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Pesticide Doses and Spraying Method for Optimal Pest Control in Paprika Cultivation

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The effects of pesticide spraying amounts per plant on insect pest control were investigated in a paprika cultivation. The paprika plant lengths of 1 m 20 cm and 2 m 20 cm were selected. In the case of 1 m 20 cm high plants, 125 ℓ, 60 ℓ and 30 ℓ per 10 a were sprayed for individual application doses. When 125, 60 and 30 ℓ of pyrifluquinazon 10% WG were sprayed, control effects of 100%, 100% and 65.5% were shown 7 days later respectively. When the same quantities of clothianidin 8% SG were sprayed, control effects of 91.5%, 87.5% and 55.5% were obtained, respectively. The 2 m 20 cm high plants were sprayed with 250 ℓ, 125 ℓ and 60 ℓ per 10 a for individual application doses. When sprayed with pyrifluquinazon 10% WG, the plants showed control effects of 100%, 100%, and 58.5% 7 days later, respectively. When the clothianidin 8% SG was sprayed, control effects of 91.5%, 87.5%, and 55.5% were observed 7 days later, respectively. *Frankliniella occidentalis* control effects were tested using spinetoram 5% WG and abamectin 1.8% EC. In the case of 1 m 20 cm high paprika plants, when 125 ℓ, 60 ℓ, and 30 ℓ per 10 a of spinetoram 5% WG were sprayed, control effects of 93.1%, 90.1%, and 27.2% were shown 7 days later, respectively. In the case of abamectin 1.8% EC, control effects of 92.5%, 85.5%, and 56.5% were shown, respectively. When 2 m 20 cm high paprika plants were sprayed with 250 ℓ, 125 ℓ, and 60 ℓ per 10 a of spinetoram 5% WG, they showed control effects of 93.5%, 94.9%, and 67.5% 7 days later, respectively. In the case of Abamectin 1.8% EC, control effects of 90.5%, 87.5%, and 47.3% were shown, respectively.

Key words: Paprika, Pest control effect, Spray water volume, Total active elements, Water sensitive paper (WSP)

INTRODUCTION

Recently, the interest in health has been increasing due to the improvement of the living standard of the South Korean people. Therefore, demands for fresh agricultural products, which are related to well–being, have been increasing centered on cereals and vegetables because South Korean people prefer plant–based eating habits and eco–friendly organic foods. Paprika, which is representative among such agricultural products, is an annual plant belonging to Solanacae, Capsicum and Annuum (Kim *et al*., 2013). In South Korea, the cultivation area and yield of paprika have been consistently increasing after paprika began to be cultivated in 1994 (Kim *et al*., 2013; Cho *et al*., 2011).

In the case of paprika cultivation, pest control is one of the most difficult problems because paprika cultivation follows the form of cultivation under structure and, in particular, diverse major small insect pests such as mulberry thrips, spider mites, white flies, and aphids occur (Lee *et al*., 2005). The occurrence of such sucking insect pests not only causes damage as insect pests but also causes many problems as mediators of viruses (Lee *et al*., 2005). Among the insect pests, *Frankliniella occidentalis* is mainly found in flowers and its larvae cause severe damage. The larvae inhabit in the gaps near the calyxes and gnaw the surfaces of fruits, enlarging the gaps between the calyxes and fruits leading to the browning of the surfaces of fruits, and even malformed fruits in severe cases. In addition, *Aphis gossypii* encroaches on the plant leaves, stems, flowers, and fruits of plants causing wilting and growth inhibition (Jung *et al*., 2006). These small insect pests lay dozens to several hundred eggs per time and breed several dozen times per year as their life cycles are short. In particular, their populations increase rapidly as they live hidden in places not exposed to chemical control and these characteristics are reported to swiftly develop resistance to pesticides (Shim *et al*., 1997). Therefore, small insect pests quickly develop pesticide resistance in general, thereby not only increasing the concentrations and the number of times of use of agricultural chemicals but also increasing the number of similar agricultural chemicals mixed, leading to the abuse of agricultural chemicals (Cho *et al*., 2011; Jin *et al*., 2014). Even those agricultural chemicals that show excellent control effects are subject to increases in selection pressure when the dose or frequencies of use of them increase so that the resistance can develop easily, leading to the shortening of their useful life (Jin *et al*., 2016). Therefore, to improve control methods, pesticide application doses and spraying methods should be optimized while standardizing the agricultural materials used such as the nozzles of sprayers, if

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possible (Choi *et al*., 2005).

