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Ecological Characteristics and Environmentally Friendly Control Strategies of *Pochazia shantungensis* (Hemiptera: Ricaniidae) in Korea

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For processing based control strategy of *Pochazia shantungensis*, chemical synthetic pesticides and environmentally friendly agricultural materials were compared in laboratory and field conditions. The environmentally friendly control strategies also considered with ecological survey of packaging condition that is a repellent and an attractive effect using *Lilium longiflorum* and *Clerodendrum trichotomum* plant–derived substances. *P. shantungensis* were hatched from over–wintering eggs in late–May, and the peak of occurrence of nymph of *P. shantungensis* showed in mid–July. Fifth instar nymphs emerged to adult from early–August and shows the peak of occurrence of adult at late–August. Adults were begun to lay egg from early September when was emerged after 3–4 weeks, at that time they also damaged to young stems of apple tree until October and then died. When applying chemical pesticides for the control of *P. shantungensis*, high insecticidal effect on most chemical pesticides showed. In addition, when plant extracts as the environmentally friendly agricultural materials sprayed, *Sophora matrine* and rotenone from Derris extract showed high insecticidal effect to *P. shantungensis*. As a member of the environmentally friendly control strategies, *L. longiflorum* for repellent effect and *C. trichotomum* for attract effect of *P. shantungensis* were examined. When the treatment of *L. longiflorum* appeared repellent effects with plant and methanol extraction of *L. longiflorum* at the laboratory experiments, however, there is no repellent response with concentrate of *L. longiflorum*. When the treatment of *C. trichotomum* appeared attract effects with plants, methanol extracts and concentrates.

Key words: Attract effect, Environmentally friendly control, Plant extracts, *Pochazia shantungensis*, repellent effect

INTRODUCTION

As global warming continues, the average temperature of the Korean Peninsula has been increased by 1.5°C, which is twice as high as global average temperature increase rate over the last 100 years (Meehl *et al.*, 2007; Choi *et al.*, 2012). Under such environmental changes, changes take place in domestic insect species and both inflow of foreign pests and emergence of sudden pests continue to increase.

Damage caused by the emergence of unexpected insect species is referred to as sudden pest damage. *Pochazia shantungensis* (Hemiptera: Ricaniidae) gave the damage to apples and blueberries in Gongju and Yesan areas of Chungnam in May 2010 and it was discovered for the first time (Choi *et al.*, 2011) (Fig. 1). *P. shantungensis* was reported as an exotic pest that was introduced from foreign country when it was discovered, but it has been considered as the unidentified native species. It is the species that completes all life cycles from eggs to adults in hills in Korea. However, its population is rapidly increased in a short period of time due to the changes in climate and vegetation and, therefore, it gives damage to crops. *P. shantungensis* is classified into *Pochazia* sp. (Rahman *et al.*, 2012) and *Ricania* sp. (Choi *et al.*, 2011) of Ricaniidae.

P. shantungensis has a very wide host range including apple, blueberry, Korean black raspberry, *Schisandra chinensis*, lacquer tree, *Aralia elata*, Jujube, apple, *Cedrela sinensis*, chestnut, magnolia, quince, plum and acacia (Choi *et al.*, 2011). As phloem and xylem are destroyed by the habits of the female adults that lay eggs on the branch of 1–year–old host, it withers. Thus, it fails to propagate and harvest, and damage is directly given to crop harvest. In addition, as the secondary effect, the tree vigor declines and marketability of fruits falls due to occurrence of soot caused by honeydew *P. shantungensis* excretes through ingestion (Choi *et al.*, 2011). However, the biggest problem of *P. shantungensis* is the damage caused by laying eggs (Fig. 1). Spawning season begins in September and it lasts until the end of October. Because it is the time of harvest of fruits, the use of chemical pesticides should be limited.

Therefore, farmers' desire is increasing to use eco–friendly farming materials which have excellent insecticidal effects and ensure the safety in crops. Plant extract materials are widely being used as control measures to obtain safe agricultural products and they are successfully developed and used as eco–friendly pesticides, insect repellents and feeding inhibitors (Schmutterer, 1980). The advantages of pesticides using the plant extracts are as follows. Because it has less residual problems than chemical pesticides, it is safe for humans and animals (Arnason *et al.*, 1989). It contains various bioactive materials (Wink, 1993). It inhibits the development of insec-

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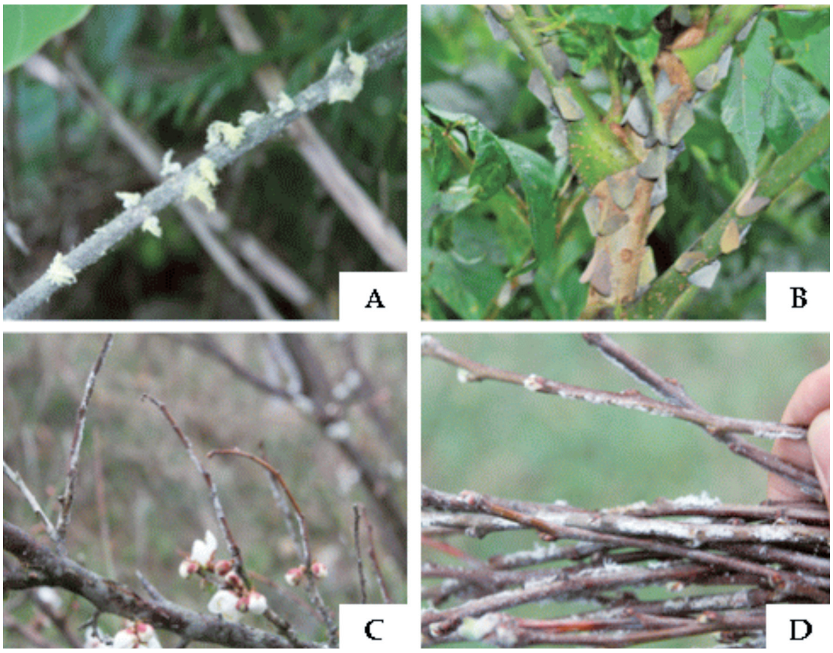

Fig. 1. Various damage aspects by *Pochazia* sp. (A: Damage by nymph; B: Damage by adult; C and D: Damage by spawning *Pochazia* sp.)

ticide resistance to the target pests and it prevents the destruction of the surrounding ecosystem. Thus, it is required to select the effective eco–friendly farming materials to control *P. shantungensis* as the alternative way of chemical pesticides to be applied with targets of crops sensitive to residual toxicity during the harvest period. In this study, we sought the eco–friendly control strategies on the basis of ecological and physiological characteristics of *P. shantungensis*. In addition, we confirmed the insecticidal activity using plant extracts with targets of *P. shantungensis*. Moreover, we selected plant extract materials representing a repellent effect and attraction effect and sought eco–friendly control strategies against *P. shantungensis* which was the sudden pest by applying it in actual crop fields in order to examine the possibility as the effective eco–friendly control agent against *P. shantungensis*.

MATERIALS AND METHODS

Test insect

Eggs, nymphs and adults of *P. shantungensis* were collected in an apple orchard in SeonhakRi, SinpoongMyeon, Gongju, Chungnam, an omija (*Schizandra chinensis*) orchard in HyewolRi, SinpoongMyeon, Gongju, Chungnam and a blueberry orchard in HancheonRi, WooseongMyeon, Gongju, Chungnam. Collected nymphs and adults were placed in an acrylic cage. Feeding conditions are as follows: Temperature of 25±1°C, relative humidity of 50–70% and light period of 16L: 8D.

