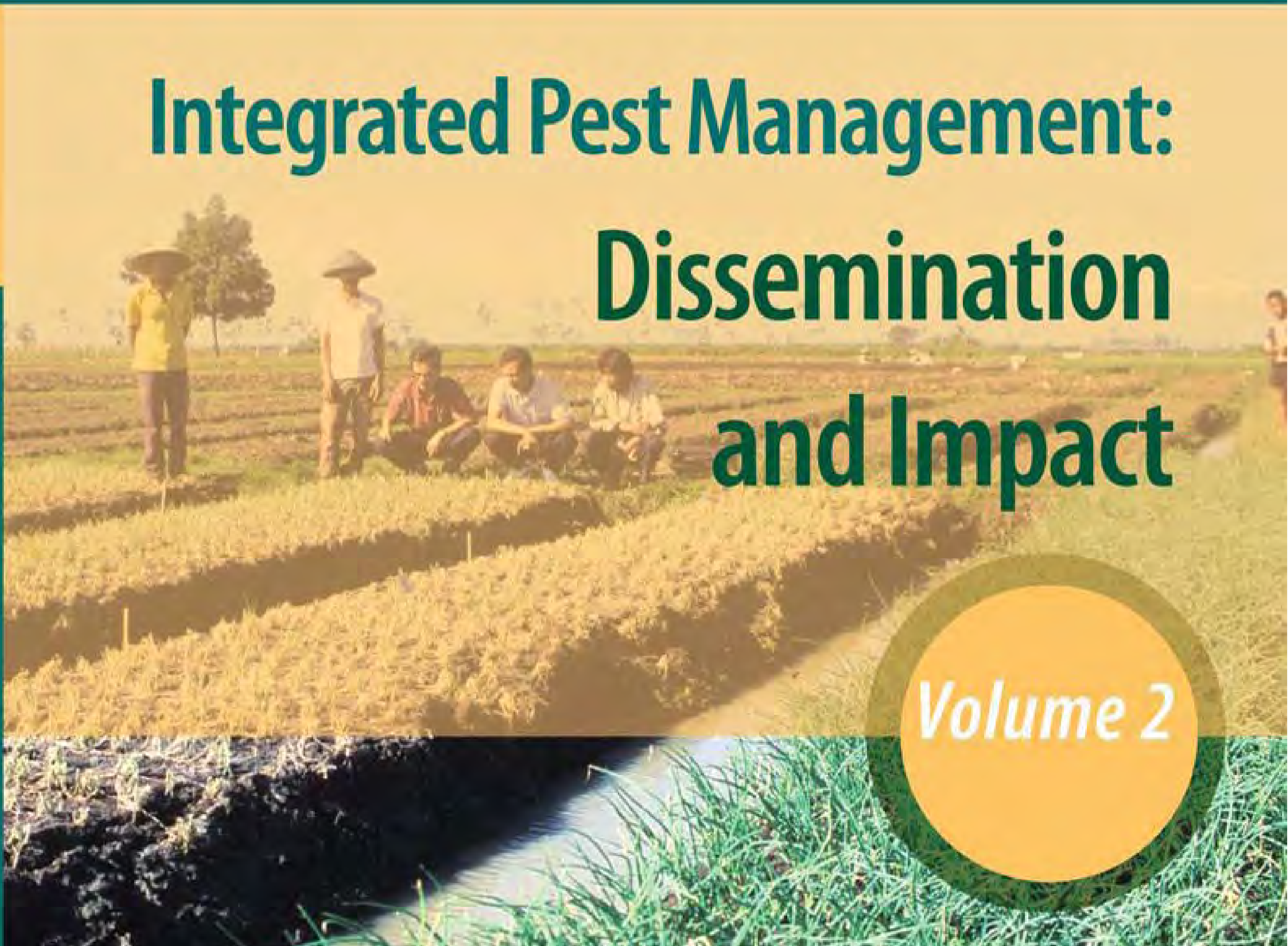
Rajinder Peshin
Ashok K. Dhawan
Editors

Integrated Pest Management: Dissemination and Impact



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Editors
Rajinder Peshin
Sher-e-Kashmir
University of Agricultural Sciences
and Technology of Jammu
Division of Agricultural Extension Education
FOA Chatha
Jammu-180009
India
rpeshin@rediffmail.com

Ashok K. Dhawan
Punjab Agricultural University
Department of Entomology
Ludhiana-141004
India
ashokdhawan@yahoo.com

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Farmer field school for vegetable IPM in Sibayak Valley, North Sumatra, Indonesia (Courtesy: Photo by Mike Hammig, Clemson University, Clemson, South Carolina, USA).

Onion beds where virus-infected *Spodoptera exigua* are used by farmers as spray in biological control program. Onion beds where virus was applied (right) compared to heavily damaged control where no virus was applied. Ciladug, West Java, Indonesia. (Courtesy: Photo by Merle Shepard, Clemson University, USA).

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For
Devansh, Udit, Sahil and Salil

Preface

Integrated Pest Management – Dissemination and Impact, Volume 2 is a sequel to Integrated Pest Management – Innovation-Development Process, Volume 1. The book focuses on the IPM systems in the developed countries of North America, Europe and Australia, and the developing countries of Asia, Latin America and Africa. One of the major impediments in the dissemination and adoption of the IPM innovation is the complexity of the technology and reaching the vast population of farmers especially in the developing countries. The IPM-innovation development process is incomplete without the diffusion and adoption of IPM methods by the end users, and through its consequences. In spite of all the efforts in the developed and developing countries, the adoption of IPM is still low with few exceptions.

The book covers the underlying concepts and methodologies of the diffusion of innovation theory and the program evaluation; and reviews the progress and impact of IPM programs implemented in the industrialized, the green revolution and the subsistence agricultural systems of the world. Forty-four experts from entomology, plant pathology, environmental science, agronomy, anthropology, economics and extension education from Africa, Asia, Australia, Europe, North America and South America have discussed impact of IPM with an interdisciplinary perspective. Each one of the experts is an authority in his or her field of expertise. The researchers, farmers' education, supporting policies of the governments and market forces are the elements of the IPM innovation system to achieve wider adoption of IPM strategy in agriculture.

The diffusion theory and adoption of the IPM innovation is discussed in the first chapter to provide theoretical foundation to biological scientists for developing farmers' compatible IPM systems. Protocols for evaluation to measure socio-economic impact of the IPM programs are provided in Chapters 2 to 4. Identifying the farmers' needs, attitudes and skills for developing location specific IPM technology is detailed in Chapter 5. Implementation of IPM programs, farmers' education in the context of developed, and developing countries are documented in Chapters 6 and 7. The focus of Chapter 8 is on the impact of extension in disseminating IPM technology to smallholder farmers. The implementation, impact and the impediments of IPM programs in the green revolution lands of Asia and Latin America, and subsistence agriculture of sub-Saharan Africa is the focus of Chapters 9 to 13. The insight into the IPM programs in Europe and the initiatives of the European Union in popularising integrated protection in its member states, the IPM programs in Russia and the Commonwealth of Independent States, tracking down the history of IPM in erstwhile USSR are covered in Chapters 14 and 15. Dissemination and impact of IPM technology in the US agriculture is discussed in the subsequent Chapter 16. To explore the advances in IPM with respect to introduction of transgenic in Chinese and Australian agriculture and the controversy surrounding the trangenics and its compatibility with IPM, Chapters 17 to 19 have been included. The world food shortage because of conversion of agriculture crops like corn and soybean for production of bio-fuels in the USA is one of the hotly contested issues. The concluding chapter on IPM, bio-fuels and a new green revolution provides an insight to the changes in the patterns of agriculture in the USA. Renewed efforts are needed to develop the IPM innovation system for the wider adoption of IPM.

We are indebted to the contributing authors whose thought provoking insight, cooperation and guidance made it possible to realise the dream of updating IPM literature from an interdisciplinary and global perspective. We owe a great deal to Prof. A. K. Tiku for his insight in bringing out these two volumes. The book provides an invaluable resource material to the scientists, professionals, students, program planners, farmers and market forces.

Rajinder Peshin
Ashok K. Dhawan

Contents

Contributors

Jesus Alcazar International Potato Center (CIP). Integrated Crop Management Division, Apartado 1558, Lima 12, Peru, J.Alcazar@cgiar.org

Jeffery W. Bentley Agricultural Anthropologist, International Consultant, Casilla 2695, Cochabamba, Bolivia, jefferywbentley@hotmail.com

Ernst F. Boller Swiss Federal Research Station of Horticulture, Agroscope ACW, CH-8820 Wädenswil, Switzerland, ernst.boller@acw.admin.ch

Bernard L. Canapi International Rice Research Institute, Los Baños, Philippines bernardlcanapi@yahoo.com

G. R. Carner Department of Entomology, Soils and Plant Sciences, Clemson University, Clemson, South Carolina, 29634, USA, gcarner@clemson.edu

A. K. Dhawan Department of Entomology, Punjab Agricultural University, Ludhiana 141004, India, dhawan@sify.com

R. Dilts Environmental Services Programme, Jl. Slamet Riyadi, No. 6., Medan, North Sumatra, Indonesia, Russ_Dilts@dai.com

Gary Fitt Commonwealth Scientific & Industrial Research Organization (CSIRO) Entomology, Long Pocket Laboratories, 120 Meiers Indooroopilly, Qld, Australia 4068, Gary.Fitt@csiro.au

Bernd Freier Julius Kuehan Institute (JKI), Federal Research Centre for Cultivated Plants, Institute for Strategies and Technology Assessment in Plant Protection, D-14532 Kleinmachnow, Germany, bernd.freier@jki.bund.de

George B. Frisvold Department of Agricultural and Resource Economics, 319 Cesar Chavez Building, University of Arizona, Tucson, AZ 85721, USA, frisvold@ag.arizona.edu

Kevin D. Gallagher Food and Agriculture Organisation, FAO Representative in Sierra Leone, Kevin.Gallagher@fao.org

Kristopher L. Giles Department of Entomology and Plant Pathology, Oklahoma State University, Stillwater, OK 74075, USA, kris.giles@okstate.edu

M. D. Hammig Department of Applied Economics and Statistics, Clemson University, Clemson, South Carolina, 29634, USA, mhammig@clemson.edu

Arnold van Huis Laboratory of Entomology, Wageningen University, PO Box 8031, 6700 EH Wageningen, The Netherlands, arnold.vanhuis@wur.nl

K. S. U. Jayaratne Department of Agricultural and Extension Education, North Carolina State University, 214 Ricks Hall Raleigh, North Carolina, 27695–7607 USA, jay_jayaratne@ncsu.edu

