농약과학회지 (Korean J. Pestic. Sci.)
Vol. 21, No. 4, pp. 364-372 (2017)
Open Access https://doi.org/10.7585/kjps.2017.21.4.364
ORIGINAL ARTICLES

Online ISSN 2287-2051
Print ISSN 1226-6183

Toxicity of Pesticides to Mycophagous Ladybrid, *Illeis koebelei* Timberlake (Coleoptera: Coccinellidae: Halyziini)

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(Received on September 7, 2017. Revised on September 25, 2017. Accepted on November 10, 2017)

Abstract This study is the first to report the toxicity of pesticides to mycophagous ladybird, *Illeis koebelei*, which feeds on powdery mildew fungi. We investigated the selective toxicities of synthetic or environment-friendly biopesticides to *I. koebelei* for integrated powdery mildew management programs. Three synthetic insecticides, bifenthrin + imidacloprid WP, acetamiprid + indoxacarb WP, and acetamiprid + etofenprox WP were very toxic (IOBC classification, Class 4) to *I. koebelei*. Spiromesifen SC showed low toxicity to the survival and fecundity of *I. koebelei* when the third instar larvae or newly emerged adults were exposed to this pesticide via feeding with spiromesifen SC-treated cucumber powdery mildew. Pyriproxyfen EC showed very high residual toxicity, and the pupation rate and fecundity decreased significantly. Many environment-friendly biopesticides restricted the population of *I. koebelei*. However, Q pact (a.i. *Ampelomyces quisqualis* 94013) and Top seed (a.i. *Paenibacillus polymyxa* AC-1) showed toxicity to *I. koebelei* larvae. BT one (a.i. *Bacillus thuringiensis*) showed no residual toxicity on the fecundity of *I. koebelei* adults.

Key words Ladybeetle, *Illeis koebelei*, Mycophagous, Pesticide, Toxicity

Introduction

Pesticide use results in the unavoidable exposure of natural enemies of pests to these pesticides. Therefore, using of selective pesticides that have low toxicity to natural enemies is essential for the conservation of natural enemy populations (Tanaka et al., 2000). Thus, the use of selective pesticides is important in integrated pest management (IPM). The International Organization for Biological Control (IOBC) is active in identifying pesticides compatible with biological control. Based on IOBC classification, the effect of pesticides on natural enemy is categorized as Class 1 (harmless), Class 2 (slightly harmful), Class 3 (moderately harmful) and Class 4 (harmful) toxicity levels.

Powdery mildew disease is the most common and economically important plant disease in agricultural ecosystems worldwide (Amano, 1986). This disease damages a wide range of agricultural plant species (Glawe, 2008). The management of powdery mildew heavily relies on fungicides. However, owing to various adverse effects, such as development of pesticide resistance, environmental pollution, and killing of natural enemies (Razdan and Sabitha, 2009), the application of biological agents including microorganisms, and mycophagous arthropods has been increasingly studied (Bhattacharjee et al., 1994; English-Loeb et al., 2007; Lee et al., 2007; Romero et al., 2007; Segarra, 2009; Hegazi and El-Kot, 2010).

Of the Coccinellid group, mycophagous ladybeetles in the tribe Halyziini are considered biological control agents against powdery mildew. Halyziini ladybeetles feed primarily on powdery mildews and are distributed worldwide in regions where powdery mildews commonly occur (Sasaji, 1998; Giorgi et al., 2009; Sutherland and Parrella, 2009; Tabata et al., 2011). Mycophagous ladybird, *Illeis koebelei* is generally distributed in Asian countries, including China,

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Japan, Korea, Philippines, and Taiwan (Kim et al., 1994; Recuenco-Adorada and Gapud, 1998; Takeuchi et al., 2000; Lin et al., 2006; Wu et al., 2011). A recent study by Lee et al (2015) reported that *I. koebelei* was found from early July to early November in Korea, and has the potential for controlling cucumber powdery mildew.

Despite the broad distribution of mycophagous *I. koebelei* and its potential as a biological agent against powdery mildew disease in Korea, no information is available on the toxicity of pesticides to *I. koebelei*. Information on pesticide toxicity to *I. koebelei* would help farmers to select the appropriate pesticides for the chemical control of other pest and to develop a successful IPM program to control cucumber powdery mildew using this mycophagous ladybeetle. Therefore, in this study, we aimed to determine the toxicity of pesticides, which are, commonly used in cucumber production in Korea, to *I. koebelei.* The results of this study would provide a guideline for selecting appropriate pesticides for controlling powdery mildew using *I. koebelei*.