Occurrence of populations in the outdoors

To investigatethe outdoor occurrence ecology of *P. shantungensis*, we investigated density and outdoor life cycle of *P. shantungensis* in a blueberry orchard in HancheonRi, WooseongMyeon, Gongju, Chungnam from late May to early November when nymphs are hatched from overwintered eggs in 2011 and 2012. Because nymphs and adults of *P. shantungensis* move in different ways, the density survey of *P. shantungensis* was performed using different methods. In the period of nymphs, we used beating method by using black cotton cloth (70 cm × 70 cm). We counted the number of nymphs dropped off the cotton cloth when we beat at the host with a stick 10 times. We installed a sticky trap by using characteristics of flying in the period of adults and counted the number of adults captured in the trap for 7 days. We captured adults by selecting a yellow sticky trap showing high attraction effects to *P. shantungensis* through indoor experiment. Survey was repeated three times at intervals of 7 days.

Indoor growth period of nymphs

To investigate the life cycle of *P. shantungensis* by using overwintered eggs collected in February 2012, we maintained insect feeding condition with temperature of 25±1°C, relative humidity of 50–70% and light period of 16L: 8D, after we laid the gauze in the glass tube (length 25 cm, diameter 3 cm) and sprayed distilled water. We inoculated Forsythia Koreana branch which was a host plant with 1st nymph which was hatched within 24 hours. We placed them in insect breeding square dish (65.4 × 65.4 × 196.4 mm) and provided the moisture by placing cotton balls wet with 10% sugar water on the vents of a top dish. At the time, cutting area of Forsythia Koreana branch which was used as a host plant was wrapped with gauze and then it was kept moistened with water. As we observed it every day, we removed exuviae which came off and recorded the date. On the basis of recorded dates, we examined the development period in each stage of *P. shantungensis* and a total development period from 1st

instar nymphs to adults.

Treatments with eco–friendly agricultural materials

Among plant extracts which are effective for Homoptera pests and commercially available, 9 kinds of plant extract single active ingredients were selected and used for treatment in order to examine the control effects of eco–friendly agricultural materials against *P. shantungensis* (Table 1).

Table 1. Component of plant extracts and component content

Components	Plants	Component contents (%)
Emodin	Cassia seed	50.0
Eugenol	Clove tree	0.3
Matrine	Sophora root	5.0
Neem oil	Neem tree	2.7
Oxymathrin	Sophora	1.0
Rotenone	Derris	5.0
Tobacco leaf	Tobacco	25.0
Toosandonine	Subtripinnata	1.0
Veratrine	Liliaceae	0.5

Effects of drug treatment indoors

To examine the insecticidal effects of eco–friendly agricultural materials on *P. shantungensis*, we performed the experiments by directly spraying 9 kinds of plant extract materials presented in Table 1 into worm body by using spray tower (Burkard, UK). After second–third instar nymphs were inoculated into each leaf disc, drugs was diluted 2,000 times, 1,000 times and 500 times and 2 ml of solution was sprayed. Treated leaf discs were placed on 15% agar medium in order to prevent leaves from being dried. A control group (no treatment) was treated with tap water. All treatments were repeated three times. Mortality % and control value % was calculated in 24 hours, 48 hours and 72 hours after the treatment.

Outdoor control effects

To examine the insecticidal effects of eco–friendly agricultural materials on *P. shantungensis* in outdoor fields, we performed the experiment with *Sophora matrine* and rotenone from Derris extracts which showed excellent insecticidal effects in indoor treatment in a blueberry orchard in HancheonRi, WooseongMyeon, Gongju, Chungnam. Plant extracts were diluted 1,000 times and 3 L of solution was evenly sprayed to the host where 20–30 nymphs of *P. shantungensis* at the third–fourth instar by using a handheld sprayer. A control group (no treatment) was treated with tap water. All treatments were repeated three times. Mortality % and control value % was calculated by counting the number of dead insects in 3 days and 7 days after the treatment.

Repellent and attraction effects using plant extracts

We performed repellent and attraction effects on *P. shantungensis* by using plant extracts for effective eco–friendly control. As *L. longiflorum* had less damage caused by pests and showed the repellent effect on *Limois delicatula*, it was used for repellent effects. *C. trichotomum* which had a noticeable high density of nymphs around the field was used in the experiment for attraction effects. Olfactory responses of *P. shantungensis* were examined in indoor condition and outdoor field condition.

Repellent effect on P. shantungensis indoors

To examine the repellent effect of *L. longiflorum* on *P. shantungensis*, blueberry which *P. shantungensis* preferred was placed in both edges in an acrylic cage (40 cm × 40 cm × 55 cm) with the conditions of temperature of 26±1°C, humidity of 50–60% and light period of 16L: 8D. One edge of blueberry was treated with *L. longiflorum* plants, *L. longiflorum* methanol extracts, *L. longiflorum* concentrates and methanol.

For treatment of *L. longiflorum* plants, the stalk region of *L. longiflorum* plants was cut and cutting side was kept it moistened with cotton balls wet with water. It was placed next to blueberry in one edge. For *L. longiflorum* methanol extracts, we used the modified method of Kim *et al*. (2008) as follows. Two hundred gram of cut flower of *L. longiflorum* was placed in a mortar and mashed with 300 ml of 98% methanol by using pestle. It was extracted for 2 hours and filtered 2–3 times. After 2–3 ml of filtered extracts were added on the filter paper, blueberry was treated with the filter paper in one edge. For *L. longiflorum* concentrates, *L. longiflorum* methanol extracts were concentrated under reduced pressure at 45°C by using a vacuum evaporation (EYELA CA–2500, JAPAN). Twenty mg of lyophilized extracts were dissolved in 5 ml of 97% chloroform and transferred into a new FALCON tube (50 ml). It was stored in a refrigerator. After 2–3 ml of these concentrates were added on the filter paper, blueberry was treated with the filter paper in one edge. For a group without treatment, no treatment was given in a cage. For a control group, blueberry was treated with the filter paper in one edge after 2–3 ml of methanol was added on the filter paper. Twenty nymphs of *P. shantungensis* at third–fourth instar were placed in the center of the cage in each group of treatment. The movement of *P. shantungensis* was observed in the cage for 1 hour and 2 hours after the treatment and the number of *P. shantungensis* located in the blueberry was counted. Experiments were repeated 5 times in each treatment.

Attraction effects on P. shantungensis indoors

To examine the attraction effects of *C. trichotomum* on *P. shantungensis*, blueberry which *P. shantungensis* preferred was placed in both edges in an acrylic cage (40 cm × 40 cm × 55 cm) with the same conditions of experiments for repellent effects. One edge of blueberry was treated with *C. trichotomum* plants, *C. trichotomum* methanol extracts, *C. trichotomum* concentrates and methanol. For treatment of *C. trichotomum* plants, the port in which *C. trichotomum* was planted was placed next to blueberry in one edge. For *C. trichotomum* methanol extracts and *C. trichotomum* concentrates, plant extracts were extracted with the same methods for *L. longiflorum* methanol extracts and *L. longiflorum* concentrates. For a group without treatment, no treatment was given in a cage. For a control group, blueberry was treated with the filter paper in one edge after 2–3 ml of methanol was added on the filter paper. Twenty nymphs of *P. shantungensis* at third–fourth instar were placed in the center of the cage in each group of treatment. The movement of *P. shantungensis* was observed in the cage 1 hour and 2 hours after the treatment and the number of *P. shantungensis* located in the blueberry was counted. Experiments were repeated 5 times in each treatment.