Janice Jiggins Communication and Innovation Studies, Wageningen University Research, The Netherlands, janice.jiggins@inter.nl.net

Rajinder Kalra Department of Extension Education, Punjab Agricultural University, Ludhiana 141004, India, rajinderkaurkalra@yahoo.com

David Kelly Cotton Seed Distributors, PO Box 1121, Goondiwindi QLD, Australia, 4390, dkelly@csd.,net.au

Peter E. Kenmore Chief Plant Protection Service of Food and Agriculture Organisation Viale delle Terma di Caracalla, Rome 00153, Italy, Peter.Kenmore@fao.org

Jürgen Kroschel International Potato Center (CIP). Integrated Crop Management Division, Apartado 1558, Lima 12, Peru, j.kroschel@cgiar.org

Edgar M. Libetario Philippine Rice Research Institute, Muñoz, Philippines, edmlibetario@yahoo.com

James A. Litsinger IPM and Farming Systems Specialist, California, USA; 1365 Jacobs Place, Dixon CA 95620 USA, jlitsinger@thegrid.net

Francesca Mancini IPM Specialist, Sustainable Agriculture & Farmer Education FAO, TST Office Tarnaka, Hyderabad, Andhra Pradesh, India mancini_fao@sify.com

Edhi Martono Department of Plant Protection, Faculty of Agriculture, Gadjah Mada University, Bulaksumur, Yogyakarta 55281, Indonesia, aunu@indo.net.id edmart35@hotmail.com

Robert Mensah New South Wales Department of Primary and Cotton Catchment Communities CRC, Australian Cotton Research Institute, Narrabri, NSW, Australia, 2390, robert.mensah@dpi.nsw.gov.au

George W. Norton Agricultural and Applied Economics, Virginia Polytechnic Institute and State University, 205-B Hutcheson Hall, Blacksburg, VA, 24061, USA, gnorton@vt.edu

Peter A. C. Ooi Regional Director of Asian Regional Center for AVRDC-The World Vegetable Center, Bangkok, Thailand, peter.ooi@worldveg.org

Ricardo Orrego International Potato Center (CIP). Integrated Crop Management Division, Apartado 1558, Lima 12, Peru, r.orrego@cgiar.org

Oscar Ortiz International Potato Center (CIP). Integrated Crop Management Division, Apartado 1558, Lima 12, Peru, o.ortiz@cgiar.org

Yi Pang Research Institute of Entomology, School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China, pangy@mail.sysu.edu.cn

John H. Perkins The Evergreen State College, Olympia, WA 98505, USA, perkinsj@evergreen.edu

Rajinder Peshin Division of Agricultural Extension Education, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Chatha, Jammu-180009, India, rpeshin@rediffmail.com

Willy Pradel International Potato Center (CIP). Integrated Crop Management Division, Apartado 1558, Lima 12, Peru, w.pradel@cgiar.org

A. Rauf Department of Plant Pests, Bogor Agricultural University (Institute Pertanian Bogor), Bogor 16680, Indonesia, aunu@indo.net.id

B. M. Shepard Clemson University, Coastal Research and Education Center, 2700 Savannah Highway, Charleston, South Carolina, 29414, USA, MSHPRD@exchange.clemson.edu

Gurdeep Singh Department of Entomology, Punjab Agricultural University, Ludhiana 141004, India, sidhu_gurdeep79@yahoo.co.in

J. P. Smith Clemson Cooperative Extension Service, Clemson University, 605 Main St., Suite 109, Lexington, South Carolina 29072, USA, jpsmith@clemson.edu

Eugeny S. Sugonyaev Laboratory Experimental Entomology and Bio-control, Zoological Institute, Russian Academy of Sciences, 199034 St. Petersburg, Russia, sreznik@zin.ru

Scott M. Swinton Department of Agricultural, Food and Resource Economics, Michigan State University, East Lansing, MI 48824–1039, USA, swintons@anr.msu.edu

J. Vasanthakumar Department of Agricultural Extension, Annamalai University, Annamalainagar, Chidambaram, India,
kumarjv.in@gmail.com

Kamal Vatta Department of Economics and Sociology, Punjab Agricultural University, Ludhiana 141004, India, kmlvatta@yahoo.com

Nathan R. Walker Department of Entomology and Plant Pathology, Oklahoma State University, Stillwater, Oklahoma 74075, USA, nathan.walker@okstate.edu

Lewis Wilson CSIRO Plant Industry and Cotton Catchment Communities CRC, Australian Cotton Research Institute, Narrabri, NSW, Australia, 2390, lewis.wilson@csiro.au

WenJun Zhang Research Institute of Entomology, School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China, zhwj@mail.sysu.edu.cn

Chapter 18
Impact of IPM and Transgenics in the Chinese Agriculture

WenJun Zhang and Yi Pang

Abstract The cultivation of transgenic pest-resistant crops may reduce pesticide application, improve production and increase economic benefit. Breeding and planting transgenic pest-resistant crops is expected to be a promising way to control pests.

Pest-resistant transgenic researches in China began in the early 1990s. In 1992, China developed the country's first Bt protein gene (CryIA gene) with the intellectual property right of its own. Up till now, the exogenous genes, such as Bt protein gene, trypsin inhibitor gene (CpTI gene), etc., have been transformed into cotton, and more than 50 commercially approved transgenic cotton varieties were developed. Since the 1970s, with the widely uses of chemical pesticides in cotton production, the pesticide-resistance of cotton bollworm (*Helicoverpa armigera* (Hübner)) dramatically enhanced. Cotton acreage in China declined from 6.835 million ha in 1992 to 4.985 million ha in 1993. In subsequent years, cotton bollworm seriously occurred every year. Since 1998 the adoption of insect-resistant varieties has effectively controlled the outbreak of cotton bollworm. Since the late 1990s, the cultivation area of transgenic insect-resistant cotton in China has been rapidly expanding, and its proportion in the total domestic cotton planting area has been increasing year by year. In 1998, transgenic insect-resistant cotton began to be planted in the Yellow River valley, and that year's acreage reached 240,000 ha, only 5.4% of the total cotton planting area; The planting area increased to 647,000 ha, 1.2 million ha, 1.933 million ha, 1.867 million ha, 3.067 million ha, and 3.104 million ha in the years 1999–2004, accounting for 17%, 31%, 40%, 45%, 60%, and 50% of the total area, respectively. The planting area of domestic transgenic insect-resistant cotton accounted for 30%, 60%, and 70% in the years 2002–2004. Due to the cultivation of transgenic insect-resistant cotton, pesticide application in China reduced by 123,000 t and cotton yield increased by 9.6% during the three years 1999–2001. Currently, almost all of the planted cotton in Hebei, Henan, and Shandong Province is transgenic insect-resistant cotton. In the Yangtze River valley, transgenic insect-resistant hybrid cotton holds the dominant position and its planting

W.J. Zhang (✉)
Research Institute of Entomology, School of Life Sciences, Sun Yat-sen University, Guangzhou 510275, China
e-mail: zhwj@mail.sysu.edu.cn

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area has been growing in the past years. So far, the total planting area of transgenic insect-resistant cotton in China has reached 4.667 million ha, with an average income of 2,130∼2,400 RMB Yuan/ha. Annual reduction in chemical pesticide application reaches 20,000∼31,000 t, equivalent to 7.5% of China's annual total production of chemical insecticides. Breeding of transgenic insect-resistant rice in China developed quickly in the past years. To date, CryI, CpTI, and GNA genes, etc., have been transformed into the rice, and some insect-resistant rice varieties (strains) were developed in China. They can be used to suppress rice insect pests such as *Chilo suppressalis* (Walker), leafrollers, and brown planthopper. Researches showed that the adoption of transgenic insect-resistant rice can reduce 70∼80% of insecticide application and would not affect the rice biodiversity. From recent years' field trials in Hubei and Fujian, indicated that insecticides were seldom used throughout the growing season and rice yield can increase by 12%. So far, the safety evaluations and experiments on the commercial production of transgenic insect-resistant rice have not yet showed any significant security issues. However, as rice is the main food crop in China, the application for commercialization of transgenic rice has never been approved. In addition to cotton and rice, the insect-resistant transgenics for wheat, soybean, maize, and other crops have being made in China. China has imported some of the transgenic crops and resulted in certain impacts. For example, due to the low production cost and better quality, the transgenic soybean of the United States exhibits the obvious economic advantages. The import of transgenic soybean of the United States resulted in the serious stock of domestic soybean production, and undermined the economic interests of Chinese farmers.

So far, the most significant negative impacts for planting transgenic insect-resistant crops, in particular cotton, are the outbreak of secondary pests and the impairment of arthropod community, etc. Due to the problems of planting transgenic insect-resistant crops, such as the narrow insect-resistance spectrum, the increased resistance of insect pests to transgenic crops, the possible outbreak of secondary insect pests, and the potential environment and biodiversity risks, it is necessary to follow IPM principles and combine the other control measures. Chinese scientists have summarized the practical problems in planting transgenic insect-resistant crops and explored various IPM measures, such as resistance management, intercropping, seed purifying, protection of natural enemies, etc., to address these problems. The IPM measures have being implemented in China.

Keywords Transgenics · IPM · insect pests · resistance · agriculture · China

18.1 Introduction

A major way to achieve greater crop yields is to minimize the pest associated losses, which are estimated at 14% of the total agricultural production: 84% in cotton, 83% in rice, 74% in potato, 59% in maize, 58% in soybean, and 52% in wheat (Oerke et al. 1994; Sharma et al., 2000). Transgenic pest-resistant crops are strongly lethal to pests. Transgenic pest-resistant crops are the plants carrying exogenous pest-resistant genes that artificially separated, constructed, and introduced into plant, which can be efficiently expressed in vivo and can maintain the genetic stability, and through which plants may synthesize not less than one kind of substance that are toxic to specific pests (Gu et al., 2005; Xiong et al., 2006). Breeding and planting transgenic pest-resistant crops is a promising way to control pests. Cultivating transgenic pest-resistant crops provides a new way to reduce pesticide application, improve production and increase economic benefit (Qiu et al., 2005; Wang et al., 2006).