In South Korea, high pressure sprayers are used for pest control in most paprika cultivations although fog sprayers are used in some cases. However, when high pressure sprayers are used, although chemicals can be rapidly sprayed, the control effects are not sufficient because the chemicals do not reach the underside or inner lateral side of leaves and the inside of flowers, which are the main habitats of mulberry thrips, leading to the development of resistance (Kim, 2012; Jin *et al*., 2014). Some presumable causes of the development of insect pests' resistance to pesticides in South Korea are; 1) similar pesticides are uniformly selected by all farms in a village in some cases, 2) a farm spray the same pesticide many times consecutively in other cases, and 3) many blind areas are formed when pesticides are sprayed using high pressure sprayers so that insect pests are exposed to pesticides at doses lower than the appropriate doses. However, cases of research and development regarding the improvement of sprayers and nozzle conditions, spraying workers' habits, or crop cultivation methods can be hardly found in South Korea. Therefore, the development of methods that can exhibit the best control effects with the optimum doses of pesticides against the insect pests occurring in crops is desperately needed. In addition, since South Korean research & development of pesticides have focused on consumer–oriented safety thus far, the degree to which users are exposed to pesticides has not been well understood. Therefore, optimum spraying methods in the field should be developed considering the safety of users.

In the present study, experiments were conducted with a view to setting appropriate pesticide application doses at paprika cultivations and improving spraying methods to make standard spraying methods. To figure out appropriate application doses of pesticides for several major insect pests occurring in paprika and standardize the pesticides application doses while reducing the pesticide application doses, application doses were set by plant height and resultant pest control effects and active components of pesticides were reviewed.

MATERIALS AND METHODS

Test pesticides and sprayers

Among those chemicals that have been registered for *A. gossypii* occurring in paprika farms, pyrifluquinazon water–dispersible granules (Pyrifluquinazon 10% WG, brand name: Fanfare), which was registered recently, was selected considering the development of resistance and clothianidin soluble granules (Clothianidin 8% SG, brand name: Ttoksoli), which has been used for several years, was selected as a comparison chemical. As control chemicals for *F. occidentalis*, spinetoram water–dispersible granules (Spinetoram 5% WG, brand name: Delegate) and abamectin emulsifiable concentrate (Abamectin 1.8% EC, brand name: All Star) diluted to the dilution magnification for safe use of pesticides were sprayed. U–shaped high pressure sprayers [engine sprayer (BCET–25A), Korea B&C] were used as pesticide sprayers.

Target crop and test site

A preliminary experiment to check the *A. gossypii* control effects of the pesticides registered with South Korean government agencies according to their application doses was conducted in the laboratory with red pepper (variety: Sinheung) leaves by applying the pesticides diluted to the recommended dilution magnifications using trace topical appliers [trace injection device, stoelting, US/200]. An experiment to check the control effects according to plant heights divided into two levels was conducted with a paprika crop [variety: Rubato, two experimental plots (plant heights: 1 m 20 cm and 2 m 20 cm)] at a glasshouse farm located in Yangnam–myeon, Gyeongju–si. The area of the farm was approximately 6,600 m^2 and *A. gossypii* and *F. occidentalis* occurred sufficiently for tests as shown in Fig. 1 because the conventional cultivation method was used.

Water sensitive papers discolored according to application doses and preliminary pest control test

To control *A. gossypii*, the pesticide pyrifluquinazon 10% WG was diluted to the recommended dilution magnification and different spraying quantities (0–10 mℓ; 6 levels) were sprayed. To identify the results of the

(A) (B)

Fig. 1. Pictures of insect pests on paprika, *Frankliniella occidentalis* (A), *Aphis gossypii* (B).

test, pest control effects were identified based on the degrees of discoloration of the water sensitive papers (52 × 76 mm, TeeJet Tech. Switzerland) (Chung *et al.*, 1997; Koo, 2007) according to application doses. The pesticide pyrifluquinazon 10% WG was diluted to the recommended dilution magnification and different spraying quantities (0–10 mℓ; 6 levels) of the diluted pesticide were applied using trace topical appliers [trace injection devices, stoelting, US/200]. Thereafter, the degrees of discoloration of the water sensitive papers were checked and control values were checked at days 3 and 7 after spraying.

