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Plant biotechnology in Asia - Past, present and future

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Abstract

Plant biotechnology including plant tissue culture is the most important science to rescue human beings from the crisis of biosphere of the earth which they will face in the 21st century. Global area other than Asia of trangenic crops increased more than 16 times from 1996 to 1998. In Asian countries, micropropagation using tissue culture techniques has been well developed and has contributed to agricultural production. Although researches on levels of laboratory and test field trial of transgenic crops have been performed actively in some Asian countries, areas of growing transgenic crops are still small in Asian countries except in China. In this paper, the status of plant biotechnology in global and Asian countries are reviewed and the future prospect of plant biotechnology in Asia and roles of Korean and Japanese plant scientists in it are discussed.

The most serious problem which we, human beings, should face in the just coming century is how we can overcome the shortage of crop supply, which will be caused by increase in population, and the critical damage of environments, which is due to pollution caused by development of industries and increased input of chemicals to agriculture as well as elevating standard level of life. Plant biotechnology is the most potent tool to overcome these two difficulties. In this paper, 1) global status of growing of transgenic crops and effects of transgenic crops on agricultural production and environment and 2) the past and present situations of plant biotechnology in some Asian countries are reviewed and finally, 3) perspectives of plant biotechnology in Asia are discussed.

Global status of transgenic crops

Plant biotechnology can be divided to three categories: Production of seedlings of useful plants by cell manipulation techniques including micropropagation, somatic embryogenesis and others, and productions of transgenic plants by gene engineering. The third one is production of useful substances by plant cell culture systems. The first area in plant biotechnology is dominant one in Asian countries and the second one, which will be the most important area in future, is actively being intended at field level in North America, and at laboratory level in most industrial countries in the world. The third is active in Korea and Japan as compared with other countries.

Population in the world is 5.8 billions at present and 87 million people are still increasing annually in 1997 (Table 1) [5]. Global population will attain to 10 billions in 2050. The present agriculture can not produce enough food to support 10 billions people. It is true that global crop production continues to rise, but because of higher growth rate of population, agricultural production per capita has flattened (Figure 1, 2) [7], probably followed by deficiency of crop supply in next century. Thus, trangenic plants are required to improve productivity of crops, to expand global area available for cultivation and to preserve environments directly or indirectly.

Combining of molecular biological techniques with plant cell manipulation has brought about the progress of production of transgenic plants in laboratories of industrial countries. After biosafety assessments, growing of transgenic crops in fields started in 1995 in USA, but area of transgenic crops in fields has increased very rapidly (Table 2 and Figure 3) [4]. As shown in Table 2, total global area of transgenic crops is 27.8 million ha in 1998. Since these data exclude China, it may be more than 30 million ha. Increment is more than 16 times from 1996 to 1998. Field trial of transgenic crops has been conducted from 1986 or earlier. Table 3 shows that field trials were conducted in 45 countries including China, India, Japan and Thailand from 1986 to 1997, but global area except China where transgenic crops are growing is shown in Table 4 and in Figure4 [4]. Data show that USA ccupied nearly 90% including

Table 1. World Population and growth Rates 1997

Industrial and Developing Countries

Population	Millions	Growth Rate
Developing Countries	4,600	1.9
Industrial Countries	1,200	0.1
Global	5,800	1.5

Selected Information for Developing Countries

Population	Millions	Growth Rate
China	1,200	1.1
India	950	1.9
Least Developed	560	2.8

Note: 87 million people added to global population annually.
Source: Kendall *et al.* 1997.

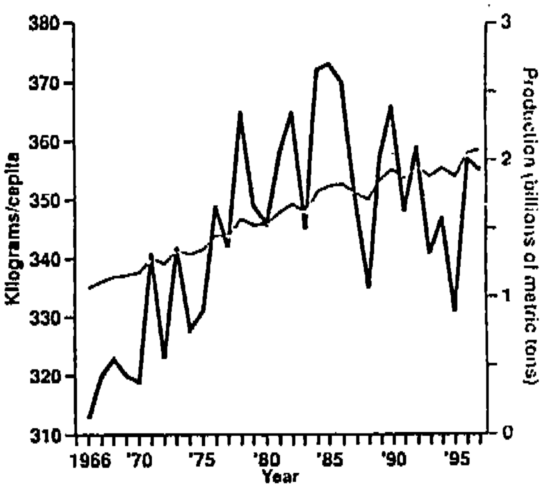

Figure 1. Change in global crop production [7]
Just keeping up. World grain harvests contains to rise, but because of population growth, per capita production has flattened.

