Role of Biological Control in Grain Storage in the Tropics

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Abstract

Although only few studies on the biological control of stored-product insects in grain storages in Southeast Asia have been carried out, several reports suggest that there is a large number of natural enemies in the region and that they could be used for biological control. Studies on insect infestation in rice storages in Thailand indicated that various natural enemies, including parasitoids, predators and intruders such as ants, spiders and geckoes play a key role in the suppression of the pest population. However, high infestation cases were also sometimes reported. Thus, more efficient control of insect pests could be achieved by "augmentative release of selected mass-cultured natural enemies". Tables of biocontrol agents and their hosts in grain storages were prepared from the available literature to examine potential candidates for the region. Newly identified predacious bug, *Joppeicus paradoxus*, from Thailand is also listed as a possible control agent in the storages. Use of natural enemies in grain storages has recently attracted the attention in the USA and in Europe in terms of safety and sustainability, although comparison with the use of conventional chemicals in terms of effectiveness should be determined. Nevertheless, the region may be endowed with abundant resources in natural enemies, optimal climate for mass-production and moderate labor cost which can minimize the competition with chemicals. However for the use of natural enemies for biological control, extensive studies should be carried out, with emphasis placed on the identification of species and their hosts, the selection of candidates, mass-production techniques, and timing of, and numbers in the release.

Introduction

Although the hot and humid climate in Southeast Asia is suitable for rice cultivation, it also brings about serious damage to rice grains after harvest due to the occurrence of stored-product insects which can complete their life cycle rapidly and cause explosive outbreaks.

To reduce the insect infestation problem after harvest, many efforts have been made in the region through international collaboration in the past two decades. As a result, well-adapted technologies such as fumigation, use of grain protectants, controlled atmosphere with CO_2 and airtight storage have been developed in the region. However, it seems that problems have not yet been resolved because these costly measures were mostly imported, and hence, they have not spread enough to storages where insect disinfestation is needed. Moreover, some important technologies employed are associated with problems on a worldwide scale for further use due to the adverse effects on man and the environment. Thus, the region as well as the rest of the world needs to seek alternatives to the conventional technologies. As one of the alternatives,

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biological control using natural enemies to the insect pests in the storages has attracted the attention in the USA and some European countries, since it may be safe and sustainable for either people or the environment (Brower *et al.*, 1996; Scholler *et al.*, 1997). As a successful example of biological control of stored-product insects, it was reported that the larger grain borer, *Prostephanus truncatus* (Horn), a newly invading pest in Africa had been well controlled by its natural enemy, *Teretriosoma nigrescens* Lewis, imported from Central America (Mutlu , 1994; Richter *et al.*, 1997). This is a typical case of the "classical biological control" in which exotic insect pests invading new geographical areas can be controlled by imported natural enemies from the region where the insect pest originated.

On the contrary, most of the major stored-product insects have been widely disseminated with their natural enemies by trade and human migration. Thus, "classical biological control" may not be adopted to regulate common troublesome insects. In this case, "augmentative biological control", which reduces host-pests by the release of mass-reared natural enemies would be effective to regulate the insect pest populations below the economic injury level. In the USA, several natural enemies have been registered for EPA for augmentative release (Brower *et al.*,1996).

In Southeast Asia, the concept of use of biological control in the storage environment has been long ignored by entomologists. However, in a few studies, the abundance and role of natural enemies for pest control in the region (Haines and Pranata, 1982; Visarathanonth *et al.*, 1994) have been indicated. The author has also observed many cases in which the pests were effectively regulated by natural enemies in rice storages in Thailand during the period 1988-1991 (Nakakita *et al.*, 1991), although he had sometimes encountered high infestation level cases. Thus, more efficient control is expected with "augmentative release of selected natural enemies" to solve the problems of stored-product insects in Southeast Asia. In this paper, the possibility to use natural enemies against insect pests of stored products in the region is considered from several aspects: outline of natural control observed in storage environments in Thailand, brief review of research on biological control, candidates for biological agents, augmentative release and possibility of practical application of biological agents in IPM.