Water sensitive papers discolored according to application doses and pest control effect investigation

To investigate the control effects of individual pesticides according to two different plant heights and the control effects according to the application doses of individual pesticides, the test plots were divided into sections to have three repetitions per pesticide and each section was set to 10 a. Each of the test pesticides diluted to the standard dilution magnifications according to the pesticide use safety standards was sprayed using a U–shaped high pressure sprayer ensuring that the sprayed pesticide was sufficiently deposited on the leaves and the insides of the flowers. In the case of the paprika in the test plot with the longer plants, which were 2 m 20 cm high, the pesticide was sprayed in three steps while reducing the quantity of pesticide solution from 250 ℓ per 10 a for sufficient deposition of the pesticide solution on the crop to 125 ℓ and 60 ℓ per 10 a. Meanwhile, in the case of the paprika in the test plot with the shorter plants, which were 1 m 20 cm high, the pesticide was sprayed in three steps while reducing the quantity of pesticide solution from 125 ℓ per 10 a for sufficient deposition of the pesticide solution on the crop to 60 ℓ and 30 ℓ per 10 a. With regard to the times of pesticide application and investigation methods, in the case of *A. gossypii*, the pesticides were sprayed to foliage once in the period when many of the insect pests occurred and the numbers of live insect pests on at least 20 leaves per section were investigated before spraying and on 3 and 7 days after spraying. Meanwhile, in the case of *F. occidentalis*, the pesticides were sprayed to foliage twice in the early stage of occurrence of the insect pests and the numbers of live insect pests were investigated before spraying and on 3 and 7 days after spraying to calculate control values. The tests were conducted referring to a book for education of persons in charge of pesticide registration and tests published by the Rural Development Administration. In addition, to predict the degrees of discoloration of water sensitive papers according to application doses, before spraying in the field, the pesticide pyrifluquinazon 10% WG was diluted to the recommended dilution magnification in the laboratory and used to check the degrees of discoloration of water sensitive papers according to sprayed quantities (0–10 mℓ) with a the trace topical applier [trace injection device, stoelting, US/200].

Investigation of the quantities of active components of pesticides according to plant heights

After spraying the pesticides, the residues of the active components of the pesticides according to paprika plant heights were investigated by the laboratory of the

Table 1. LC/MS operating conditions for the analysis of spinetoram 5% WG and spinosad10% WG

HPLC	Instrument	Hewlett Packard SeriesⅡ 1090 (USA)
	Column	Phenomenex, Kinetex 2.6 μm C18 100A, (100 mm × 4.6 mm)
	Oven Temp.	40°C
	Injection Volume	5 μℓ
	Run time	20 min
	Flow rate	0.3 mℓ/min
	Mobile phase	MeOH : 0.5 mM ammonium acetate/90:10 (v/v)
	Instrument	Shimadzu LC/MS–2020, Japan
	Tuning Mode	Auto
	Acquisition Mode	SIM (Positive)
MS	MS–ESI	Ion Monitored 223 m/z Retention time 7.3 min Interface ESI Detector Voltage 1.30 kv Interface Voltage 4.50 kv DL temp. 250°C Heat block Temp. 200°C Nebulizing gas 1.5 ℓ/min Drying gas 15 ℓ/min

Department of Environmental Chemistry, Chungnam National University on commission. Before spraying the pesticides spinetoram water–dispersible granules (Spinetoram 5% WG, brand name: Delegate) and abamectin emulsifiable concentrate (Abamectin 1.8% EC, brand name: All Star), paprika leaves of similar sizes were collected from the middle of plant heights of the crop in every experimental section and used as untreated samples. To investigate the active components, paprika leaves were collected from areas close to the areas where paprika leaves were collected before the spraying of pesticides when the pesticides were dried ca. 7 hours after spraying and the paprika leaves were put into zipper bags. The zipper bags were sealed, wrapped with black bags to prevent photolysis, and frozen at −20°C. The frozen samples were put into a grinder (Hanil HMF–595, Korea) together with dry ice and ground into the smallest possible particles. The particles were put into zipper bags and the zipper bags were sealed and kept at −20°C until the samples were analyzed.

Sample extraction and purification for investigation of the quantities of active components

The paprika leaves collected as a test material were ground and 5 g of the ground leaves was quantified and put into a 50 mℓ Falcon® tube. Acetonitrile containing 1% acetic acid was put into the tube together with 20 pieces of 5 mm diameter glass balls for ensuring that the chemicals and the sample can be well mixed, and the tube was strongly shaken for 30 minutes at 20°C to extract the sample. To separate the water layer from the organic solvent layer, 2.5 g of ammonium acetate was added in accordance with the improved QuEChERS method. In addition, d–cleanup was conducted with different compositions of PSA, C18, and GCB. After the cleanup, the solution was centrifuged for 1 minute at 4,000 rpm, 0.5 mℓ of the supernatant was taken and put into a 1 mℓ vail, and the supernatant was analyzed with LC–MS by injecting 5 μℓ of the supernatant per time. A Hewlett Packard SeriesⅡ 1090(USA) and a Shimadzu LC/MS–2020 (Japan) were used as analysis instruments under the analysis conditions as shown in Table 1.