Host preference of P. shantungensis

To examine the repellent effects and attraction effects of *L. longiflorum* and *C. trichotomum* on *P. shantungensis* in outdoor fields, we carried out host preference survey of blueberry and *L. longiflorum*, blueberry and *C. trichotomum*in a blueberry orchard in HancheonRi, WooseongMyeon, Gongju, Chungnam. Survey was performed as follows. After *L. longiflorum* and *C. trichotomum* pots were placed around a blueberry orchard, the number of adults of *P. shantungensis* that were attracted and captured by yellow sticky trap was compared. It was repeated 3 times in each treatment and it was performed for 5 weeks at intervals of 7 days.

Repellent and attraction effects on P. shantungensis in outdoor fields

To examine the repellent and attraction effects of *L. longiflorum* extracts on *P. shantungensis* in outdoor fields, two experiments were performed. To examine the repellent effects, each group was treated with methanol, *L. longiflorum* methanol extracts and *L. longiflorum* concentrates around the blueberry orchard (1,000 m^2) in HancheonRi, WooseongMyeon, Gongju, Chungnam. To examine the attraction effects, effects, each group was treated with methanol, *C. trichotomum* methanol extracts and *C. trichotomum* concentrates. After 2–3 ml of extracts and concentrates in each treatment group were added on the filter paper, it was attached to the yellow sticky trap. For a group without treatment, the filter paper without treatment was attached. For a control group, methanol was added on the filter paper and it was attached to the yellow sticky trap. Each treatment group maintained a gap of 5 m and the experiment was repeated 3 times. It was performed at interval of 7 days for 5 weeks. The number of adults of *P. shantungensis* captured by the yellow sticky trap was counted.

Movement patterns of P. shantungensis in outdoor fields

We examined the movement patterns of *P. shantungensis* in the blueberry orchard when *L. longiflorum* and *C. trichotomum* plants were placed around the blueberry orchard. *L. longiflorum* and *C. trichotomum* plants were placed in one edge of the blueberry orchard (1,000 m^2). In a group treated with *L. longiflorum* plants, flower pots in which 15 blooming flowers of *L. longiflorum* were plated were placed. In a group treated with *C. trichotomum* plants, flower pots in which 15 trees of *C. trichotomum* were plated were placed. To prove the permanent attraction effects of *C. trichotomum*, chemical pesticide, dinotefuran, was diluted at recommended concentration. It controlled adults of *P. shantungensis* by applying dinotefuran to *C. trichotomum* at interval of 7 days by using a handheld sprayer. Movement patterns of adults of *P. shantungensis* were examined in the orchard by installing the yellow sticky trap in both edges of the blueberry orchard.

The experiment was repeated 3 times. It was performed at interval of 7 days for 5 weeks. The number of adults of *P. shantungensis* captured by the yellow sticky trap was counted.

Statistical analysis

For statistical analysis inthis study, we performed the significance test for mortality of *P. shantungensis* when it was treated with eco–friendly agricultural materials with $p<0.05$ between each result through SPSS (PASW Statistic 18.0) one way ANOVA. The significant difference between treatment sections was examined through DUNCAN analysis. In addition, SPSS (PASW Statistic 18.0) one way ANOVA was performed in results of experiments for repellent effects and attraction effects of plant extracts for *P. shantungensis*. The significance test between each recorded results was performed with $p<0.05$.

RESULTS

Occurrence pattern of *P. shantungensis*

Outdoor occurrence ecology of *P. shantungensis* was surveyed in a blueberry orchard in HancheonRi, WooseongMyeon, Gongju, Chungnam and an apple orchard in SeonhakRi, SinpoongMyeon, Gongju, Chungnam in 2011. As the results, nymphs of *P. shantungensis* were hatched from overwintered eggs in late May and they shed their first skins and became the second instar nymphs in early June. In the middle of June, they shed their second skins and became the third instar nymphs. In early July, they shed their third skins and became the fourth instar nymphs. Population of nymphs gradually increased and the maximum number of population was recorded in the middle of July. In addition, in the middle of July, they shed their fourth skins and became the fifth instar nymphs. From this stage, the number of nymphs gradually decreased. In early August, adults started to be transformed from the fifth instar nymphs. The maximum number of adults was recorded in late August. Adults started to lay eggs 3–4 weeks after they were transformed. From early September to October, they gave damage. As the temperature fell, the number of adults decreased. In late October, they began to die and the number of population tended to decrease (Fig. 2). Occurrence density was observed in the blueberry orchard in 2011 and 2012. As the results, it was

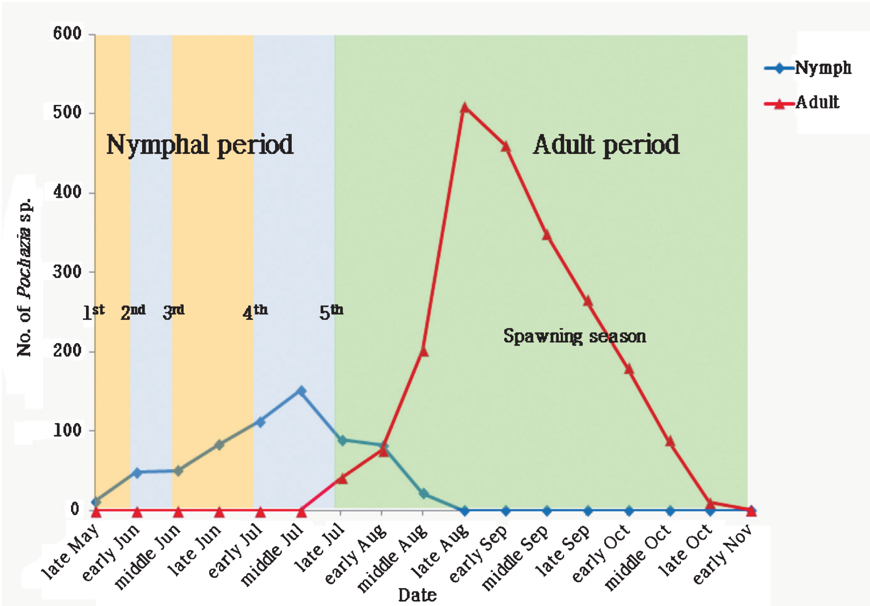

Fig. 2. Changing of seasonal population of *Pochazia* sp. nymph and adult of developmental period at blueberry orchard in Gongju from late May to early November, with the average of 2011 and 2012.

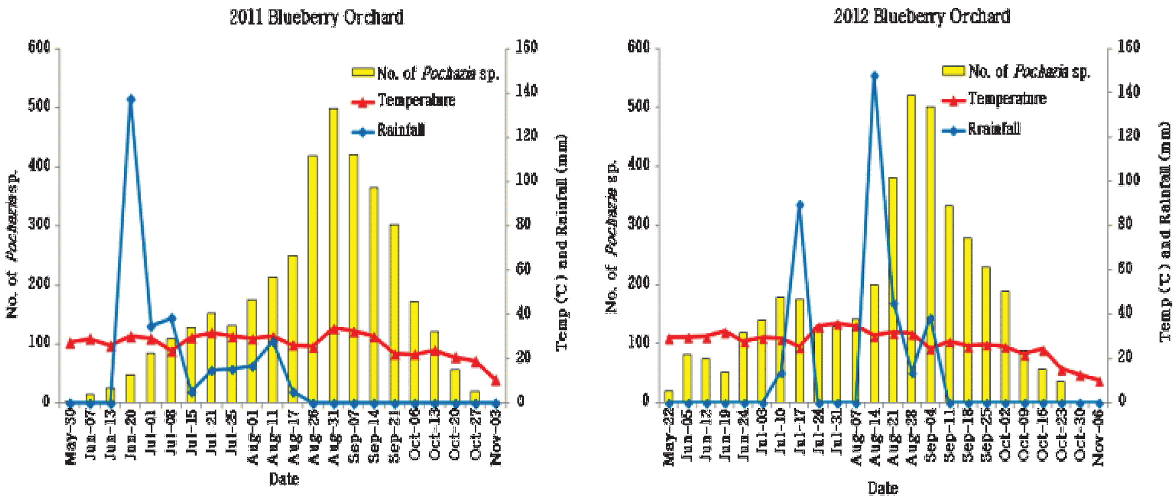

Fig. 3. Relation among temperature, rainfall and population density of *Pochazia* sp. around blueberry orchard at Gongju from late May to early November, 2011 and 2012.

found that density of *P. shantungensis* was increased in 2012 compared with that in 2011 (Fig. 3). In addition, when the amount of occurrence of *P. shantungensis* was compared with climatic conditions from late May to early November, the maximal occurrence of nymphs was shown in high temperature in the middle of August and high rainfall in late August (Fig. 3).

