1**) and it is hoped that it can contribute to stable production for fruit farmers. In this paper, we introduce the developmental history of "Robinhood", and the practical effects and points of use of the product are described.

Fig. 1 "Robinhood"

Developmental history

1. Current State of Synthetic Pyrethroids in Domestic Agriculture

In domestic agriculture, trends in the use of insecticides have been toward "selective insecticides" that have little effect on beneficial organisms, e.g. natural enemies and flower visiting insects, and the amount of use of synthetic pyrethroids has been decreasing since the 1990s. However, as shown in the level of control of some fruit moths, e.g. *Carposina sasakii* and *Grapholita molesta*, against apples and pears, sufficient control effects cannot be obtained without using synthetic pyrethroids. This indicates that if we can find new applicable fields for synthetic pyrethroids, which can utilize the superior characteristics of high knockdown effect, rapid action, residual activity, etc., this chemical class may still have some possibilities for expanding and/or maintaining sales of existing products and development of new products.



Many holes and tunnels bored by the larvae were observed on the surface and inside of apple tree, *Malus domestica*.

Fig. 2 Adult (a) and larvae (b) of *Cossus insularis*

2. Wood Boring Insects and The Damage They Cause

Wood boring insects which feed inside trunks or branches of trees include a wide range of taxonomic groups, e.g. the order Lepidoptera, such as Cossidae, Hepialidae, Sesiidae, and Pyralidae; the order Coleoptera, such as Cerambycidae, Buprestidae, Limnoridae, Platypodidae, and Curculionidae; and the order Hymenoptera, such as Siricidae. Most of them are classified as forest insects and they mainly damage forest trees[2] but some of them cause damage to fruit trees[3] and roadside trees or garden trees.[4), 5]

The life cycle of typical wood boring insects is summarized as follows. Adult insects fly to the host trees and lay eggs. Hatched larvae mine into the trees and feed through the vascular cambium of the trunks and/or branches and often made large cavities inside the trees. Injured trees suffer various kinds of damage, such as declining vigor, breaking trunks and branches, and secondary damage arising from the risk of disease infestation, and in the worst case the trees die. Such damage causes economic losses for the farmers, not only in reductions in yield but also in an increase in the number of pesticide applications against diseases and insect pests and in replanting of trees.

3. Current Problem of Wood Boring Insects in Domestic Orchards

Cerambycid beetles, e.g. *Anoplophorachinensis malasiaca* and *Psacothea hilarishilaris,* have been well known wood boring insect pests in domestic orchards in Japan for a long time.

Recently, feeding damage by *Cossus insularis* has occurred in pear and apple orchards in Japan and it has become a serious problem for domestic fruit production. *Cossus insularis* is a medium sized Noctuid moth (**Fig. 2**), belonging to the Cossidae, and their damage to cultivated fruit trees was first reported in Tokushima Prefecture in 2005.[6] Thereafter, extensive damage by them in orchards has been reported in several prefectures throughout Japan, including the apple producing regions of the prefectures of Tohoku, Nagano and Gumma in the central part of Honshu, and the pear producing regions of Saga, Tokushima and Yamaguchi prefectures.[7]

On the other hand, control methods for wood boring insect pests are limited, such as treating entire or focal parts of the trees with insecticides to prevent adult attacks, mating disruption using sex pheromones, trunk spraying or trunk brush coating of insecticides onto the surfaces of pest habitats, trunk injection of insecticides into the tunnels of pests and treatment using systemic pesticide granules on the root of the trees etc. Registered pesticides for wood boring insects are few and in 2013, when we started to try methods of controlling wood boring pests, trunk spraying using only one diamide insecticide from another company was the only registered method for the control of *Cossus insularis*, and it could not control the larvae digging inside the trees. In addition, for *Anoplophorachinensis malasiaca*, the preventative control of adults by chemical spraying of entire orchards during the emergence season of the adults has been widely used in citrus orchards, but control of larvae mining into trees is minimal. Therefore, we received strong demands from the producers and leaders of several prefectures for the development of control methods and/or products using agricultural chemicals which target larvae inside trees.

Initial Trials

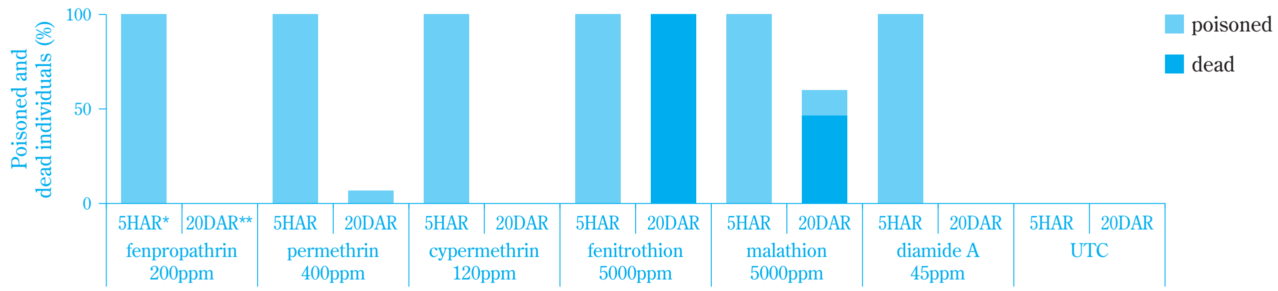
1. Screening of Insecticides

At first, we investigated the possibilities of the control of wood boring insect pests by using Sumitomo Chemical brand insecticides.

As a first stage in the investigation, we selected several compounds with high insecticidal activities for both Lepidoptera and Coleoptera, which are among the more important wood boring insect pests. In addition, to emphasize the choice of the compounds, we focused on compounds with low risk of phytotoxicity on the plants because they might possibly be used by directly spraying on and/or injecting into living trees.