Natural control of stored-product insects in Thailand

Thailand, located in the wet monsoon zone where a large number of farmers are engaged in paddy production, is the largest rice-exporting country in the world. More than 50 species of stored-product insects have been recorded (Sukprakarn, 1985), but, the author observed many incidences of low level infestation by them in rice storage facilities where no disinfestation measures were employed and the level of hygiene and sanitation was substandard with contamination with broken and spilled rice, dust, etc.

To investigate in detail the situation of the insect problem in Thailand, collaborative research between the Department of Agriculture in Thailand and the Tropical Agriculture Research Center (predecessor of JIRCAS) was initiated by setting up food traps in farmers' warehouses, seed storages, rice mills and godowns in 11 provinces of the country from 1988 to 1991. The food traps containing 500g of paddy brown or milled rice packed separately in plastic net bags(ca.30 mesh) in a wirenet(ca.16 mesh) cage (10 x 25 x 18 cm) were installed at each site of the rice storage facilities and were renewed every four months to examine insect species and determine their numbers and also to evaluate both quantitative and qualitative losses of rice. As a result, paddy was found to be the most resistant among the three rice forms to insect infestations whereas brown rice was the most susceptible. Based on the distribution of the size of the insect populations in rice bags, it was apparent that populations of insect pests (Coleoptera) tended show to opposite trends, very small size (indicative of suppression, less than 100 adults) and explosive multiplication (outbreak, more than 2,000 adults obtained) as shown in Table 1.

Table 1 Frequency of occurrence of suppression and outbreaks of stored-product insects recorded in the traps installed for 4 months in storage facilities

Facilities	Paddy		Brown rice		Milled rice	
	Suppression n (%)	Outbreak n (%)	Suppression n (%)	Outbreak n (%)	Suppression n (%)	Outbreak n (%)
Farmer	9 (27.2)	4 (12.1)	5 (15.6)	8 (25.0)	8 (25.0)	9 (28.1)
Station	10 (31.2)	2 (6.2)	2 (7.4)	6 (22.2)	9 (30.0)	2 (6.6)
Rice mill	9 (24.3)	1 (2.7)	1 (2.7)	18 (48.6)	5 (13.8)	8 (22.2)

Suppression : samples which recorded less than 100 adults of Coleopteran pests.
Outbreak : samples which recorded more than 2,000 adults of Coleopteran pests.
n = number of traps

Generally under humid tropical climatic conditions, insect pests develop and reproduce rapidly, causing explosive outbreaks. Hence, the observed low frequency of the insect occurrence indicated the existence of certain factors that suppressed insect populations. If we examine the factors involved in the populations, four factors can be considered as shown in Fig. 1. By analyzing the data, we concluded that the factor for the suppression must be associated with natural control because the traps also captured large numbers of natural enemies as shown in Fig.2. In addition to the recorded natural enemies, we also captured or observed many spiders, mites and geckoes which might have played a role in the reduction of the number of insect pests in the storage environment. Hence, the level of conservation of natural enemies in the environment should be very high which offers a unique ecosystem for reducing the populations of the insect pests. However, as indicated in Table 1, there were also many severe outbreak cases. Thus, we need to develop pest management strategies in these unique ecosystems which might be common to other areas in Southeast Asia.

Relation between natural enemies and their hosts, stored-product insects

The concept to use natural enemies to control insect pests in the stored environments is very old. The complete control of a population of *Ephestia kuehniella* (Zeller) by the parasitoid, *Habrobracon hebetor* Say was reported in 1887 in a large flour house in London (Brower *et al*., 1996). Then, Berliner in 1915 firstly isolated *Bacillus thuringiensis* from *E. kuehniella* to determine its potential as a control agent for stored-product insects. After that, many researchers investigated different types of parasitoids, predators and pathogens for the control