Transforming pest-resistant gene and constructing transgenic pest-resistant crops must be conducted through such techniques as gene gun, *Agrobacterium*-mediated transformation, PEG, electroporation, and other methods (Zhang et al., 2001). There are currently three kinds of the most studied insect-resistant genes (Gu et al., 2005): (1) *Bacillus thuringiensis* (Berliner) (Bt) toxic protein gene. The Bt gene has many different strains and the δ-endotoxin gene within different strains is specific to different insects. Bt has been discovered to have more than 60 sub-species, and their genes are in general classified as six major categories in accordance with their insecticidal spectrum, of which CryI is only toxic to lepidopterans, CryII is toxic to lepidopterans and coleopterans, CryIII is only toxic to coleopterans, CryIV is only toxic to dipterans, CryV and CryVI are specifically toxic to nematodes. The insecticidal crystal protein that resists hymenopterans and nematodes has also been discovered (Hu et al., 2006). At present transgenic Bt crops account for the largest proportion of transgenic insect-resistant crops. In the United States alone, there are dozens of crops for field experiments. As early as in 1997, Bt cotton, Bt maize and Bt potato were commercially produced in the United States, Australia, Japan, Canada, South Africa, Argentina and some of the European countries (Sun et al., 2002). The Bt crystal protein is toxic to insects. It will be hydrolyzed into toxic peptides in the alkaline intestinal environment after it was fed by insect, and thus the intestinal epithelial cells and organs can be damaged. (2) Protease inhibitor (PI) gene. Plant protease inhibitors are the most abundant proteins in the nature. They are abundant in the seeds and tubers of plants. Currently used genes of plant protease inhibitors in breeding of transgenic insect-resistant cotton, which have been transformed into plants, include soybean trypsin inhibitor gene (SKTI), cowpea trypsin inhibitor protein gene (CpTI), and Arrowhead trypsin inhibitor protein gene (API). Compared with Bt gene, they exhibit certain advantages, such as the broader spectrum of insect-resistance, no side effects on human, and the lower insect tolerance, of which CpTI was studied in-depth and widely used at present. CpTI gene exhibits a broader spectrum of insect-resistance. It is resistant to spodopterans, the Chrysomelidae insects, the Sphingidae insects, and cereal insects. It can kill cotton bollworm (*Helicoverpa armigera* (Hübner)), the Curculionidae insects, and corn borers, and is toxic to locusts. Once the insect feeds on protease inhibitor, the later can affect the normal digestion of food protein. Meanwhile, EI composite formed by protease inhibitor and digestive enzymes stimulates the excessive secretion of digestive enzymes, and through feedback from the nervous system the insect yields anorexia reaction, ultimately causing the abnormal development and death of the insect. (3) Exogenous lectin gene. Exogenous lectin is a protein widely existed in the plant tissue. It is particularly rich in storage organs and reproductive organs. Once it is fed by insect it will be released from the digestive tract and will be combined with the glycoprotein on gastrointestinal membrane, and thus retard the normal absorption of food nutrients. Meanwhile, it will likely induce disease lesions in the digestive tract, promote the proliferation of digestive bacteria, and thus kill the insect. In addition to the above three types of genes, there are several additional genes, like the amylase inhibitor gene, insect neural hormone gene, chitinase gene, ribosomal protein inactivation gene, lipoxygenase gene, disease infection gene of cotton bollworm, synthesis gene of toosendanin, and peroxidase gene, are available.

The first transgenic crop born in 1983. In 1986, Abel and his colleagues firstly obtained a CP gene transgenic TMV-resistant tobacco plant. In 1987 the Belgian scientists firstly reported the transformation of exogenous insect-resistant gene to tobacco (Vaeck et al., 1987), followed by Barton (Barton et al., 1987) and the Monsanto's Fischhoff (Fischoff et al., 1987), who reported their transgenic insect-resistant tobacco and tomato plants. Transgenic rice plants also came out in 1988. All of these achievements created a new area for plant pest-resistance breeding (Zhang et al., 2001; Sun et al., 2002). In 1993 the transgenic tomato featured by fresh preservation and ripening delay, developed by Cagene, was licensed for marketing in the United States, which initiated the commercial application of transgenic crops in the world. Up till now a variety of insect-resistant genes have been transformed into tobacco, rice, maize, cotton, potato and other crops, and insect-resistant transgenic plants were obtained. Some transgenic insect-resistant plants have been licensed for commercial production or for field releases (Hu et al., 2006).

So far, the global transgenic crops for commercial cultivation include soybean, maize, cotton, rapeseed, potato, tobacco, tomato, pumpkin, and papaya, etc. Most of them carry insect-resistant genes; about 18% of transgenic maize varieties (lines) carry insect-resistant genes, while the other varieties contain both herbicide-tolerant and insect-resistant genes; 73% of the transgenic soybeans, maizes and rapeseeds have herbicide-tolerant genes. In 2002, transgenic soybeans and rapeseeds were all herbicide-tolerant; and 32% of transgenic cottons were herbicide-tolerant. The major transgenic crops that resist both herbicides and insects are maize and cotton. Transgenic crops with both herbicide-tolerant and insect-resistant traits in the world account for about 8% of total planting area (Yang et al., 2005). According to the statistics, in 2004 there were 14 countries with planting area of transgenic crops larger than 50,000 ha. From the largest to the smallest acreage, they were the United States, Argentina, Canada, Brazil, China, Paraguay, India, South Africa, Uruguay, Australia, Romania, Mexico, Spain, and the Philippines. In 1996 transgenic plants began to be commercially produced, and the planting area in that year was 1.7 million ha. After about 10 years' development, it reached more than 81 million ha in 2004 (Zhu and Ni, 2006), and reached 114.3 million ha in 2007 (ISAAA, 2007).

In China, as early as the 1950s, the insect-resistant wheat varieties "Xinong 6028" and "Nanda 2419" were cultivated to control wheat midges (Wang et al., 2006). In 1987, the transgenic insect-resistant Bt tobacco and tomato were obtained for the first time. In 1991, China's "863" high-tech development plan initiated a project on transgenic insect-resistant crops, and then the state transgenic plant projects, the special fund for cotton production from the Ministry of Agriculture, Chinese agricultural science and education fund, and the industrialization projects of National Planning Commission were sequentially implemented in China. In 1992 the CryIA insect-resistant gene with independent intellectual property right was artificially synthesized in China, which made China the second country after the United States for independently constructing the insect-resistant gene with intellectual property right (Qing and Zhao, 2004; Xia et al., 2004).

At present, nearly 50 transgenic plant species, involved about 100 genes, are being studied in China. Many of the pest-resistant genes and the genes related to resilience, yield, quality and fresh preservation have been cloned, seven BYDV-resistance, powdery mildew-resistant, and wheat scab-resistant wheat varieties have been validated, and the accumulated planting area has reached 100×10^4 ha (Yang et al., 2005). More than 100 genes, involved about 50 transgenic plant species like rice, wheat, maize, soybean, potato, peanut, poplar, papaya, tobacco, sweet melon, and pepper, etc., are being at different stages of development (Yang et al., 2005). The plants such as cotton, tomato, sweet pepper, and *Petunia hybrida* (Vilm), etc., genetic engineering vaccines, and some microorganisms for forage uses, were licensed for commercial production. Cotton, soybean, tobacco, tomato, pepper, potato, rice, cucumber, poplar, maize, and several microorganisms have been approved for environmental release. In February 2004, the Ministry of Agriculture of China issued the notice No. 349 for safety certificates of the first batch of imported agricultural transgenic organisms, including the transgenic Kangnonda soybean applied by Monsanto, the transgenic insect-resistant and herbicide-tolerant maize, transgenic insect-resistant cotton, and herbicide-tolerant cotton (Wang et al., 2005). Currently, the development of transgenic insect-resistant cotton and rice in China has been at the advanced level in the world (Zhang et al., 2004).

18.2 Pest-resistant Transgenics and Its Impact

18.2.1 Transgenic Insect-Resistant Cotton

18.2.1.1 Breeding of Transgenic Insect-Resistant Cotton

China is a major country of cotton production in the world. Since the 1920s, China has started to collect cotton germplasm resources. China's cotton germplasm resources were further expanded and enriched through numerous surveys, collection, and exchanges on international cotton germplasm (Gu et al., 2005). In order to find ways to control cotton bollworm, China's "863" high-tech development plan approved the "transgenic insect-resistant cotton" research in 1991. In 1992, the Chinese Academy of Agricultural Sciences (CAAS) synthesized an insect-resistant Bt gene, i.e., CryIA gene, which was different from the one of Monsanto in the United States, and obtained China's own intellectual property right. Collaborating with Shanxi Academy of Agricultural Sciences and Jiangsu Academy of Agricultural

Sciences, CAAS transformed the modified CryIA gene into cotton and obtained the engineering plants with high resistance to cotton bollworm. Moreover, the whole sequence of Bt insect-resistant gene was artificially synthesized and a high efficient expression vector was successfully constructed based on Bt protein active site and the principle of codon preference (Kong et al., 2004; Gu et al., 2005). In 1993, by using *Agrobacterium*-mediated transformation and a new invented method, the pollen tube channel technique, the insect-resistant gene constructed earlier were successfully transformed into the major cotton varieties in China, Zhongmian 12, Simian 3, etc., and yielded a positive response in the molecular detection. Their insect-resistance surpassed 90% in the biological test on pesticide. Meanwhile, the transgenic cotton strain with higher insect-resistance was obtained, which made China become the second country to artificially synthesize insect-resistant gene and transform it into cotton in the world. Since 1995, the construction of the insect-resistant gene has developed to bivalent gene from monovalent gene. Cotton researches on bivalent insect-resistant gene were conducted. CryIA + CpTI genes were transformed into a number of dominant cultivars and produced some bivalent transgenic cotton lines, and were approved for commercial production (Qing and Zhao, 2004). At the same time, China began to construct genes for improved quality and yield. The promoters for the expression of green top tissue and phloem tissue, genital-specific expression, fiber and boll skin specific gene expression, etc., were successfully developed. All of these works laid a solid foundation for the correct expression of functional genes, the improvement of growth and traits of cotton development, and the improvement of cotton yield and quality. Besides common used *Agrobacterium*-mediated transformation and gene gun methods, Chinese scientists invented the method of pollen tube transformation. The transformation rates for three methods reached 5%, 8% and 5%, respectively; transformation efficiencies increased by 4%, 3%, and 1%; and transformation cycle was shortened to 4.5–7 months; more than 10,000 transgenic plants were constructed. The pipeline operation for plant genetic transformation was initially realized (Xia et al., 2004).

Until 2006, China has bred 52 cotton varieties (lines), of which 21 varieties passed safety evaluation, and 12 varieties passed validation. In these varieties (lines), another 7 insect-resistant hybrid cotton varieties and 3 bivalent transgenic insect-resistant cotton varieties were included. Moreover, Hebei Province and Anhui Province have also founded joint ventures with the Delta Cotton Company of the United States and imported seven transgenic insect-resistant cotton varieties (Xiong et al., 2006).