Materials and Methods

Rearing of *I. koebelei*

I. koebelei and cucumber powdery mildews were collected from pear orchards and cucumber plants in commercial greenhouses, respectively in Gyeonggi-do, Korea. *I. koebelei* was cultured on cucumber seedlings infected with powdery mildew in laboratory at 24 ± 1°C, 60-80% (RH) and a photoperiod of 16:8 (L:D) h. Approximately 30 adult *I. koebelei* were placed in acrylic containers (30 × 30 × 30 cm) with two pots of cucumber seedlings infected with powdery mildew. The eggs laid on cucumber leaves were transferred to a translucent plastic cage (232 × 165 × 95 mm) with ventilation holes on the sides. A wet paper-towel was placed at the bottom of cage to provide moisture. Neonates were moved to cucumber leaf infected with powdery mildew by using a soft brush. The larvae were always served with new cucumber seedlings before the exhaustion of food. The pupae were placed in acrylic containers until eclosion.

Pesticides tested

Sixteen synthetic insecticides (Table 1) for controlling *Trialeurodes vaporariorum* or *Bemisia tabaci*, and 22 environment-friendly commercial pesticides (Table 2), which are generally used in cucumber cultivation in Korea, were tested for toxicity to *I. koebelei*. All pesticides were diluted in water to the respective field-recommended application rate. The concentration of each pesticide was selected based on the 2012 Agrochemicals Use Guide Book (KCPA, 2012).

Toxicity bioassay

To test the toxicity of the 38 pesticides listed above, the

Table 1. List of commercial synthetic insecticides tested for toxicity against mycophagous ladybird *Illeis koebelei*

No.	Trade name	Company	Active gradient (%)	Formulation	Recommended Concentration
1	Actara	Syngenta	Thiamethoxam (10)	WG [a)]	2,000 X
2	Affrim	Syngenta	Emamectin benzoate (2.15)	EC	2,000 X
3	Acellt	Dongbangagro	Spinetoram (5)	SC	2,000 X
4	Bigcard	Hankooksamgong	Clothianidin (8)	SC	2,000 X
5	Cheonhamujuck	Agrotech	Bifenthrin + imidacloprid (2+8)	WP	2,000 X
6	Decis	Kyungnong	Deltamethrin (1)	EC	1,000 X
7	Hanaro	Farmhannong	Bistrifluron (10)	EC	2,000 X
8	Limone	Hankooksamgong	Novaluron (10)	SC	2,000 X
9	Limousine	Agrotech	Gamma-cyhalothrin (1.4)	CS	2,000 X
10	Maengta	Agrotech	Acetamiprid + indoxacarb (4+5)	WP	1,000 X
11	Manjangilchi	Kyungnong	Acetamiprid + etofenprox (2.5+8)	WP	1,000 X
12	Moseupiran	Kyungnong	Acetamiprid (8)	WP	2,000 X
13	Oshin	Farmhannong	Dinotefuran (10)	WP	1,000 X
14	Sanmaroo	Hankooksamgong	Pyridaben (20)	WP	1,000 X
15	Shingiroo	Dongbangagro	Pyriproxyfen (10)	EC	2,000 X
16	Zizone	Farmhannong	Spiromesifen (20)	SC	2,000 X

[a)]WG=water dispersible granule, EC=emulsifiable concentration, SC=suspension concentration, WP=wettable powder, CS=capsule suspension.