Survey of development period of nymphs indoors

After overwintered egg sacs captured in late February were placed in a cage with the conditions of room temperature of 25±2˚C, relative humidity of 50–70% and light period of 16L: 8D, developmental period of nymphs of *P. shantungensis* was measured within 24 hours once they were hatched from egg sacs. As the results, when overwintered egg sacs were maintained in the insect feeding conditions, they began to be hatched from egg sacs on the 19th day. Average period of the first instar nymphs was 12.79 days. Average periods of the second, third, fourth and fifth instar nymphs was 9.72, 10.90, 13.17 and 14.00 days, respectively. After the period of the fifth instar nymphs, they were transformed to adults. Development period of each stage except the first instar nymph was increased with higher stages. A total development period of nymphs was 52.25 days. Fourteen out of 42 adults were survived in indoor conditions and thus survival rate was 33.3%, which suggested it was unstable (Table 2). In addition, eggs of *P. shantungensis* were

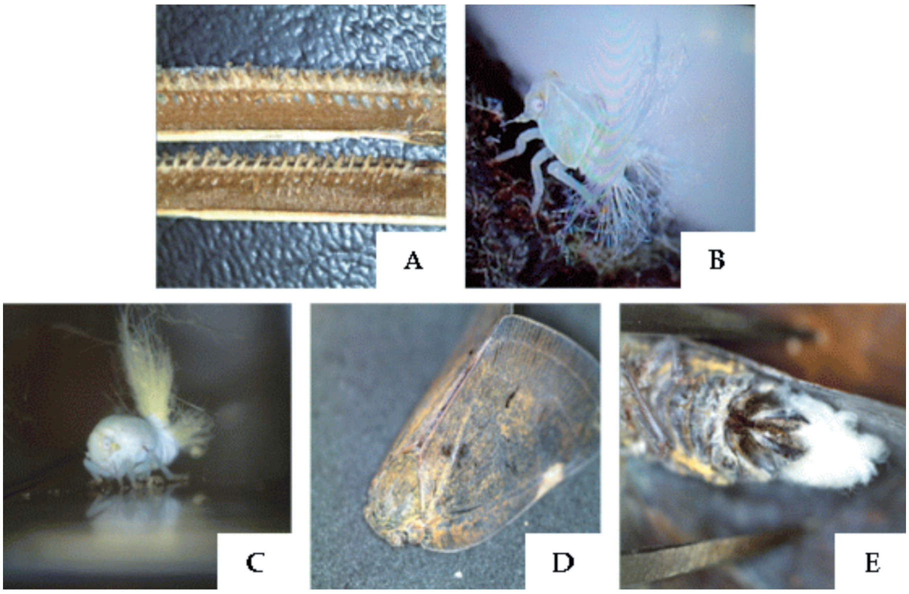

Fig. 4. Morphological character of *Pochazia* sp. each development stage. A: eggs; B: first instar nymph; C: fourth instar nymph; D: adult; E: adult (female's ovipositor).

Table 2. Developmental periods (day ± SD) of each nymphal stages of *Pochazia* sp.

Nymph Stages	eriod of *Pochazia* sp. (day)	n	Survival rates (%)
1st	12.79±4.95	42	100.0
2nd	9.72±2.62	36	85.7
3rd	10.90±2.77	32	76.1
4th	13.17±2.33	21	50.0
5th	14.00±2.16	14	33.3
Total period	52.25±4.57		

characterized by opaque and ivory white color and length of 1.5 mm. From 25 to 30 eggs were laid in two lines on average. Nymph was white and formed white wax around the abdominal end. This wax material became larger as development proceeded. Even if it came off the body due to external shocks, it would be regenerated. In addition, after nymphs molted 2–3 times, their white wax material might become yellow. The size of nymphs was 1.0, 2.2, 3.5, 6.7 and 8.1 mm in each instar nymph. Adults were characterized by dark brown color, length of 10.2 mm and the width including wings of 34 mm. When female adults laid eggs, they protected eggs from the cold in winter by forming wax on the lenticles (Fig. 4).

Table 3. The mortalities and control values of *Pochazia* sp. for 72 hrs against 9 different plant extracts that is diluted 2,000 times with direct spray at indoor condition

Plant extracts	Mortalities ± SD with hours after treatment			Control Values (%) with hours after treatment			
	24 h	48 h	72 h	*P*	24 h	48 h	72 h
Emodine	0.0±0.0a	0.0±0.0a	10.0±10.0a	0.125^{NS}	0.0	0.0	0.0
Eugenol	10.0±0.0a	10.0±0.0a	13.3±5.7a	0.422^{NS}	10.0	10.0	3.7
Matrine	36.6±20.8b	56.6±11.5b	60.0±10.0b	0.198^{NS}	36.7	56.7	55.6
Neem Oil	0.0±0.0a	0.0±0.0a	6.6±5.7a	0.079^{NS}	0.0	0.0	–3.7
Oxymathrin	0.0±0.0a	10.0±0.0a	13.3±5.7a	0.007**	0.0	10.0	3.7
Rotenone	6.6±5.7a	10.0±10.0a	13.3±11.5a	0.702^{NS}	6.7	10.0	3.7
Tobacco leaf	0.0±0.0a	3.3±5.7a	3.3±5.7a	0.630^{NS}	0.0	3.3	–7.4
Toosandonine	0.0±0.0a	6.6±11.5a	13.3±11.5a	0.296^{NS}	0.0	6.7	3.7
Veratrine	6.6±5.7a	6.6±5.7a	13.3±5.7a	0.332^{NS}	6.7	6.7	3.7
Control	0.0±0.0a	0.00±0.0a	10.0±10.0a	0.125^{NS}	–	–	–
P	0.000**	0.000**	0.000**				

Values represent by mean ± SD, *: $P<0.05$; **: $P<0.01$; Completely randomized one–way analysis of variance, ANOVA, Post Hoc Test by Duncan in SPSS version 18.0 NS; statistically not significant.

