Problems with the Management of the Golden Apple Snail *Pomacea canaliculata*: an Important Exotic Pest of Rice in Asia

R. C. JOSHI

Department of Agriculture-Philippine Rice Research Institute, Maligaya, Science City of Muñoz, Nueva Ecija-3119, Philippines

ABSTRACT The golden apple snail *Pomacea canaliculata* (Lamarck) is native to South America. It was introduced to farmers in the Philippines in the 1980s from Argentina via Taiwan, and to other countries in Asia, to increase farmers' income and enrich the protein in their diet, and also as an aquarium pet. Golden apple snail is expanding its distribution in Asia, threatening to invade Bangladesh, India, Pakistan, and also Australia. The Global Invasive Species Programme lists golden apple snail as one of the world's 100 worst invasive alien species. It has brought about economic losses to aquatic crops in the Philippines that are estimated to be up to USD 1200 million per annum without taking into account the non-crop damage to human health and natural ecosystems. It is also an environmental pest since to control this mollusc, resource-poor farmers resort to a "shot-gun approach", using toxic and non-specific agrochemicals and thereby aggravating ecosystem pollution, risking their health, and causing loss of aquatic biodiversity. The Philippine Rice Research Institute (PhilRice) focuses on (1) understanding the field ecology of the golden apple snail, and identifying "weak links" in its life cycle, and (2) using this information to manage the golden apple snail at the village level in ecologically sustainable, socially acceptable, and economically viable ways. This paper discusses how populations of this exotic pest species in transplanted irrigated lowland rice can be managed using locally available attractants during the vulnerable stage(s) of rice crop growth.

KEY WORDS invasive exotic pest species, *Pomacea canaliculata*, golden apple snail, rice, village level management

1. Introduction

The golden apple snail *Pomacea canaliculata* (Lamarck) is a freshwater mollusc native to Argentina. Its other common English names are golden miracle snail, jumbo snail, channelled apple snail, mystery snail, and South American apple snail. Some of these names have been used for more than one species of ampullariid. In South-East Asia, the common term for this species is the golden apple snail or GAS.

Golden apple snail species identification by shell morphology has limitations. This is because the ampullariid shells exhibit considerable intraspecific variation in shell colour and banding patterns. Genomic identification through DNA sequencing permits accurate and reliable discrimination and diagnosis of the true identity, geographic origins, and phylogenetic relationships of this invasive *Pomacea* species diversity through the analysis of a small segment of the genome. *P. canaliculata* and an unidentified *Pomacea* sp. were introduced to South-East Asia, aside from *Pomacea bridgesii* (Reeve) that was introduced into Sri Lanka. However, the *P. canaliculata* specimen did not cluster closely with the other species introduced into South-East Asia, and the following conclusions were arrived at: *Pomacea camena* Pain came from Venezuela, *Pomacea glauca* (L.) from Venezuela and Suriname, a species tentatively identified as *Pomacea haustrum* (Reeve) came from an introduced population in Florida, USA, and *Pomacea paludosa* (Say) is

M.J.B. Vreysen, A.S. Robinson and J. Hendrichs (eds.), Area-Wide Control of Insect Pests, 257–264.

Table 1. *Global distribution of golden apple snails (*Pomacea *spp.).*

Country	Year introduced	Area affected in hectares	Cost of control in USD
Taiwan	1979	17 000 (1982) 171 425 (1986) >100 000 (annual)	8.3 million (1983) 30.9 million (1986) 1.0 million (1982-1990)
South Korea	1981	---	---
Japan	1981	63 559 (1998) 65 000 (2001) 68 000 (2002)	---
Philippines	1982	300 (1986) 426 000 (1988) > 800 000 (1996)	---
Thailand	1982	141 257 (2001)	---
China	1985	1700 (1988)	
Vietnam	1988	260 (1994) 64 623 (1996) 109 715 (1997) 50 000 (1999) 189 210 (2002) 214 519 (2003) 256 222 (2004)	---
Cambodia	1991	---	---
East Malaysia	1992	1817 (1999)	590 000
Lao PDR	1992	It appeared in 10 out of 17 provinces of the country	---
West Java, Indonesia	1995	1995 - only 12 districts were affected by the golden apple snail 1999 - 16 districts were affected	---
Hawaii, USA	1990's	---	---
South America		1993 - several hectares of wet seeded rice in Brazil were infested 1997 – the golden apple snail was found in all regions of Argentina	----

native to Florida (Cowie and Hayes 2004).