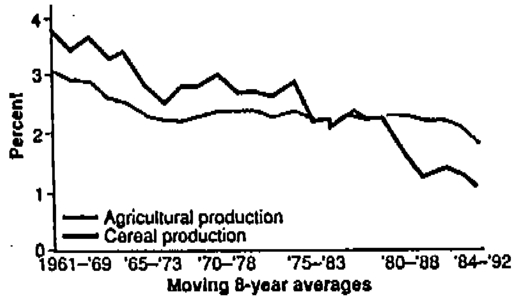

Figure 2. Annual increases in cereal production [7]
Slower growth. Annual increase in cereal production have s;owed since the Green revolution of the 1960s nd 1970s.

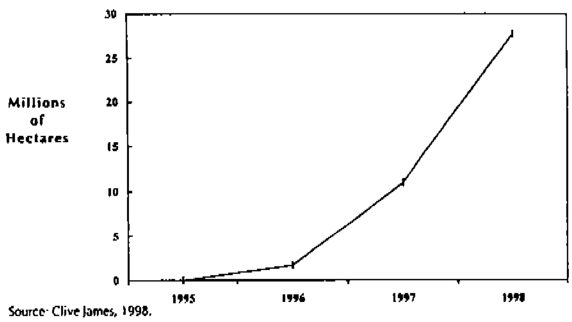

Figure 3. Global Area of transgenic Crops (excluding China): 1995 to 1998

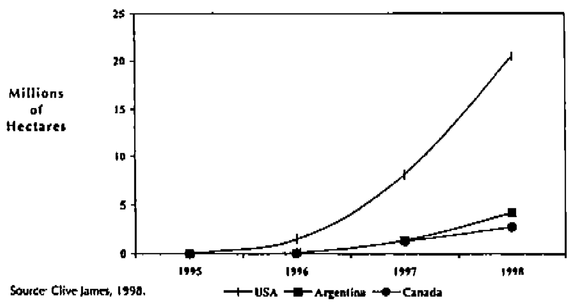

Figure 4. Global Area of Transgenic Crops: 1995 to 1998: **By Country**

Argentina of global area of transgenic crops which have not been commercialized except China. Table 5 and Figure 5 [4] show global area of transgenic crops by crop. Soybean, corn occupy more than 80% of trangenic crops and the remainder, 20% includes cotton, canola and potato in 1998. As regards trait, herbicide tolerance such as "round up" and insect resistance, such as Bt, -transgenic crops occupy 71% or 28% in 1998, respectively (Table 6) [4]. Herbicide tolerant soybean and insect resistant corn occupy 52% or 24% of global area in 1998, respectively.

Benefits from transgenic crops

Most transgenic crops which are growing in fields in USA and Canada are herbicide tolerant or insect resistant (Bt) crops as shown in Table 7. Benefits of such transgenic crops come from reduction of herbicide or insecticide usage; it results in reduction of residual chemicals in soil which brings about better conservation of environments. On the other hand, it results in increase of yield of crops growing with reduced chemicals, which also provides economic return to growers along with reduced cost of usage of insecticides or herbicides. As shown in Table 8, Bt cotton in USA provided net return of about $60 million in 1996 and more in 1997 to grower and 250,000 gallons of insecticides per year (reduced cost is $140-280 per ha) were reduced, contributing to conservation of environments and to increment of agricultural

Table 2. Global Area* of Transgenic Crops in 1996, 1997 and 1998

	Hectares (million)	Acres (million)
1996	1.7	4.3
1997	11.0	27.5
1998	27.8	69.5

* Excluding China
Increase in area from 1996 to 1997 was 9.3 million hectares (23.2 million acres)
Increase in area from 1997 to 1998 was 16.8 million hectares (42.0 million acres)
Source: Clive James, 1998.

Table 3. 45 Countries that have Conducted Transgenic Crop field trials from 1986 to 1997

Argentina	Denmark	Malaysia	Sweden
Australia	Egypt	Mexico	Switzerland
Belgium	Finland	New Zealand	Thailand
Belize	France	Norway	The Netherlands
Bolivia	Georgia	Rumania	Turkey
Bulgaria	Germany	Russia	Ukraine
Canada	Guatemala	Poland	United Kingdom
Chile	Hungary	Portugal	USA
China	India	Slovakia	Uzbekistan*
Costa Rica	Italy	Spain	Yugoslavia
Cuba	Japan	South Africa	Zimbabwe
Czech Republic			

*Reported; reconfirmation in process
Source: Clive James.