RESULTS AND DISCUSSION

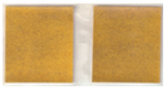
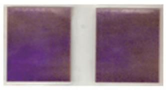
Recently, in South Korea, safe use of pesticides has become more necessary as agricultural products have been frequently exported and imported due to FTAs and other reasons. In addition, resistance to pesticides used in South Korea is developed faster compared to foreign countries because of uniform selection of pesticides and insect pests in blind areas formed when pesticides are sprayed are exposed to pesticides at doses lower than the appropriate doses. Since the pesticides developed in South Korea thus far have been researched and developed focusing on consumer–oriented safety, the degrees to which the users of the pesticides are exposed to the pesticides have not been well understood. Diverse elements can affect the control of insect pests in crops such as pesticide effects, spraying workers' habits, the number of times of spraying, the types of sprayers, nozzles, and the locations where insect pests occurred. Therefore, pesticide spraying methods suitable for paprika cultivations should be presented and optimum pesticide application doses per the unit area should be set. However, evidentiary materials became necessary because there is no accurate study result regarding the total quantities of pesticides to be used per the unit area. Therefore, in the present study, to define the application doses that can optimize the total quantities used per the unit area of the pesticides currently in use, the control effects and the degrees of discoloration of water sensitive papers by application dose were identified and appropriate application doses and appropriate quantities of active components of pesticides by plant height were reviewed.

Degrees of discoloration of water sensitive papers according to application doses and pest control effects

There is no clear evidentiary material regarding the application doses per the unit area of pesticides sprayed on crops in South Korea. The pesticide application doses per the unit area according to crops should vary according to the kinds and states of occurrence of diseases and insect pests and the states of cultivation of crops. However, until recently, it has been recommended to spray pesticides until the pesticides flow in drops from the leaves of crops for disease and insect pest control. Recently, optimum application doses according to the kinds of insect pests and the forms of cropping seasons were attempted for paprika, which is a representative crop for cultivation under structure of which the cultivation area has been increasing. Factors that affect the control of diseases and insect pests occurring in cultivations are considered to be the kinds of diseases and insect pests, the choices of pesticides, the specifications of spraying sprayers, paprika plant heights, cultivation methods, and the personality of the spraying workers. Investigations were conducted to predict the relationship between the degrees of discoloration of water sensitive papers according to application doses and pest control effects.

The pesticide pyrifluquinazon 10% WG was diluted to the recommended dilution magnification and sprayed to paprika plants where *A. gossypii*, which is one of major insect pests on paprika, occurred, in different sprayed quantities (0–10 mℓ; 6 levels) and the degrees of discoloration of water sensitive papers and *A. gossypii* control values were checked (Table 2). The pest control effects were identified based on the degrees to which water sensitive papers were discolored when the pesticide was sprayed in quantities at six levels with differences of 2 mℓ in a range of 0–10 mℓ. When 6 ml of the pesticide, which is level 4, was sprayed, although the water sensitive papers were not completely discolored, a high pest control effect of approximately 95.3% was shown 7 days later. It could be seen that even when water sensitive papers are not completely discolored by the pesticide, control effects should be high if a certain amount of pesticide is deposited.

Table 2. Discoloration degree of water sensitive papers and mortalities according to the application doses (mℓ) of pyrifluquinazon 10% WG

Pesticide	Application dose (mℓ)	Discoloration degree of WSP*	Control effect (%) (Mean ± SD**)	
			3 days	7 days
Pyrifluquinazon 10% WG	0		0 ± 0	0 ± 0
	2		23 ± 7	30 ± 5.5
	4		32 ± 8	60 ± 0
	6		80 ± 5	95.3 ± 0.7
	8		77 ± 8	96 ± 2
	10		73 ± 7	100 ± 0

* Water Sensitive Paper
** Standard Deviation

Effects of application doses according to plant heights on *A. gossypii* control effects

Domestic crop protectant guidelines indicate only crop names, applicable insect pests, right time and method of use, the quantities of chemicals to be used per 20 ℓ of water, and the times and number of times of use. No regulation for total quantities of pesticide components has been standardized. Since the method of use indicated in the guidelines just reads, "evenly spray the chemicals so that the chemical solution is sufficiently deposited on the crop", cases where the appropriate dosage is exceeded occur. Therefore, to prevent the abuse of pesticides, the assessment of optimum pesticide application doses was attempted. As a test method, pesticides with obvious effects were selected and sprayed equally and sufficiently to all areas so that the pesticides reach the target insect pests.