18.2.1.2 Insect-Resistant Effect of Transgenic Cotton

An on-site investigation and field survey in China indicated that the number of eggs of cotton bollworm on Bt cotton and conventional cotton had not significant difference (Wang et al., 1999; Xu et al., 2004), but there was a significant difference in the residual number of larvae; the number of larvae on Bt Cotton was significantly lower than that on conventional cotton. Bt cotton would not yield any significant impact on the occurrence of cotton aphid, *Aphis gossipi* (Glover) (Wang et al., 1999).

Different tissues and organs of the insect-resistant cotton exihibit different resistance capacity to cotton bollworm. Insect-resistance of vegetative organs is stronger than that of reproductive organs. The general orders of the resistance to larvae of cotton bollworm is: mature leaves > young leaves > boll > young boll > flower (Zhang et al., 2001; Pei et al., 2005). Bt cotton has a strong resistance to younger larva, particularly the 1st instar larva, and the resistance capacity tends to be weak as the increase of instars.

According to the surveys, the resistance capacity of transgenic Bt cotton to cotton bollworm declined steadily as the growth and development of cotton plant (Chai et al., 2000). The resistance of transgenic Bt cotton plant to the larva of cotton bollworm was 97%, 72%, 48% on June, July, August, and September, respectively (Zhang et al., 2001). Resistant effects of bivalent cotton (CryIA + CpTI) to sensitive and resistant strains of cotton bollworm may remain on “very strong resistance” and “strong resistance” levels respectively, and resistance level of the boll of bivalent cotton was significantly higher than Bt cotton, which demonstrated the obvious advantages of bivalent cotton over Bt cotton (Fan et al., 2001; Xu et al., 2004). Application value of bivalent cotton in IPM is not only maintaining a certain level of control effect on the target insects with certain resistance to bivalent cotton, but also slowing down the development of insect’s resistance to bivalent cotton, because bivalent cotton can simultaneously express two distinct genes with different resistance mechanisms.

Most of the transgenic insect-resistant cottons contain Bt gene only. Bt cottons show a narrow insect-resistance spectrum and mainly control a few lepidopterans as cotton bollworm, pink bollworm (*Pectinophora gossypiella* (Saunders)), etc. They have only weak resistance to the larvae of *Spodoptera exigua* (Hübner), and *Agrotis ypsilon* (Rottemberg) (Dong et al., 1996; Xia et al., 2000). Bt cottons are not effective to most of the insect pests fed on cotton (Kong et al., 2004; Miao et al., 2004; Gu et al., 2005; Xiong et al., 2006; Huang et al., 2007).

Even to target lepidopterans such as *Spodoptera litura* (Fabricius), the bivalent cotton varieties like Zhongmiansuo 45 and 41, etc., show a weak resistance only (Huang et al., 2006). Transgenic insect-resistant cotton could mildly inhibit cotton aphid, whitefly (*Bemisia tabaci* (Gennadius)), *Lygocoris lucorum* (Meyer-Dür), *Empoasca flavescens* (Fabricius), and other non-target insects while preserving a strong resistance to cotton bollworm (Zhang et al., 2001; Zhou et al., 2004). However, it was also reported that transgenic insect-resistant cotton was not effective on such sucking insect pests as cotton aphid, red mite (*Tetranychus cinnabarinus* (Boisduval)), the Miridae insects, and their occurrence tended to be more serious (Wang et al., 1999; Chen, 2006).

The gene expression of transgenic insect-resistant cotton is unstable with time and space, i.e., Bt crystal protein can be synthesized in all of the newborn cells but, newborn cells will decrease and the resistance will weaken with the growth and aging of cotton plant. Thus, the insect-resistance of transgenic cotton will decline as the growth of cotton, i.e., the resistance capacity will be mainly released in the first and second generations of cotton bollworm, and it will significantly decline in the third and fourth generations (Zhang et al., 2001; Wang et al., 2002; Xiong et al., 2006). As a consequence, IPM is still needed in the late phase of cotton growth.

18.2.1.3 Impacts of Transgenic Insect-Resistant Cotton on Community Structure and Arthropod Diversity

Biodiversity is an important natural control mechanism on insect pests in cotton field. There are many kinds of natural enemies in the cotton fields of China. China scientists have conducted a number of surveys and trials to understand the impacts of transgenic insect-resistant cotton on community structure and arthropod diversity in cotton fields (Pei et al., 2005).

According to a field survey, the evenness index of insect community in Bt cotton field was higher than conventional cotton field and insecticide treated cotton field; the diversity index on Bt cotton was the highest, seconded by that on bivalent cotton, conventional cotton, and insecticide treated cotton; the cultivation of bivalent cotton would not reduce the stability of insect community, and the stability of insect community, pest sub-community, and natural enemy sub-community would be improved; the populations of insect pests and natural enemies tended to be stable (Cui et al., 2006a). Due to the reduction of insecticide application in transgenic insect-resistant cotton field, the diversity of arthropod community in the middle and late phases of cotton growth were significantly improved, which is conducive to the stability of cotton ecosystem and IPM (Li et al., 2003a, b). It was also found that the structure of arthropod community was more stable in wheat-cotton intercropping system than in cotton system, the former demonstrated a stronger buffering capacity to environmental changes and population fluctuations (Xia et al., 1998).

A field investigation demonstrated that on average there were 15 insect families, 19 species in Bt cotton, 14 families, 17.5 species in conventional cotton field, and 13.5 families, 17.5 species in insecticide treated cotton field, were found respectively; The number of individuals of major insects in Bt cotton field was greater than that in conventional cotton field and insecticide treated cotton field. These results indicated that Bt cotton was conducive to the protection of biodiversity and ecosystem management in cotton field (Wang et al., 1999; Li et al., 2003). Another survey showed that there was no significant difference between transgenic cotton and conventional cotton in dominant natural enemies (Zhang et al., 2001). Bivalent cotton would not exert an obvious impact on predators; the individual number of some natural enemies, such as *Propylaea japonica* (Thunberg), *Chrysoperla sinica* (Tjeder), increased and became the dominant species in Bt cotton field (Cui and Xia, 1999; Zhou et al., 2004; Cui et al., 2006b). Bt cotton was also proved to exert a positive impact on *Harmonia axyridis* (Pallas) and *Erigonidium graminicolum* (Sundevall) (Cui et al., 2006b). Compared with the conventional cotton, planting transgenic Bt cotton would further proliferate predators by 24.0% (Xia et al., 1999). However, the number of some major natural enemies would be reduced (Zhou et al., 2004).

According to another field survey, the species richness of insect community in Bt cotton (110 species) was slightly higher than conventional cotton (109 species), and the relative abundance of insect pests (71.5%) in Bt cotton was lower than conventional cotton (73.1%); the species and abundances changed in Bt cotton field, the chewing insect pests such as cotton bollworm were effectively controlled, and the sucking pests such as red mite, the Miridae insects, cotton aphid and other secondary insect pests became the dominant pests (Xia et al., 1998).

To date most of the studies tended to demonstrate that the structure and composition of arthropod community could not be substantially changed in transgenic insect-resistant cotton field.

18.2.1.4 Impacts of Planting Transgenic Insect-Resistant Cotton on IPM and Economic Benefits

Based on a two years' questionnaire survey on 245 farmers in 6 counties, Hebei Province, Wu et al. (2005) conducted a comprehensive comparison on benefit-cost and IPM effects between transgenic Bt cotton and conventional cotton. The results showed that in 2002 and 2003, the cotton yield, pesticide cost, total cost and revenue of the transgenic Bt cotton variety were higher than conventional cotton. According to a report, during 1994–1998, the results achieved in the indoor, cages, field plots and field experiments demonstrated that planting transgenic Bt cotton and adopting some control measures in earlier, middle, and late phases of cotton growth would save insecticide application by 60∼80% as compared to conventional cotton (Xia et al., 1999). Transgenic Bt cotton varieties showed a better insect resistance in the seriously occurred area of cotton bollworm; resistance capacity was greater than 80%; Bt cotton demonstrated a good performance in yield; chemical insecticide application declined by 50∼80%, and there was not an obvious yield difference between Bt cotton and conventional cotton (Kong et al., 2004; Hu et al., 2006). In China, the insecticide application on transgenic insect-resistant cotton may be reduced by 24∼63 kg/ha compare to conventional cotton (Zhu and Ni, 2006). According to the statistics in China (Huang et al., 2002), during 1999–2001, about 12∼29% of the farmers planting conventional cotton varieties were poisoned by pesticide because they have exposed to a higher dosage of pesticides. However, only 5∼8% of the farmers planting Bt cotton varieties were poisoned by pesticides. Insecticide application was obviously lower on Bt cotton than on conventional cotton, and the insecticide application would be reduced by 70∼80% in some areas.

In the 20th century, cotton bollworm was the major pest to affect China's cotton production. Since the 1970s, with the widely uses of chemical pesticides in cotton production, the pesticide-resistance of cotton bollworm dramatically enhanced. In 1992, cotton bollworm seriously occurred in the Yellow River valley, which resulted in a direct economic loss of over 8 billion RMB Yuan and posed a serious threat on the steady development of China's cotton production. Cotton acreage in China declined from 6.835 million ha in 1992 to 4.985 million ha in 1993, a 27% sharp reduction. In subsequent years, cotton bollworm seriously occurred every year, and cotton production stagnated. A new insect-resistant Bt cotton variety, 33B, developed by Delta Cotton Company in the United States, and domestic insect-resistant varieties were used in cotton production in 1996 and 1998, and have effectively controlled the outbreak of cotton bollworm. China's cotton production thus started to be stabilized (Xia et al., 2004).