Table 2. List of environment-friendly commercial pesticides tested for toxicity against mycophagous ladybird *Illeis koebelei*

No.	Trade name	Company	Active gradient (%)	Formulation	Recommended Concentration
1	Barogaru alpha	Greenbiotech	Plant Extracts + *Bacillus subtilis*	EC [a)]	1,000 X
2	Barojin alpha	Greenbiotech	Plant Extracts + Microorganism	EC	1,000 X
3	Barotok alpha	Greenbiotech	Plant Extracts + *Bacillus subtilis*	EC	1,000 X
4	Bijin alpha	Greenbiotech	Plant Extracts	EC	1,000 X
5	BT one	Koreabio	Bacillus thuringiensis	WP	1,000 X
6	Daeyou ecocide	Daeyu	*Bacillus thuringiensis* serovar	EC	2,000 X
7	Daeyou eungjinssak	Daeyu	Natural seed extracts	EC	1,000 X
8	Daeyou plazmaneem	Daeyu	Neem extracts	EC	500 X
9	Ddook plus	Bioagro	Plant Extracts + Microorganism	EC	1,000 X
10	Dyna	BIG	Plant Extracts	EC	1,000 X
11	Eungaetan alpha	Greenbiotech	Plant Extracts + *Bacillus subtilis*	EC	1,000 X
12	Eungsami	Koreabio	Plant Extracts + Microorganism	EC	1,000 X
13	Jinap	BIG	Plant Extracts	EC	1,000 X
14	Jinsami	Koreabio	Plant Extracts	EC	1,000 X
15	Neem seed oil	Ozone	Neem extracts	EC	1,000 X
16	Nobug	Koreabio	Plant Extracts	EC	1,000 X
17	Onsami	Koreabio	Plant Extracts	EC	1,000 X
18	Q pact	Greenbiotech	*Ampelomyces quisqualis* 94013	WP	1,000 X
19	Solbitchae	Greenbiotech	Microorganism	EC	400 X
20	Suncho	BIG	Plant Extracts	EC	1,000 X
21	Toggagi power	Koreabio	Plant Extracts	EC	1,000 X
22	Top seed	Greenbiotech	*Paenibacillus polymyxa* AC-1	SC	200 X

[a)]EC=emulsifiable concentration, WP=wettable powder, SC=suspension concentration.

third instar larvae and adults of *I. koebelei* (<48 h old) were exposed to pesticides at the recommended field application rate of each commercial formulation. The larvae were sprayed with pesticide or water control until the body was soaked, and then placed in the insect breeding dish (Ø 150 × H 73 mm, ventilation allowed). The adults were dipped in pesticide or water control for 5 s and placed in the insect breeding dish (Ø 150 × H 73 mm, ventilation allowed). Cucumber leaf disc (Ø 100 mm) infected with powdery mildew was provided in the dish as a food source. The experiment was repeated three times with 15 individuals in each replicate for each treatment. Kimwipe (Kimberly-Clarke®, Kimwipes® EX-L) was placed at the bottom of the dish and moistened with water every day. Mortality was assessed 48 h after treatment. An insect was recorded as dead if it did not move or could not turn the body by itself when touched.

Pesticides that showed low toxicity to *I. koebelei* were further tested to evaluate the residual toxicity on survival and fecundity of *I. koebelei* at the same concentration. For the evaluation of residual toxicity to larvae, 30 third instar larvae were provided with cucumber leaves infected with powdery mildew, which had been exposed to pesticides. The amount of leaves provided was sufficient to feed the larva to pupation. After adult emergence, 10 adult couples were provided with pesticide-free cucumber seedlings, and the number of eggs laid by female adults was investigated for 20 days after the pre-oviposition period. For the evaluation of residual toxicity to adults, 15 adult couples (<24 h) were treated, and the survival rate, pre-oviposition period and fecundity were investigated by the same method.

All experiments were conducted in the laboratory at 24 ± 1°C, 60-80% RH and a photoperiod of 16:8 (L:D) h.

Statistical analysis

The mortalities (%) caused by synthetic insecticides and commercial environment-friendly pesticides were corrected for control mortality using the Abbott's correction formula. Then, the mortalities (%) were transformed using the arcsine square root function prior to analysis of variance (ANOVA) test. The survival rate (%), pre-oviposition period, and fecundity of *I. koebelei* adults by the residual toxicity of pesticides, and pupation rate (%), emergence rate (%), pre-oviposition period, and fecundity of *I. koebelei* by the residual toxicity of pesticides were analyzed by one-way ANOVA. The means were separated with the Tukey's Studentized Range (HSD) Test (SAS Institute, 2008).