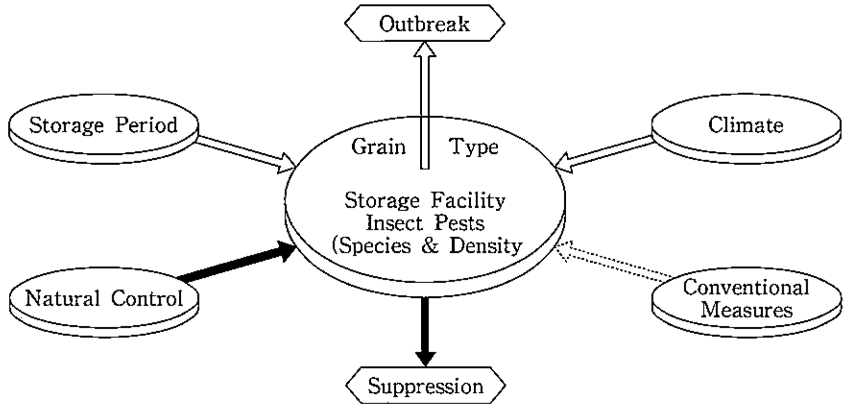

Fig.1 Factors influencing population fluctuations of insect pests in storage facilities

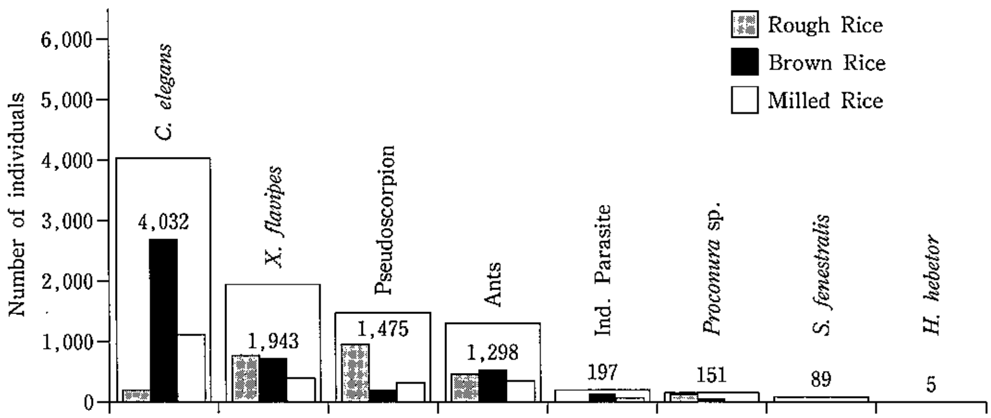

Fig.2 Species and number of natural enemies captured in food traps set up in rice mills

of stored-product insects although very little attention had been devoted to this work after World War II because of the widespread use of synthetic pesticides. However, now just before the 21st century, natural enemies are again attracting the attention of researchers as biological control agents for stored-product insects because of their safety for both people and the environment.

Tables 2-A and -B show a list of natural enemies, parasitoids, predators, pathogens, etc. with their hosts identified in the stored-product environment. In Southeast Asia, research work on natural enemies has been almost neglected for a long time. Thus, the species of natural enemies have not still been well identified. Haines and Pranata (1982) reported the presence of 29 natural enemies in storages in Indonesia based on a survey of insects in stored produce, although the species were not accurately listed. Recently a new predator, *Joppeicus paradoxus* Puton had been identified in stored environment in Thailand (P. Visarathanonth, 1997, personal communication), suggesting that more species of natural enemies could be added based on taxonomic studies.

