Int. J. Indust. Entomol. Vol. 1, No. 2, 2000, pp. 95~102

[Review]

International Journal of
Industrial Entomology

The Strategy for the Development of Bio-Resources Utilizing Sericultural Products and Insects

Won Chu Lee* and Iksoo Kim

Department of Sericulture and Entomology, National Institute of Agricultural Science and Technology, R. D. A., Suwon 441-100, Korea.

(Received 10 October 2000; Accepted 19 October 2000)

Experiments related to the field of sericulture started in the year, 1900, in Korea. The sericultural experimental station in Korea was first organized among agricultural fields in Korea, indicating that sericulture in Korea was regarded as an important field of agriculture. Sericulture has been devoted to a great deal for the improvement of Korean economy during the past 100 years even under the coarse social circumstance, caused particularly by the Korean War. However, the traditional Korean sericulture, aimed to produce silk yarn, was weakened, because of several reasons such as diminishment in silk consumption, increased labor charge in Korea, and so on. After this difficulty time, the Korean sericulture was revolutionized by shifting into functional sericulture from 1995, and the Korean sericulture now plays an important role for the improvement of human health. Mulberry tree, silkworm, and silk have a boundless potential to be developed as resources. We expect the know-how obtained through silkworm research would expand to the other insect research too. Thus, an area of entomological industry is hoped to prosper owing to insect research as well as sericulture. Mulberry tree is known to possess many bio-active substances, so it can be utilized as a resource for substitute medicine and a raw material for the functional food. In addition, an invention of genetically engineered mulberry variety, which will produce more bioactive substances, is expected. Silkworm is one of the most extensively studied insect organisms on the genome so far. Thus, silkworm is expected to be an "insect bio-factory", enabling mass-production of useful proteins by transformation, in which useful foreign genes are assimilated into silkworm. Silk can be transformed into several phases, because it possesses useful functional groups, which are sensitive to chemical reaction. Also, because silk fibrin itself is protein, it has a superior applicability as tissue membrane. Due to this usefulness, many researchers are now working on the silk as food, cosmetic, medical resource, and bioengineering resource, and even an expanded application is expected using silk in the future. Until now, the researches on insects were largely focused on the prevention of the damage caused by pest, instead of a beneficial aspect. However, insects are thought to be the fourth natural resource in the world, possessing unlimited potential as world resources in the near future. Therefore, our entomological research effort should be focused on the subject with potential for industrialization. Such subject includes selecting the insect species useful for environmental evaluation, construction of environment-friendly agricultural ecosystem, pollen mediation, pet, and advanced bio-resources.

Key words : Sericulture, Mulberry, Silkworm, Silk, Insect, Bio-resources, Substitute medical materials

Introduction

The traditional agriculture, which has mostly been focused on the production is now shifted into development of functionality to increase an additional value, generation of high quality, biotechnology-based production, and development of environment protection- oriented agricultural techniques. Particularly, development in biotechnology is expected to play a large role in the economic improvement with the development of information trans-

*To whom correspondence should be addressed.
Department of Sericulture and Entomology, National Institute of Agricultural Science & Technology, R. D. A., Suwon 441-100, Korea. Tel: +82-31-290-8400; Fax: +82-31-295-2176; E-mail: wclee@rda.go.kr

ferring system. Therefore, all the countries in the world are competitively making efforts for the improvement of this field, allowing ones to expect a rapid technical renovation in most industrial as well as agricultural field.

Most insects have traditionally been regarded as pests, which are directly related to the decrease in yield, in the agricultural field. However, recently concerns are also paid to the beneficial ones, such as silkworm and bee. Furthermore, previously unknown insects are also watched for their potential as a natural resource. Silkworm is one example of such effort. Silkworm, one of the most extensively studied insects, is being expected for the generation of biotechnology industry throughout genome research in Korea and Japan.

The effort to utilize mulberry tree as alternative medicines is also being made through the scientific study of the pharmacological effect, on the basis of the traditional medical books. Furthermore, fruitful results were obtained using the silk, which was traditionally utilized as a raw material for dress, as a medical resource after an extensive study on this subject.