Results

The effects of 16 synthetic insecticides on the mortality of *I. koebelei* under laboratory conditions are shown in Table 3. The susceptibility of *I. koebelei* to insecticides varied according to the insecticide and developmental stages. In general, the larvae were more susceptible to pesticides than the adults were. Neonicotinoid insecticides and a mixture chemicals, such as acetamiprid WP, acetamiprid + indoxacarb WP, acetamiprid + etofenprox WP, bifenthrin + imidacloprid WP, clothianidin SC, and dinotefuran WP showed strong toxicity to *I. koebelei*. However, thiamethoxam WG was relatively less toxic to *I. koebelei* than other neonicotinoid insecticides. In particular, thiametoxam WG showed very less toxic effect on adult *I. koebelei*. Pyrethroid insecticides and a mixture with pyrethroids, such as bifenthrin + imidacloprid WP, deltamethrin EC and gamma-cyhalothrin CS were also highly toxic to *I. koebelei*, regardless of its developmental stages. The insect growth regulator, pyriproxyfen EC and the new class of spirocyclic tetronic acids, spiromesifen SC, were less toxic to *I. koebelei* with < 20% mortality. Other insect growth regulators, bistrifluron EC and novaluron SC, were also less toxic to adult *I. koebelei*, but were highly toxic to its larvae

The effects of 22 environment-friendly pesticides on the mortality of *I. koebelei* under laboratory conditions are presented in Table 4. Most of the biological or botanical pesticides were more toxic to larvae than adults of *I. koebelei* similar to synthetic pesticides. Several botanical or biopesticides (e.g., Barogaru alpha, Bijin alpha, Eungaetan alpha, Eungsami, Nobug, Suncho) were highly toxic to larvae, or adult, or both stages of *I. koebelei*. However, Barogaru, Bijin alpha and Neem seed oil showed low toxic effects on adult *I. koebelei*. Among the biological or botanical pesticides tested, six commercial products (Barojin alpha, BT one, Daeyou ecocide, Q pact, Solbitchae, and Top seed) showed low mortality against the larvae and adults of *I. koebelei,* with < 20% mortality.

The effects of residual toxicity of several pesticides, which are less toxic to *I. koebelei,* on *I. koebelei* adults are presented in Table 5. The synthetic pesticides pyriproxyfen EC and spiromesifen SC showed low residual toxicity to *I.*

Table 3. Effects of commercial synthetic insecticides on mortality of *Illeis koebelei* under laboratory conditions

No.	Pesticide	Mortality (%, mean ± SE)	
		Larvae	Adults
1	Thiamethoxam	78.0 ± 7.35 bc[a)]	6.8 ± 3.90 efg
2	Emamectin benzoate	92.7 ± 7.30 ab	72.7 ± 13.65 b
3	Spinetoram	46.4 ± 7.68 d	25.0 ± 6.80 cd
4	Clothianidin	100 a	68.2 ± 10.41 b
5	Bifenthrin + imidacloprid	100 a	100 a
6	Deltamethrin	100 a	90.9 ± 3.90 a
7	Bistrifluron	60.1 ± 8.43 cd	0 g
8	Novaluron	43.9 ± 8.43 d	6.8 ± 3.90 efg
9	Gamma-cyhalothrin	100 a	90.9 ± 7.85 a
10	Acetamiprid + indoxacarb	100 a	100 a
11	Acetamiprid + etofenprox	100 a	100 a
12	Acetamiprid	100 a	93.2 ± 6.80 a
13	Dinotefuran	60.1 ± 8.43 cd	34.1 ± 3.96 c
14	Pyridaben	75.6 ± 11.17 bc	100 a
15	Pyriproxyfen	8.1 ± 10.18 e	9.1 ± 3.90 ef
16	Spiromesifen	3.2 ± 2.79 e	15.9 ± 3.96 de

[a)]Means followed by the same letter within a column are not significantly different at p=0.05 by Tukey's Studentized Range Test (SAS Institute, 2008).