In paprika cultivations, varieties with diverse plant heights are cultivated. To identify accurate pest control effects according to application doses, tests were separately conducted with each of two different representative plant heights; 1 m 20 cm and 2 m 20 cm.

First, the pesticides pyrifluquinazon 10% WG and clothianidin 8% SG were sprayed to 1 m 20 cm high paprika plants where *A. gossypii* occurred. Pyrifluquinazon 10% WG is a pesticide that has not been used in farms but is known to have high insecticidal activities. On the contrary, clothianidin 8% SG is a pesticide that has been sprayed for several years in farms. The two pesticides were selected and used in the test because the comparison and review of the two pesticides were expected to be easy. To ensure that the crop would be sufficiently smeared with the chemical solutions, 125 ℓ, 60 ℓ, and 30 ℓ of each of the chemical solutions per cultivation area of 10 a were sprayed respectively and the pest control effects were checked (Table 3). When 125 ℓ per 10 a was sprayed, pyrifluquinazon10% WG, which is one of the sprayed pesticides, showed a control effect of ca. 68.5% 3 days later and showed a control effect of 100% 7 days later. When 60 ℓ, which is ca. a half of 125 ℓ, was sprayed, pyrifluquinazon10% WG showed a control effect of ca. 55.5% 3 days later and showed a control effect of 100% 7 days later. Therefore, 60 ℓ per 10 a is considered to be a sufficient quantity of the pesticide. However, when 30 ℓ was sprayed, pyrifluquinazon10% WG showed a control value of ca. 55.5% 3 days later and showed a control value of ca. 65.5%. Therefore, 30 ℓ per 10 a was judged to be an insufficient quantity of the pesticide.

Meanwhile, when 125 ℓ per 10 a of clothianidin 8% SG, which had been exposed to insect pests for several years after it began to be sold on the market, was sprayed, a control effect of ca. 70.5% was shown 3 days later and a control effect of ca. 92.5% was identified 7 days later. When 60 ℓ per 10 a of clothianidin 8% SG was sprayed, a control effect of approximately 65.5% was shown 3 days later and a control effect of approximately 88.5% was identified 7 days later. On the contrary, when 30 ℓ of clothianidin 8% SG was sprayed, a control effect of approximately 35.5% was shown 3 days later and a control effect of ca. 55.5% was identified 7 days later

Table 3. *Aphis gossypii* control effects of pyrifluquinazon 10% WG and clothianidin 8% SG according to application doses (ℓ/10 a) by plant height (1 m 20 cm)

Target pest	Plant height	Pesticide	Application dose (ℓ/10 a)	Control effect (%)	
				24 hr	72 hr
Aphis gossypii	1 m 20 cm	Pyrifluquinazon 10% WG	125 ℓ	68.5	100
			60 ℓ	55.5	100
			30 ℓ	30.5	65.5
		Clothianidin 8% SG	125 ℓ	70.5	92.5
			60 ℓ	65.5	88.5
			30 ℓ	35.5	55.5
		Control	–	0	3.2

Table 4. *Aphis gossypii* control effects of pyrifluquinazon 10% WG and clothianidin 8% SG according to application doses (ℓ/10 a) by plant height (2 m 20 cm)

Target pest	Plant height	Pesticide	Application dose (ℓ/10 a)	Control effect (%)	
				24 hr	72 hr
Aphis gossypii	2 m 20 cm	Pyrifluquinazon 10% WG	250 ℓ	88.5	100
			125 ℓ	85.5	100
			60 ℓ	52.5	58.5
		Clothianidin 8% SG	250 ℓ	75.5	91.5
			125 ℓ	73.5	87.5
			60 ℓ	42.5	55.5
		Control	–	0	5.5

indicating that the effect of the pesticide decreased a little.

In the case of 2 m 20 cm high paprika plants, 250 ℓ per 10 a, which was considered necessary for the chemical solutions to be sufficiently deposited on paprika plants, 125 ℓ, which is approximately a half of 250 ℓ, and 60 ℓ were sprayed respectively and the pest control effects were checked (Table 4). In the case of the pesticide pyrifluquinazon 10% WG, when 250 ℓ was sprayed, high control effects were identified as a control effect of approximately 88.5% shown 3 days and a control effect of 100% was shown 7 days later. When 125 ℓ was sprayed, sufficiently high control effects were shown as a control effect of ca. 85.5% shown 3 days later and a control effect of 100% was shown 7 days later. However, when 60 ℓ was sprayed, a control effect of ca 52.5% was shown 3 days later and a control effect of 58.5% was shown 7 days later indicating that the pest control effects decreased than when 125 ℓ was sprayed.