As briefly explained above, many agricultural fields regarding sericulture and insect are now faced with a rapid change for the utilization of them as resources. In this article, we would like to introduce the current situation of these aspects and examine the possible strategy to utilize sericultural products and insects as bio-resources.

Developmental strategy in the field of mulberry tree

In the last 100 years, there has been a great advance in the field of mulberry tree in terms of research and technology in Korea. The productivity in the mulberry field was increased throughout breeding of new varieties, changes of planting, pruning and harvesting methods, introduction of new management technique and labor-saving equipment, soil improvement, fertilization, and prevention of disease, insect, and disasters. For example, the cocoon production, increased from 130 Kg/ha of mulberry field in 1910 to 1,100 Kg/1ha in about 1995, showing about nine fold increase. This progress of the cocoon production can be attributed to the increased productivity in the mulberry field owing to the reasons referred above.

Although the Korean sericulture was on the face of decline after the peck in 1976, several kinds of effort to recover the Korean sericulture managed to endure the situation. Such effort includes cost reduction and development of the techniques for productivity increase. Nevertheless, the Korean sericulture was almost vanished in the early 1990, due to high production cost (4 fold higher) in comparison with newly started countries as well as China. Fortunately, this difficulty was turned into an opportunity by the highlighted researches on the functional mulberry leaves possessing additional value and powdery silkworm with blood glucose lowering effect.

Mulberry leaves have long been used as a stable food for silkworm, although they were also used negligibly as a folk medicine, according to old record. During the last 10 years, the effort to develop functional foods was made utilizing the sericultural products, because the major sericultural countries reached to the uppermost limit in their sericulture. As a result of this effort, Korea and Japan made a substantial visible result in the form of manufactured product, and the products are at the point to be exported to the West. An active research on the mulberry leaves discovered them to possess a diverse functional effect, such as a descent in blood glucose, blood pressure, cholesterol, and neutral fat levels, recovery from arteriosclerosis, liver lipid removal, anti-oxidation, repression of mutagenicity and active oxygen, and an increase in the defense enzyme activity.

Some have cast doubts that mulberry research is at the uppermost limit. Nevertheless, it appears to have a huge research space, because research results suggest mulberry tree still to possess many functions and merits as follows:

1. Mulberry tree is one of the many plant species, established in its systematized cultivation and developmental techniques through long period of research.
2. It can be easily obtained and utilized, because of its wide distribution from the tropics to subtropics, enabling international co-operation possible.
3. It is highly likely to develop new varieties because of an abundant ploidy state 9 from 2n to 22n chromosomes).
4. Tissue culture technique was developed at the point put to practical use for mass-production.
5. Genetic variation was increased through tissue culture, and foreign genes can be introduced into mulberry tree.
6. The potential to be developed as substitute medicines is high because mulberry tree possesses many functional ingredients in a vast volume.

Because the mulberry tree has the merits mentioned above, it could be utilized as a natural resource for alternative medicine and high protein- and calcium-containing food. Thus, we hope it contribute to the well-being of the mankind.

To maximize the potential of mulberry tree as a natural resource, we would like to suggest some directions in the research of mulberry tree. First, we suggest that researches should be focused on the breeding of mulberry variety with the enhanced functionality (*e. g.*, in blood glucose and blood pressure lowering effect) throughout biotech-

nology. Second, an effort to breed a mulberry variety, bearing mulberry syncarp with high functionality, should be made. Third, the abandoned, slant land should be preserved for the future use. These efforts all together will allow us to mass-produce the purposed product throughout, for example, the tissue culture of the genetically engineered varieties possessing new functionality. These new varieties may possibly be used as the resource for the substitute medicine and as silkworm feed with high protein content, by which silkworm can produce cocoons with a large quantity of silk fiber. Furthermore, the silkworm itself fed, highly functional mulberry leaves might be utilized as a substitute medicine with special function.