Table 4. Effects of commercial environment-friendly pesticides on mortality of *Illeis koebelei* under laboratory conditions

No.	Pesticide	Mortality (%, mean ± SE)	
		Larvae	Adults
1	Barogaru alpha	95.1 ± 4.25 ab[a)]	20.5 ± 7.91 ghi
2	Barojin alpha	9.7 ± 4.25 h	3.0 ± 2.64 i
3	Barotok alpha	85.4 ± 7.30 abc	31.8 ± 6.80 fgh
4	Bijin alpha	100 a	0 i
5	BT one	7.3 ± 4.25 h	0 i
6	Daeyou ecocide	2.5 ± 8.43 h	3.0 ± 2.64 i
7	Daeyou eungjinssak	82.9 ± 4.25 bcd	93.4 ± 6.81 ab
8	Daeyou plazmaneem	53.6 ± 4.25 g	65.9 ± 6.80 cd
9	Ddook plus	70.7 ± 7.30 cdef	36.3 ± 3.96 efg
10	Dyna	75.6 ± 8.49 cde	70.4 ± 10.41 cd
11	Eungaetan alpha	100 a	43.2 ± 7.85 ef
12	Eungsami	100 a	100 a
13	Jinap	63.4 ± 7.30 efg	50.0 ± 10.41 def
14	Jinsami	82.9 ± 4.25 bcd	56.8 ± 10.41 cde
15	Neem seed oil	68.3 ± 11.17 defg	11.4 ± 6.80 hi
16	Nobug	100 a	20.5 ± 3.96 ghi
17	Onsami	75.6 ± 8.49 bc	77.3 ± 7.91 bc
18	Q pact	0 h	0 i
19	Solbitchae	1.6 ± 2.79 h	5.3 ± 5.69 i
20	Suncho	100 a	100 a
21	Toggagi power	56.1 ± 7.35 fg	65.9 ± 11.81 cd
22	Top seed	0 h	0 i

[a)]Means followed by the same letter within a column are not significantly different at p=0.05 by Tukey's Studentized Range Test (SAS Institute, 2008).

Table 5. Effects of residual toxicity of several pesticides on the survival and fecundity adult *Illeis koebelei*

Pesticide	Survival rate (% ± SE)	Pre-oviposition period (day ± SE)	Fecundity (eggs/female ± SE)
Pyriproxyfen	90.0 ± 10.00 ns	9.7 ± 1.15 ns	68.7 ± 25.77 d[a)]
Spiromesifen	93.3 ± 5.77	9.3 ± 1.04	134.1 ± 31.09 bc
BT one	100	8.3 ± 1.08	144.0 ± 29.55 ab
Solbitchae	96.7 ± 5.77	9.0 ± 0.42	131.2 ± 28.93 c
Control	100	10.0 ± 0.40	149.7 ± 27.15 a

[a)]Means followed by the same letter within a column are not significantly different at p=0.05 by Tukey's Studentized Range Test (SAS Institute, 2008).

koebele, in terms of mortality and pre-oviposition period. However, pyriproxyfen EC decreased fecundity significantly. The biopesticides BT one and Solbitchae did not show significant residual toxicity.

The effects of residual toxicity of several pesticides, which are less toxic to *I. koebelei*, on *I. koebelei* larvae are presented in Table 6. The synthetic pesticide pyriproxyfen EC showed significant residual toxicity, resulting in unsuccessful pupation. Another synthetic pesticide spiromesifen SC showed a rather low residual toxicity, resulting in 70% pupation rate. In addition two environment-friendly pesticides, BT one and Solbitchae, did not affect survival and showed low residual toxicity on fecundity of *I. koebelei*. Meanwhile, Solbitchae somewhat shortened the pre-oviposition period and decreased the fecundity of adults.

Table 6. Effects of residual toxicity of several pesticides on the survival and fecundity of *Illeis koebelei* larva

Pesticide	Pupation rate (% ± SE)	Emergence rate (% ± SE)	Pre-oviposition period (day ± SE)	Fecundity (eggs/female ± SE)
Pyriproxyfen	0 c [a)]	0 b	0 c	0 b
Spiromesifen	70.0 ± 10.00 ab	57.1 ± 12.30 a	8.8 ± 0.25 a	144.3 ± 12.50 ab
BT one	86.7 ± 11.55 a	71.7 ± 15.88 a	8.7 ± 0.56 a	131.3 ± 17.56 b
Solbitchae	66.7 ± 11.55 b	59.7 ± 8.69 a	7.3 ± 0.36 b	127.3 ± 17.95 b
Control	86.7 ± 5.77 a	73.2 ± 5.77 a	9.4 ± 0.55 a	155.0 ± 15.52 a

[a)]Means followed by the same letter within a column are not significantly different at p=0.05 by Tukey's Studentized Range Test (SAS Institute, 2008).