The golden apple snail is one of the 100 world's worst invasive alien species (GISD 2005). It has brought about economic losses to aquatic crops in the Philippines that are estimated to be up to USD 1200 million per annum without taking into account the non-crop damage to human health and natural ecosystems (Naylor 1996). Its invasiveness is related to its high reproductive rate and easy adaptation to harsh environmental conditions; its ability to colonize and invade diverse habitats by multiple pathways; its wide host range and voracious appetite; and the fact that there are no efficient biological control agents in its new habitat or competition with native snail species and other native fauna (Halwart 1994).

A female golden apple snail can lay 50-500 eggs at a time, with an 80% hatchability rate, and 10-15 days of incubation. The golden apple snail has a gill and a lung-like organ enabling it to survive in or out of water. By closing its operculum and bedding in the soil, it can withstand drought for several months. It moves only when the depth of water is half or more of its shell height. Approximately twice as many females than males occur in the field, suggesting that females live longer than males (Mochida 1991, Estebenet and Cazzaniga 1992). It is a voracious nocturnal herbivore. When there is standing water in the field, it can destroy newly transplanted or direct-seeded rice. It cuts the base of young seedlings with its layered tooth (radula) and chews on the succulent, tender sheaths of rice. The damage that the golden apple snail can do to a rice crop depends on its size and density, and on the growth stage of the rice plant. Three snails in one square metre of rice can cause significant yield loss. Snails with a shell height of around 3.5 centimetres can eat up to 12 rice seedlings per day. This translates into crop losses over 50% if the snail density is high. Golden apple snails that are 20-40 millimetres long are the most destructive, regardless of the method of rice establishment (Joshi et al. 2002). The snail also feeds on a wide variety of other substrates including livestock feeds, decaying matter, animal flesh, and other crops.

This snail is a threat to human health since it is a host of the rat lungworm parasite *Angiostrongylus* (*Parastrongylus*) *cantonensis* (Chen) that causes eosinophilic meningoencephalitis (Mochida 1991). Hence, thorough cooking is needed if intended for food. Moreover, its sharp-edged empty shells can injure bare-footed farm workers (Joshi 2005a).

2. Global Distribution of the Genus *Pomacea*

Golden apple snails of the genus *Pomacea* have become one of the most important rice pests in countries where direct seeding has become more popular than transplanted rice, such as the Philippines, Thailand, and Vietnam (Wada 2004) (Table 1). In Asia, these

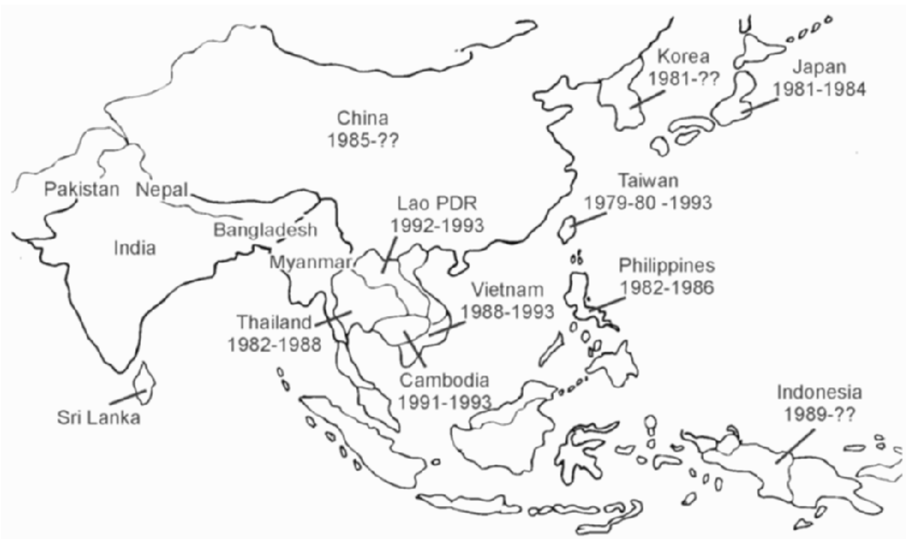

Figure 1. *Map of South-East Asia indicating the areas golden apple snails have invaded since 1979 and where the snail causes massive damage to rice, taro, and other aquatic plants.*

snails were first introduced to Taiwan in 1979 (Fig. 1) and it continues to expand in Asia with large rice-growing areas and water bodies of Bangladesh, India, Pakistan and Australia facing threats of golden apple snail invasion. These species and possibly several other related species, have invaded the Indo-Pacific from Hawaii to South-East Asia since 1979 and cause massive damage to rice, taro, and other aquatic plants.