Table 4. Global Area of transgenic Crops in 1997 & 1998: **By Country** (millions of hectares)

Country	1997	%	1998	%	Increase 1997 to 1998	(Ratio)
USA	8.1	74	20.5	74	12.4	(2.5)
Argentina	1.4	13	4.3	15	2.9	(3.0)
Canada	1.3	12	2.8	10	1.5	(2.1)
Australia	0.1	1	0.1	1	<0.1	(1.0)
Mexico	<0.1	<1	<0.1	<1	<0.1	(- -)
Spain	0.0	0	<0.1	<1	<0.1	(- -)
France	0.0	0	<0.1	<1	<0.1	(- -)
South Africa	0.0	0	<0.1	<1	<0.1	(- -)
Total	11.0	100	27.8	100	16.8	(2.3)

Source: Clive James, 1998.

production as well as to economical benefit to farmers [4].

Status of plant biotechnology in Asia

Plant biotechnology in Asian countries shows different aspects from those in North America; production of seedlings of useful plants including crops and ornamental plants is dominant in most Asian countries. Commercialization of it is active and this area of plant biotechnology is contributing to agricultural production in a large extent. As regards transgenic plants, research works in laboratories are being done actively in many Asian countries and many successful achievements have been obtained, but growing transgenic crops in large areas of fields has been performed only in China so far. Status of plant biotechnology in each selected country of Asia is described below in alphabetical order.

1. China

China is the first country in Asia as well as in the world which commercialized transgenic plants (tobacco). Since the first transgenic plants of tobacco and potato were obtained in 1983, great progress has been made in the past 15 years. In 1992, transgenic

Table 5. Global Area of Transgenic Crops in 1997 & 1998: **By Crop** (millions of hectares)

Crop	1997	%	1998	%	Increase (Ratio)	
Soybean	5.1	46	14.5	52	9.4	(2.9)
Corn	3.2	30	8.3	30	5.1	(2.6)
Cotton	1.4	13	2.5	9	1.1	(1.8)
Canola	1.2	11	2.4	9	1.2	(2.0)
Potato	<0.1	<1	<0.1	<1	<0.1	(-.-)
Total	**11.0**	**100**	**27.8**	**100**	**16.8**	**(2.5)**

Source: Clive James, 1998.

Table 6. global Area of transgenic crops in 1997 & 1998: **By Trait** (millions of hectars)

Trait	1997	%	1998	%	Increase (Ratio)	
Herbicide tolerance	6.9	63	19.8	71	12.9	(2.9)
Insect resistance	4.0	36	7.7	28	3.7	(1.9)
Insect res. & Herbicide tolerance·	<0.1	<1	0.3	1	0.2	(-.-)
Quality Traits	<0.1	<1	<0.1	<1	< 0.1	(-.-)
Global Totals	**11.0**	**100**	**27.8**	**100**	**16.8**	**(2.5)**

Source: Clive James, 1998.

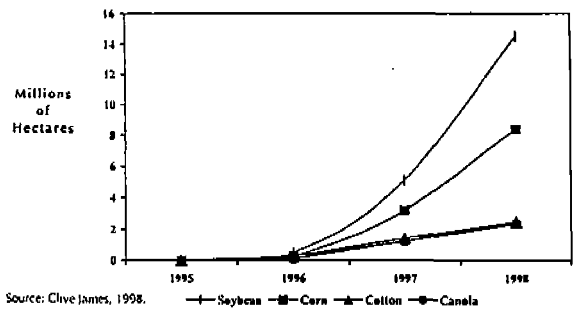

Figure 5. Global Area of trnsgenic Crops: 1995 to 1998: **By Crop**

tobacco, resistant to cucumber masaic virus (CMV), incorporating a single coat protein construct, was sown on approximately 40 ha for commercial seed increase. In 1994/1995, a double construct (CMV and TMV (tobacco mosaic virus)) was developed and introduced into commercial production. 70% of area of cultivation of tobacco will be occupied by transgenic tobacco in early 2000s in China. Beside CMV and TMV resistant tobacco, the main research projects on transgenic plants in China cover insect and disease resistance, stress tolerance, male sterility and nutrition improvement. In Table 9, traits already commercialized, in field trials and under development in 1997 in China are shown. Traits and crops for producing transgenic plants will increase rapidly. In fact, China started the growing Bt cotton in a large area field (63,000 ha) in 1998 as shown in Table 10. In 1996 and 1997, China occupied 39% or 14% of global area of transgenic crops, respectively (Table 11). China is the second largest country of area of growing transgenic crops in the world and occupied nearly 90% of global area of transgenic crops with USA in 1997 [4, 5].

Plant tissue culture has been very active and productive part of biotechnology in China. Micropropagation has been extensively used for mass production of virus or clonal propagation of sugar cane, cassava, potato, Eucalyptus, Populous and medicinal plants.

Haploid plants have been obtained by using anther and microspore culture. Some new varieties from more than 50 species including rice, wheat, barely and rape have been released in agricultural production. Hybrid rice of high yield was also obtained [8].