Developmental strategy in the field of silkworm

There has been a great advance in the field of silkworm rearing. For example, the recent cocoon yield increased about 50%, length of silk fiber about 70%, and raw silk yield per 10,000 individual silkworms about 2.14 fold compared to those in 1940s.

Silkworm is one of the most extensively studied organisms, including world famous fruit flies and honeybees. It consists of more than 2,000 breeds in the world, and a substantial number of lines possessing independent mutations are present. Silkworm together with fruit fly traditionally has been utilized as a model organism for the genetic and physiological studies. At present, the West including USA mostly accomplished the fruit fly genome research. This accomplishment was partially possible, because the indoor rearing technique was available for fruit fly. The genome project result confirmed that the fruit fly possesses similar genes to human genomes. Although the genome study on the silkworm is lagging compared with that of fruit fly, gene mapping of the silkworm has already been completed and genome project is to some degree under process mainly by Japan and Korea.

Although innumerable, the up-to-date results listed below provide a background for the justification of the onset of silkworm research:

1. The body of silkworm possesses blood glucose lowering effect.
2. Silkworm can be utilized as "bio-factory", which enables a mass-production of pure proteins.
3. In comparison with pig, silkworm is much more time-saving organism (10, 000 fold) for the production of useful substances in the fresh weight.
4. Genome analysis of the silkworm has been accomplished to some degree.
5. The test system for GMO and deleterious substances has already been established using silkworm.

With the merit mentioned above in mind, we would like to suggest some possible ways for the silkworm research to direct:

1. Generation of an additional value by the breeding of new silkworms
   1) Breeding of new breeds possessing functionality and suitable for special purpose
   2) Breeding of new silkworm suitable for healthy, high yield, and laborsaving sericulture
2. Utilizing method of silkworm itself
   1) Establishment of the methods for separation and purification of bio-active substances
   2) Test of a single substance and utilization of the substance as substitute medicine through clinical experiment
3. Application of biotechnology for the utilization of silkworm
   1) Genome research
   2) Production of useful substances by transformation
   3) Establishment of insect bio-system utilizing silkworm body

Generation of an additional value by the breeding of new silkworms

1) Breeding of new breeds possessing functionality and suitable for special purpose

Studies on the powdery silkworm for glucose lowering effect showed no differentiation in its effect among silkworm breeds. Thus, it would be proper to focus our effort to breed a large sized silkworm bred regardless of lineage. However, it would be wise to breed the silkworm lineage from the naked pupa, because it does not make a cocoon, allowing ones to save time for cocoon cutting. This is especially urgent for Cordyceps ("winter-bug-summer-fungus") production because 31% cost for Cordyceps production are spent for cocoon cutting. At present, a silkworm breed, which fulfils this purpose, was developed by the Department of Sericulture and Entomology, National Institute of Agricultural Science and Technology (NIAST) and this breed was experimentally provided to the sericultural farms in Korea.

2) Breeding of new silkworm suitable for healthy, high yield, and labor-saving sericulture

The recent sericulture is mainly focused on the production of powdery silkworm. Thus, silkworm rearing only continues until the 2nd day of 5th instar. This trend tends to result in retreat of the rearing techniques, because much technique and labor require thereafter. Therefore, it is urgent to breed a new breed, which catches less disease under less care, requires less labor, and grows easily. Furthermore, a resistant breed, growing under the temperature below the normal, under short nutrition, and under

inferior environment is also required. It is also necessary to breed a silkworm breed, which can be reared with a diversified source of artificial feeds.

Utilizing method of silkworm itself

The traditional sericulture sifted from the cocoon production to silkworm powder production in the spring of 1995. This, in fact, signifies change from the dress-centered textile business to the bio-industry and the functional resource industry.