3. Old Management Practices

3.1. Molluscicides

Molluscicides have been used to control golden apple snails, but they also kill non-target organisms. Consequently, in some countries molluscicides have been banned. Niclosamide, endosulfan, camellia seed cake (residue), and copper sulphate – often used to control golden apple snails in Asian countries – cannot be registered in Japan because of their negative effects on the environment (Wada 2004). Some farmers in the Philippines stopped using molluscicides because of their high costs and adverse effects on humans and animals. The chemicals that are used for the control of golden apple snails are mostly persistent, dose-cumulative organotins that create health effects such as falling out of nails, skin problems, blurring vision, and blindness (Mochida 1991).

Niclosamide 250EC is preferred over metaldehyde by rice farmers because of its "quick kill" action on the snail. Unfortunately, niclosamide 250EC is lethal to non-target beneficial water-inhabiting organisms such as frogs, fish, etc. Recently, Joshi et al. (2004) observed the detrimental effects of niclosamide 250EC applied at pre-seeding in direct-seeded rice culture. Treated seedlings had low and uneven emergence, and were stunted. Also, uneven crop establishment exposed seedlings to golden apple snail damage for a much longer time, and at all concentrations of niclosamide, underground effects on the seedlings included marked reductions in root growth and development.

Calcium cyanamide is used in Japan against golden apple snails in direct-seeded rice at 200-300 kg/ha. This is ten times higher than the rates of other chemicals used. However, it causes phytotoxicity if farmers did not apply it 7-10 days before sowing rice (Wada 2004), and it is less effective when the water temperature is lower.

Crude extracts of two botanicals, *Derris elliptica* (Wallich) Benth and *Azadiracta indica* A. Juss, have been evaluated for their effects on golden apple snails. Extracts from a number of African plants also are potential organic molluscicides. However, none of the botanical molluscicides identified has been produced commercially because syntheses of the compounds are currently not cost-effective and farmers' preference is for "instant-kill" chemicals.

3.2. Non-Chemical Methods

In 1989, the Food and Agriculture Organization of the United Nations (FAO), the International Rice Research Institute (IRRI), Visayas State College of Agriculture (now Leyte State University), and the Department of Agriculture-Philippine Rice Research Institute (DA-PhilRice) launched the strategic extension campaign. This introduced the use of non-chemical methods to control these snails, e.g. duck pasturing in rice fields after harvest, hand-picking, destroying egg clusters before final harrowing, transplanting older seedlings, and installing screens in water inlets. However, most of these practices remain untested in the rain-fed lowland, direct-seeded, and hybrid rice production environments. Moreover, farmers have observed that no single control tactic is better than the "best mix" of various management options, as each option has some constraints (IRRI 1991, Cagauan and Joshi 2003). For these and other reasons, it is important to stabilize and increase production in direct-seeded and transplanted rice systems by preventing golden apple snail damage through low-cost, technically effective, and environment-friendly options.

4. Golden Apple Snail in Direct-Seeded Rice: Possible Management Strategies

The shift from transplanted rice to direct-seeded-rice culture in Japan, the Philippines, Thailand and Vietnam has caused even greater golden apple snail problems, as control thresholds are much lower in direct-seeded rice than transplanted rice. Small snails, which are disregarded in transplanted rice, are harmful to sprouts and very young seedlings in direct seeding. These small snails are 150 times more serious in direct-sown rice fields that in transplanted fields. Good field levelling and shallow water management practices can reduce snail damage in transplanted irrigated lowland rice systems, but this practice is extremely difficult to carry out in direct-seeded and flood-prone areas. While farmers could experiment with a combination of preventive or corrective control measures, many of these are labour-intensive. For instance, missing hills (open areas created by dying rice plants) can be replanted up to four times, and could drain the physical and financial resources of rice farmers as it entails costs for additional seedlings and replanting time. The unprotected application of non-specific pesticides also does not help since snail populations recover quickly because they can avoid exposure by burying in the soil or simply crawling out of treated water onto clay clumps or standing vegetation.