In 1997 the Ministry of Agriculture of China approved transgenic insect-resistant cotton varieties for environmental releases in five provinces Hebei, Henan, Jiangsu, Liaoning, and Xinjiang, and for commercial production in Shandong, Shanxi, Anhui and Hubei Province (Qing and Zhao, 2004). Since the late 1990s, the cultivation area of transgenic insect-resistant cotton in China has been rapidly expanding, and its proportion in the total domestic cotton planting area has been increasing year by year. In 1998, transgenic insect-resistant cotton began to be planted in the Yellow River valley, and that year's acreage reached 240,000 ha, only 5.4% of the total cotton planting area; The planting area increased to 647,000 ha, 1.2 million ha, 1.933 million ha, 1.867 million ha, and 3.067 million ha in the years 1999 to 2003, accounting for 17%, 31%, 40%, 45% and 60% of the total area, respectively, an average annual rate of over 10% (Xia et al., 2004; Fig. 18.1). The planting area of domestic transgenic insect-resistant cotton accounted for 30%, 60%, and 70% in the years 2002–2004. Due to the cultivation of transgenic insect-resistant cotton, pesticide application in China reduced by 123,000 t and cotton yield increased by 9.6% during the three years 1999–2001 (Zhang et al., 2004). Currently, almost all of the planted cotton in Hebei, Henan, and Shandong Province is transgenic insect-resistant cotton. In the Yangtze River valley, transgenic insect-resistant hybrid cotton holds the dominant position and its planting area is growing year by year (Zhu

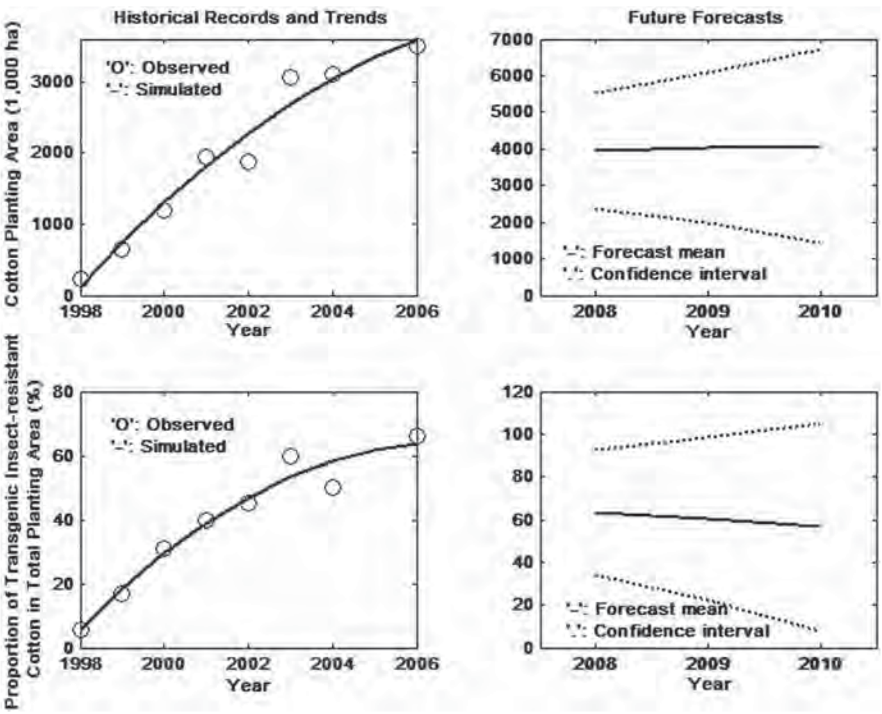

Fig. 18.1 Production situation of transgenic insect-resistant cotton in China. The forecasts for the years 2008–2010 were given by polynomial function (Mathworks, 2002). The 95% confidence intervals of the forecasts for the years 2008–2010 were also indicated

and Ni, 2006). So far, the total planting area of transgenic insect-resistant cotton in China has reached 4.667 million ha, with an average income of 2,130∼2,400 RMB Yuan/ha (Xiong et al., 2006). Annual reduction in chemical pesticide application reaches 20,000∼31,000 t, equivalent to 7.5% of China's annual total production of chemical insecticides. Cotton bollworm problem has become a history in China.

According to an estimate, the cultivation of transgenic insect-resistant cotton will annually yield the welfare of one billion US dollars for China (Yang and Li, 2006).

18.2.2 Transgenic Insect-Resistant Rice

18.2.2.1 Breeding of Transgenic Insect-Resistant Rice

Rice is the staple food crop in China. Rice stem borers (*Chilo suppressalis* (Walker), *Tryporyza incertulas* (Walker), *Cnaphalocrocis medinalis* (Guenée)) and rice planthoppers (*Nilaparvata lugens* (Stal), *Sogatella furcifera* (Horvath), *Laodelphax striatellus* (Fallen)) are the most important insect pests in rice fields of China. Insect-resistant resources are poor in rice. Therefore the breeding of transgenic insect-resistant rice varieties provides a new way for rice pest control (Feng et al., 2000; Wang et al., 2005).

As early as in 1989, Yang Hong, a Chinese scholar and colleagues transformed Bt gene into the protoplast of rice varieties Taigeng 209, Taipei 309, and Zhonghua 8 using protoplast fusion technology, and obtained the regenerated transgenic plants (Wang et al., 2004). So far, the countries that have been reported to successfully obtain transgenic rice plants include China, United States, Philippines, United Kingdom, Japan, and India, etc. The transformation technology goes to mature and transformation frequency increases gradually (Zhang et al., 2001). Currently, the major techniques for rice resistant gene transformation include gene gun method, followed by *Agrobacterium*-mediated transformation, PEG method, electroporation method; the most widely used genes are Bt toxin gene, pin, CpTI, and GNA gene, etc. (Wang et al., 2004).

In China, the scientists in Zhejiang University have transformated Bt gene CryIA (b), in which the codon had been optimized, into rice variety Xiushui 11 using *Agrobacterium*-mediated transformation. The Bt toxic protein expression of the resistant strain obtained accounted for 0.5∼0.3% of the total soluble protein, and can kill 100% of the 1st to 5th instar larvae of *C. suppressalis, C. medinalis*, and *Naranga aenescens* (Moore); it was also highly resistant to eight lepidopterans. The resistant strain has been formally named as "Kemingdao". A batch of insect-sensitive rice cultivars such as early indica rice Zhefu 504, Zhefu 123, Jiazao 935, late japonica rice Daoxiushui 63, Bing 9402, Bing 9311, and some of the indica-preserving strains and restoring strains, were transformed and some transformed plants were obtained. The transformed plants shared the similar agronomic traits with the original cultivars (Xiang et al., 1999; Cui et al., 2001). Zhu (2001) fused CpTI gene, signal peptide, and coding sequence on endoplasmic reticulum that localizes signal KDEL, and obtained the fusion gene signal-cpti-KDEL (SCK). Using the gene, some transgenic rice plants highly resistant to lepidopterans such as *C. suppressalis*, etc., including Minghui 81 and Minghui 86, were obtained. Hybrid combinations prepared from these plants have put into field trial. Tang et al. (2001) have transformed GNA (*Galanthus nivalis* (L. Agglutinin)) into japonica rice varieties Eryi 105 and Erwan 5 using gene gun method and obtained a batch of transgenic strains which could significantly reduce the survivorship, fecundity, and feeding amount, and retard the development of brown planthopper, *N. lugens*. Using gene gun technique, Feng et al. (2001) transformed alkaline chitinase genes RC24, RCH10, rice acidic chitinase genes RAC22 and alfalfa β-1,3-glucose enzyme gene (β-1, 2Glu) to indica rice varieties Qisiruanzhan, Teqing, Qimiaoxiang, Jiuliuling, and japonica rice variety Zhonghua 8, and obtained a batch of transgenic lines that were highly resistant to rice blast disease and rice sheath blight disease, such as Zhuzhuan 68 and 70, etc. Zhai et al. (2000) transformed Xa21 gene into China's five rice varieties using *Agrobacterium*-mediated method, and obtained preserving strains and restoring strains of the white blight disease resistant rice, Minghui 63, Yanhui 559, and Zhengshan 97B. Transgenic hybrid indica rice varieties Shanyou 63 and 559 were developed using these strains. The results demonstrated that the two transgenic hybrid rice varieties exhibited a broad-spectrum resistance, and their resistance spectrum was similar to IRBB, the XA21 gene source. Currently these hybrid combinations have been put into field trial. In addition to the above, there are many other examples for introducing insect-resistant genes into rice and obtaining insect-resistant plants (Wang et al., 2004). In recent years, the transgenic researches on Bt gene have been increasing. Transgenics has been successfully used in indica rice, fragrant rice, Java rice, hybrid rice, and deep-water rice. Bt rice has gone to the phase of environmental release. Some insect-resistant rice varieties that can be used in the rice production were expected (Wang et al., 2005).

Up till now, transgenic insect-resistant rice varieties (strains) are mainly effective to a few of lepidopterans like *C. suppressalis, C. medinalis*, and some homopterans as brown planthopper (Wang et al., 2005). Some transgenic rice varieties are resistant to rice blast, sheath blight, and bacterial blight, etc.

18.2.2.2 Impacts of Transgenic Insect-Resistant Rice on Community Structure and Arthropod Diversity

There are many arthropod species, including insect pests, natural enemies, and neutral species in and around the conventional rice field (Zhang et al., 2004; Zhang and Barrion, 2006; Zhang, 2007a,b,c; Fig. 18.2). A study made by Chinese scientist showed that Bt rice exhibited a stronger resistance to major target insect pests such as *C. suppressalis, T. incertulas*, and *C. medinali* (Han et al., 2006). Chen et al. (2004) tested the feeding and ovipostion behaviors of brown planthopper (BPH) on CryIA(b) transgenic indica rice, SCK transgenic rice restoring lines, and their respective parent controls. The results showed that three tested transgenic insect-resistant rice materials were unfavorable to BPH feeding, but no significant impact on oviposition of BPH. After two years of extensive field research, it was demonstrated that bivalent (CryIA(c) + SCK) rice would unlikely trigger the catastrophic outbreak of non-target BPH (Fu et al., 2003; Liu, 2004). Liu et al. (2005) investigated the impacts of bivalent rice and its hybrid offspring on insect pest community

Fig. 18.2 Conventional rice fields in Qinxing County, a famous scenic spot in Guangdong Province, China. Guangdong Province, adjacent to Hong Kong and Macau, is one of the most developed provinces in China. Agricultural intensification and excessive pesticide application has been threatening the food security and farmers' health in some areas of the province. Biodiversity in and around rice fields is always a stabilization mechanism for sustainable natural control of rice pests. Biodiversity conservation, biological control and pesticide use reduction are being implemented in Qinxing County and some other areas of Guangdong Province (Photo by W.J. Zhang, August 2007)

and found that bivalent rice was extremely resistant to rice leafroller, *C. medinali*; the hybrid offspring also exhibited the stronger resistance to the rice leafroller.