Table 4. The mortalities and control values of *Pochazia* sp. for 72 hrs against 9 different plant extracts that is diluted 1,000 times with direct spray at indoor condition

Plant extracts	Mortalities ± SD with hours after treatment			Control Values (%) with hours after treatment			
	24 h	48 h	72 h	*P*	24 h	48 h	72 h
Emodine	3.3±5.7a	3.3±5.7a	3.3±5.7a	1.000^{NS}	3.3	3.3	–7.4
Eugenol	10.0±10.0a	13.3±5.7a	20.0±0.0ab	0.252^{NS}	10.0	13.3	11.1
Matrine	56.6±20.8b	70.0±10.0c	76.6±5.7c	0.269^{NS}	56.7	70.0	74.1
Neem Oil	0.0±0.0a	0.0±0.0a	6.6±5.7a	0.079^{NS}	0.0	0.0	–3.7
Oxymathrin	6.6±5.7a	10.0±0.0a	23.3±23.0ab	0.355^{NS}	6.7	10.0	14.8
Rotenone	10.0±0.0a	30.0±10.0b	40.0±17.3b	0.048*	10.0	30.0	33.3
Tobacco leaf	6.6±11.5a	6.6±11.5a	6.6±11.5a	1.000^{NS}	6.7	6.7	–3.7
Toosandonine	3.3±5.7a	6.6±11.5a	13.3±11.5a	0.373^{NS}	3.3	6.7	3.7
Veratrine	3.3±5.7a	13.3±15.2a	20.0±10.0ab	0.256^{NS}	3.3	13.3	11.1
Control	0.0±0.0a	0.00±0.0a	10.0±10.0a	0.125^{NS}	–	–	–
P	0.000**	0.000**	0.000**				

Values represent by mean ± SD, *: $P<0.05$; **: $P<0.01$; Completely randomized one–way analysis of variance, ANOVA, Post Hoc Test by Duncan in SPSS version 18.0 NS; statistically not significant

Table 5. The mortalities and control values of *Pochazia* sp. for 72 hrs against 9 different plant extracts that is diluted 500 times with direct spray at indoor condition

Plant extracts	Mortality ± SD			Control Values (%) with hours after treatment			
	24 h	48 h	72 h	*P*	24 h	48 h	72 h
Emodine	3.3±5.7ab	3.3±5.7ab	20.0±10.0ab	0.053^{NS}	3.3	3.3	11.1
Eugenol	3.3±5.7ab	10.0±10.0ab	23.3±5.7ab	0.042*	3.3	10.0	14.8
Matrine	70.0±17.3c	93.3±5.7d	100.0±0.0c	0.012*	70.0	93.3	100.0
Neem Oil	0.0±0.0a	6.6±5.7ab	6.6±5.7a	0.216^{NS}	0.0	6.7	–3.7
Oxymathrin	3.3±5.7ab	10.0±0.0ab	13.3±5.7a	0.098^{NS}	3.3	10.0	3.7
Rotenone	23.3±20.8b	36.6±15.2c	40.0±20.0b	0.552^{NS}	23.3	36.7	33.3
Tobacco leaf	13.3±15.2ab	16.6±11.5b	16.6±11.5a	0.936^{NS}	13.3	16.7	7.4
Toosandonine	6.6±5.7ab	13.3±5.7ab	16.6±5.7a	0.178^{NS}	6.7	13.3	7.4
Veratrine	3.3±5.7ab	3.3±5.7ab	16.6±20.8a	0.401^{NS}	3.3	3.3	7.4
Control	0.0±0.0a	0.00±0.0a	10.0±10.0a	0.125^{NS}	–	–	–
P	0.000**	0.000**	0.000**				

Values represent by mean ± SD, *: $P<0.05$; **: $P<0.01$; Completely randomized one–way analysis of variance, ANOVA, Post Hoc Test by Duncan in SPSS version 18.0 NS; statistically not significant.

Effects of treatment with eco–friendly agricultural materials

Effects of indoor treatment

To examine the insecticidal effects of eco–friendly agricultural materials on *P. shantungensis*, we diluted single active ingredients of plant extract materials from 9 kinds of eco–friendly agricultural materials 2,000, 1,000 and 500 times and then directly sprayed them in indoor conditions. In 24, 48 and 72 hours after the treatment, a group treated with matrine showed high mortality of 36.6%, 56.6% and 60.0% compared to other groups with treatment (Table 3). When 1,000–fold diluted solution was directly sprayed, groups treated with drugs except matrine showed the mortality of 10% or less in 24 hours after treatment. On the other hands, a group treated with matrine showed a high mortality of 56.6%. The group treated with matrine showed a high mortality of 70.1% in 48 hours after treatment. A group treated with rotenone showed a relatively high mortality of 30.0%. In 72 hours after treatment, groups treated with matrine and rotenone showed a relatively high mortality of 40.0% and 76.6%, respectively (Table 4). When 500–fold diluted solution was directly sprayed, groups treated with matrine and rotenone showed a high mortality of

70.0% and 23.3% in 24 hours after treatment, respectively. All groups treated with drugs showed the mortality of 20% or less in 48 hours after treatment. Groups treated with matrine and rotenone showed a high mortality of 93.3% and 36.6%, respectively. In 72 hours after treatment, the group treated with matrine showed a high mortality of 100.0% (Table 5).

Effects of treatment in outdoor fields

To examine the insecticidal effects of eco–friendly agricultural materials on *P. shantungensis*, we directly sprayed 2 kinds of plant extract solutions which had high insecticidal effects indoors in the outdoor fields. In 3 days after the treatment, groups treated with matrine and rotenone showed a high mortality of 86.3 and 72.5%, respectively. In 7 days after the treatment, groups treated with matrine and rotenone showed a high mortality of 91.6 and 85.8%, respectively. The group treated with matrine showed a control value of 77.2 and 90.0 in 24 hours and 48 hours after the treatment, respectively. The group treated with rotenone showed a control value of 72.7 and 84.0 in 24 hours and 48 hours after the treatment, respectively. Matrine and rotenone showed effective insecticidal effects on *P. shantungensis* in outdoor fields. In addition, even after 7 days passed, the insecticidal effects of eco–friendly agricultural materials were maintained in outdoor fields (Table 6).

Repellent and attraction effects using plant extracts

Repellent effects of L. longiflorum indoors

We performed the experiment to examine the repellent effects of *L. longiflorum* to *P. shantungensis* indoors. As the results, 29 and 19% of population contacted it in a control group and a group treated with *L. longiflorum* plants 1 hour after the treatment, respectively. 54 and 16% of population contacted it in a control group and a group treated with *L. longiflorum* plants for 2 hours after the treatment, respectively. *P. shantungensis* showed a repellent effect when it treated with *L. longiflorum* plants. Twenty and 30% of population contacted it in a control group and a group treated with *L. longiflorum* concentrates for 1 hour after the treatment, respectively. Twenty–one and 41% of population contacted it in a control group and a group treated with *L. longiflorum* concentrates for 2 hours after the treat-

Table 6. The mortalities and control values of *Pochazia* sp. during 7 days against 2 different plant extracts with diluted 1,000 times with direct spray at outdoor condition

Names	Mortalities ± SD with days after treatment		Control Values with days after treatment		
	3 days	7 days	*P*	3 days	7 days
Matrine	86.3±0.0c	91.6±14.4c	0.043*	77.3	90.0
Rotenone	72.5±0.0b	85.8±7.2b	0.008**	72.7	84.0
Control	11.42±0.0a	16.6±7.2a	0.027*	–	–
P	0.024*	0.523^{NS}			

Values represent by mean ± SD, *: P<0.05; **: P<0.01; Completely randomized one–way analysis of variance, ANOVA, Post Hoc Test by Duncan in SPSS version 18.0 NS; statistically not significant.