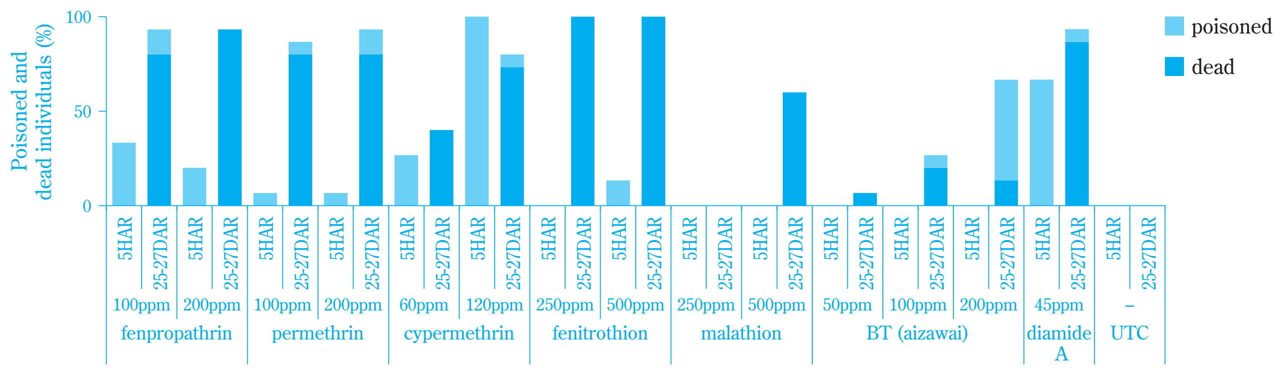
For test insects, we selected *Cossus insularis* and *Monochamus alternatus* which have caused remarkable damage to orchards and forests in Japan. For the tests, we obtained the larvae of *Cossus insularis* from the Tohoku region, and the larvae of *Monochamus alternatus* were obtained from the dead red pines, *Pinus densiflora*, at Kasai Experimental Farm of Sumitomo Chemical in winter. To evaluate the insecticidal activity, we tested the two treatments of insect dipping and filter paper dipping. Insect dipping was conducted by dipping the larvae for 20 seconds in a chemical solution and they were reared with a non-treated artificial diet, and filter paper dipping was done by rearing the larvae on filter paper which was immersed in a chemical solution and with a non-treated artificial diet. Each treatment was assumed to be a case where the larval bodies were directly revealed by the compound, and the larvae were exposed to the compound at the habitat of the larvae. Then, the survival rate and mortality of the larvae were checked.

With the insect dipping treatments, middle aged *Cossus insularis* larvae immediately showed symptoms of poisoning after treatment with all tested insecticides, but only the organophosphate of fenitrothion (SUMITHION® EC, etc.) and malathion caused the larvae to die at 20 days after treatment. After the insect dipping,



Insect : Carpenter moth (*Cossus insularis*)
Method: Larvae were dipped into diluted solution of insecticides and mortality of larvae were recorded by rearing with artificial diet.
*HAR: hours after release, **DAR: days after release

Fig. 3 Insecticidal activity of various insecticides on middle aged larvae of Carpenter moth, *Cossus insularis*, by dipping of larval body



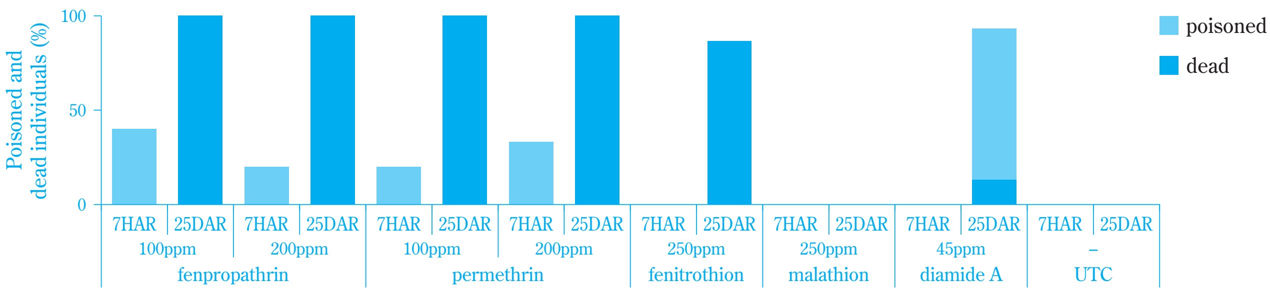
Insect : Carpenter moth (*Cossus insularis*)
Method: Mortality of larvae were recorded by rearing with filter paper of which was dipped into diluted solution of insecticides and with artificial diet.

Fig. 4 Insecticidal activity of various insecticides on middle aged larvae of Carpenter moth, *Cossus insularis*, by the dipping of filter paper of rearing cage most individuals survived even with high concentrations of synthetic pyrethroids of 200–400 ppm (**Fig. 3**). With filter paper dipping, cypermethrin caused symptoms of poisoning for many of the larvae, but mortality of the larvae was not so high at around 80% even at 120 ppm. While symptoms of poisoning did not appear as fast for fenpropathrin, permethrin and fenitrothion compared to cypermethrin, mortality of the larvae was higher than that of cypermethrin (**Fig. 4**). A similar trend was confirmed with old aged larvae (**Fig. 5**), and we thought that fenpropathrin, permethrin and fenitrothion would be candidates for the control of *Cossus insularis* larvae.

For *Monochamus alternatus*, clothianidin (DANTOTSU® WSG, etc.) and permethrin had superior insecticidal effects to fenpropathrin (**Fig. 6**), but 200 ppm of fenpropathrin also exhibited a 100% rate of mortality on the larvae by filter paper dipping (**Fig. 7**). Therefore clothianidin, fenpropathrin and permethrin were selected as the candidates.

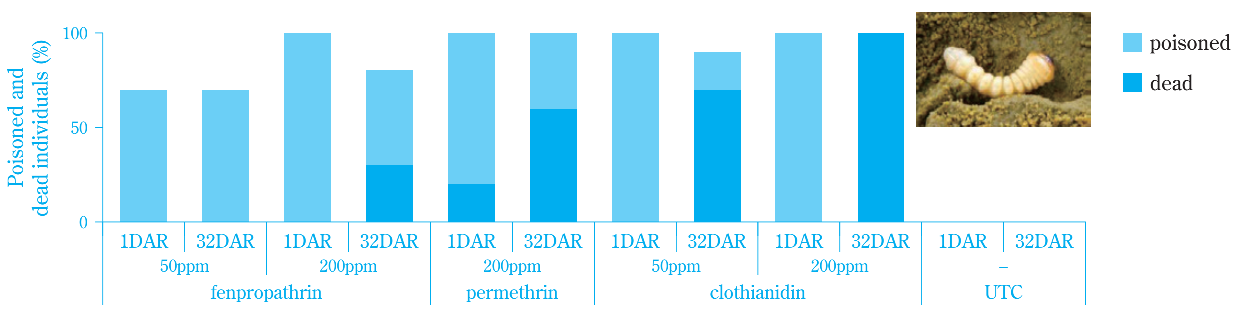
With such a wide range of target pests and applicable trees, characteristics of broad spectrum of insecticidal activity and low risk of phytotoxicity are needed for the compounds. Because of these points, clothianidin and fenitrothion are not fit for our use because the former compound is weak against Lepidopteran pests and the latter one has a risk of phytotoxicity on apples, etc. Thus, investigations into practical treatment methods were carried out using synthetic pyrethroids fenpropathrin and permethrin.