There are few practices that can avoid or reduce damage in direct-seeded rice by golden apple snail. The rotary cultivator used during land preparation for tillage and soil puddling efficiently decreases snail density before rice planting. It results in 67-75% snail mortality compared with unploughed fields (Wada 2004). Draining fields for two to three weeks after seeding is the most effective way to avoid snail damage. However, there are two problems associated with this practice – the weeds and heavy rains followed by flash floods. Making ditches or ridges can enhance drainage but neither is highly successful. In such cases, pesticide application is indispensable, and a bait-type pesticide (metaldehyde) is currently used. Crop rotation, including growing an upland crop such as soybean, is a practical way to abate snail damage to the next rice crop as this reduces snail densities without pesticides.

5. New Strategies in Managing the Golden Apple Snail

5.1. Use of Attractants

For collection of golden apple snails, rice farmers use leaves of papaya, banana, and taro as attractants. However, such materials are not readily available and their excessive removal threatens plant biodiversity. Discovery of newspaper as a new snail attractant facilitates manual handpicking. Newspaper can be used in rice fields prior to crop establishment (direct-seeding/transplanting) and both types of attractant reduce further the misuse of synthetic commercial molluscicides (Joshi and Dela Cruz 2001), and encourage snail collection for food.

5.2. Vulgarone B

Recently, vulgarone B, a sesquiterpene from the plant *Artemisia douglasiana* Besser, has been shown to have molluscicidal activity against the golden apple snail (Joshi et al. 2005b). Laboratory bioassays showed that vulgarone B has molluscicidal activity at an LC_{50} value comparable to that of the commercial synthetic molluscicide metaldehyde. This corresponds to about 6.5 mg/litre of the vulgarone B and 4.4 mg/litre of the metaldehyde. In practical terms, a rice farmer using about 250 litres of water to spray one hectare will require 4.8 grams of pure vulgarone B for golden apple snail control. In addition, vulgarone B has fungicidal activity.

The potential of vulgarone B in controlling this agriculturally important mollusc species is high. Since it is not toxic to rice seedlings, it can be sprayed; it can also be put on attractant materials, or into ponds or rice paddy water. Furthermore, vulgarone B has the advantage of acting faster than metaldehyde against *P.*

canaliculata, since bioassays indicated mortality within 24 hours. Since vulgarone B is present as a major component in the essential oil of *A. douglasiana*, by steam-distillation, which is a simple and low-cost process, it can be concentrated to more than 80%. Also, since many *Artemisia* species are weeds in many parts of the world, the use of vulgarone B as an organic molluscicide could be both cost-effective and environment-friendly.

5.3. A Possible Agent for Paddy Weeding

Aside from being a pest, the golden apple snail has some profitable uses, e.g. in managing weeds in transplanted irrigated lowland rice fields, and as food for animals and humans. In transplanted irrigated lowland rice fields, the golden apple snail is a potential agent for paddy weeding. Two or three snails per square metre successfully control paddy weeds (Okuma et al. 1994a,b). Organic and some inorganic farmers in Japan, the Philippines, and South Korea grow rice without herbicides to produce organic rice by using the golden apple snail for paddy weeding. This approach is now spreading to other organic and inorganic farmers. The benefits from using the golden apple snail as a biological weeding agent far exceed those of using ducks or carp (Yusa et al. 2003). Joshi et al. (2005a) evaluated this innovation by Japanese and Korean farmers at PhilRice's Central Experimental Station using large-sized fields (each 0.5 hectare), and subsequently in several farmers' fields. When used in transplanted irrigated lowland rice systems, the golden apple snail changes its behaviour and is converted from a pest into a beneficial organism. However, fields must be well levelled to control movements of the snail, and seedlings should be sturdy and at the 3-leafs stage (21 days old).