As the powdery silkworm was illustrated to have a blood lowering effect almost without side effect, the powdery silkworm production increased from 121 tons in 1995 to 288 tones in 1998. This, in turn, allows ones to assume that the income of the sericultural farms increased about 2.2 fold. It has been shown that the effect of powdery silkworm for blood glucose descent revealed variability in its effect depending on preservation methods. For example, the hot wind dry method is easy to perform, but the lowering effect was lower than the freezing dry method, and the product from the method turned out to be apt to decay. Another method, freezing dry after cold storage, showed a higher effect and hygienic compared with others, but it costs more. Furthermore, sometimes the lowering effect was shown to drop due to a long transportation distance to the cold storage company, depending on the region of the farms located. Recently, therefore, a new method, freezing dry by liquid nitrogen after freezing, has been developed and practiced in the sericultural farms.

1) Establishment of the methods for separation and purification of bio-active substances

The major, blood glucose lowering substance has been turned out to be a dioxynojirimycine (DNJ) by separation and identification methods. This substance even was crystallized to the pure form, and now an adequacy of this substance as an indicator for the quantification of the DNJ in the mulberry leaves is going to be tested. It would be necessary to isolate the other substances, showing the lowering effect as like in DNJ to utilize them as a medical resource. By this, we expect more powdery silkworm be consumed by the general, and exportation to foreign countries is promoted.

2) Test of a single substance and utilization of the substance as substitute medicine through clinical experiment

Although much progress has been made on the blood glucose lowering substances in the powdery silkworm, still much work should be done to improve the quality of the powdery silkworm product. For example, the powdery silkworm product is not yet standardized, rendering the sericultural farmers inconvenient. Thus, subsequent research should focus on the establishment of the methods for quantification and qualification of the content in the powdery silkworm.

Application of biotechnology for the utilization of silkworm

1) Genome research

Silkworm, belonging to the lepidopteran, possesses unlimited possibility compared to the fruit fly in the aspect of molecular genetic utilization. In recognition of the importance of agricultural pest insects, especially lepidopterans, USA and Europe prepared for the genome research of the organisms belonging to this taxonomic group and Japan actually initiated silkworm genome project in 1999. In Korea, researches are under progress on the genetic characteristics of the Chinese oak silkworm and the Japanese oak silkworm as well as the domestic silkworm. Furthermore, development of the genome analysis techniques and decision of the gene loci of silk-producing insects are under progress.

2) Production of useful substances by transformation

Silkworm possesses the merit as an experimental organism and also the characteristics, which can be utilized as a stock for the mass-production of the pure proteins such as fibroin. This can be substantiated in a way that the fibroin protein gene is transformed by genetic manipulation to mass-produce useful protein for the benefit of human being. Although the fruit fly contains transposon, enabling transformation easy, but silkworm is lacking such transposon, making it impossible throughout transposon.

Korea and Japan recently were successful partially in making transgenic silkworm by inserting the jellyfish fluorescent gene. For the full establishment of this condition, several aspects of the study are proceeding. When the transformation techniques based on this one is established, mass-production of useful substances such as spider silk, Japanese oak silkworm silk, and collagen, possessing the possibility of industrialization, is expected to be realized.

3) Establishment of insect bio-system utilizing silkworm body

Insect bio-system (or insect bio-factory) means that insect body is transformed by inserting useful genes, which produces useful substances via vector systems, such as nuclear polyhedrosis virus. Korea and Japan have already established the vector system, and this will be utilized in many fields of related researches. For the production of useful substances throughout insect body, Japan is making efforts, and systematizes the field of artificial feed, mass indoor rearing system, breeding and selection of suitable silkworm breed, efficient way to collect silkworm blood, virus infection technique, and automatic rearing technique. In the near future, mass-production of useful sub-

stances via insect bio-system will direct to produce beneficial ones for mankind.

The field of genetic recombination techniques, which should direct can be listed as follows:

1. Isolation and illustration of expression systems of the proteins coding for the genes inducing hormonal bio-active substances, which is related to silkworm ecdysis and metamorphosis.
2. Production of useful substances, such as bio-active peptide, enzyme, and antibody utilizing genetic recombination techniques.
3. Breeding of the silkworm breeds, by gene transformation, by which useful substances are produced throughout the year.

Developmental strategy in the field of silk yarn processing

The basic aim of sericulture is obtaining the silk fiber as a dress material. For several thousand years, sericultural science was continuously developed in silkworm breeding, rearing technique, silk process, and weaving without satisfaction even when beautiful, high quality silk dress made of silk fiber was available. By the result, it now reached at the upper boundary.