From the results of chemical screening tests, we obtained hints of the treatment methods to increase control efficiency on wood boring insects. For both *Cossus insularis* and *Monochamus alternatus*, the method of filter paper dipping treatment exhibited a higher insecticidal effect than that of insect body dipping. This phenomenon suggests that the larvae of wood boring insects must have a tough skin in order to bore into hard wood and so the uptake of the chemical through the skin of the larvae would be low. On the other hand, the filter paper dipping treatment which postulated that the insecticides would reach the vicinity of the larvae would ensure an the oral route of uptake of insecticide and would extend the exposure time for the larvae. Thus, chemical spraying in the vicinity of boring holes



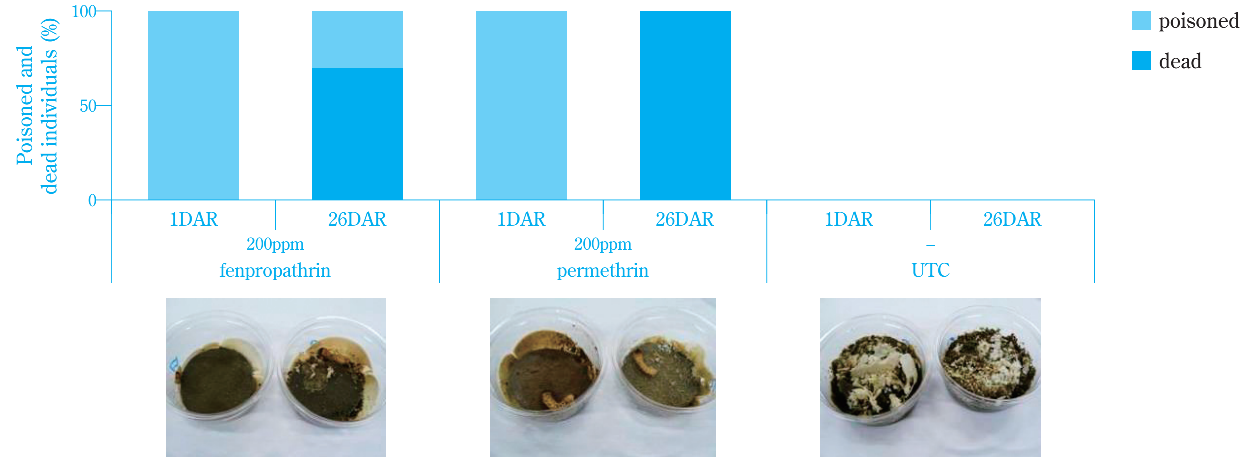
Insect : Carpenter moth (*Cossus insularis*)
Method: Mortality of larvae were recorded by rearing with filter paper of which was dipped into diluted solution of insecticides and with artificial diet.

Fig. 5 Insecticidal activity of various insecticides on old aged larvae of Carpenter moth, *Cossus insularis*, by the dipping of filter paper of rearing cage



Insect : Japanese pine sawyer (*Monochamus alternatus*)
Method: Larvae were dipped into diluted solution of insecticides and mortality of larvae were recorded by rearing with artificial diet.

Fig. 6 Insecticidal activity of various insecticides on old aged larvae of *Monochamus alternatus*, by dipping of larval body



Insect : Japanese pine sawyer (*Monochamus alternatus*)
Method: Mortality of larvae were recorded by rearing with filter paper of which was dipped into diluted solution of insecticides and with artificial diet.
Photos were views of rearing cage of the larvae at 18 days after release.
Food and filter paper were broken by the larval feeding in untreated cage.

Fig. 7 Insecticidal activity of various insecticides on old aged larvae of *Monochamus alternatus*, by the dipping of filter paper of rearing cage.

or trunk injection of trees would be more effective for wood boring insect control by delivering insecticides to the larvae or larval habitat.

The two synthetic pyrethroids permethrin and fenpropathrin were selected for the agents of control for wood boring insects. To compare the two compounds, fenpropathrin has a higher knockdown effect even in low concentrations, although the killing activity of permethrin was higher on *Monochamus alternatus*. However, fenpropathrin also completely inhibits the feeding of *Monochamus alternatus* larvae (**Fig. 7**), suggesting that it could be expected to provide a sufficient control on Lepidoptera and Coleoptera. In the field of fruit trees, resurgence is a serious problem for the control of insect pests, and the characteristics of fenpropathrin, which is low risk in this case, were preferable to permethrin. Thereafter, we tested improvements in application methods by using fenpropathrin with the development of the compound in mind.

2. Trunk Spraying

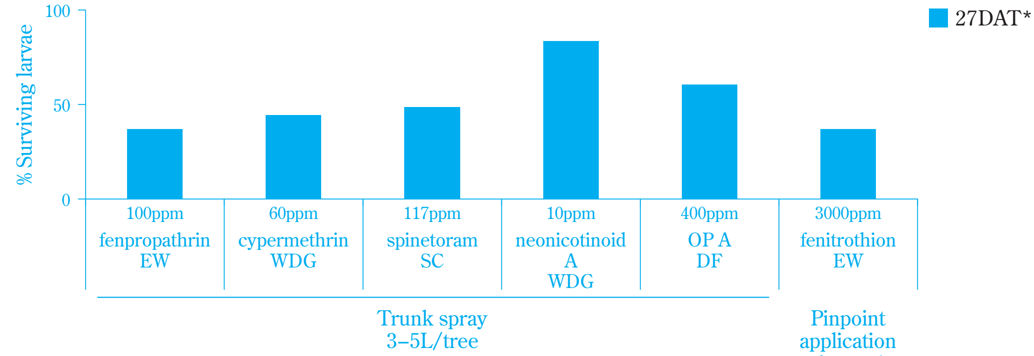
Trunk spraying is a control method to kill the larvae and pupae boring into the tree and/or to inhibit oviposition or feeding of adults by directly spraying a chemical solution onto the trunk and/or branches of trees.

At the Sumitomo Chemical Kasai Experimental Farm, serious damage by *Synanthedon hector*, which is an important wood boring pest, has been observed on pears (**Fig. 8**). Therefore, to evaluate the efficacy of this treatment method, we examined trunk spraying of various compounds for this species.