Transgenic insect-resistant rice yielded no significant impacts on development and growth of non-target insects, planthoppers, leafhoppers, predatory natural enemies, and on the stability of arthropod community in rice field (Jia et al., 2005; Han et al., 2006); it could increase the number of predatory arthropod individuals, and increase species richness in predatory arthropod sub-community (Fu et al., 2003; Liu, 2004). Liu et al. (2006) found that at the community level, bivalent insect-resistant rice had no significant negative impacts on species richness, diversity index, evenness index, predominant index, the temporal dynamics of these indices, and total number of individuals of parasitic wasps. However, transgenic rice could reduce individual number of parasitic wasps during mid-term of cotton growth. The number of individuals of parasitic wasps that parasitize the target pest, rice leafroller, but not other parasitic wasps, was significantly lower in transgenic rice field. Throughout the growing season there was no significant difference between Bt rice and conventional rice in both species and individual number of spiders (Cui et al., 2002; Liu et al., 2002; Qiu et al., 2005). Bt rice yielded no significant impacts on species composition and individual number of aquatic organisms (Chen et al., 2003b). The composition of major insect pests on bivalent rice were found to be similar to that on conventional rice; the reduction of target pest population had not obvious impacts on rice pest community and had not resulted in any changes of predominant insects (Liu et al., 2005).

18.2.2.3 Impacts of Transgenic Insect-Resistant Rice on IPM and Economic Benefits

The research showed that planting transgenic insect-resistant rice can reduce pesticide application by 70∼80% in China. Recent years' experiments conducted in Hubei, Fujian, and other provinces demonstrated that throughout the growing season the pesticide could basically not be used in transgenic insect-resistant rice field, and rice yield may rise by 12%. The effectiveness of insect-resistance of Bt rice has been evaluated under greenhouse conditions worldwide, despite the Bt rice is not licensed for planting in practice (Jia et al., 2005). In China, Bt rice has been put into field trials and environmental releases. So far, no obvious safety risks were found in the safety evaluation and experiments for commercial production of transgenic insect-resistant rice (Zhang et al., 2004; Wang et al., 2005). However, because rice is the staple food crop in China, genetically modified rice products have been cautiously treating in China (Wang et al., 2005). Since 2004, the application for commercial production of transgenic rice was annually submitted to the Biosafety Committee of Agricultural Transgenic Organisms for discussion, but they have never been approved due to serious disputes among various members.

According to an estimate, the cultivation of transgenic insect-resistant rice would annually bring China with three billion US dollars of welfare. If the planting percentage of transgenic rice increases from 50% to 80%, the national welfare would rise from 2.65 to 3.11 billion US dollars (Yang and Li, 2006).

18.2.3 Other Transgenic Pest-Resistant Crops

Transgenic maize holds an important position in the world. There are more than 20 lines for transgenic maize. The majority of them are herbicide-resistant maize; about 50% of them are both insect- and weed-resistant (Liu and Chen, 2005). In total of 17 transgenic maize varieties (lines) have been licensed for commercialization, and have achieved significant economic benefits. But transgenic maize meet some limitations and the successful cases for gene transformation are not common, due to the lower transformation frequency, poor repeatability, higher randomness, the dependence of regeneration capacity on genotypes, etc. (Li and Hu, 2006). Transgenic maize researches in China are still backward compared to the advanced international level, and there are not any commercial varieties up till now.

There are currently more than 10 commercial lines of transgenic soybean, of which the herbicide-resistant transgenic soybean is the main transgenic crop for commercial production. In 2000, the acreage of transgenic soybean accounted for

59% of all transgenic crops. As early as in 1994, Monsanto developed a transgenic soybean: glyphosate-resistant soybean, and has been licensed in the United States for human consumption.

Since mankind obtained the first transgenic wheat plant in 1992, the researches on transgenic wheat have achieved many significant advances. Approximately 200 cases on transgenic wheat have been reported at home and abroad, of which about 80 cases are transgenic herbicide-resistance wheat, about 50 cases are transgenic insect- or disease-resistant wheat, about 30 cases are transgenic quality-improvement wheat, about 20 cases are transgenic salt-tolerant and drought-resistant wheat, and other cases (Zhao et al., 2006; Table 18.1). For example, transforming aphid-resistant gene into wheat plants and thus inducing the differentiation of transgenic cells, finally obtaining the insect-resistant transgenic wheat plants, which are resistant to homopterans such as aphids, brown planthopper, and leafhoppers.

There are currently about 20 transgenic rapeseed strains for commercial production, and some of them are herbicide-resistant (Liu and Chen, 2005).

At present, transgenic soybean holds the largest growing area (58.60 million ha) in all of transgenic crops worldwide, seconded by maize (35.20 million ha), cotton (15.00 million ha), and rapeseed (5.50 million ha) (ISAAA, 2007). A growing proportion of transgenic maize and soybean are being used to manufacture bio-fuels.

In respect to the insect-resistant transgenic potato breeding in China, Bu et al. (2005) constructed an expression vector of diploid potato protease inhibitor II gene. Jiang (2001) constructed CryIB(a) plant expression vector, and transformed it into potato variety Desiree, which showed a high insect-resistance (Wu et al., 2006). CAAS has constructed CryIB (a3)+CryIIIA(a7) plant expression vector and obtained transgenic potato line. The results indicated that the insect-resistance of transgenic potato was improved significantly (Wu et al., 2006).

The pollen of transgenic CryIA gene maize was reported to yield no adverse effect on the survival of three species of predators, *Coleomegina acucatum, Orius insidious* (spp.), *Chrysoperla carnea* (Stephens) (Plicher et al., 1997; Duan et al., 2002; Wu et al., 2007). However, the Swiss scientists studied the impacts of Bt maize on *C. carnea*, and found that compared with the control, *C. carnea* feeding European corn borer that fed on Bt maize, showed a high mortality rate, and a sluggish development (Hibeck, 1998).

Table 18.1 Breeding status of some transgenic crops

	Reported cases	Proportion of total varieties (lines)		
Transgenic Crops	Wheat	Maize	Soybean	Rapeseed
	a + b (50 cases)	a (18%)	c (100%)	c (100%)
Pest-resistant types	c (80 cases)	a + c (82%)		
Main references	Zhao et al., 2006		Yang et al., 2005	

Note: The symbols a, b, and c mean insect-resistant, disease-resistant, and herbicide resistant, respectively. a + b means both insect- and disease-resistant. a + c means both insect- and herbicide-resistant Some data were derived from the authors.

18.3 Prospects and Risks of Transgenic Pest-Resistant Crops

18.3.1 Prospects on the Impacts of Transgenic Pest-Resistant Crops

The most direct impact of foreign transgenic crops on the plantation industry in China is the planting of transgenic soybean (Xiao, 2003). Due to the low production cost and better quality, the transgenic soybean of the United States exhibits the obvious economic advantages compare to China's soybean. The imports of China's soybean jumped to the 10.4191 million t in 2000 from 801 t in 1991, occupying a 21.4% of import volume in the world. The export fell to 211,000 t in 2000 from 1.109 million t in 1991. The import of transgenic soybean of the United States resulted in the serious stock of domestic soybean production, and undermined the economic interests of Chinese farmers (Xiao, 2003). In exception of wheat, the crops maize, wheat, cotton and oil will also face the impact of foreign transgenic products in the future, and the majority of them are expected to be transgenic varieties. Impacts of transgenic insect-resistant crops on IPM and economy of China should be frequently evaluated.

The main rice producing areas are distributed in the developing countries of Asia, and the major part of rice production is for local consumption. In 2000, China's rice production reached 0.188 billion t while rice import reached 458,900 t and export reached t 5.6801 million t. Annual trade volume of rice of China accounted for only 3.27% of total production. Thus the import and export of rice is expected to yield a small impact on rice production and IPM in China (Xiao, 2003).

18.3.2 Potential Negative Impacts of Planting Transgenic Pest-Resistant Crops

While transgenic pest-resistant crops, especially cotton, have been extensively planted in China, and have produced the significant economic and social impacts, however, there are also potential risks and negative impacts for planting transgenic pest-resistant crops and some have begun to exhibit the adverse consequences.

18.3.2.1 Impacts on Yield and Quality of Crops

Compared to conventional varieties, the yield and quality of transgenic insect-resistant cotton bred by China are not ideal, which further affect the economic gain of farmers. According to a survey in Jiangsu Province (Xu et al., 2004), despite the cultivation of Bt cotton may reduce the pesticide application in cotton fields and save labor costs, but the yield of Bt cotton was significantly lower than conventional cotton, along with the high cost of Bt cotton seeds, the direct economic benefit of Bt cotton farmers declined, and the biggest decline was recorded as 10.36% of yield and 1,710 RMB Yuan/ha of income in Lianyungang City. In another experiment conducted in Anhui Province, in four transgenic Bt cotton varieties the weight of single boll of three varieties was between 4.26 g and 4.81 g. The average yield of transgenic insect-resistant cotton, with mildly occurred cotton bollworm, was 1,178.4 kg/ha, a reduction of 8.95% relative to the conventional cotton. The yield of transgenic insect-resistant cottons was overall similar to or lower than conventional cottons (Chai et al., 2000). These situations may partially explain the decreasing proportion (of the increment) of transgenic insect-resistant cotton forecast for the years 2008 to 2010 in Fig. 18.1.

A reason for the low yield of transgenic insect-resistant cotton is that the reproductive traits and morphological features have been changed based on conventional cotton. If the conventional measures for cultivation are still used, the yield potential of transgenic insect-resistant cotton cannot be normally exhibited, and the yield even decreased significantly in different ecological areas of cotton cultivation. For example, in the higher fertilized fields of the Yangtze River valley, Zhongmiansuo 41 showed an excessive reproductive and vegetative growth, while in the Yellow River valley it exhibited the early weak symptom. Transgenic cotton, GK22, exhibited the excessive vegetative growth, falling of many bolls, and declined yield in the Yangtze River valley.

Thus, the cultivation and management technologies in transgenic cotton fields cannot follow the conventional varieties. They must be conducted based on their own laws of growth and development, and the corresponding high quality cultivation techniques must be matched in transgenic cotton fields. By doing so, the reproductive advantage, insect-resistance advantage, and yield advantage may be realized (Gu et al., 2005).

Anyway, improving yield and quality by breeding new varieties will still be the major focus in the future. Field management and cultivation techniques should always match the improved traits of new crop variety.

18.3.2.2 Problems on Pest Resistance to Crop

The insect-resistance of transgenic crop is unstable (Gu et al., 2005; Wang et al., 2006). Gene silence and deactivation seriously affects the application of transgenic insect-resistant crops in agricultural production. It is also the reason why many transgenic insect-resistant crops have not stepped to commercial production. Therefore, how to improve the expression of exogenous insect-resistant genes in the plant is an important research topic in insect-resistant genetic engineering (Sun et al., 2002).