Pseudoscorpion

Table 2-A Useful parasitoids and predators and their host insect-pests

Natural Enemies \ Insect Pests	Major				Secondary							Q.S.*	
	Sitophilus spp.	*Rhyzopertha dominica*	*Sitotroga cerealella*	*Corcyra cephalonica*	*Oryzaephilus* spp.	*Tribolium* spp.	*Cryptolestes* spp.	*Latheticus oryzae*	*Lasioderma serricorne*	*Ephestia* spp.	*Plodia interpunctella*	*Trogoderma granarium*	*Prostephanus truncatus*
Parasitoids (Hymenoptera)													
Anisopteromalus calandrae	◎	◎	◎						◎			○	○
Lariophagus distinguendus	◎	◎	○						◎				○
Theocolax (Choetospila) elegans	◎	◎	◎				◎		◎				
Pteromalus (Habrocytus) cereallelae	○	○	◎										
Habrobracon hebetor			◎	◎						◎	◎	○	
Habrobracon brevicornis				◎						◎	◎		
Israelius carthami									◎				
Cephalonomia gallicola						◎			◎				
Cephalonomia tarsalis	○				◎	○	◎						
Cephalonomia waterstoni						○	◎						
Holepyris sylvanidis	○			◎	◎	◎	◎						
Holepyris hawaiiensis				◎									
Rhabdepyris zea						◎							
Rhabdepyris spp.	○					○							
Trichogramma evanescens				◎							◎		
Trichogramma spp.			◎	◎						◎	◎		
Venturia canescens			◎	◎						◎	◎		
Predators (Hemiptera)													
Lyctocoris campestris					◎	◎						◎	
Xylocoris flavipes		○	○	○	◎	◎			◎	◎			
Xylocoris cursitans					◎	◎							
Joppeicus paradoxus						◎							
Sycanus affinis				◎								◎	
Amphibolus venetor				◎				◎					
Triphelps sp.								◎					
(Coleoptera)													
Teretriosoma nigrescens	○				◎								◎
Thaneroclerus buqueti									◎				

* : Quarantine-significant insect pests

Table 2−B Useful pathogens and their hosts and other characteristics

Pathogen	Toxic stage (mode of entry)	Host range	Type of toxicity	Formulation
Bacteria:				
Bacillus thuringiensis; Bt	Spores	Lepidoptera	Acute	Dust, wettable powder and liquid (commercialized)
Bt (Tenebrionidae)	(Ingestion)	Coleoptera		
Viruses:				
nuclear polyhedrosis (NPV)	inclusion bodies	Mostly Lepidoptera species	Acute	Release of infected virgin females, freeze-dried powder of infected body (lab.scale)
granulosis viruses (GV)	(Ingestion, transmission)			
cytoplasmic polyhedrosis (CPV)				
Fungi:	Spores	*B.bassiana* has been extensively studied in stored-product insects; effective to *Sitophilus* spp.	Dose-dependent	Water suspension ("Boverosil") dry powder and fat pellet (lab. scale)
Beauveria bassiana	(Contact or ingestion)			
Protozoa:	Spores		Chronic	Infected insect of powder with medium
Mattesia trogodermae	(Ingestion and transmission)	*Trogoderma* spp.		
Farinocystis tribolii		*Tribolium* spp.		
Nosema whetei		*Tribolium* spp. *Oryzaephilus* spp.		
Nosema oryzaephilus		wide range species in both moth and beetle		
Nosema plodiae		*Plodia interpunctella*		

Potential natural enemies for augmentative release

1 Parasitoids

Parasitoids are classified as an insect group of parasites whose immature stage develops on another insect and kills it before emergence. Many wasps belonging to Hymenoptera are parasitoids occurring in stored-product environments. In Southeast Asia, major stored-product insects on rice grain are *Sitophilus zeamais* Motsulsky, *S. oryzae* (Linne), *Rhyzopertha dominica* (Fabricius), *Sitotroga cerealella* (Oliver) and *Corcyra cephalonica* (Stainton) which, except for *C. cephalonica*, are all kernel-feeding (feeding on internal parts of grain) species during their larval stages. *Tribolium castaneum* (Herbst), *Oryzaephilus surinamensis* (Linne), *Lophocateres pussilus* (Klug), etc. are also significant species in the storage environment but possibly act more as scavengers on rice grains as secondary insect pests. Thus, we must look for two types of parasitoids: parasitoids for pests feeding on internal parts of grain, and parasitoids for pests feeding on the surface of grain.