Nevertheless, this approach is not appropriate and cannot be recommended for direct-seeded rice since rice and weeds sprout at the same time. Moreover, it cannot be carried out in an upland environment where the golden apple snail is in the soil, or in flood-prone areas where it is difficult to control water depth. A video, which documents step-by-step how Japanese farmers deploy *P. canaliculata* for paddy weeding in transplanted rice fields is available at: http://www.openacademy.ph/old_web/elearning/goldenkohol/. In addition, all available information on the golden apple snail has been compiled on a CD-ROM (Joshi et al. 2003), at http://www.applesnail.net under the "pest alert section", and at the National Biological Information Infrastructure golden apple snail page, which includes the option to download the database at the following URL: http://invasivespecies.nbii.gov/goldenapplesnail.html (Joshi 2005b).

5.4. A Palatable Food for Animals and Humans

The snails can replace meat meal or fish meal as a concentrate feed supplement for animals. Also, Mallard ducks can be pastured in rice fields after harvest so that they can feed on the golden apple snail. Duck herding and a little feed supplementation can yield up to 60-70% increase in egg production (Tacio 1987). A project to control golden apple snail infestations by turning the snails into a marketable processed product was implemented in Hawaii (Tamaru et al. 2004). In one field, the snails were given different types of food (lettuce and chicken, chicken feed, catfish feed, trout feed, or mahimahi feed), while in another field, they were fed taro tops, catfish feed, or trout and chicken feed. The taste and texture of the golden apple snail were tested using a "taste test" in Princeville Resort, Hanalei, Kauai, which is a four-star establishment. Using the snails from the feeding trials, the chef of the resort was asked to prepare dishes at his discretion; two dishes were created. It was found that snails fed with catfish feed were superior to all other snails in both taste and texture. In the Philippines, PhilRice developed a recipe called "chicharon" (cracker) which is unique compared with other golden apple snail recipes in that it is devoid of water, has no offensive odour, has a longer shelf-life, and can be used as an ingredient in other Filipino recipes.

6. Conclusions

Once established, the golden apple snail is not easy to control. The economic, health, and environmental problems it causes are irreversible, and the cost of dealing with it is enormous. Old management practices to manage the snail are labour-intensive, uneconomic and non-sustainable, and many are harmful to the environment. However, new options are now being introduced, and these measures are environment-friendly and cost effective. They include using the golden apple snail for paddy weeding and as food for humans and animals. An area-wide approach that integrates the above described systems with existing farmer-based pest management practices, especially in direct-seeded rice systems where managing the golden apple snail is still difficult, could be a promising new direction to control this invasive exotic pest in the future.

7. Acknowledgements

The author expresses his sincere gratitude to L. S. Sebastian (PhilRice), Alumanda M. de la Rosa (PNRI), and J. D. Dargie, J. Hendrichs, A. Robinson, and M. Vreysen of the Joint FAO/IAEA Programme, for their encouragement, support, and kind assistance.

8. References

Cagauan, A. G., and R. C. Joshi. 2003. Golden apple snail *Pomacea* spp. in the Philippines: review on levels of infestation, control methods, utilization and future directions. Journal of Agriculture and Life Sciences 37: 7-32.

Cowie, R. H., and K. A. Hayes. 2004. Invasive ampullariid snails: taxonomic confusion and some preliminary resolution based on DNA sequences, pp. 7-16. *In* Lai, P.-Y., Y.-F. Chang, and R. H. Cowie (eds.), Proceedings: APEC Symposium on the Management of Golden Apple Snail, 6-11 September 2004, Pingtung. National Pingtung University of Science and Technology, Pingtung, Chinese Taipei. http://www.npust.edu.tw/apec.2004.gas/index.html

Estebenet, A. L., and N. J. Cazzaniga. 1992. Growth and demography of *Pomacea canaliculata* (Gastropoda: Ampullariidae) under laboratory conditions. Malacological Review 25: 1-12.

(GISD) Global Invasive Species Database. 2005. http://www.issg.org/database

Halwart, M. 1994. Fish as biocontrol agents in rice: the potential of common carp *Cyprinus carpio* (L.) and Nile tilapia *Oreochromis niloticus* (L.). Tropical Agroecology: 8. Margraf Verlag, Weikersheim, Germany.

(IRRI) International Rice Research Institute. 1991. Rice IPM network. Report of a workshop on the management of golden snail in the Philippines, 27-31 October 1991. International Rice Research Institute, Manila, The Philippines.

Joshi, R. C. 2005a. The golden apple snail: raiders of the rice fields. Outlooks on Pest Management 16: 23-26.

Joshi, R. C. 2005b. Managing invasive alien mollusc species in rice. International Rice Research Notes 30: 5-13.