Fig. 8 Feeding damage of Cherry treeborer, *Synanthedon hector* on peach tree (a, b), Larvae of the species inhabit beneath the bark (c)

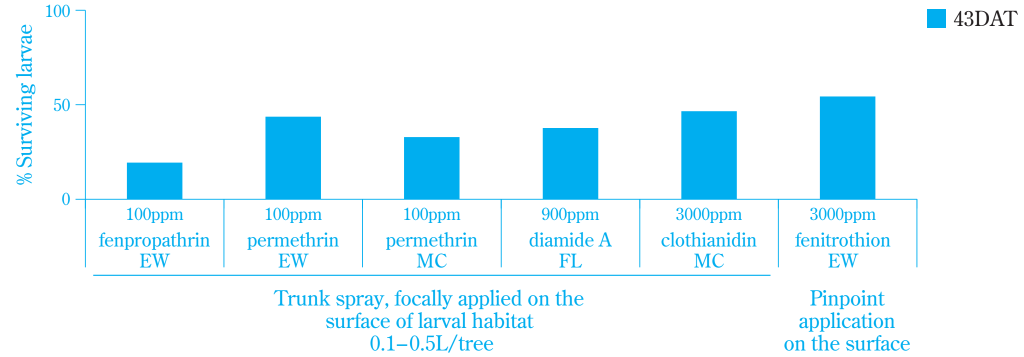
To confirm on the fundamental efficacy, the surfaces of damaged trunks and branches were uniformly sprayed with a sufficient amount of chemical solution, and the control effects on the larvae in the trees were examined. As a result, more than 30% of the larvae survived at fenpropathrin and cypermethrin treated trees (**Fig. 9**).

However, the control effect of the two synthetic pyrethroids were higher than those of fenitrothion, another company's neonicotinoid insecticide and another company's organophosphorous insecticide.



Insect : Cherry treeborer (*Synanthedon hector*)
Plant : Peach (var. Kawanakajima)
Method: Trunk spray
*DAT: days after treatment

Fig. 9 Efficacy of trunk spray on Cherry treeborer, *Synanthedon hector*, on peach tree



Insect : Cherry treeborer (*Synanthedon hector*)
Plant : Peach (var. Kawanakajima)
Method: Trunk spray

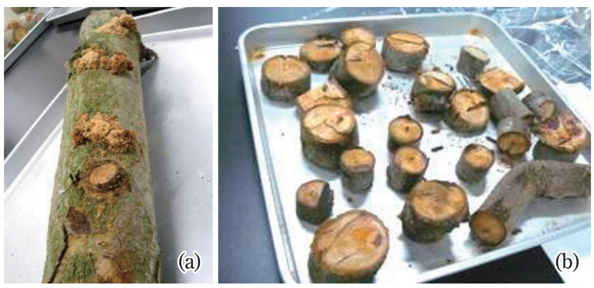
Fig. 10 Efficacy of trunk spray of focally sprayed on the larval habitat of Cherry treeborer, *Synanthedon hector*, on peach tree

Secondly, we checked the control effects of spot treatment which was spraying of chemical agents focally on the larval habitats which where identified by the frass (sawdust, feces, etc.) of the larvae of *Synanthedon hector*. As a result, the control effect was increased more than the spraying of entire tree trunks, and the control effects of the two synthetic pyrethroids were shown to be higher than the other compounds (**Fig. 10**). However, even by the treatments of the high insecticidal activity, 20 to 30% of larvae still survived spot treatment. It indicated perfect control of larvae living inside the trees is difficult by the trunk spray and we should deliver a practical level of insecticide to the larvae by direct injection into the tunnels.

3. Trunk Injection

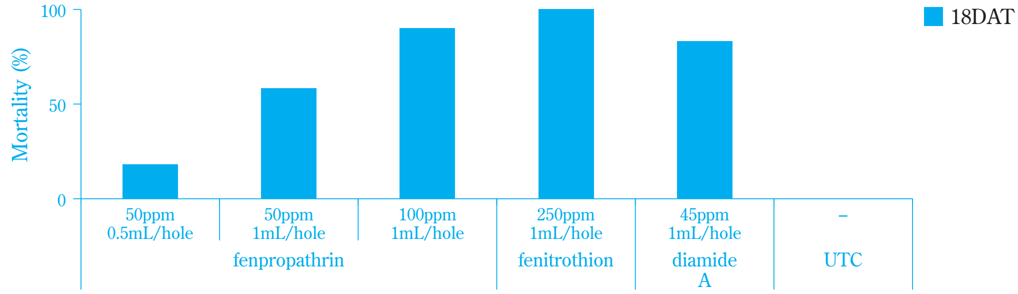
The control effects of trunk injection were investigated by injecting chemical solutions into the tunnels of trees which were artificially inoculated with larvae.

Middle or old aged larvae of *Cossus insularis* were released into pruned branches of pear trees and 0.5–1 mL of chemical solution was injected into the tunnels by a syringe, then survival and mortality of the larvae was determined by dissection of the branches (**Fig. 11**). Branches of different diameters (1–1.5 cm ϕ and



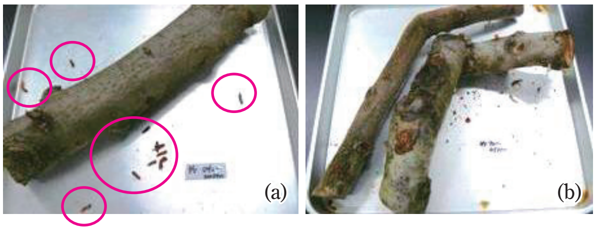
(a) : larvae infested branch of pear
(b) : dissected branch for evaluation

Fig. 11 Views of branch injection test



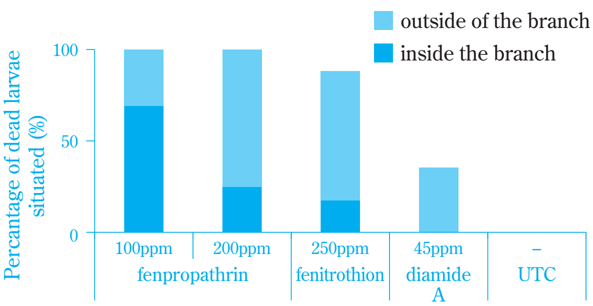
Insect : Carpenter moth (*Cossus insularis*)
Plant : Pear
Method: Diluted solution of insecticides was injected into the entrance of larval tunnel of pear branch.

Fig. 12 Insecticidal activity of various insecticides on middle aged larvae of Carpenter moth, *Cossus insularis*, by the liquid injection into the larval tunnel of pear branch (ϕ1–1.5cm)



(a) : fenpropathrin 200ppm
(b) : diamide A 45ppm

Fig. 13 Flushing out effect of synthetic pyrethroid on Carpenter moth larvae



Insect : Carpenter moth (*Cossus insularis*)
Plant : Pear
Method: One ml of diluted solution of insecticides was injected into the entrance of larval tunnel boring on pear branch.