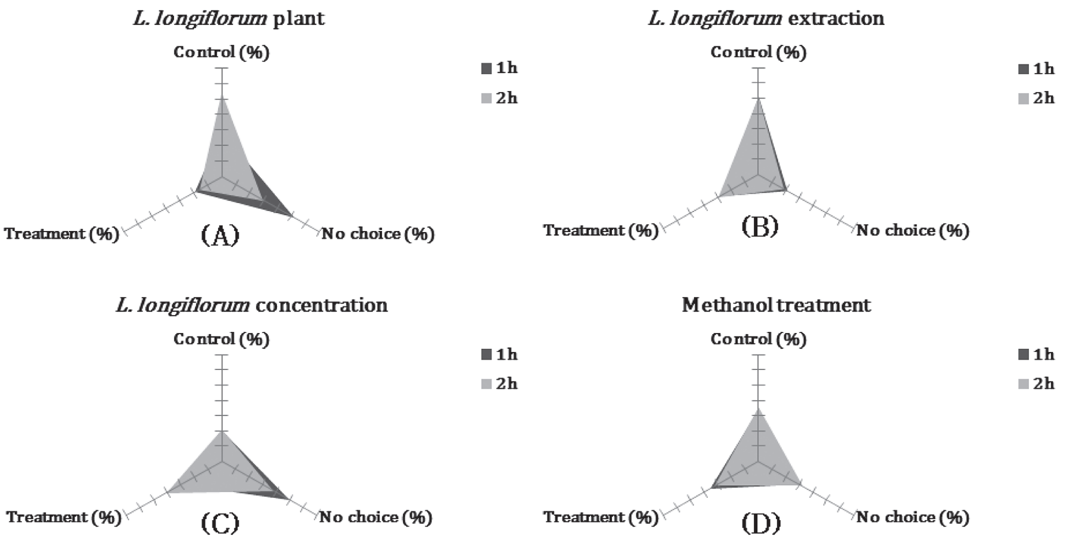

Fig. 5. Percentage of arrive *Pochazia* sp. when treatment *L. longiflorum* plant, *L. longiflorum* extraction, *L. longiflorum* concentration and methanol during 2 hours.

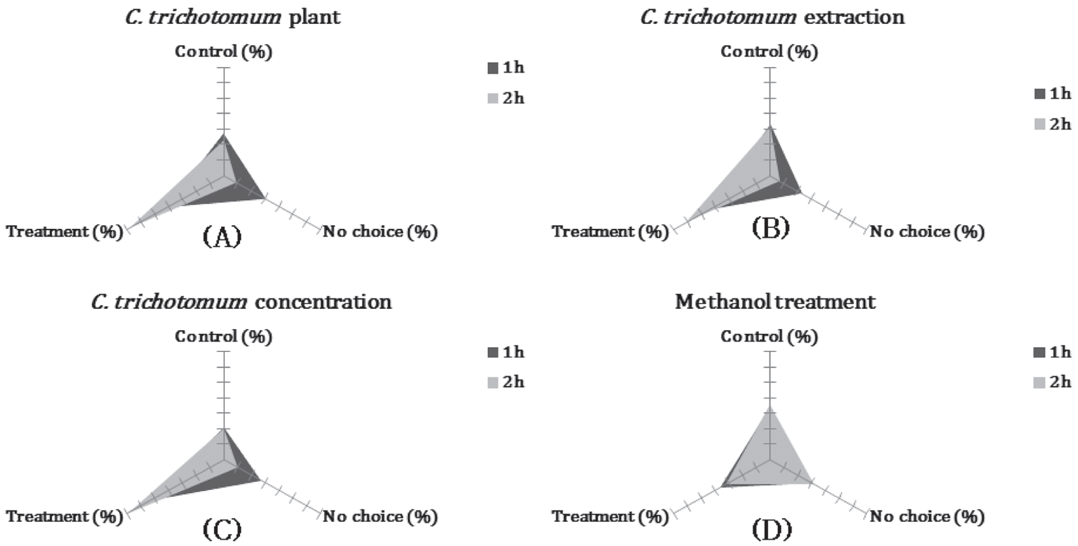

Fig. 6. Percentage of arrive *Pochazia* sp. when treatment *C. trichotomum* plant, *C. trichotomum* extraction, *C. trichotomum* concentration and methanol during 2 hours.

ment, respectively. *P. shantungensis* did not show a repellent effect when it treated with *L. longiflorum* concentrates. Thirty–four and 36% of population contacted it in a control group and a group treated with methanol for 1 hour after the treatment, respectively. Thirty–six and 32% of population contacted it in a control group and a group treated with methanol for 2 hours after the treatment, respectively. *P. shantungensis* did not show a repellent effect when it treated with methanol (Fig. 5).

Attraction effects of C. trichotomum at indoors

We performed the experiment to examine the attraction effects of *C. trichotomum* to *P. shantungensis* at indoors. As the results, 27% and 42% of population contacted it in a control group and a group treated with *C. trichotomum* plants for 1 hour after the treatment, respectively. Twenty–three and 68% of population contacted it in a control group and a group treated with *C. trichotomum* plants for 2 hours after the treatment, respectively. *P. shantungensis* showed an attraction effect when it treated with *C. trichotomum* plants. 33% Thirty–three and 44% of population contacted it in a control group and a group treated with *C. trichotomum* extracts for 1 hour after the treatment, respectively. Thirty–two and 61% of population contacted it in a control group and a group treated with *C. trichotomum* extracts for 2 hours after the treatment, respectively. *P. shantungensis* showed an attraction effect when it treated with *C. trichotomum* extracts. Twenty–one and 52% of population contacted it in a control group and a group treated with *C. trichotomum* concentrates for 1 hour after the treatment, respectively. Twenty and 70% of population contacted it in a control group and a group treated with *C. trichotomum* concentrates for 2 hours after the treatment, respectively. *P. shantungensis* showed an attraction effect when it treated with *C. trichotomum* concentrates. Thirty–four and 36% of population contacted it in a control group and a group treated with methanol for 1 hour after the treatment, respectively. Thirty–six and 32% of population contacted it in a control group and a group treated with methanol for 2 hours after the treatment, respectively. *P. shantungensis* did not show the attraction effect when it treated with methanol (Fig. 6).

Host preference of P. shantungensis on L. longiflorum and C .trichotomum at the fields

We carried out host preference survey of *P. shantungensis* about blueberry and *L. longiflorum*, blueberry and *C. trichotomum* for 5 weeks. When compared with blueberry and *L. longiflorum*, higher number of insects was captured in a yellow sticky trap installed around blueberry. On the other hands, lower number of insects was captured in a yellow sticky trap installed around *L. longiflorum*. Thus, adults of *P. shantungensis* showed the significant difference. It preferred blueberry and avoided *L. longiflorum*. Thus, the repellent effect of *L. longiflorum* was confirmed (Fig. 7). When compared with blueberry and *C. trichotomum*, lower number of insects was captured in a yellow sticky trap installed around blueberry. On the other hands, higher number of insects was captured in a yellow sticky trap installed around *C. trichotomum*. Thus, adults of *P. shantungensis* showed the significant difference. It preferred *C. trichotomum* to blueberry. Thus, the attraction effect of *C. trichotomum* was confirmed (Fig. 8).

Repellent effects of L. longiflorum at the fields

We examined the repellent effects on *P. shantungensis* when it was treated with *L. longiflorum* methanol extracts, *L. longiflorum* concentrates and methanol in outdoor fields. As the results, 72.8 adults of *P. shantungensis* on average were captured in a yellow sticky trap in a control group. 45.0, 68.4 and 0.0 adults of *P. shantungensis* were captured in groups treated with *L. longiflorum* methanol extracts, *L. longiflorum* concentrates and methanol, respectively. Significant repellent effects were found in a group treated with *L. longiflo-*

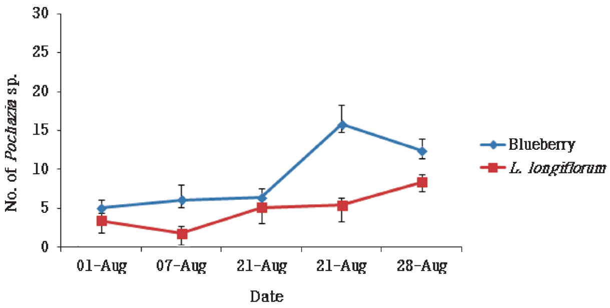

Fig. 7. Number of *Pochazia* sp. was caught in which attracted between *L. longflorum* and blueberry during 5 weeks.