As like the saying, "silk is only silk", any fiber can not substitute silk even though an attempt to develop artificial silk has been made. Silk is excellent in feel, heat insulation, hygroscopic property, ultraviolet ray blockage, and skin affinity. Thus, silk is known to show the therapeutic effect to skin disease and other unusual skin symptom.

During the last 100 years, the Korean silk processing techniques have been developed into the world-famous level enough to go shoulder to shoulder with Italy and Japan. The reeling labor was reduced from 200 persons per 60 Kg to 17 persons (decrease of one tenth) and reeling efficiency increased from 0.4 Kg per person to 6.0 Kg of raw silk (increase of 15 fold).

When several lately started, sericultural countries lost competitive power in the production of silk fiber for dress material in the late 1980s, Japan and Korea started to notice that silk is composed of protein, and changed research direction from silk production to silk utilization as protein. Silk possesses an abundant merit. For example, it can be modified into several forms, such as powder, membrane, perforated substance, and gel. Furthermore, it includes several functional groups with high chemical reactivity, enabling change in property, such as crystallization, solubility, and molecular adhesion. By utilizing these properties, the traditional silk industry was shifted from dress industry to new resource industry, which generates additional value. These include functional food, cosmetic material, and medical/pharmacological substance. Furthermore, one thing should be remembered is that the raw materials being utilized to generate an additional high value is not the raw intact silk itself, but the traditionally abandoned material produced from silk reeling, spin, and so on. These materials are recycled as water-soluble fibroin, fibroin film, and powdery fibroin after chemical and biological decomposition.

Generally, there are four ways to utilize silk proteins as bio-resources:

1. Food resource
2. Cosmetic resource
3. Medical and pharmacological resources
4. Industrial resource

In the following section, we would like to examine the functionality of each categorical resource.

Food resource

The effort to utilize silk protein as a food resource was problematic at the early stage, because of a low digestion and absorption level in the stomach. However, this problem was solved when fibroin was decomposed as oligopeptide or amino acids by biochemical methods. Now, more than 99% of the fibroin is absorbed in the stomach. Once absorbed, it is known to exert the effect of descent in the cholesterol and blood glucose level, prevention and remedy of Parkinsons disease and imbecility, and facilitation of alcohol metabolism. There has been an experiment to test if the functionality shown in the silk fibroin was stemmed simply from the amino acid consisting of the silk fibroin. Specifically, therapeutic effect of silk fibroin with the synthetic amino acids, the level and kind of which are similar to silk fibroin was compared. As a result of this experiment, silk fibroin showed remarkably superior effect to that of the synthetic amino acid when cholesterol level was low, indicating that silk fibroin may possess somewhat unique substance, which does not exist in the amino acids themselves.

In case of Japan, silk fibroin is utilized as many kinds of foodstuff. For example, taffy, soup noodles, drink, candy, soybean paste, and bean curd are some of them. Followed by Japan, Korean product is also expected on the market.

Cosmetic resource

Utilization of silk fibroin as a cosmetic resource is possible mainly because it is excellent in skin affinity, ultraviolet ray blockage, moisture retention, skin adhesion, and feel. When silk fibroin was applied to the hair with cosmetic, it was excellent for hair recovery from damage, prevention of color change, and maintenance of shines and gloss, suggesting its utility as hair tonic. Particularly,

because silk fibroin easily combines with pigment, it would be possible to make fashionable cosmetic. These aspects may enable silk fibroin to use as a major cosmetic resource.

Medical and pharmacological resources

There has been a diverse research for the utilization of the silk fibroin as medical and pharmacological resources. Expecting products include the wound covering material for the substitution of natural skin, oxygen permeable contact lens, embolus substance for the blockade of bleed on the operative part, and thrombus-free artificial blood vessel, suitable for repetitive contraction and expansion.