1) Parasitoids for pests feeding on internal parts of grain: The parasitoids in the Pteromalid group have attracted the attention of many researchers since the four species in the group, *Anisopteromalus calandrae* (Howard), *Theocolax* (Choetospila) *elegans* (Westwood), *Lariophagus distinguendus* (Förster) and *Pteromalus* (Habrocytus) *cerealella* (Ashmood) which can attack insect pests feeding on internal parts of grain. Their female wasps can detect infested kernels, drill through the grain and sting the ovipositor to deposit an egg on the immature host, and finally kill it. Most of the parasitoids found in the stored environment show a rather wide host range: for example, *A. calandrae* can attack not only major stored-product insects, but also *Lasioderma serricorne* (Fabricius), *Stegobium paniceum* (Linne), *Callosobruchus chinensis* (Linne) and *Zabrotes subfascius* (Boheman). Recently, *A. calandrae* has attracted the attention as a biological agent for the control of *S. zeamais* on corn in the USA. The parasitoid is well adapted to tropical climatic conditions, since at the high temperature of 35℃, it produced 42.6 progenies (mean number) over the lifetime, while only 10.4 at 20℃ although female longevity was highest at 20℃ (14.5 days) and shortest at 30 - 35℃ (6 days) (Smith, 1992). It was estimated that the intrinsic rate of increase of this parasitoid is higher than that of its major hosts, *S. zeamais* and *S. oryzae*. These results suggest that *A. calandrae* can suppress the population of *Sitophilus* spp. in the tropics. Regarding the control efficacy of *A. calandrae*, a suppression of more than 90% of the maize weevil in drums containing 43.36kg of shelled corn after 33 weeks was successfully obtained by a single release (5 - 40 pairs at initial release) and multiple release (2 - 20 pairs every week for the subsequent 29 weeks) of the parasitoid (Wen and Brower, 1994).

T. elegans, a parasitoid commonly found in infested grains showed a less effective suppression of *Sitophilus* spp. in infested corn in USA (Williams and Floyd, 1971), but the parasitoid suppressed effectively *R. dominica* population at 25℃ (Flinn, 1998). *L.distinguendus* showed a lower activity in both rates of search and reproduction on the rice weevil in rice grain compared with *A. calandrae* (Ryoo *et al.*, 1996). However, *A. calandrae* and *L. distinguendus* could successfully suppress more than 95% of a rice weevil population in a laboratory rice storage system and they could coexist in the suppression (Ryoo and Choi, 1997). The optimum temperature for growth of *L. distinguendus* was around 32℃.

In Southeast Asia, *A. callandrae* was reported to be the most abundant parasitoid in

Indonesia (Haines and Pranata, 1982) and the Philippines (Sayaboc, 1997, personal communication). However, most of the collected wasps in Thailand were not *A. calandrae*, but *T. elegans* (Visarathanonth *et al.*, 1994).

2) Parasitoids for pests feeding on the surface of grain: *Trichogramma* spp., *H. hebetor* and *Venturia canescens* are effective parasitoids on Lepidoptera. *Trichogramma* spp. are wasps used commercially and are mass-produced by using lepidopterous eggs of stored-product insects such as *E. kuhniella, P. interpunctella* and *C. cephalonica*. However, *Trichogramma* spp. are mainly used as biocontrol agents for many agricultural pests, because they are egg-parasitoids acting on a wide range of hosts.

H. hebetor and *V. canescens* are larval parasitoids of Lepidopterous insects. *H. hebetor*, which is cosmopolitan, attacks large larvae of most of the pyralid moths such as *Ephestia* spp. and *P. interpunctella*, but its effectiveness on *C. cephalonica*, an injurious moth on rice in Southeast Asia is still unknown. *Holepyris sylvanidis* (Brethes), *Cephalonomia waterstoni* Gahan and *C. gallicola* (Ashamed) are parasitoids attacking Coleoptera. Among these, *H. sylvanidis* could be a useful parasitoid as a biocontrol agent for stored beetles since it shows a wide host range compared with the other wasps (Brower *et al.*, 1996).