Joshi, R. C., and M. S. Dela Cruz. 2001. Newspaper: a new attractant for golden apple snail management. International Rice Research Notes 26: 49-50.

Joshi, R. C., M. S. Dela Cruz, A. R. Martin, A. V. Duca, and E. C. Martin. 2002. Relation of golden apple snail size to rice seedling damage in transplanted and direct-seeded rice cultivation. International Rice Research Notes 27: 37-38.

Joshi, R. C., N. S. Baucas, E. E. Joshi, and E. A. Verzola. 2003. Scientific information database on golden apple snail (*Pomacea* spp.). CD-ROM. Baguio, Department of Agriculture-Cordillera Administrative Region, International Rice Research Institute, Manila, The Philippines.

Joshi, R. C., M. S. Desamito, A. R. Martin, L. S. Sebastian, and J. B. Coupland. 2004. Detrimental effects of niclosamide 250EC at preseeding in direct-seeded rice culture.

International Rice Research Notes 29: 36-37.

Joshi, R. C., E. C. Martin, T. Wada, and L. S. Sebastian. 2005a. Role of golden apple snail in organic rice cultivation and weed management, pp. 112-115. *In* Kopke, U., U. Niggli, D. Neuhoff, P. Cornish, W. Lockeretz, and H. Willer (eds.), Proceedings: Researching Sustainable Systems. First Scientific Conference of the International Society of Organic Agriculture Research (ISOFAR), the International Federation of Organic Agriculture Movements (IFOAM) and the National Association for Sustainable Agriculture, Australia (NASAA), 21-23 September 2005, Adelaide, Australia. Research Institute of Organic Agriculture FiBL, CH-Frick, and International Society of Organic Agriculture Research (ISOFAR), c/o Institute of Organic Agriculture (IOL), University of Bonn, Bonn, Germany.

Joshi, R. C., K. M. Meepagala, G. Sturtz, A. G. Cagauan, C. O. Mendoza, F. E. Dayan, and S. O. Duke. 2005b. Molluscicidal activity of vulgarone B from *Artemisia douglasiana* (Besser) against the invasive, alien, mollusc pest, *Pomacea canaliculata* (Lamarck). International Journal of Pest Management 51: 175-180.

Mochida, O. 1991. Spread of freshwater *Pomacea* snails (Pilide, Mollusca) from Argentina to Asia. Micronesia Supplement 3: 51-62.

Naylor, R. 1996. Invasions in agriculture: assessing the cost of the golden apple snail in Asia. Ambio 25: 443-448.

Okuma, M., Y. Fukushima, and K. Tanaka. 1994a. Feeding habitat of apple snail (*Pomacea canaliculata*) to paddy weeds and damage avoidance to rice seedlings. Weed Research 39: 109-113.

Okuma, M., K. Tanaka, and S. Sudo. 1994b. Weed control method using apple snail (*Pomacea canaliculata*) in paddy fields. Weed Research 39: 114-119.

Tacio, H. D. 1987. Raise snails for your ducks. Agribusiness Weekly (Manila, Philippines), November 6-12: 16-17.

Tamaru, C. S., H. Ako, and C. T. Tamaru. 2004. The apple snail, *Pomacea canaliculata*, pest to profit: challenge or opportunity, pp. 47-60. *In* Lai, P.-Y., Y.-F. Chang, and R. H. Cowie (eds.), Proceedings: APEC Symposium on the Management of Golden Apple Snail, 6-11 September 2004, Pingtung. National Pingtung University of Science and Technology, Pingtung, Chinese Taipei. http://www.npust.edu.tw/apec.2004.gas/index.html

Wada, T. 2004. Strategies for controlling the apple snail *Pomacea canaliculata* (Lamarck) (Gastropoda: Ampullariidae) in Japanese direct-sown paddy fields. Japan Agricultural Research Quarterly 38: 75-80.

Yusa, Y., T. Wada, and K. Takahashi. 2003. Apple snails in Japan: their problems, control strategies and possible benefit, pp. 105. *In* Book of Abstracts: Korea-Japan Joint Conference on Applied Entomology and Zoology, 28-31 May 2003, Haeundae, Busan, South Korea. Korean Society of Applied Entomology, School of Agricultural Biotechnology, College of Agriculture and Life Sciences, Seoul National University, Suwon, Korea.