Fig. 14 Insecticidal activity of various insecticides on old aged larvae of Carpenter moth, *Cossus insularis*, by the liquid injection into the larval tunnel of pear branch (ϕ4–6.5cm)

4–6.5 cm ϕ) were prepared for the tests and the differences of the efficacy between trees by changing the injection volume of insecticide were also investigated in the small-diameter branches.

In the results of the investigation with small-diameter branches, insecticidal effect was low at fenpropathrin 50 ppm, but at 100 ppm, most of the larvae died (**Fig. 12**). In addition, the insecticidal effect was increased with an increase in the amount of insecticide. In these tests, although the mortality rate at 100ppm of fenpropathrin did not reach 100%, this phenomenon was caused by the survival of larvae from overlooked tunnels at treatment. This indicates that the careful search of the tunnels without overlooking any is important for controlling of wood boring insects using the trunk injection method.

In the tests using large diameter branches, we carefully injected insecticides into all of the tunnels. As a result, most of the larvae writhed and were flushed out from the tunnels immediately (**Fig. 13**) and all larvae died inside and/or outside the branches with both 100 and 200 ppm fenpropathrin treatment (**Fig. 14**).

By the results above, we can expect that the injection of insecticide into the larval tunnels would be effective for the control of *Cossus insularis* and reliable lethality and flushing-out effect for larvae would be expected by 100 and 200 ppm of fenpropathrin. Then, we concluded that if this technology could be applied for the control of wood boring insects, a high level of appeal will be gained from the users.

Development of Aerosol

Although we decided to work on the development of trunk injection of fenpropathrin for the control of wood boring insects, we needed to effectively elaborate this technology to be applicable for the diversified environment of actual pest damage, such as damage occurring on different species, ages and shapes of trees. To consider the method of trunk injection of fenpropathrin, we first conceived the diversion of Rody® EC, which is a fenpropathrin product which has already been launched and is in general use in fruit production, to trunk injection by using power sprayers. However, in 2014 another company registered the product of parasitic nematodes for the control of *Cossus insularis* by using a power sprayer for trunk injection improved by a special attachment. But this method would be cumbersome for the users by forcing the purchase of special devices, and difficulty of handling in bringing the nozzles and hoses close to the damage occurred on complicated sites, e.g. under surfaces of main branches, would be expected. To deal with these points, a compact-shaped aerosol-type product could rapidly reach even the damaged points of complex leaves and branches and/or on the lower surfaces of branches, and suitable treatment would be possible for them. In terms of product performance, including the form of the product, to be required for the control of actual field , many leaders of research organizations in the prefectures of Fukushima, Akita, Yamagata, Tokushima and Ehime, where they have a problem with *Cossus insularis* and *Anoplophorachinensis malasiaca*, had a keen interest in our challenge and we received useful information based on a strong support system. This information became an important advantage in accelerating product development.

As a result, Sumitomo Chemical developed a 480 mL canned aerosol product containing 0.02% fenpropathrin as an active ingredient which operated by inserting a spray nozzle into the pest tunnels and spraying. The product had a two-way nozzle that could be used for two treatments of (1) spraying the insecticide inside trees by inserting the nozzle into tunnels and (2) foliar spraying on harmful insects, such as caterpillars, on the trees (**Fig. 1**).

For product manufacturing, we cooperated with Sumitomo Chemical Garden Products Inc. for the product development policies, such as filling pressures, and with Toyo Aerosol Industry Co. Ltd., which has a long manufacturing history for various types of aerosol agents for forming the product. To respond to the demands from areas of wood boring insect damage in Japan, development of the product was decided upon to follow a rapid developmental schedule for release into the market in 2016 (developmental code: S-1675 aerosol).

Practical Evaluation

1. Control Effects

Practical evaluations were carried out on several pest species starting in 2013. Evaluations for *Cossus insularis*, which was initially set as an important target for this product, were conducted by consigned tests by research organizations. To control wood boring insects, the spray volume (amount of spray liquid) has to be set at a sufficient volume of the compound to expose it to targeted insects living inside trees, and the treatment method decided upon for this product was to insert the nozzle into the tunnel and spray sufficiently so that the liquid will flow back from the entrance of the tunnel, so that sufficient insecticide will reach the vicinity of the habitat of the larvae.

As a result, "Robinhood" exhibited good control effects for various wood boring insects including *Cossus insularis* at a practical level (**Table 1**). Control effects were also confirmed against Cerambycid beetles such as *Bacchisa fortunei japonica* and

Table 1 Results of contract trials of "Robinhood" by trunk injection

Crops	Target Pests	No. of trials	Degrees of the test results*				Application method
			Excellent	Good	inferior	no efficacy	
Apple	Carpenter moth	6	2	3	1	0	trunk injection
Pear	Carpenter moth	4	2	2	0	0	trunk injection
Apple	Cerambycid beetles	6	5	1	0	0	trunk injection
Fig	Cerambycid beetles	2	2	0	0	0	trunk injection
Citrus	Cerambycid beetles	4	4	0	0	0	trunk injection
Loquat	Cerambycid beetles	1	1	0	0	0	trunk injection
Grape	Sesiids moth	3	3	0	0	0	trunk injection
Peach	Sesiids moth	1	0	1	0	0	trunk injection
Grape	Swift moth	1	0	1	0	0	trunk injection

Results at March 10th, 2017
*Degrees of the results was followed on the basis of Japan Plant Protection Association.

Anoplophorachinensis malasiaca and Lepidopteran pests such as *Synanthedon hector* and *Zeuzera multistrigata leuconota* (**Fig. 15–20**), from the tests conducted at Kasai Experimental Farm of Sumitomo Chemical. With the foliar spray, effectiveness was generally exhibited for caterpillars, lace bugs and aphids on various species of trees, flowers and ornamental plants (**Table 2**).