2 Predators

As mentioned previously, in the rice storages in Southeast Asia, spiders, ants and geckoes which could play a very important role as predators for the regulation of stored-product insects in the region are commonly observed. In addition, there are large numbers of a predacious bug, *Xylocoris flavipes* (Reuter) which is well adapted to the storage environment and is referred to as warehouse pirate bug. The optimum conditions for reproduction are 29-30℃ and 60-80%RH (Arbogast *et al.*, 1971). The bug has a high potential to reduce populations of nearly 30 species of stored-product insects (Brower *et al.*, 1996). The bug attacks mostly eggs and larvae of a wide array of smaller beetles and moths although all stages of *T. castaneum* and adults of *R. dominica* were reported as preys of the bug. In the storage test, populations of *Ephestia cautella* (Walker), *T. castaneum* and *O. surinamensis* did not increase in a room containing grain debris when *X. flavipes* was released in small numbers, whereas all three populations increased remarkably when no bugs were released (Arbogast, 1984 a). Several terpenes secreted by the pirate bug cause toxicity to preys (Phillips *et al.*, 1995). Now, the bug is commercially available for use in stored products in the USA. In addition, recently an other bug *Lyctocoris campestris* (Fabricius) has attracted the attention as a biological control agent due to its wide range of preys from the small *O. surinamensis* to the large *Galleria mellonella* (Linne) (> 20mm) (Parajulee and Phillips, 1994) although this bug attacks people (Parajulee and Phillips, 1992). *Dufouriellus ater* is another predacious bug occurring sometimes in storages in Eurasia and North Africa but is not found in Southeast Asia. This bug attacks various species of moths, beetles and psocids (Arbogast, 1984 b). Psocids often cause serious problems due to their large number on the surface of milled rice bags in Southeast Asia.

Recently, a very rare bug, *Joppeicus paradoxus*, has been detected in Thailand (specimen captured by P. Visarathanonth in 1997 and identified by T. Yasunaga in 1998). Although the bug was sometimes captured in Israel, Egypt and Sudan (Davis and Usinger, 1970; Stays, 1971), its biological characteristics have not been well elucidated except for the report of Davis and

Usinger (1970). This bug has been placed in an independent taxonomical family which consists of only this species. The bug was found to attack larvae of *Tenebrio molitor* and other insects. Therefore, the bug is feeding on whatever small insects it encounters (Davis and Usinger, 1970). The bug found in Thailand was the first case discovered in monsoon Asia. Now the bug has been mass-produced with pupae of *T. castaneum* as prey, suggesting that the bug could act as a biocontrol agent since it preys on a wide range of insect pests. Currently, *T. nigrescens* is the most well known predator for the biological control of stored-product insects since *P. truncatus*, a newly invading insect pest which damages seriously stored maize in Africa, has been well regulated by the release of a predatory histerid imported from Central America, as a typical example of successful "classical biological control" (Mutlu, 1994; Richter *et al*., 1997). However, this histerid is very specific to *P. truncatus*, although both *Oryzaephilus surinamensis* and *O.mercator* were attacked (Poschko, 1994). Thus, *T. nigrescens* does not attract researchers in Southeast Asia due to the absence of *P. truncatus* in the region.

3 Pathogens

Many different types of pathogens such as protozoa, bacteria, fungi, viruses and rickettsia have a potential to infect stored-product insects, through auto-dissemination whereby pathogens spread through living insects to suppress their populations in a larger area. However, the pathogens in Southeast Asia have not been well studied in the storage environment.

1) Viruses:

Nuclear polyhedrosis virus (NPV), granulosis virus (GV), cytoplasmic polyhedrosis virus (CPV), and a number of non-occluded viruses have been isolated from stored-product pests, mostly from the moths (Brower *et al*., 1996). Some of the viruses are very effective to suppress the insect pest population because of their high virulence, acute type infection and stability. The auto-dissemination is performed by the activity of carrier individuals for spreading the viruses to the healthy individuals through the ingestion of larvae on contaminated food products. Few studies on the viruses have demonstrated their high potential as microbial control agents for stored-product insects. Treatment with an aqueous solution of IMMGV, granulosis obtained from *P. interpunctella* showed a very high level of control of the moths infesting stored wheat and corn (McGaughey, 1975). As an application of the viruses, Vail *et al*.(1993) showed that a pheromone lure containing a freezed-dried powder of IMMGV successfully transferred the agents to the targeted population of *P. interpunctella* by adults males attracted to the spread IMMGV, resulting in 60%(F1) and 50%(F2) mortality. However, entomopathogenic viruses on stored-product insects have not been produced commercially.