Discussion

This study is the first to report the toxicity of pesticides to the mycophagous predator, *I. koebelei*, of powdery mildew of agricultural crops. The pesticides tested are synthetic or environment-friendly products, and are used for controlling insect or microbial pests on cucumber in Korea. Many studies on toxicity against the multicolored Asian ladybeetle, *Harmonia axyridis* Pallas have been conducted with various insecticides, biopesticides, fungicides, herbicides, and insect-resistant transgenic crops (Koch, 2003). Cho et al. (1997) reported that synthetic pyrethroid insecticides were less toxic to *H. axyridis* than to aphids. Insect ecdysone agonists, halofenozide and methoxyfenozide are known to cause premature larval molting, interruption of feeding, and incomplete pupation (Carton et al., 2003). Several terpenoids derived from plants, such as camphor, menthol, catnip, and grapefruit, are known to repel ladybeetles (Riddick et al., 2008). In the case of ladybeetle *Hippodamia variegata* (Goeze), Almasi et al. (2013) selected pirimicarb and pymetrozine as a low toxic pesticide in contrast to proteus that showed high mortality rate. Rahmani et al. (2013) reported that a new neonicotinoid insecticide, thiamethoxam, decreased the pre-adult developmental period, while it showed not effect on the adult developmental period. In the case of ladybeetle Imidacloprid and deltamethrin have been reported to be relatively harmful (Bozsik, 2006) to ladybeetle *Coccinella septempunctata* L., while the two biopesticides Bioshower (a.i. 100% fatty acid) and insecticidal soap (a.i. 20% fatty acids) showed no toxicity (Raudonis et al., 2010). Radha (2013) reported the comparative toxicity of biopesticides and synthetic pesticides against cowpea aphid (*Aphis craccivora*) and its natural enemy ladybeetle *Micrapis discolor*. Botanical insecticides (neem seed extracts) and microbial pesticides (spinosad) as were recommended as alternatives to chemical insecticides for the IPM of *A. craccivora* in cowpea.

In this study, The toxicities of various synthetic insecticides and environment-friendly pesticides to *I. koebelei* were significantly different (Table 3, 4). In particular, bifenthrin + imidacloprid WP, deltamethrin EC, gamma-cyhalothrin CS, acetamiprid + indoxacarb WP, acetamiprid + etofenprox WP, and acetamiprid WP showed strong toxicity to *I. koebelei*. Based on the IOBC classification, the three insecticides, bifenthrin + imidacloprid WP, acetamiprid + indoxacarb WP, and acetamiprid + etofenprox WP, were classified as toxicity Class 4 (harmful). Pyriproxyfen EC and spiromesifen SC caused < 20% mortality and are classified as toxicity Class 1 (harmless).

This study showed that *I. koebelei* is very sensitive to neonicotinoid insecticides. Neonicotinoid insecticides are commonly used against a wide range of herbivorous insect pests such as aphids, mealybugs and whiteflies in greenhouses or farms in Korea (KCPA, 2012). This result is consistent with the results of Lucas et al. (2004) who reported that imidacloprid is highly toxic to both adult and larval stages of ladybeetle *Coleomegilla maculata* under laboratory conditions. Neonicotinoid insecticides, including proteus, are toxic to both larvae and adults of Coccinellids (Almasi et al., 2013). Bifenthrin + imidacloprid WP, acetamiprid + indoxacarb WP, and acetamiprid + etofenprox WP classified as toxicity Class 4 need to be tested in semi-field or field conditions to determine their effects on mycophagous *I. koebelei.* Meanwhile, spiromesifen SC, which was placed in Class 1, could be used as a part of the cucumber powdery mildew IPM program in combination with *I. koebelei*. According to the IOBC, if insecticides were harmless in the laboratory test, it is not necessary to perform further semi-field or field studies (Almasi et al., 2013). However, we suggest that performing further residual toxicity tests may be important for pesticides that showed low contact toxicity to natural enemies in laboratory tests. For example, pyriproxyfen EC, which had low toxicity in the laboratory test, showed markedly high residual toxicity to *I. koebelei* by decreasing fecundity.