Bt gene is expressed continuously in plant cell, the insect pest by surviving on Bt insecticidal protein across the whole season of plant growth promotes the resistance of insect to transgenic plant. It is known that at least 10 species of moths, two species of beetles and four species of flies have generated the resistance to Bt toxin (Wang et al., 2006). According to a survey, successive planting of transgenic cotton resulted in heavy occurrence of cotton bollworm, due to the increased resistance of cotton bollworm to Bt toxin and degradation of toxin protein after multiple generations of planting of Bt cotton (Gould, 1994; Wang et al., 2006). Transgenic insect-resistant cotton has been in the earlier years planted in Hebei Province, but the residue individual number of the second and third generations of cotton bollworm in 1999 were greater than that in 1998 although the overall occurrence in 1999 was still lower than that in 1998. In Shandong Province, the cultivation of transgenic cotton began in 1997. However the third generation of cotton bollworm in some areas was more seriously occurred in 1999 than in 1998 (Wang et al., 2005).

The survey in a main cotton-producing region, Zaoyang, Hubei Province, demonstrated that with the popularization of transgenic insect-resistant cotton, a lot of problems arose, such as too many varieties, varying quality of cotton seeds, a larger difference between insect-resistances of different varieties. All of these have resulted in the declining trend of cotton yield (Chen et al., 2005). Therefore, it is necessary to standardize the cotton breeding and seed market, and maintain seed purity and stable traits.

Presumably, the effectiveness of monovalent transgenic insect-resistant cotton could preserve 8 to 10 years, and for bivalent cotton the resistance would persist for 20 to 30 years (Gu et al., 2005).

18.3.2.3 Problems on Narrow Insect-Resistance Spectrum and Secondary Pest Outbreaks

Transgenic insect-resistant crop has the narrow insect-resistance spectrum (Gu et al., 2005; Wang et al., 2006). According to the statistics, there are currently dozens of major insect pests damaging cotton in China, including cotton bollworm, pink bollworm, cotton aphid, and red mite, etc. (Xiong et al., 2006). The transgenic insect-resistant cottons used in China's cotton production are effective to some lepidopterans such as cotton bollworm and pink bollworm. However, the species and community of insect pests will likely change after a period of the planting of transgenic insect-resistant cotton; some secondary sucking insects and the lepidopterans that occurred slightly in the early period tend to heavily occur. The research showed that the individual number of red mite and the cotton aphid in the seedling stage were significantly higher than the control. The scientists in Chinese Academy of Sciences have conducted a tracing investigation on the production of Bt cotton in North China from the beginning of 1999, and found that the pesticide application used against secondary insect pests, in particular the Miridae insects, appeared to increase since 2004 (Huang et al., 2007). Currently, the insect pests seriously occurred in transgenic cotton fields, include mainly cotton aphid, red mite, beet armyworm (*S. exigua*), the Miridae insects, thrips, and vegetable leafminer (*Liriomyza sativae* (Blanchard)). In particular, the Miridae insects have become the predominant cotton insect pests in northern China.

The serious outbreak of secondary insect pests may significantly reduce the advantages of transgenic insect-resistant crop, or even lead to more serious insect pest problems. Huge resurgence risk of secondary insect pests is expected to be the most significant problem in planting transgenic insect-resistant crop. This would also partially result in the decreasing trend (of the increment) of proportion of transgenic insect-resistant cotton forecast for the years 2008–2010 (Fig. 18.1).

18.3.2.4 Potential Impacts on Biodiversity and the Environment

As a "foreign factor" released into the ecosystem, whether transgenic crops will destroy the original relative balance of ecosystem and produce the other adverse biological impacts on human health or even cause damages (Klig, 1996; Thacker, 1998; Wei and Yang, 2006), is the world focus (Asako, 1998, 1999). It was reported the results of a study, in which the pollen of Bt maize was fed by a non-harmful butterfly larva and resulted in the death of the later (John et al., 1999). The report attracted a widespread concern on the ecological safety of transgenic crops (Ehsan, 1999). Some study abroad showed that the genetically engineered herbicide-resistant maize gene bleached to the surrounding areas of wild millet plants; the genetically engineered herbicide-resistant rapeseed gene bleached to the nearby wild plants (Xia et al., 2001). In summary, the ecological risks of transgenic insect-resistant crops include genetic pollution of the surrounding plants resulted from gene drift (Han et al., 2006; Wang et al., 2006), the toxic accumulation effects resulted from biological toxic protein, and the injury of ecological balance.

The genes of transgenic crops drift and genetically pollute the surrounding plants by, such as generating a new type of weed after being released. There are four possibilities of becoming weeds (Chen and Zhang, 2000; Zhang et al., 2005): (1) transgenic plants themselves become weeds. The introduction of new genes would result in a plant that exhibits the better survival and competitiveness than its parents or wild plant species; (2) genetic plants are extremely vital, which would destroy the natural diversity of plants and become weeds; (3) the resistant genes of transgenic plants are transferred to the wild flora and transform the wild plants into weeds; (4) transgenic plants invade into new ecological regions and thus undermine the ecological balance. For rice, once the exogenous genes escape and are fused into the wild rice species (including weedy rice) and expressed normally, it may proliferate or expand in wild rice population through sexual and asexual reproduction. If exogenous transgenic genes do not affect the ecological fitness of wild rice, such as high-protein content, improved genes, special vitamins, and the natural selection pressure for wild rice survivor are not related to these genes, then the gene drift of transgenic crops generally do not lead to any significant ecological risk. If some of the exogenous genes from transgenic crops are related to the ecological adaptability of wild rice, such as pest-resistance, and various resistant genes are accumulated in wild rice, then these exogenous genes will likely improve the ecological adaptation of wild rice, and the wild rice will rapidly grow and expand its distribution to become the weeds. On the other hand, the hybrids and their offspring of wild rice carrying the exogenous genes will spread further and may lead to the pollution on original types of wild rice species, or even result in the disappearance of the endangered wild rice in the local area (Zhang et al., 2005; Han et al., 2006). Cotton is a highly domesticated crop. It is not affinitive to the weeds reported. So cotton is unlikely to become weeds. However, the pollen drift of transgenic cotton would yield genetic pollution between different cotton varieties and lines (Liu and Chen, 2005).

Accumulated toxic effects of biological toxin proteins include poisonous effect on natural enemies, and on other neutral organisms. It was reported that after Bt cotton have been extensively cultivated the population of natural enemies reduced or even disappeared due to natural enemies' feeding on the cotton bollworm that carries Bt toxin protein (Gould, 1994). Studies have found that (John et al., 1999; Cui, 2001), the aphids sucked Bt toxin protein on transgenic Bt crop were preyed by predatory bettles and the Bt toxin protein was thus transferred to the beetles, and ultimately affects the reproduction of beetles; Bt insect-resistant crops could kill hymenopterous natural enemies; the pollen of Bt insect-resistant maize would also poison a beautiful butterfly in America. The toxin protein of Bt insect-resistant crops could also leak into soil from the root or reach soil through leaves, thus damage the invertebrates in the soil and water. After Bt toxin protein has leaked into the soil, it would lead to a certain changes in species and quantity of soil microorganisms and changes in activity of soil enzymes (Wang, 2005; Chen and Su, 2006). Toxin protein was also reported to generate certain toxicity to human. A British survey showed that the consumption of transgenic food has resulted in the human allergies of 1.4∼1.8% (Jiang and Yin, 2002).

Planting transgenic insect-resistant crop would negatively affect the composition and structure of arthropod community, and impair the ecological balance. Some research demonstrated that the diversity index of pest-natural enemy community directly depended on that of pest sub- community; the diversity indices of insect community, pest sub-community, and natural enemy sub-community in transgenic Bt cotton field were lower than that in conventional cotton and IPM cotton fields; and the ecological stability of insect community was lower in transgenic Bt cotton field than in conventional cotton and IPM cotton fields (Cui and Xia, 2000).

A popular argument is that planting transgenic crops will save much of the insecticide application. However, a good IPM plan and biodiversity conservation strategy will also largely reduce the insecticide application and, in particular reduce the impairment of beneficial organisms (Andow, 1991; Pimental et al., 1992; Kremen et al., 1993; Way and Heong, 1994; Zhang et al., 2004; Zhang, 2007a,b,c; Fig. 18.3). Our focus is not Yes-or-No on impacts of transgenic crops, but what kind of the impacts and, in what extent will transgenic crops exert impacts on biodiversity and the environment. Risks and impacts of transgenic crops on biodiversity and the environment should be studied extensively in the future.

18.4 IPM and Transgenic Pest-Resistant Crops

Due to the problems of planting transgenic insect-resistant crops discussed above, such as the narrow insect-resistance spectrum, the increased resistance of insect pests to transgenic crops, the possible outbreak of secondary insect pests, and the potential environment and biodiversity risks, it is necessary to follow IPM principles and combine the other control measures, in order to control insect pests effectively, and maintain the natural ecological balance (Kong et al., 2004; Huang et al., 2007). Chinese scientists have summarized the practical problems in planting transgenic insect-resistant crops, and explored various IPM measures to address these problems