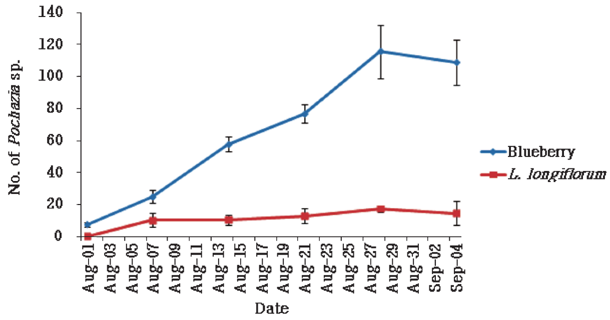

Fig. 9. Move disposition of *Pochazia* sp. was planted *L. logiflorum* around blueberry orchard during 5 weeks.

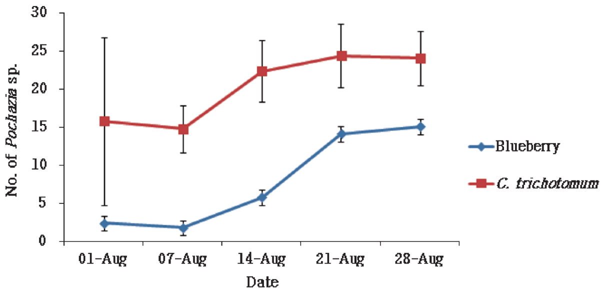

Fig. 8. Number of *Pochazia* sp. was caught in which attracted between *C. trichotomum* and blueberry during 5 weeks.

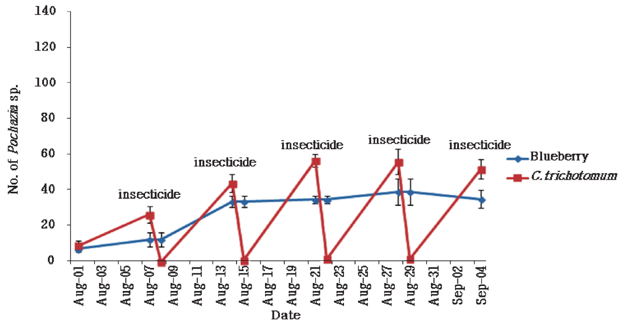

Fig. 10. Move disposition of *Pochazia* sp. was planted *C. trichotomum* around blue berry orchard during 5 weeks using chemical pesticide each 7 days.

Table 7. Number of *Pochazia* sp. repellent effect of *L. longiflorum* treated plant extraction and plant concentration

epellent effect of *L. longiflorum*	Extract	Concentrate	Methanol	Control	*P*
	45.0±19.8a	68.4±20.4b	73.6±7.4b	72.8±8.5b	0.033*

Values represent by mean ± SD, *: $P<0.05$; **: $P<0.01$; Completely randomized one–way analysis of variance, ANOVA, Post Hoc Test by Duncan in SPSS version 18.0 NS; statistically not significant.

Table 8. Number of *Pochazia* sp. attraction effect of *C. trichotomum* treated plant extraction and plant concentration

Attraction effect of *C. trichotomum*	Extract	Concentrate	Methanol	Control	*P*
	76.6±19.2b	78.7±13.1b	63.2±4.2a	61.5±9.6a	0.004*

Values represent by mean ± SD, *: $P<0.05$; **: $P<0.01$; Completely randomized one-way analysis of variance, ANOVA, Post Hoc Test by Duncan in SPSS version 18.0 NS; statistically not significant.

rum methanol extracts. However, the repellent effects were not found in a group treated with *L. longiflorum* concentrates where solvent was evaporated. In addition, the repellent effects were not found in a group treated with methanol (Table 7).

Attraction effects of C. trichotomum at the fields

We examined the attraction effects on *P. shantungensis* when it was treated with *C. trichotomum* methanol extracts, *C. trichotomum* concentrates and methanol at the fields. As the results, 61.5 adults of *P. shantungensis* on average were captured in a yellow sticky trap in a control group. At this result, 76.6, 78.7 and 0.0 adults of *P. shantungensis* were captured in groups treated with *C. trichotomum* methanol extracts, *C. trichotomum* concentrates and methanol, respectively. Significant attraction effects were found in a group treated with *C. trichotomum* methanol extracts and *C. trichotomum* extracts (Table 8).

Experiments for Movement patterns of P. shantungensis at the fields

We examined the movement patterns of *P. shantungensis* in the blueberry orchard when *C. trichotomum* and *L. longiflorum* were placed around the blueberry orchard. As the results, when *L. longiflorum* was placed around the blueberry orchard, the density of adults was gradually increased in the blueberry orchard for 5 weeks. Low density of adults was maintained in the blueberry orchard where *L. longiflorum* was placed for 5 weeks. Thus, the repellent effects of *L. longiflorum* was confirmed (Fig. 9). When *C. trichotomum* was placed around the blueberry orchard, the density of adults was initially increased and then maintained in the blueberry orchard. On the other hands, the density of adults was higher in the place where *C. trichotomum* was placed than the blueberry orchard. Chemical pesticides were applied mainly around *C. trichotomum* at interval of 7 days. As the results, the density of adults was not increased and maintained in the blueberry orchard. In addition, even if chemical pesticides were applied mainly around *C. trichotomum* for 5 weeks, *C. trichotomum* maintained the attraction effects on *P. shantungensis* (Fig. 10).

DISCUSSION

Sudden pests are referred to as pests which suddenly emerge in a large number and give the damage (Choi *et al*., 2012). In this study, we sought the efficient control strategies as the eco–friendly method using physiological and ecological characteristics of *P. shantungensis* which is the sudden pest.

P. shantungensis had been discovered in Chungnam area since 2008 and it was reported in 2010 for the first time. In this study, we observed the ecology of *P. shantungensis* through the outdoor survey with targets of the blueberry orchard in 2011 and 2012. As the results, it was found that crops were damaged from May to late October. In particular, adults were transformed from late July and they gave the serious damage to crops by laying eggs from late August to October. These results were partially similar to those in study of Choi *et al*. (2012) in which outdoor life cycle of *P. shantungensis* was investigated with targets of Gurye area in Jeonnam. Even if there was a slight variation in the time when adults were transformed from nymphs, it could be explained by the geological difference between Jeonnam and Chungnam area. In addition, the number of population of *P. shantungensis* has been increased every year. With the increase of annual average temperature every year, the survival rate of overwintered eggs was increased and the time of hatching got faster. Thus, it was thought that the number of population was increased. It was found that adults were concentrated inside the orchard as nymphs which inhibited around the orchard were transformed to adults. *P. shantungensis* preferred laying eggs on woody plants at the stage of adults and nymphs could not inhibit the orchard due to frequent treatment of drugs in cultivation of crops. Thus, they inhabited around crops. In addition, we conducted the outdoor survey in an apple orchard in SeonhakRi, SinpoongMyeon, Gongju, Chungnam, and a blueberry orchard in HancheonRi, WooseongMyeon, Gongju, Chungnam. These orchards were characterized by geographic features such as being enclosed by the valley and mountain stream. Thus, it was consistent with the characteristics of *Scolypopa australis* which gave a severe damage to a kiwi orchard in Australia andNew Zealand and inhabited mainly around mountain streams (Logan *et al*., 2002). It was consistent with characteristics of the area where *P. shantungensis* initially emerged in the study of Choi *et al*. (2011).