In addition, silk fibroin can be used as a surface material for petri dish and a biosensor. For the adhesive cell line, silk fibroin can substitute the membrane of several plates, such as collagen, silicon rubber, and polystyrene. Particularly, silk fibroin from Chinese oak silkworm has been known to facilitate surface adhesion, enabling a rapid cell growth.

Industrial resource

Silk fiber, treated with alkaline solution and followed by pulverization, can be processed as silk powder less than 10 μm in diameter. When this finely ground silk powder is sprayed on the vinyl, mixed with paint, synthetic silk leather is generated. This type of paint improves surface softness, resulting in promoted product value. Thus, such silk paint can be applied to various materials, including steel, wood, textile, and so on.

The application fields and developing status of the silk fibroin protein according to the physical forms are arranged in Fig. 1.

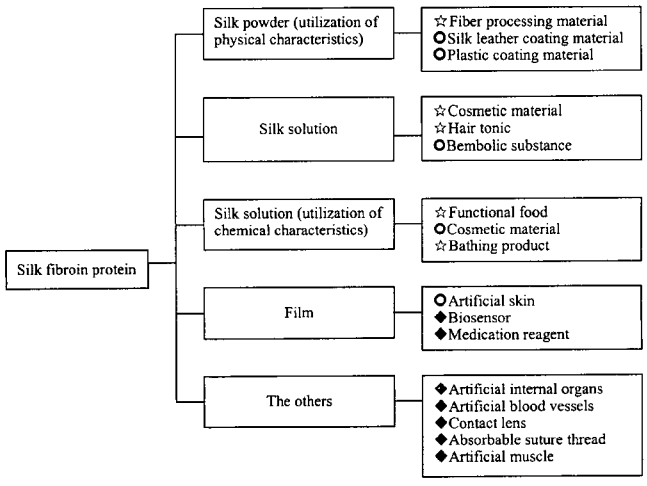

Fig. 1. The application fields and developing status of the silk fibroin protein according to the physical forms. ☆, at the stage of practical use; ○, under development; and ◆, under research.

Developmental strategy in the field of insect

Insects are recognized as the fourth natural resources with significant and prospective utility. There are three major reasons for this. One is that insects are the largest animal group in all organisms: there are at least 1.8 million species in the world (~12,000 species in Korea), and still many new species are being discovered nowadays. Another is that insects have a shorter generation time and population growth is rapid. Also, indoor rearing of insect species is relatively easy compared generally with other organisms and year-round rearing is possible in some species. The other is that the compounds beneficial to human being and domestic animals can be produced via insects, because insect metabolism is similar to that of mammals in many aspects.

Insects have a diverse characteristic function, such as silk synthesis, ecdysis, metamorphosis, defense system different from other organism, and so forth. Elucidation of mechanism of such functions throughout analysis of involved genes, proteins, and chemicals will make it possible to produce new and/or valuable compounds, through cheaper process in large quantity. At the same time, considerable efforts are invested in the development of insect- or pathogen-resistant crops and biological methods of pest control throughout the study of interaction between insects and their natural enemy, and insect-added feed for domestic animals.

We think that the insect industry might be one of the most promising ones in the 21st century, because it cost less time, labor, and space. However, the output will never be less and inefficient in the countries like Korea, which is small in size and deficient in natural resources. Nevertheless, researches on insects, especially in the field of biotechnology, still stay at the beginning stage: only a few colleges and research institutes are involved in this field.

It may take a while to establish bioengineering techniques, such as genome interpretation, transformation, and protein engineering. Therefore, an application of these techniques to the general field of industry may take an additional time period.

Researches for insect utilization in the world nowadays are followed.

- Research of bio-inorganic compounds extracted from the wings of butterfly to utilize as pigment for the prevention of counterfeit note.
- Research of Korean traditional insect medicine, such as winter-bug-summer-fungus (Cordyceps), larvae of the members of Cetoniidae, centipede, etc.
- Research for semi-artificial pollination of fruits and vegetables using polliniferous insects such as honey bee, carpenter bee, etc.

- Screening of insects-derived bio-active substances for new antibiotics.
- Research of friendly insects such as butterfly, beetle, etc. for insect pet.

