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Abstract

The greenhouse, a protected ecosystem for crop production, can be infested by a number of pests and their population can rapidly grow because of the ideal environmental conditions. These conditions are also well suited for many natural enemies that can be used in biological control programs. Korea has a large greenhouse areas (82,544 ha) and an insect pest population are also high compared with greenhouses in the western countries. In strawberries and tomatoes, pests are not much of concern since biological control can be easily employed using only several natural enemies. The biological control systems have been developed for insect pests of these crops in Korea through RDA. RDA has developed several mass rearing techniques including rearing of predatory mite, *Phytoseiulus persimilis*. This technique has been transferred and disseminated to Agricultural Extension Centers and three natural enemy companies. This year *Phytoseiulus persimilis* was used to control two-spotted spider mite on commercial strawberry planted in about 215 ha, banker plants for aphids control were used on commercial leaf vegetable planted in 34 ha, and *E. formosa* was used on tomato planted in 1 ha.

Key words: *Phytoseiulus persimilis. Encarsia formosa. Aphidius colemani.* biological control, greenhouse, vegetable

Introduction

The greenhouse environment represents an isolated ecosystem that can be conducive to outbreaks of arthropod pest populations. Pests can colonize greenhouses through the importation of infested plant and soil materials, migration via open vents and doorways, movement of plant and materials within the ecosystem, or survival during non-cropping periods. During crop production

inside greenhouses, mortality of pest species from density independent factors, such as moisture, wind, temperature extremes, etc., does not generally occur. Even though the greenhouse environment favors the build up of pest populations, it is also an ideal setting for successful biological control programs (Kaya and Parrella, 2001).

Spider mites, aphids, thrips, greenhouse whiteflies, and leaf miner are serious greenhouse insect pests in Korea (Kim et al., 2001). These pests damage a range of crops, especially strawberry, cucumber, pepper, tomato, and lettuce. Their population size can rapidly increase. To control these pests, farmers apply high levels of pesticides. Thus, too much pesticide has resulted in insecticide resistance and harmful residues which have been the recent concern of consumers. Consumers are aware of the harmful affects of pesticides on products and environment. Many countries are now trying to reduce pesticide usage. Biological control, therefore, is a viable alternative control method (Kim et al., 2001).

In Korea, biological control is used more often in strawberry than other crops because *P. persimilis* can control two-spotted spider mites under greenhouse conditions. Strawberry has the lowest pest and disease spectrum, and thus, systems for mass rearing of predatory mite were developed. Due to consumers' demand for chemical-free vegetables, biological control on commercial green vegetable crops including lettuce, started in 2001. The banker plants for *Aphidius colemani* were used for aphids control in these crops.

This paper describes the current situation of biological control of greenhouse insect pests in Korea.

Production of vegetable crops

An overview of the greenhouse area for major greenhouse crops in Korea is presented in Table 1. In 2002, watermelon has the biggest cultivation area followed by oriental melon, strawberry, cucumber, red pepper and tomato. Total greenhouse acreage for vegetables, fruits, and flowers were 82,544 ha, 3,426 ha, and 3,338 ha, respectively. The data represent the total area cultivated throughout the year. greenhouse area was 47,940 ha in 1999. Korean greenhouse acreage is larger compared with Netherlands (10,125ha), Italy (25,000 ha), and Spain (42,500 ha). Production cells (ton) per ha was 6.8 (cucumber), 5.6 (tomato), 3.4 (both oriental melon and red pepper), 3.3 (watermelon), and 2.6 (strawberry).

Table 1. Greenhouse vegetable production in Korea, 2002

Crops	Area (ha)	Production (t/ha)	Total Production (t)
Watermelon	19,740	3.5	692,099
Oriental melon	7,490	3.2	237,373
Strawberry	7,451	2.7	204,830
Cucumber	5,494	7.4	406,849
Red pepper	4,620	4.1	188,403
Tomato	3,353	6.5	218,485

Insect pests of greenhouse vegetable crops

There are 818 known species of vegetable insect pests in Korea (Choi, 199 0). However, less than 20 species are of major importance such as *Tetranychus u rticae*, *Myzus persicae, Trialeurodes vaporariorum, Frankliniella occidentalis*, a nd *Heliothis assulta* (Table 2). Strawberry and tomato have only a few pests whi ch are of major importance, but other crops have five problem pests. Thus, biolo gical control was focused in strawberry and tomato.

The cotton aphid (*Aphis gossypii*) is a key pest in watermelon, oriental melon, cucumber, and strawberry. Two-spotted spider mite (*T. urticae*) also attacks many kinds of crops including strawberry, melon and cucumber. Thus, the biological control against these mites and aphids were also given importance.