Many environment-friendly pesticides (e.g., Barogaru alpha, Barotok alpha, Daeyou eungjinssak, Eungaetan alpha, Eungsami, Iinsami, Nobug and Suncho) were highly toxic to *I. koebei* larvae. Daeyou eungjinssak (a.i. natural seed extracts), Eungsami (a.i. *Azadirachta indica* + *Sophora flavescens* + microorganism) and Suncho (a.i. *Azadirachta indica*) were highly toxic to *I. koebelei* adults and classified as toxicity Class 3 or 4 in the IOBC category. However, Barojin alpha (a.i. Plant extracts) and BT one (a.i. *Bacillus thuringiensis*) were less toxic to *I. koebelei* larva. Q pact (a.i. *Ampelomyces quisqualis* 94013) and Top seed (a.i. *Paenibacillus polymyxa* AC-1) are microbial fungicides for controlling powdery mildew disease of various agricultural crops (Lee et al., 2004; Kim et al., 2013). The microbial fungicides Q pact, Top seed, and BT one were less toxic to *I. koebelei*. However, the toxicities of pesticides could differ according to the developmental stages of insects. In this study, *I. koebelei* larvae were more susceptible to pesticides than adults were. Although BT one did not show residual toxicity to *I. koebelei* adults, the fecundity of adults from third instar larvae, which had been exposed to BT one, decreased (Table 5, 6). These results show that many botanical or microbial pesticides could decrease the population of *I. koebelei*.

To date, no study has reported the toxicity of biological or botanical pesticides to mycophagous *I. koebelei*. We found that many botanical pesticides made from plant extracts or microorganisms could destroy or reduce the population of *I. koebelei*. The deposit amount of active ingredient on plants can differ according to the formulation or supplement agent of the commercial products. Although, the results of laboratory toxicity test provided some useful information on selective pesticides for *I. koebelei*, the long-term effect of these pesticides on *I. koebelei* populations under field conditions could not be explained. Therefore, further field studies regarding these aspects need to be conducted.

Acknowledgments

This study was performed with the support of the cooperative research program for Agricultural Life & Industrial Technology Development (project No. 116089-03-1-SB010), Korea Institute of Planning and Evaluation for Technology in Food, Agriculture and Forestry, Republic of Korea.

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시판 농자재의 식균성 천적 노랑무당벌레(*Illeis koebelei*)에 대한 독성

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요 약 본 연구는 흰가루병원균 포식성 곤충인 노랑무당벌레 (*Illeis koebelei*)에 대한 시판 농자재의 독성을 분석한 최초의 연구로써 흰가루병 종합적관리의 기초자료를 확보하고자 수행하였다. 오이에 등록된 살충제와 유기농업자재를 대상으로 노랑무당벌레의 유충과 성충에 대한 독성을 검정한 결과, bifenthrin + imidacloprid (WP), acetamiprid + indoxacarb (WP), acetamiprid + etopheprox (WP)약제들은 IOBC 기준을 적용할 경우 Class 4 (harmful)에 속하는 높은 독성을 나타내었다. 단기간 독성평가시 저독성 살충제였던 spiromesifen (SC)은 노랑무당벌레 3령 유충과 갓 우화한 성충이 흰가루병원균과 동시에 섭식하더라도 생존율과 번식력에는 영향이 적었던 반면, pyriproxyfen (EC)의 경우는 유충의 용화율과 성충 번식력을 크게 떨어뜨리는 것으로 나타났다. 한편 유기농업자재인 큐팩트 (a.i. *Ampelomyces quisqualis* 94013)와 탑시드 (a.i. *Paenibacillus polymyxa* AC-1)는 3령 유충과 성충에 독성을 보이지 않았으며, 비티원 (*Bacillus thuringiensis*)은 갓 우화한 성충의 생존율과 번식력에 영향을 미치지 않았다. 따라서, 천적에 대한 독성 평가시 노출 이후 생존율과 번식력에 대한 장기적 검토가 필요하며, 위의 저독성 농자재들은 오이 흰가루병 종합적 방제에 노랑무당벌레와 함께 이용이 가능할 것으로 사료된다.

색인어 무당벌레, *Illeis koebelei*, 식균성, 농자재, 독성