When the pesticide clothianidin 8% SG was sprayed, relatively high control effects were identified as the pest control effects shown 3days and 7 days after 250 ℓ and 12ℓ were sprayed were 75.5%, 91.5% and 73.5%, 87.5% respectively. On the contrary, when 60 ℓ was sprayed, a little lower control effects were identified as the control effect shown 3 days later was 42.5% and the control effect shown 7 days later was approximately 55.5%. It could be seen that in the case of both pesticides, rather than the quantity sufficient for flowing down in drops, the half quantity could show similar control effects if they would be carefully sprayed. In addition, the reason why the activity of clothianidin 8% SG is lower is considered to be the increase in *A. gossypii's* resistance to the pesticide because this pesticide had been used in farms for a long period of time. It could be seen that, as such, pest control effects would vary not only with pesticide application doses but also with the choice of pesticides.

F. occidentalis control effects according to application doses by plant height

To control *F. occidentalis*, two pesticides–spinetoram 5% WG and abamectin 1.8% EC–were applied at different application doses according to plant heights and their pest control effects were investigated. Considering the problem of resistance, the two pesticides used in the experiment were selected from among those pesticides that have not been repeatedly used by the relevant test farm.

In the case of 1 m 20 cm high paprika plants, 125 ℓ per 10 a, which was considered enough for the chemical solution to be deposited on plants, and 60ℓ, which is about a half, and 30 ℓ of each pesticide were sprayed separately and their pest control effects were checked (Fig. 2). When 125 ℓ of the officially announced pesticide spinetoram 5% WG was sprayed, a control effect of approximately 85.5% was shown 3 days later and a control effect of approximately 93.1% was shown 7 days later. When 60 ℓ was sprayed, a control effect of approximately 83.2% was shown 3 days later and a control effect of approximately 90.1% was shown 7 days later.

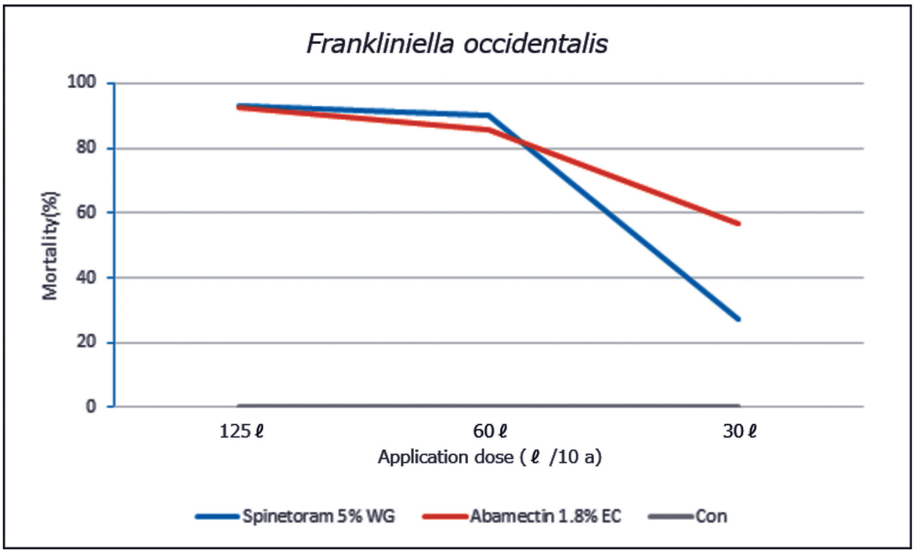


Fig. 2. *Frankliniella occidentalis* control effects of of spinetoram 5% WG and abamectin 1.8% EC according to application doses (ℓ/10 a) by plant height (1 m 20 cm).