2) Bacteria:

Bacillus thuringiensis (Bt) has been well studied although several other bacteria were known to be effective to suppress insect pests. Bt is an insecticidal bacterium which was first discovered in Japan in 1901, when it killed silkworms in culture (Ishiwata, 1901). About ten years later, Berliner (1915) found another strain from the larvae of *E. kuhniella* in the province of Thuringen in Germany. Then, Berliner recognized the potential of this bacterium for use as a control agent for stored-product insects. Bt produces crystalline inclusions which contain insecticidal proteins, called sigma-endotoxins, that are lethal to the insect after the protein is digested at a specific high pH. Although it was considered for many years that the spectrum of Bt was confined to the larvae of Lepidoptera due to the high pH, recently, several strains have been identified for Diptera and Coleoptera. For Coleoptera, a new Bt strain, Darmstadt, isolated from *Tenebrio molitor* (Kreig *et al.*, 1983) was found to be effective to control *R. dominica* (Mummigatti *et al.*, 1994). Bt occurs almost everywhere in habitats ranging from the Arctic to the tropics. Although annually more than 10,000 tons of Bt have been commercially used to control Lepidoptera in agricultural pests, very small amounts have been targeted to control stored-product moths such as *P. interpunctella* and *E. cautella* in some countries like the USA.

3) Fungi:

Entomopathogenic fungi are important due their facultative and acute toxicity to insects. The infection occurs mostly through ingestion and penetration of the cuticle, but also through spiracles. Among such fungi, *Beauveria bassiana* (Balsamo) has been well studied in stored-product insects. In Czechoslovakia, "Boverosil", a commercial formulation of *B. bassiana*, combined with the insecticide pirimiphos-methyl emulsion concentrate is registered for treatment of residual insect pests (Hluchy and Samsinakova, 1989) in empty stores or silos. It was considered that *B. bassiana* needed a high humidity of more than 90% RH. However, recent work using a strain of *B. bassiana* obtained from Brazil showed that it was highly toxic even under low humidity conditions and that it could be used as a dry powder against *S. zeamais* (Adane *et al.*, 1996). After about 24 hours of direct contact of *S. zeamais* with the fat pellet formulation containing 10^{10} conidia (Brazil strain of *B. bassiana*)/g, 100% mortality was obtained after 7 days (Hidalgo *et al.*, 1998).

In Southeast Asia, it was reported from a Vietnam laboratory that spraying of a water suspension of *B. bassiana* resulted in more than 50% mortality of *Sitophilus* spp. and *T. castaneum* after 20 days at 31.8℃ under 71.3% RH (Thuy *et al.*, 1994).

4) Protozoa:

Although many protozoa have been identified from stored-product insects, no practical use has been demonstrated. In Table 2-B, several important protozoa are listed with their hosts.

Augmentative release of natural enemies in IPM in Southeast Asia

The concept of integrated pest management (IPM) was developed by Smith and Allen(1954) to describe a system of crop insect pest control "Integrated pest control is a pest management system that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods in as compatible manner as possible and maintains the pest population at levels below the economic injury level (EIL)". The main rationale is to induce conditions favorable for the crop and the natural enemies but unfavorable for pests. In the stored environment in temperate countries, until quite recently, natural enemies such as parasitoids and predators have been considered to be a source of contamination for grain commodities and other foods because EIL of insect contamination of such commodities should be almost zero. Thus, biological control has long been neglected as a control measure for stored-product insects. However, the situation is gradually changing since the use of biological agents has been adopted in the USA and some European countries as safe and sustainable measures for disinfestation.