In our opinion, it is desirable that research on insect be directed like mentioned below for insect industrialization:

1. Screening and evaluation of beneficial insects
2. Understanding of physiology and ecology of beneficial insects in order to achieve mass-production
3. Evaluation of environment using insects and construction of environment-friendly agricultural ecosystem
4. Utilization of polliniferous insect for semi-artificial pollination
5. Creation of new biomaterial industry

In the following section, we would like to introduce some directions to conduct the items mentioned above.

Screening and evaluation of beneficial insects

Based on the general decision, the insect species, that have a potential for use, should be collected, assorted into several groups based on their utility, and evaluated for their ecological characteristics. An example of such assortment based on utility is as follows: insect pet, edible insects, medicine, pollination, environment estimation, laboratory work, decomposition of the excretion by domestic animals, and so on.

Once these insects are grouped, such insects should be subjected to classification using the techniques such as RAPD, RFLP, mtDNA sequencing, etc. and the database of them should be constructed.

Understanding of physiology and ecology of beneficial insects in order to achieve mass-production

The prior key to insect industrialization is an ecological research of useful insects followed by their mass production. An artificial feed for silkworm is in practical use, and that of other insects such as longicorn, butterfly, and gold beetle species is also under rapid development.

The second priority for insect industrialization should be given to prevent annihilation by pathogene. Thus, research of insect pathology should be run parallel with development of mass-production technique. In the advanced countries, mass indoor rearing is usually undertaken by private company for commercial purpose, public research institute appears to be more suitable for the research focused on the illustration of insect physiology and ecology.

Evaluation of environment using insects and construction of environment-friendly agricultural ecosystem

Many living insects in agricultural environment have been disappeared because of development and excessive use of fertilizer and pesticide. Indicator insects selected through investigation of insect species according to different agricultural environment will be used in environment evaluation. Moreover, research of insects capable of decomposition followed by fertilization of domestic animal excrement will be helpful for sustainable agriculture. The fire fly, of which mass production is almost achieved, and by which it is possible to estimate the agricultural environment, is a potential candidate for indicator insect, and the research of dung beetle and the dung fly is in progress for decomposition of domestic animal excrement.

Utilization of polliniferous insects for semi-artificial pollination.

There are over 41 thousand apicultural farmhouses which numbers more than 10-times of sericulture farmhouses. The market scale of apicultural procuct including honey reaches into over 100 billion won, much bigger than that of sericultural product. Nevertheless, Department of Sericulture and Entomology in NIAST is the only national organization in Korea, and only a few institute are involved in the apicultural research.

Last year, the market scale of polliniferous insects for fruits and vegetables is assumed to be 66 billion won in Korea. However, there are two kinds of problem in Korean apiculture. One is that use of honey bee is restricted in honey production itself in Korea, while the revenue from insect-mediated pollination is 50-times higher than that from honey production in America. Another is that Korean honey is insufficiently competent with America as well as Chinese. The other is the possibility of ecological disturbance by imported humble bee. Annually, the western humble bee is imported to the amounts of two billion won or more. It was realized that the western humble bees, which were expected to die during the cold winter in Korea, hibernated and were captured in the spring season in Korea.

With these aspects in mind, apicultural research should be focused on the development of the pollination techniques, by which bees used for pollination within limited facility and fruit garden can be reused for subsequent pollination. In addition to honey bee, research for mass-production of Korean carpenter bee is in progress.

Creation of new biomaterial industry

It is possible to utilize the compounds produced by insect and insect-related microorganisms as a biotic pesticide and health subsidiary food, and substitute medicine. Blood glucose lowering effect of silkworm powder and liver protection effect of silk fibroin are mostly well-known examples. Silkworm inoculated by Cordyceps pro-

duces the compounds that exert the effect against oxidation and fatigue. Moreover, several insects and their characteristic metabolites such as beetles for liver protection are on the edge of development as new materials.