Fig. 15 Feeding damage of larvae of *Bacchisa fortunei japonica* on apple tree (a, b), Branches of which fenpropathrin was sprayed into larval tunnel were collected from the field (c) and dissected (d: Untreated, e: "Robinhood" treated)

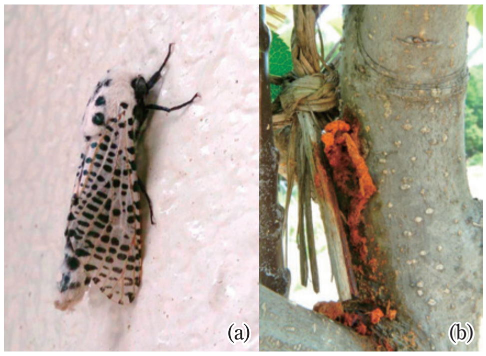
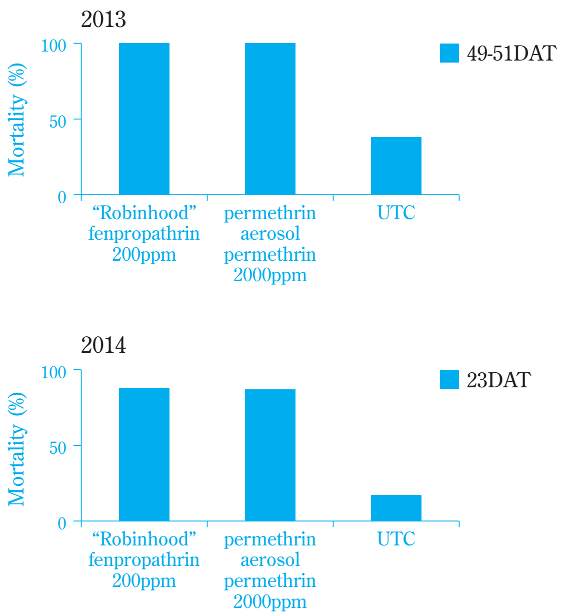
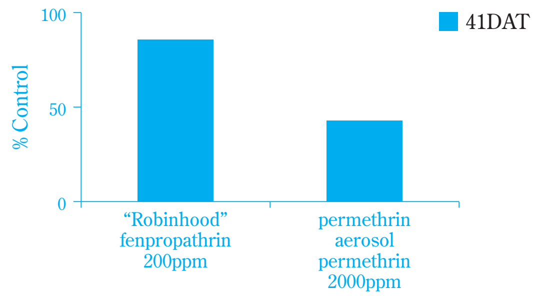


Fig. 17 Adult of *Zeuzera multistrigata leuconota* (a) and feeding damage of the larvae on the trunk of apple tree (b)

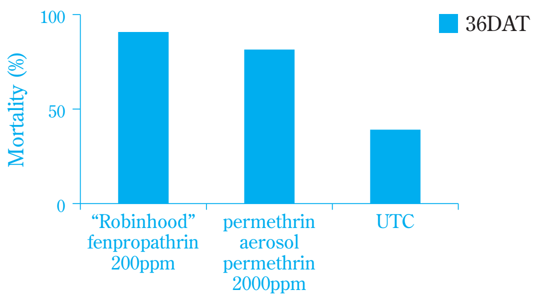


Insect : Pear borer, *Bacchisa fortunei japonica*
Plant : Apple
Method: Enough volume of insecticides were sprayed into the entrance of larval tunnel of *Bacchisa fortunei* inhabit on the apple trees.

Fig. 16 Efficacy of "Robinhood" against *Bacchisa fortunei* by spray injection from the entrance of larval tunnel on the apple tree



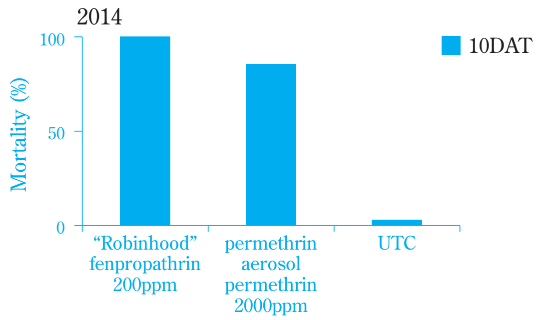
Insect : Oriental leopard moth, *Zeuzera multistrigata leuconota*
Plant : Apple
Method: Enough volume of insecticides were sprayed into the entrance of larval tunnel.



Insect : Cherry treeborer *Synanthedon hector*
Plant : Peach
Method: Enough volume of insecticides were sprayed into the entrance of larval tunnel.

Fig. 18 Efficacy of "Robinhood" against *Zeuzera multistrigata leuconota* and *Synanthedon hector*

Fig. 19 Adult of *Anoplophora malasiaca* (a) and feeding damage of the larvae on the trunk of citrus tree (b, c)



Insect : White-spotted longicorn beetle, *Anoplophora malasiaca*
Plant : Citrus
Method: Enough volume of insecticides were sprayed into the entrance of larval tunnel of white-spotted longicorn beetle which inhabit on the citrus trees.

Fig. 20 Efficacy of “Robinhood” against *Anoplophora malasiaca* by spray injection from the entrance of larval tunnel on the citrus tree

Table 2 Results of contract trials of “Robinhood” by foliar spray

Plants	Target Pests	No. of trials	Degrees of the test results*				Application method
			Excellent	Good	inferior	no efficacy	
Cherry tree	Moth larvae	2	2	0	0	0	foliar spray
Sycamore	Moth larvae	2	2	0	0	0	foliar spray
Camellia	Moth larvae	2	2	0	0	0	foliar spray
Azalea	Lace bugs	2	2	0	0	0	foliar spray
Sycamore	Lace bugs	3	3	0	0	0	foliar spray
Pieris japonica	Lace bugs	1	1	0	0	0	foliar spray
Chrysanthemum	Aphids	2	1	1	0	0	foliar spray
Salvia	Aphids	3	3	0	0	0	foliar spray
Pansy	Aphids	3	0	2	1	0	foliar spray

Results at March 10th, 2017
*Degrees of the results was followed on the basis of Japan Plant Protection Association.

2. Phytotoxicity

No harmful effects were found at any test locations when the insecticide was sprayed inside trees.

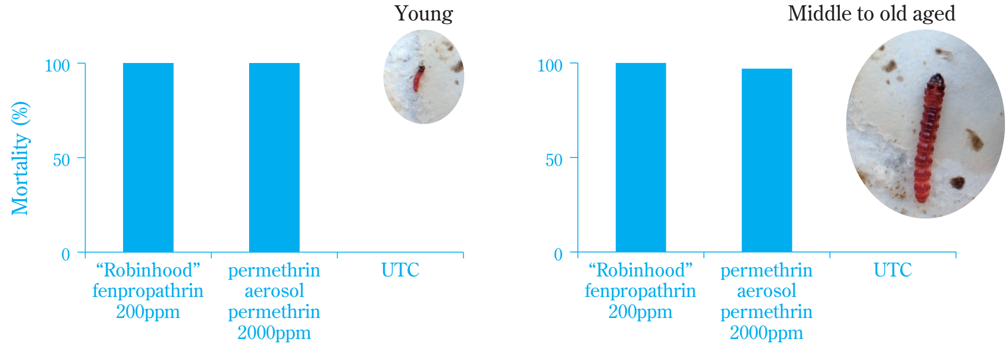
However, when foliar spraying was conducted for pests on the upper parts of trees etc., curling leaves, leaf burn, etc., were observed in two trials. These phenomena were concluded to be “freezing damage” arising from the freezing of chemical solution on the plants when sprayed close to the plants at high pressure, because both tests were clearly done by closely approaching the plants. Therefore, to solve the problem of freezing damage, we noted on the label of the product that the preferred method of use is foliar spraying for 1 – 3 seconds at a time in one location, approximately 30 cm away from the plant body.