Insect pests populations start to increase from February to March or earlier in greenhouses with higher temperatures than open fields. The pest species in greenhouse crops depends on the host plants, temperature, and cropping system used. For biological agents to be effective and economical, it is best to apply them as soon as insect pests occur. Therefore, the monitoring of pest densities is very important in biological control.

Table 2. The pests of five important protected crops in Korea.

		Water-melon & oriental melon	Straw-berry	Cucumber	Red pepper	Tomato
Mites	*Tetranaychus urticae*	#	#	#	#	+
	T. kanzawai	+	+	+	+	¤
Aphids	*Myzus persicae*	*	*	*	#	+
	Aphis gossypii	#	#	#	+	¤
	Others	¤	+	¤	¤	+
Whiteflies	*Trialeurodes vaporariorum*	#	+	#	+	#
	Bemisia tabaci	¤	¤	¤	¤	+
Thrips	*Frankliniella occidentalis*	#	+	+	#	+
	Thrips palmi	+	¤	#	¤	¤
	F. intonsa	+	+	¤	#	¤
Leaf miners	*Liromyza bryoniae*	#	*	#	*	#
Others	*Heliothis assulta*	¤	¤	¤	#	¤
	Palpita indica	+	¤	+	¤	¤
	Spodoptera exigua	+	+	+	+	+
	S. litura	+	+	+	+	+

#: Pest of major importance, +: pest of minor importance, ¤: pest of negligible importance,

*: potential threat.

Production system and distributions of biological agents

Most countries using biological control have the ability to supply biological control agents either by commercialized production systems (Europe, USA, and Canada), governmental production systems (China), or self-production systems (Russia). Thus, an important research priority is the development of rearing techniques for natural enemies. RDA has initiated development of mass rearing systems for *P. persimilis, E. formosa, and A. colemani* and has began to transfer this technology to private companies and Agricultural Extension Centers. Now, these organizations are working mainly on the production and utilization of biological control agents.

Recently, demand for biological control of pests is rapidly increasing due to the need to limit pesticide application. This change has resulted from the social demand for food safety and environment conservation, increase in labor cost in

pesticide sprays, concerns about the health of growers, and increase in insect pollinator utilization. The government guarantees safe agricultural and animal products that do not use any chemical materials like agricultural chemicals, chemical fertilizer, and fodder additive, or use them below the optimum level. The non-chemical products are sold at a higher price than common products. Farmers who previously culture products using native materials which are less effective to insect pests now prefers to use natural enemies. Strawberry and leaf vegetable growers also prefer using natural enemies to control pests to avoid pesticide residues.

In 2001 and 2003, *P. persimilis* was used to control two spotted spider mite in 100 and 215 ha of strawberry greenhouse (Table 3). Other natural enemies were used only on small areas due to incomplete rearing systems.

Table 3. Greenhouse (ha) released with natural enemies.

Natural enemies	Target pests	Crops used	Area (ha) used			
			1998	1999	2001	2003
Phytoseiulus persimilis	Two-spotted mite	Strawberry	3	10.0	100.0	215.0
Aphidius colemani	Aphid	Leaf vegetables		0.1	3.3	34
Encarsia formosa	Greenhouse whitefly	Tomato		0.1	0.6	1
Orius stigicollis	Thrips	Red pepper		0.1	0.1	0.1

Control effects

Two-spotted spider mite in strawberry

Strawberry is one of the most popular fruit vegetables during the winter and spring seasons, with the total production ranking 7th in the world. However, strawberries are also affected by one major insect pest. The two-spotted spider mite (TSSM), *T. uricae*, is a major insect pest that is extremely difficult to manage on strawberries. This problem is primarily due to excessive use of pesticides, which kill not only TSSM but also the bees that pollinate the strawberries. Pesticide use has resulted in the development of highly resistant strains of TSSM. In addition, chemical control of TSSM on strawberries has become highly restricted in Korea because of increasing social concerns about pesticide residues on fresh fruits. Fortunately, the predatory mite, *P. persimilis* is now available for control of TSSM on strawberry inside greenhouses.

Strawberries are usually harvested in February and May, but recently, several strawberry growers in Korea began to harvest from December to May to command a higher price. Harvesting the strawberry fruits early would mean maintaining strawberries under high temperature without cooling. This condition leads to early development of two-spotted mites than normal cultivation.

Strawberries are cultivated in greenhouses, where temperatures are kept at ℃ from October to April. This temperature condition is preferred for the reproduction and dispersal of P. *persimilis*. The rate at which P. *persimilis* develops is a function of temperature and is described by a straight line over the range of temperatures between 15 to 30 ℃.

Port and Scopes (1981) showed that small numbers of predacious mite could control TSSM on strawberries in walk-in plastic tunnels in southern England, providing that the overwintering populations of TSSM were reduced by introducing predators in the autumn. Cross (1984) showed that introductions of predatory mites in March or early April at a rate of one mite per plant were consistently successful.