In Japan, there was a trial for mass production of swine growth hormone using baculovirus as a vector, and it was considerably successful. On the other hand, National Institute of Sericultural & Entomological Science in Japan announced that they succeeded in culturing leaf curling-resistant rice by inserting gene that produces cecropin, antibacterial peptide in silkworm.

Industries that make insect-producing valuable compounds into medicines or that make insect itself into functional food will be promising in the future.

References

Asano, N., E. Tomioka, H. Kizy and K. Matsui (1994) Sugars with nitrogen in the ring isolated from the leaves of *Morus bombycis*. *Carbohyd. Res.* **254**, 235-245.

Ashida, M. and P. Brey (1995) Role of the integument in insect defense: pro-phenol oxidase in the cuticular matrix. *Proc. Natl. Acad. Sci. USA* **92**, 10698-10702.

Choi, J. H., D. I. Kim, S. H. Park, D. W. Kim, K. G. Lee, J. H. Yeo, J. M. Kim and Y. W. Lee (2000) Effects of silk fibroin on oxidative stress and membrane fluidity in the liver of SD rats. *Korean J. Seric. Sci.* **4**, 58-64.

Doi, K., T. Kojima and Y. Fujimoto (2000) Mulberry leaf extract inhibits the oxidative modification of rabbit and human low density lipoprotein. *Biol. Pharm. Bull.* **23**, 1066-1071.

Ferrari, F., B. Monacelli and I. Messana (1999) Comparison between *in vivo* and *in vitro* metabolite production of *Morus nigra*. *Planta Medica* **65**, 85-87.

Furuhata, K., D. Deno and M. Sakamoto (1997) Immobilization of alkaline phosphatase onto aminated silk fabrics. *J. Seric. Sci. Jpn.* **66**, 11-16.

Kim, S. Y., J. J. Gao, W. C. Lee, K. S. Ryu, K. R. Lee and Y. C. Kim (1999) Antioxidative flavonoids from the leaves of *Morus alba*. *Arch. Pharm. Res.* **22**, 81-85.

Kim, S. Y., K. S. Ryu, W. C. Lee, H. O. Ku, H. S. Lee and K. R. Lee (1999) Hypoglycemic effect of mulberry leaves with anaerobic treatment in alloxan-induced diabetic mice. *Kor. J. Pahrmacogn.* **30**, 123-129.

Kimura, M., F. Chen, N. Nakashiima, I. Kimura, N. Asano and S. Koya (1995) Antihyperglycemic effects of N-containing sugars derived from mulberry leaves in streptozonic-induced diabetic mice. *J. Trad. Med.* **12**, 214-219.

Lee, H. S., K. S. Chung, S. Y. Kim, K. S. Ryu and W. C. Lee (1998) Effect of several sericultural products on blood glucose lowering for alloxan-induced hyperglycemic mice. *Korean J. Seric. Sci.* **40**, 38-42.

Lee, S. M. (1998) Prospect of research development in the 21st century insect bio-I industrialization by the development of insect function. *Korean J. Seric. Sci.* **40**, 185-190.

Maeda S. (1997) Korean Society of Sericultural Science, 40th Anniversary Commemoration Symposium. pp. 73-101. Suwon, Korea.

Minamizawa, K. (1974) Science of mulberry cultivation, Meitho-sha, Japan Science Press. pp 157. Japan.

Nagaraju, J. and T. Kanda (1996) Attempt at transgenesis of the silkworm, *Bombyx mori*, by egg-injection of foreign DNA. *Appl. Entomol. Zool.* **31**, 587-596.

Park, Y. H. (1998) A recent trend in the resource development using silk fibroin. *Korean J. Seric. Sci.* **40**, 203-212.

Sahoo, Y., S. K. Pattnaik and P. K. Chand (1997) Plant regeneration from callus cultures of *Morus indica* L. derived from seedlings and mature plants. *Scientia Horic.* **69**, 85-98.

Vijaya Chitra, D. S. and G. Padmaja (1999) Clonal propagation of mulberry (*Morus indica* L. cultivar M-5) through *in vitro* culture of nodal explants. *Scientia Horic.* **80**, 289-298.