While most of the results of evaluations were excellent, there was an example in which sufficient control was not obtained in a consigned evaluation on *Cossus insularis*. At this point, there were many unknown issues, e.g. dynamics of the chemical solution injected into the tree, and if they were not cleared before registration, ineffectiveness or other problems might occur after being placed on the market. Thus, we needed to extract and organize the unknown problems and to find solutions to each of them.

Problems During Treatment and Handling Methods

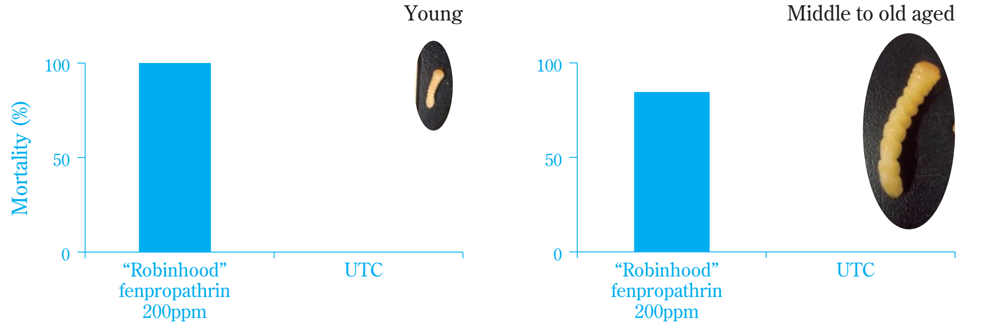
1. Relationship Between Developmental Stage and Efficacy

It is known that developmental duration and/or developmental stage of wood boring insects vary among individuals in the trees. These phenomena are



Insect : Carpenter moth (*Cossus insularis*)
Method: Enough volume of insecticide was directly sprayed for each stage of thirty larvae and mortality of larvae were recorded at 13 days after rearing with artificial diet.

Fig. 21 Efficacy of "Robinhood" on different developmental stages of larvae of Carpenter moth



Insect : Japanese pine sawyer, *Monochamus alternatus*
Method: "Robinhood" was directly sprayed for the different developmental stages of larvae and mortality of larvae were recorded at 76 days after rearing with artificial diet.

Fig. 22 Efficacy of "Robinhood" on different developmental stages of larvae of Japanese pine sawyer, *Monochamus alternatus*

mainly caused by the state of the host trees, and development is varied even among the eggs for which the oviposition timing is the same.[8)–10)] Therefore, in the control of wood boring insects, different developmental stages of larvae often coexist in the same tree, and the differences in control effects among individuals can arise from the development stages of the larvae in the tree. When comparing the insecticidal activities between young larvae and middle and old aged larvae of *Cossus insularis* and *Monochamus alternatus* by directly spray on larval bodies, the results indicated that "Robinhood" showed high insecticidal activities against all stages of the larvae (**Fig. 21**, **22**), and it was judged that good control effects could be obtained regardless of the development stage of the larvae within the tree.

2. Reachability of Insecticide in the Trees

For many wood boring insects, tunnels made by larvae in the trees are complex, and there is a great difference in the lengths of the tunnels. In addition, the internal states of the tunnels differ in the amount of frass and/or exuviae ejected by the larvae. It can easily be expected that varying conditions of tunnels greatly affect the efficiency of control because the reachability of the chemical solution to the larvae and/or their habitat by means of trunk injection will fluctuate according to the state of the tunnels.

Thus, we made test products containing red colored chemical solution, and the reachability of the sprayed liquid after treatment inside actual damaged trees (with large diameter) containing *Cossus insularis* and those containing *Anoplophorachinensis malasiaca* were investigated in Akita and Fukushima Prefecture and in Ehime Prefecture, respectively. Reachability of the liquid was confirmed by stained parts in the tunnels after dissecting each tree (**Fig. 23**). In all of the tests, two treatment methods were attempted, and the first stage of treatment was applied to all tunnels that could be confirmed by sight without peeling off the bark before

Enough volume of liquid solution of red-colored products were sprayed in all entrance of the larval tunnel of Carpenter moth, which infested inside apple trees before (a) and after stripping the bark (b), respectively.
Treated trees were split by the log cutter (c) and the red-stained portion were investigated focusing on whether the liquid could reach to the larvae or not (d).

Fig. 23 Evaluation method of achievement of "Robinhood" to the larval tunnel of Carpenter moth, *Cossus insularis*

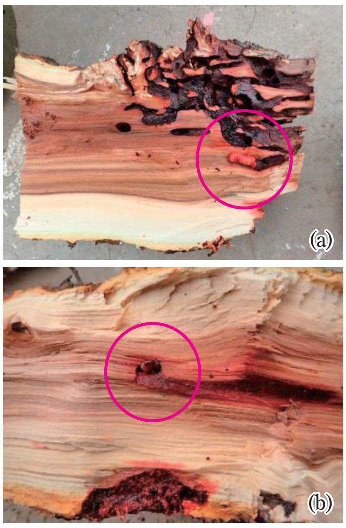
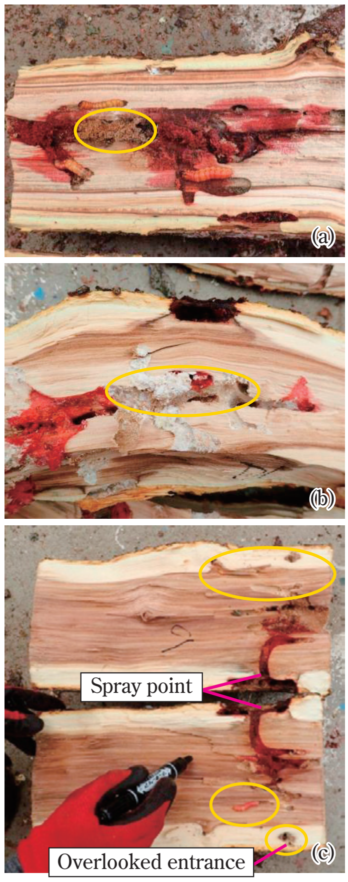


Fig. 24 Achievement of the solution of "Robinhood" to the tunnel of larvae of Carpenter moth which infested in the apple trees (a, b)

treatment, and the second stage of treatment carried out inside the tunnels after peeling off the bark around the damaged parts of the trees so as not to overlook the entrances of the tunnels (**Fig. 23**).