Greenhouse whitefly in tomato

In Korea, the greenhouse whitefly (GWF, *Trialeurodes vaporariorum*) was first found in 1977 on imported crops such as *Stevia*, lavender, and other medicinal herbs in Suwon. As the acreage of greenhouse crops increased since the late 1980s, damage and occurrence of GWF have increased. GWF has become one of the most serious pests on greenhouse crops such as tomato, cherry tomato, and cucumber.

Encarsia formosa is a parasitoid of the greenhouse whitefly that has been used as a biological control agent since the 1930s in Europe, and it is one of the most commercialized biological control agents used in more than 20 countries at present. *Encarsia formosa* was first imported by Korea in 1993 from the Netherlands when greenhouse whitefly started to cause problems in greenhouse tomato and cucumber.

After *E. formosa* was introduced, many experiments have been conducted to evaluate the control effect of this agent in experimental plots or farmer's greenhouses. Temperature turned out to be a limitation to the effectiveness of *E. formosa* because the minimum temperature of greenhouses during winter season is maintained below 10℃. Such temperature level can cause severe retardation of *E. formosa* emergence.

Removing lower leaves from tomato plants was too fast for newly parasitized mummy in the lower leaves to emerge. The grower insisted on

defoliating lower leaves to eliminate diseased leaf and for better quality of cherry tomato. In this case, the seasonal inoculative release method would not be effective and another implementation method should be developed to compromise with cultural practice. Van Lenteren et al. (1996) suggested keeping the defoliated leaves containing the mummies on the ground for parasite emergence.

Aphids in vegetables

Aphids are one of the most problematic insect pests of greenhouse crops because aphids can quickly develop to high population densities and develop resistance to insecticides in a short period of time. In particular, *Aphis gossypii* and *Myzus persicae*, polyphagous species with a worldwide distribution, are the most prevalent aphids species in Korean greenhouses. These species cause reduce yield and quality of crops and they can transmit virus, as well.

Aphids have been controlled largely through broad-spectrum insecticides, which can inhibit application of biological control agents of other insect pests. In order to avoid this harmful effect of insecticides, natural enemies with host specificity should be employed to control the aphids as well as implement IPM programs.

The endoparasitoid *Aphidius colemani* and the predatory gall midge *Aphidoletes aphidimyza* have already been commercialized in many countries because of their effectiveness against aphids on greenhouse crops. *Aphidius colemani* attracts much attention because it has 41 aphid host species (Stary, 1975). *Aphidoletes aphidimyza*, an aphidophagous species of Cecidomyiidae, is widely distributed over the world, and is highly effective against aphids, particularly in glasshouse (Meadow *et al.*, 1985).

The application of banker plants for introduction of *A. colemani* showed effective and economic biological control of aphids in watermelon and cucumber. Thus, the introduction of banker plants carrying the parasitoid before the incidence of the aphid should be useful aids in protecting the plants. Further work is necessary to improve control efficacy with small numbers of *A. colemani*. Improvement on the longevity and productivity of *A. colemani* on the banker plant is another subject to resolve. Inundative release of *A. colemani* was also effective to control aphids in greenhouses. However, direct comparison of the two methods was not made in this study.

Thrips on red pepper

Frankliniella occidentalis, Thrips palmi, and *T. tabaci* have become increasingly important agriculture pests of greenhouse crops in Korea. *Frankliniella occidentalis* and *T. palmi* which came from Southeast Asia has invaded agricultural crops in Korea in 1973. The occurrence of this pest has been widespread in greenhouses. To control thrips the indigenous *Orius* spp. and *Amblyseius barkeri* have been used since 1996. Another exotic species, *A. cucumeris* was also utilized in 1999 (Kim, et al. 1999).

The stored product insect pest, *Cadra cautella*, was selected as an alternative host in mass rearing predatory natural enemies. The rearing system of *C. cautella* was established using rice bran as a major dietary source. The rearing system is very convenient and efficient. With this system, about 645,000 eggs per day of *C. cautella* can be produced and around 45,000 minute pirate bugs can be reared with this production rate. The minute pirate bug, *Orius strigicollis*, will be used as a biological control agent against *F. occidentalis* in a greenhouse for red pepper.

Table 4. List of natural enemies commercialized in Korea, 2003

Natural enemies	Target pests
Aphidius colemani	Aphids
Aphidoletes aphidimyza	
Harmonia axyridis	
Phytoseiulus persimilis	Mites
Stethorus punctillum	
Encarsia formosa	Whitefly
Amblyseius cucumeris	Thrips
Orius strigicollis	
Diglyphus isaea	Leaf miner
Dacnusa sibirica	
Trichogramma evanescens	Moth and others
Steinernema carpocapsae	
Heterorhabditis sp.	

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