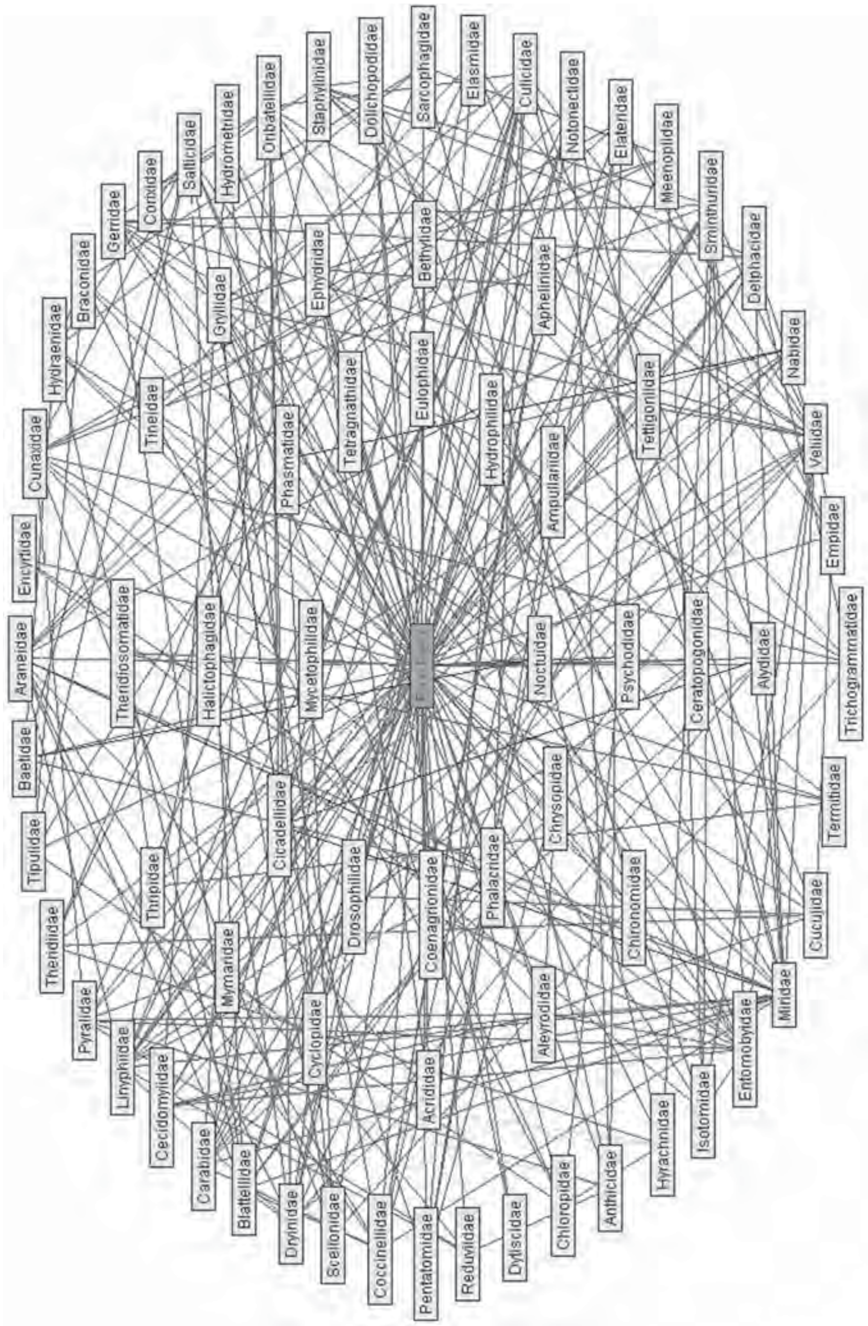

Fig. 18.3 The network of direct or indirect ecological interactions of invertebrate families in a rice field (Zhang, 2007a)

(Wang et al., 1999; Chai et al., 2000; Cui and Xia, 2000; Miao et al., 2004; Son and Gao, 2006). The IPM measures have being implemented at certain extent in China.

About the unsatisfactory performances for the insect-resistance and yield of transgenic crops, scientists have conducted a number of surveys to find some reasons. In Shandong Province, cotton farmers had been yearly reflecting the weak insect-resistance of transgenic cotton. After the field survey, it was confirmed that the reasons were summarized as follows (Miao et al., 2004): (1) a larger weed population in transgenic insect-resistant cotton field. Not weeding cotton timely, the weed population created a better growth habitat for cotton bollworm; (2) transgenic cotton was intercropped by another crop. If control measures had not been adopted for pests on another crop, then pests would seriously damage cotton plants; (3) a higher hazard for corn borer occurrence. If there was not any crop, including maize, around transgenic cotton field, then corn borers would seriously occur in cotton field; (4) no timely control; (5) the low purity of cotton varieties. In Jiucheng prefecture, Anhui Province, a popular survey indicated that transgenic insect-resistant cotton exhibited some drawbacks as compare to the conventional cottons although the former could yield certain economic benefits (Chai et al., 2000): (1) insect-resistance was unstable. The resistance of Bt cotton to cotton bollworm, pink bollworm, etc., decreased gradually with the development and growth of cotton. In 1998, cotton bollworm outbreak in Jiucheng prefecture; in total 4,167 hectares of less controlled cotton field was found to have 0.27 cotton bollworm per hundred plants and 1.52% of boll injury on July 25, they separately increased to 13.33 and 11.14% on August 25; (2) a weak growth vitality and early-exhaustion of transgenic insect-resistant cotton. In 1999, according to the survey on the transgenic cotton, Zhongkang 29, and a conventional cotton, Wanza 40F1, it was found that the vegetative growth of Bt transgenic cotton was slow and its vitality was weak; but its reproductive growth came earlier, and there was a higher rate for bolls' generation; therefore the early-exhaustion occurred easily in the late phase of cotton development due to the poor cooperation between vegetative growth and reproductive growth; (3) small bolls and low fiber content. There was not high-yield advantage for transgenic Bt cotton. Of four transgenic Bt cotton varieties, the single boll weight of three varieties was only between 4.26 g to 4.81 g. The yield of Bt cottons was generally similar to or slightly lower than conventional cottons. In 1999, the cotton bollworm occurred mildly, however the average yield of transgenic insect-resistant cotton tested was 1,178.4 kg/ha only, a reduction by 8.95% against the conventional cotton (Chai et al., 2000).

For the problems discussed above, Chinese scientists proposed some IPM measures (Table 18.2). Cui and Xia (2000) argued that because there are fewer natural enemies in the transgenic insect-resistant cotton field, the application of chemical pesticides should therefore be avoided. Moreover, measures should also be taken to protect the natural enemies, such as planting maize or sorghum for lure use, using the selective pesticides that are safe to natural enemies to control pests, such as red mite, etc. In Xinxiang City of Henan Province, the larva population of the second generation of cotton bollworm in the transgenic Bt cotton field is always below the control index and thus no control is needed. However, the third and fourth generations of cotton bollworm should be controlled according to the population size.

Table 18.2 Suggested principles for IPM of transgenic insect-resistant cotton in China

Cotton Growth Phase	Chemical Control	Biological Control	Fertilization	Others
Preparation of seeds of transgenic insect-resistant cotton	Pesticide treatment of seeds to control plant diseases and underearth insect pests			
Sowing cotton			Provide enough basal fertilizers	Weeding
Before mid-phase of cotton growth	Less insecticide application to control cotton aphid, red mite, etc.	Conservation of natural enemies; Releases of predatory or Parasitic natural enemies; Releases of microbial agent to control insect pests	Appropriate fertilizing	Intercrop by maize, sorghum, etc. Weeding
Late phase of cotton growth	Reasonable insecticide application to control cotton bollworm, cotton aphid, etc.	Conservation of natural enemies	Provide enough bolling fertilizers	Weeding

The control index of cotton bollworm in the United States is 20 larvae per hundred plants. However, this control index has not yet been established in China (Wang et al., 1999). IPM of Bt cotton should also consider the control of the seedling cotton aphid, red mite, and the summer cotton aphid in the bolling stage of cotton. Miao et al. (2004) suggested some IPM measures in Shandong Province: (1) adopting high pure cotton varieties; (2) intercropping cotton with maize but not other crops (Fig. 18.4). Maize is used to attract corn borers for oviposition, and the corn borers should be eliminated; (3) weeding cotton timely. Using herbicides, such as acetochlor, to eliminate weeds after sowing of transgenic cotton; (4) strengthening the forecast and prevention of insect pests, especially the second and third generations of cotton bollworm. When the number of $1^{st}\sim 2^{nd}$ instars larvae of the third generation of cotton bollworm reaches 15 per hundred plants, 1,000 folds of pyrethroid insecticide may be sprayed for the control. When the injury rate of plants from red mite reaches 20%, 1,000 folds of mitecide, Saomanjing, can be sprayed for the control. Chai et al. (2000) argued that the fertilizer application on transgenic Bt cotton should in general be increased by 10–30%. Of total nitrogen fertilizer, 60~70% is for basal and bolling fertilizer (Chai et al., 2000). In Xingjiang Province, the major cotton pests from seedling phase to mid-July are cotton aphid, red mite, and the second generation of cotton bollworm. During this period the biological or ecological control should be the first choice, supplemented by chemical control in which the

Fig. 18.4 A cotton-maize intercropping field in Fuping County, Shaanxi Province, China. The Chinese agriculture was initially originated in Shaanxi Province, and some other provinces, as early as 2000 B.C.∼4000 B.C. With its splendid ancient civilization, Shaanxi Province is now also a major area for cotton production in China. The cotton-maize system will increase the biodiversity, improve the ecological stability, and enhance the effect of IPM, as discussed in the context (Photo by W.J. Zhang, July 2004)

first application of pesticide should be postponed and the dosage should be reduced as soon as possible to avoid producing a direct impact on natural enemies (Son and Gao, 2006). After mid-July, cotton aphid, red mite, and the $3^{rd}\sim5^{th}$ generations of cotton bollworm are major pests of cotton. The abundance of natural enemies decline significantly due to the increasing air temperature, and insect-resistance of transgenic Bt cotton decreased also. The chemical control should be the first choice during this period, supplemented by the biological or ecological control measures, however, the natural enemies should be maximally protected (Son and Gao, 2006).

In the theory of IPM, resistance management is an important consideration. Some management strategies against resistance of pests to transgenic Bt crops, including high/low dose expression, refuges, specific/indicible expression and other tactics to supplement them were proposed (Ouyang et al., 2001). Of these strategies, refuge strategy is a major method for pest resistance management. The principle is planting non-Bt crops, i.e., the refuges of sensitive pests, around Bt crop, in order to let the sensitive individuals mate with resistant individuals randomly. The heterozygous offspring are not able to survive on Bt plants. There are two types of refuges: (1) planting the mixed seeds of Bt crop and conventional crop; the individuals of different crops will be randomly distributed; conventional crops are treated as the refuge of sensitive pest source; (2) planting non-Bt crops in specific area around Bt crop

(Han et al., 2006). The combination of "high-dose" and "refuges" strategies, easily accepted by farmers, was considered to be the best way for Bt resistance management (Zhao and Huang, 2001; Han et al., 2006). Some scientists suggested for using refuges, as done in the United States and Australia, to delay the resistance of cotton bollworm. The 80% of the transgenic Bt cotton and 20% of conventional cotton are intercropped, no chemical control or less control for insect pests on transgenic Bt cotton but normal control for insect pests on conventional cotton; or 96% of the transgenic Bt cotton and 4% of conventional cotton are intercropped or mixed, no chemical control for insect pests on both Bt cotton and conventional cotton. In China, apart from the Xinjiang cotton region and the large farms where refuges needed to be artificially established, the refuges have been naturally provided in other areas due to the intercropping system of multiple crops. However, measures should be adopted to protect these natural refuges; particularly, transgenic Bt cotton and Bt maize should not be cultivated in the same area, and the biological products of Bt should not be used on the host crops of cotton bollworm (Chen et al., 2003a).

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