The indoor feeding of *P. shantungensis* is still unstable. We succeeded in hatching overwintered eggs, development of nymphs from the first to the fifth instars and transformation into adults. However, we failed to transform to adults from eggs through mating of adults again. We found that *P. shantungensis* hatched eggs, shed skins and became nymphs four times, and became adults after they shed skins fifth times through study on developmental periods in each stage with individual rearing of nymphs. These results were consistent with average sizes of each stage from first through fifth instar nymphs in 1.1, 2.1, 3.4, 6.5 and 7.1 mm in study of Choi *et al*. (2011). However, Choi *et al*. (2012) reported that insects hatched eggs and became adults through the stages of nymphs for up to fourth instar. Thus, it was different from the results of this study. The instar nymph can be identified by examination of the presence of the cast–off skin. In this study, we confirmed the instar nymphs for up to fifth instar by examination of the presence of the cast–off skin four times with individual rearing of nymphs. Because there was no difference in size of first and second *P. shantungensis*, it was likely to mistake second instar for first instar. According to survey of indoor developmental period, the time to hatch overwintered eggs of outdoor insects was late March which was faster by two months in insect breeding conditions. In addition, there were differences in developmental period for each stage of *P. shantungensis* between outdoor and indoor population. Growth rate in outdoor population was faster than that in indoor population. It was thought to be caused by the differences in temperature condition and enriched food conditions. All stages of *P. shantungensis* were not completely established indoors. Further study on ecology of eggs and life of adults indoors should be performed.

P. shantungensis inhabited the orchard during the period of nymph and it became adults when chemical pesticides were applied less frequently in the orchard when it came to the season of harvest. Thus, it flied to the orchard in order to lay eggs. *P. shantungensis* gave more severe damages by laying eggs rather than feeding. Therefore, it is required to have control strategies against adults flying to the orchard during this period. It is very limited to use the chemical pesticides during this period due to the risk of residual pesticides in harvest crops, development of resistance of target pests and hazards to humans, animals and environment. That is the reason why we selected plant extract materials as alternative ways to replace chemical pesticides.

Plant extract materials are widely used to control pests, because they had relatively less residual risks, they inhibited the development of resistance and they were safe to humans, animals and environment.

According to the results of treatment with plant extracts in this study, it was found that *Sophora matrine* and rotenone from derris extract showed excellent insecticidal effects when they were treated indoors and in outdoor fields. These results were consistent with those in study of Choi *et al*. (2012) in which *Sophora* extract showed a high mortality of 92.3% when mortality of eco–friendly organic agricultural materials was examined. In addition, Hwang *et al*. (2009a, b) performed the experiment to treat major pests with neem and matrine. According to the results, these materials showed a high insecticidal effect against cotton aphid andplant hopper which were Homoptera pests. In this study, the experiments were treated with only plant extract materials. The results of this study confirmed a high insecticidal effect of *Sophora* extract and derris extract against *P. shantungensis*. It suggests that our study can be used as the basic material to select eco–friendly materials with targets of *P. shantungensis* as the alternative use of chemical pesticides.

As we sought the efficient way which could be combined with eco–friendly control strategies of *P. shantungensis* by using plant extract materials, we studied repellent materials and attraction materials based on plant extract materials. If attraction materials are used, mass control can be made by applying pesticides after *P. shantungensis* is attracted by treating the surrounding of the orchard with attraction materials or attraction plants. In addition, if repellent materials are used, it is assumed to inhibit *P. shantungensis* flying in to lay eggs by treating crops with repellent materials or repellent plants in the orchard. While we perform the outdoor survey, we find that more nymphs of *P. shantungensis* are placed on *C. trichotomum* than any other plants. Thus, we assume that *C. trichotomum* has materials to attract *P. shantungensis*. In addition, according to farmers saying that *L. longiflorum* has less pest damage, we assume that *L. longiflorum* has materials to repel insects. We performed indoor experiments to examine attraction effects of *C. trichotomum* and repellent effects of *L. longiflorum* to *P. shantungensis*. Repellent effects were shown in groups treated with *L. longiflorum* plants and *L. longiflorum* methanol extracts. However, repellent effects were not shown in the group treated with *L. longiflorum* concentrates. Itis thought that repellent effect is not shown because repellent material which is the volatile material is evaporated together with solvent while *L. longiflorum* methanol extracts are concentrated under reduced pressure at 45°C by using vacuum evaporation. In addition, because the repellent effect of methanol is suspected, we test it when it is treated only with methanol. Because noticeable repellent effects are not shown, it is confirmed that the repellent effects are not caused by methanol. In the case of *C. trichotomum*, all groups treated with *C. trichotomum* plants, *C. trichotomum* methanol extracts and *C. trichotomum* concentrates show high attraction effects. There are no cases to test the repellent effects and attraction effects on insects using *L. longiflorum* and *C. trichotomum*. Therefore, it is thought that efficient eco–friendly control strategies using plant extract materials can be useful through this study. We examine the host preference of adults of *P. shantungensis* by placing *L. longiflorum* and *C. trichotomum* around the blueberry orchard in the outdoor fields. *P. shantungensis* prefers *C. trichotomum*, blueberry and *L. longiflorum* in order. Thus, *C. trichotomum* and *L. longiflorum* can be used as attraction material and repellent crop to control *P. shantungensis* in the blueberry orchard, respectively. When it is treated with *L. longiflorum* methanol extracts, *C. trichotomum* methanol extracts and *C. trichotomum* concentrates, results are similar to those of indoor treatment. Thus, it demonstrates that control strategies against *P. shantungensis* by using *L. longiflorum* and *C. trichotomum* are useful in the actual fields. In addition, we examined the movement patterns of adults of *P. shantungensis* when *L. longiflorum* and *C. trichotomum* plants are placed around the blueberry orchard. The number of population is increased in the blueberry orchard over time when *L. longiflorum* is placed around the blueberry orchard, but a small number of population stays around *L. longiflorum*. On the other hand, the number of population is changed in the blueberry orchard when *C. trichotomum* is placed around the blueberry orchard. The increase rate of population is reduced in the orchard and a large number of populations are attracted in *C. trichotomum*. In addition, when chemical pesticides are applied in *C. trichotomum*, the number of population is not increased any more in the orchard and the constant number is maintained. Attraction crops must meet three requirements. First, a clear host preference should be shown rather than host crops. Second, attraction effects of attraction crops should be maintained constantly. Last, it should be invested with low expenses without economical burden. On the basis of results of this study, *C. trichotomum* must meet requirements of attraction crops. Thus, it is thought that *C. trichotomum* is used for the effective method to attract and control a large number of populations as the control strategies against *P. shantungensis* in the blueberry orchard. In addition, it can be very significant, because it can maintain the frame of eco–friendly control.

This study is the initial study to report the occurrence of *P. shantungensis* which was sudden pest and the first paper to report the results of experiment performed in outdoor conditions in order to control *P. shantungensis* as the eco–friendly strategy. As general ecological survey and derivation of control strategies against *P. shantungensis* which had not been reported were made in this study, it will reduce severe damages of *P. shantungensis* which spread across the country and give effective helps for farmers.

In addition, further studies on clear taxonomic identification of *P. shantungensis* and eco–friendly control strategy using distinction of hosts for laying eggs from hosts for feeding and ecological and physiological characteristics should be performed in the future.

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