When all tunnels were sufficiently sprayed by the product, the insecticide could reach the habitat of the larvae of *Cossus insularis* with a high probability in apple trees with a large diameter of 20 cm (**Fig. 24**).



(a): Firm frass rass was stacked inside the tunnel.
(b): Wood decaying fungi was infested inside the tunnel.
(c): Entrance of tunnel was overlooked at application.

Fig. 25 Cases of unachievement of solution of "Robinhood" to the larvae of Carpenter moth in apple trees

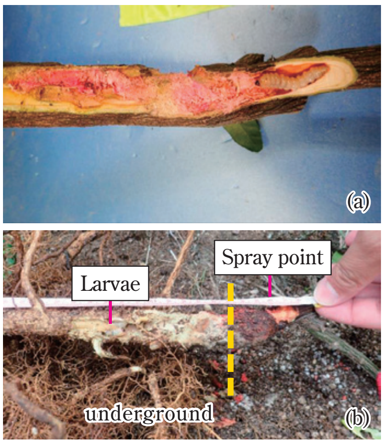
On the other hand, we confirmed just a few cases where the insecticide did not reach the habitat of the larvae, and these were classified as follows (**Fig. 25**).

(a) The insecticide could not reach tunnels ahead of the treatment site because excreted frass solidly blocked the tunnel.
(b) The insecticide could not reach tunnels ahead of the treatment site because wood decaying fungi thickly infested the tunnel.
(c) Untreated tunnels existed because they were overlooked.

These of (a) and (b) are unavoidable and there is no basic solution because these are based on the life of wood boring insects. Thus, to reduce the risk of insect outbreaks, controlling at the early stage of the larvae, which does not excrete a large amount of frass into the tunnels, is better in order to avoid infestation by fungi. However, in the case of (c), reducing the number of overlooked tunnels is possible by peeling off the barks not only on the damaged area but also by expanding the range. Therefore, we recommend peeling bark around damaged areas when treating with this product.

Regarding the control of *Anoplophorachinensis malasiaca* in citrus, the reachability rate of chemical solution to larvae and to their habitat also increased by peeling off the bark before treatment, and pre-treatment by peeling off the bark is also important in this field. However, in the case of *Anoplophorachinensis malasiaca,* there are specific cases related to the characteristics of the life of this species. For this species, adults oviposit their eggs on the stems, trunks and on the basal parts of citrus trees (**Fig. 19, 26**). When attacks are made on the aboveground part of the trees, the chemical solution has a high probability of reaching the larvae, but when damage has occurred at the basal part of the trees, where larvae sometimes feed into the roots, the chemical solution cannot reach the larvae (**Fig. 27**).

Fig. 26 Feeding damage of the larvae of White-spotted longicorn beetle, *Anoplophora malasiaca* on basal part of citrus tree



Liquid solution can achieve to the larvae inhabited at stem and/or trunk of the tree (a), but it cannot reach to the larvae which dug to the root from basal part of the tree.

Fig. 27 Achievement of solution of "Robinhood" to the larvae of White-spotted longicorn beetle, *Anoplophora malasiaca*

3. Nozzle Clogging

For many wood boring insects, larvae often excrete frass to the outside of the tree when feeding and expanding tunnels. This frass excretion is an important sign for finding the damage sites and tunnels of wood boring insects. But when treating with this insecticide, this frass sometimes causes nozzle clogging. Nozzle clogging can be reduced by eliminating frass as much as possible before inserting the nozzle, and this has been noted on the case of the product.

Recommended Treatment Timing

For *Cossus insularis*, the emergence peak of adults is June to July and adult oviposit eggs as clusters in the crevices of bark, then the hatched larvae feed through the trees.[6), 7)] As previously described, early control before the larvae burrow deep into the trees is preferable, but this insecticide can reach deep tunnels with a high probability and insecticidal activity is exhibited regardless of the development stage of the larvae. Therefore, density control of *Cossus insularis* would be possible at any time during the busy farming season to the agricultural off-season.

For *Anoplophorachinensis malasiaca*, the emergence peak of adults is mainly the end of May to the middle of July, and adults fly to various trees and feed vigorously on the leaves and bark of shoot until their sexual maturation. Mating is done on the trees, and females lay eggs under the bark after mating. Hatched larvae burrow into the trees and feed widely on the cambium layer under the bark. Then, some individuals feed down through the trunks and reach near the roots before winter. Therefore, to increase the control effect on this species, it is important to control before the larvae feed through the deep areas in the trees or the roots. We recommend finding the frass excretion of young larvae between midsummer to early autumn and carrying out control immediately.

Registration

Registration of "Robinhood" is summarized in **Table 3** (at March 10, 2017). Development of this product was done with an accelerated schedule so that it could go

Table 3 Domestic registration of “Robinhood”

Crops	Target Pests	PHI*	Maximum number of applications per year	Application method
Apple	Carpenter moth Cerambycid beetles	1 day	2	trunk injection spray
Pear	Carpenter moth	1 day	2	trunk injection spray
Trees	Moth larvae	—	6	Foliar spray

Registration situation at March 10th, 2017
*Pre-harvesting interval

into immediate use in areas with *Cossus insularis* damage to apples and pears, as a result of strong requests from leading people in various prefectures. Although the applicable crops and registered pests are few at this time, we are moving forward to make it useful against damage from many Cerambycids on a variety of trees. We are also carrying out investigations for other wood boring insects.

This product has an extremely broad usage period and it can be used until the day before harvest. Therefore, users can control wood boring insects within busy agricultural schedules. We are earnestly continuing investigations to be able to propose effective periods and methods for users according to their working schedules in various regions.

Conclusion

“Robinhood” is an aerosol type insecticide developed with the concept of preventing infestation of the larvae of wood boring insects by delivering the insecticide directly to larvae inside the tree. In terms of the concept of the product, this agent has a simple aspect and easy operability simply by inserting a spray nozzle into the tunnel and spraying. Therefore, it can easily be applied to complicated damage sites such as branches with thick growth of leaves and underparts of limbs, and it can effectively control wood boring insects which was difficult once damage had already started. The characteristics of the product are advantageous for users by letting them protect and sustain their trees by themselves in the long term. We hope that the new control concept of “protecting trees from inside of the trees” will penetrate generally to producers and it will contribute to the stable production of agricultural products.

We would like to progress with further expansion in uses of the product and to propose available utilization methods to suit different producing regions.

Acknowledgments

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PROFILE

Takashi SATO
Sumitomo Chemical Co., Ltd.
Health & Crop Sciences Research Laboratory
Senior Research Associate
Ph, D.

Naoki SATO
Sumitomo Chemical Co., Ltd.
AgroSolutions Division–Japan
Research Associate