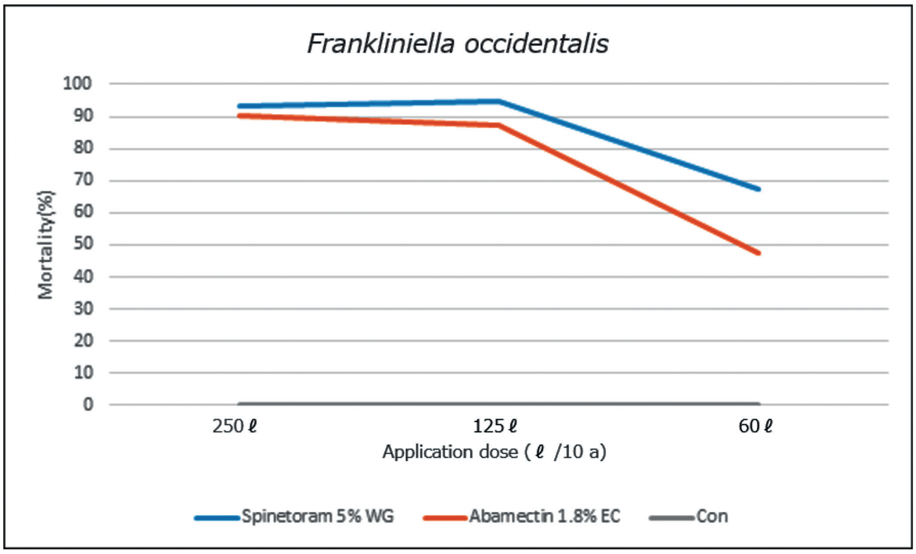


Fig. 3. *Frankliniella occidentalis* control effects of of spinetoram 5% WG and abamectin 1.8% EC according to application doses (ℓ/10a) by plant height (2 m 20 cm).

On the contrary, when 30 ℓ was sprayed, low pest control effects were shown as a control effect of approximately 25.5% was shown 3 days later and a control effect of approximately 27.2% was shown 7 days later. In addition, when 125 ℓ of pesticide abamectin 1.8% EC was sprayed, high pest control effects were identified as a control effect of approximately 80.5% was shown 3 days later and a control effect of approximately 92.5% was shown 7 days later. When 60 ℓ was sprayed, similarly high control effects to when 125 ℓ was sprayed were shown as control effects of 82.5% and 85.5% were shown 3 days and 7 days later, respectively indicating that 60 ℓ per 10a was appropriate as a recommended concentration. On the contrary, when 30 ℓ was sprayed, a little lower control effects were identified as control effects of 50.3% and 56.5% were shown 3 days and 7 days later, respectively.

In the case of 2 m 20 cm high paprika plants, when 250 ℓ of pesticide spinetoram 5% WG was sprayed, high pest control effects were identified as a control effect of approximately 89.5% was shown 3 days later and a control effect of approximately 93.5% was shown 7 days later (Fig. 3). When 125 ℓ was sprayed, similarly high control effects to when the quantity of the pesticide sufficient for flowing down in drops was sprayed as control effects of 93.5% and 94.9% were shown 3 days and 7 days later, respectively, indicating that 125 ℓ per 10 a was appropriate as a recommended concentration. When 60 ℓ was sprayed, lower control effects were identified as control effects of 65.5% and 67.5% were shown 3 days and 7 days later respectively indicating that 60 ℓ per 10 a was insufficient. As for the pest control effects of pesticide abamectin 1.8% EC, when 250 ℓ and 125 ℓ were sprayed, relatively high control effects of 79.5%, 90.5% and 75.5%, 87.5% were shown 3 days and 7 days later, respectively indicating that both 250 ℓ and 125 ℓ were appropriate. On the contrary, when 60 ℓ was sprayed, a little lower control effects were shown as a control effect of approximately 43.5% and a control effect of approximately 47.3% was shown 7 days later.

From the results of tests of *A. gossypii* and *F. occidentalis* control effects according to application doses by plant height, in the case of 1 m 20 cm high paprika plants, it could be seen that identically high control effects were shown when both 125 ℓ per 10 a, which was considered enough for the pesticide to be sufficiently deposited on paprika plants, and 60 ℓ per 10 a were sprayed. Likewise, in the case of 2 m 20 cm high paprika plants, similarly high control effects were shown when both 250 ℓ per 10 a, which was considered enough for the pesticide to be sufficiently deposited on paprika plants, and 125 ℓ per 10 a were sprayed. In addition, since none of the two pesticides had been used in the relevant farm, it could be expected that the problem of insect pests' resistance did not occur.

Therefore, it could be seen that, when pesticides were sprayed with high pressure sprayers in paprika cultivations, the control effects of pesticides identified when the pesticides were registered should not decrease even if the application dose is reduced when the pesticides are sprayed if resistance to the pesticides has not been developed. In conclusion, the standards for pesticide spray in glasshouses should be studied comprehensively considering the application doses according to sprayers, spray habits, and the ecological characteristics of insect pests.

Quantities of active components of pesticides for crops according to application doses

In general, large pesticide application doses are not directly associated with increases in the deposit amounts of active components or proportional increases in disease and insect pest control effects (Kim *et al.*, 2015; Kim *et al.*, 2016). Reducing the loss of pesticides sprayed due to soil absorption and scattering during spraying thereby ensuring that pesticides at appropriate application doses are evenly deposited is important. However, studies on the correlation between pesticide deposit amounts according to application doses and disease and pest control effects are still insufficient.