However, the application of biological control in the temperate countries is associated with two negative aspects: cost and efficacy to compete with conventional chemicals. In Southeast Asia, however, these negative factors may not be obstacles for its application because the EIL of rice and other commodities in the market may be higher than that in the temperate countries. In addition, biological control in the region should be carried out economically due to the moderate cost of manpower and mass-production. Moreover, the augmentative release of selected mass-reared natural enemies may be effectively applied in the storages where conservation of beneficial agents may be high since no adverse effects would be derived from the use of chemicals.

When we take into account the role of augmentative release of natural enemies in Integrated Stored Pest Management (ISPM) in the region, the biological agents artificially released should act jointly with the indigenous biological agents conserved in the storage environment to suppress the insect pest population under EIL. For the concept to be successful, a monitoring system to determine the time of augmentation would be important, but not essential because regular introduction of the biological agents would practically be effective to suppress insect pests under EIL.

Conclusion

All the modern disinfestation techniques for stored-product insects have been developed in temperate countries where the ecosystems of the storages are completely different from those in the tropics such as Southeast Asia. However, the researchers or organizations in the region may consider such techniques. Biological control by the increase of natural enemies for the disinfestation of stored-product insects may be suitable due to the safety to the environment.

The augmentative release of selected mass-produced natural enemies should be effectively applied in the storage environment in Southeast Asia where the conservation of beneficial agents may be high due to the lack of adverse effects derived from the use of chemicals. Moreover, this technique could lead to commercial application after basic studies are carried out in the laboratory since all the research materials would be available and the target agents may be mass-produced efficiently from a factory with low running costs.

As mentioned above, based on studies on natural enemies carried out in the USA, *A. calandrae* seems to be the most attractive parasitoid for the control of major stored-product insects, such as *Sitophilus* spp., and *X. flavipes* would be the most effective predator for secondary insect pests. Emphasis should be placed on studies on the taxonomy and the efficacy of the respective natural enemies in Southeast Asia. Fig.3 indicates the basic procedures to develop research and application of natural enemies in the region.

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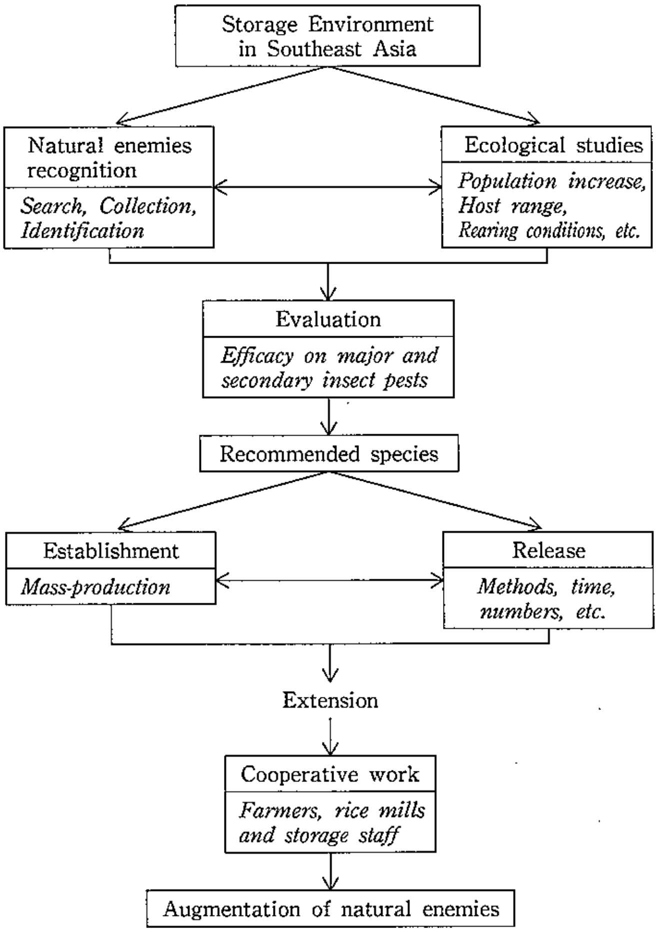

Fig.3 Scheme for research on natural enemies and application for augmentative release

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