Therefore, the present experiment was conducted to analyze the correlations among application doses, active component deposit amounts, and pest control effects. After spraying pesticides to crops according to the states of deposition of pesticides on crops using high pressure sprayers, paprika leaves were collected and the quantities of active components were investigated (Fig. 4). In the results, in the case of the pesticide spinetoram 5% WG, when 250 ℓ and 125 ℓ per 10a were sprayed to 2 m 20 cm high plants and relatively high pest control effects were shown, the average quantities of active components were 2.76 ppm (mg/kg) and 1.88 ppm (mg/kg). On the contrary, when 60 ℓ per 10 a was sprayed and a little lower pest control effects were shown, the average quantity of active components was identified as 1.4 ppm (mg/kg).

In the case of 1 m 20 cm high plants, when 125 ℓ and 60 ℓ per 10 a were and relatively high pest control effects were shown, the average quantities of active components were 1.93 ppm (mg/kg) and 1.23 ppm (mg/kg) respectively. When 30 ℓ per 10 a was sprayed, the average quantity of active components was shown to be 0.75 ppm (mg/kg).

In the case of the pesticide abamectin 1.8% EC, when 250 ℓ, 125 ℓ, and 60 ℓ per 10 a were sprayed to 2 m 20 cm high plants, the average quantities of active components were 6.61, 5.07, and 3.03 ppm (mg/kg), respectively, and when 125 ℓ, 60 ℓ, and 30 ℓ per 10 a were sprayed to 1 m 20 cm high plants, the average quantities of active components were 5.56, 2.19, and 1.35 ppm (mg/kg), respectively.

Through the identification of the quantities of active components of pesticides spinetoram 5% WG and

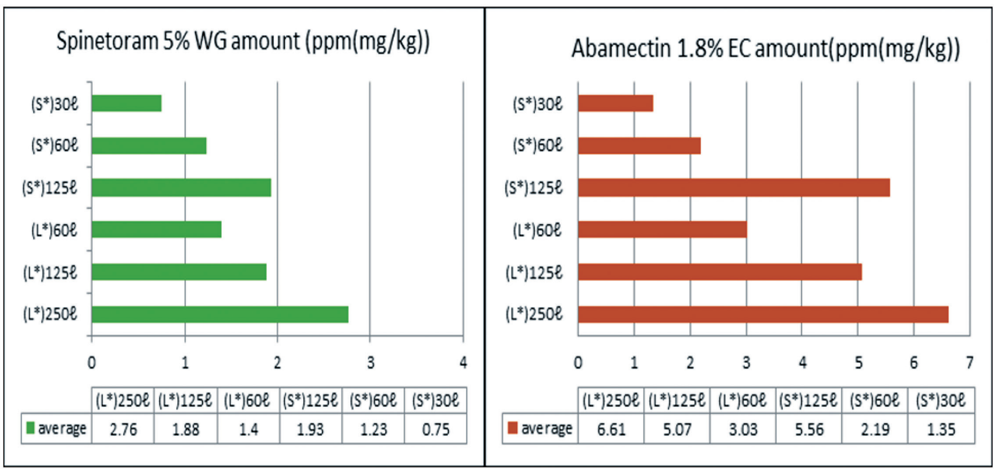


Fig. 4. Deposited amounts of spinetoram 5% WG and abamectin 1.8% EC pesticides on the paprika leaf in accordance with spray water volumes. *L: 2 m 20 cm paprika height. *S: 1 m 20 cm paprika height.

abamectin 1.8% EC, it could be seen that even when application doses were doubled, the quantities of pesticides deposited on crops did not increase proportionally. Therefore, to derive the optimum efficacy of chemicals considering costs and working time, rather than relying on application doses, the work to spray appropriate application doses evenly without any blind area should be given priority.

Excessive sprays of pesticides may increase the quantity that flows into the soil or rivers leading to environmental pollution. In addition, the same will increase the opportunities for spraying workers to be exposed to pesticides and will become a cause of high production costs. Therefore, to improve such conditions, standards for appropriate application doses and spraying methods should be urgently set. Based on the present experiment, more diverse studies of the correlation between application doses and the quantities of active components should be conducted.

AUTHOR CONTRIBUTIONS

Na Young Jin designed the study, performed the apple orchards experiments, analyzed the data and wrote the paper. You Kyoung Lee performed the water sensitive card experiments. Hee Ji Kim participated in the pest control experiments. Young Shin Kim and Chi Hwan Lim conducted the total active ingredients of pesticides analyses. Young Nam Youn edited the paper. Chisa Yasunaga–Aoki participated in the design of the study and discussed on the experiments and the results. Yong Man Yu supervised the work and wrote the paper. All authors assisted in editing of the manuscript and approved the final version.

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