2. Indonesia

Indonesia has just started to employ biotechnology for national agricultural development. They are collaborating with international net works such as Rockefeller Foundation Rice Biotechnology program, JICA, IRRI and others. Through these research collaborations, research activities have been conducted

Table 7. Global Area of transgenic Crops in 1996 and 1997: **By crop/Trait** (millions of hectares/acres)

	1996			1997			Increase 1996-97		
Crop/Trait	Ha	Acres	%	Ha	Acres	%	Ha	Acres	Ratio
Soybean/ H.T.	0.5	1.3	18.0	5.1	12.5	40	4.6	11.2	10.2
Corn/ I.R.	0.3	0.7	10.0	3.0	7.4	23	2.7	6.7	10.0
Canola/ H.T.	0.1	0.3	4.0	1.2	3.0	10	1.1	2.7	10.0
Cotton/ H.T.	<0.1	<0.1	<1.0	0.4	0.9	3.0	0.3	0.9	10.0
Tobacco/ V.R.	1.0	2.5	35.0	1.6	4.0	13	0.6	1.5	1.6
Cotton/ I.R.	0.8	1.9	27.0	1.1	2.6	8.0	0.3	0.7	1.4
Corn/ H.T.	0.0	0.0	--	0.2	0.6	2.0	0.2	0.6	--
Tomato/ V.R.	0.1	0.3	4.0	0.2	0.5	1.0	0.1	0.2	--
Canola/H.T./H.Y.	0.0	0.0	--	<0.1	<0.1	<1.0	<0.1	<0.1	--
Cotton/ I.R./ H.T.	0.0	0.0	--	<0.1	<0.1	<1.0	<0.1	<0	
Canola (Lauric)	<0.1	<0.1	<1.0	<0.1	<0.1	<1.0	<0.1	<0	
Potato/ I.R.	<0.1	<0.1	<1.0	<0.1	<0.1	<1.0	<0.1	<0.1	--
Tomato (D.Ripening)	<0.1	<0.1	<1.0	<0.1	<0.1	<1.0	<0.1	<0.1	--
Global Totals	2.8	7.0	100	12.8	31.5	100	9.9	24.5	4.5

H.T.: Herbicide Tolerance; I.R.: Insect Resistance; V.R.: Virus Resistance; H.Y.: Hybrid Technology.
Source: Clive James 1997.

Table 8. Estimated Economic benefits Associated with selected Bt transgenic crops in the USA, 1996 and 1997

	1996			1997		
Crop	National Acreage (millions)	Transgenic Crop Acreage (%)	Benefits ($ millions)	National Acreage (millions)	Transgenic Crop Acreage (%)	Benefits ($ millions)
Cotton	14	13.0	60[1]	14	18.0	n.a.
Corn	79	0.9	19[2]	80	9.0	190
Potato	1	0.9	<1[3]	1	2.4	n.a.

n.a. Not available. Based on net returns per acre of: 1 $33.00
2 $27.25
3 $19.00

to address major constrains in rice production. These include anther culture to shorten breeding time, development of molecular markers for quantative traits such as yield and drought tolerance and the use of molecular markers to study the population structure of blast and bacterial leaf blight. The production of disease-free potato and other tropical fruit trees is performed by conventional micrpropagation techniques. Biotechnological research in Indonesian agriculture is constrained by limited numbers of qualified scientists, discontinuity of fund sources and/or insufficient supporting equipments as is true for most developing countries.

3. Japan

Plant biotechnology using tissue and cell culture techniques, i.e., mericlone, embryo culture, anther culture, protoplast culture etc. has been well developed from 1980s. For example, virus free seedlings of strawberry produced by meristem cultures occupy 70% of area of growing strawberry. Production of virus free bulblet of lily in a large scale has been performed in tank culture by Mitsui Chemicals Inc. Industrial production of microtuber of potato was succeeded by Kirin Brewery Inc. Mitsui Chemicals also succeeded to produce F1 hybrid of rice, yield of which was 1.5 times of their parent plants.

Many attempts to produce transgenic crops have been carried out in laboratories of universities, national institutions and private companies in 1990s.

Table 9. Traits Already Commercialized, in Field Trials and under Development in China, 1997

Crop	Trait
Commercialized crops	
Tobacco	Virus resistance
Tomato	Virus resistance
Tomato	Quality-modified ripening
Field trials	
Cotton	Insect resistance
Maize	Insect resistance
Papaya	Virus Resistance (Ring Spot)
Potato	Disease Resistance (Bacterial Wilt)
Rice	Insect resistance
Soybean	Herbicide tolerance
Soybean	Insect resistance
Sweet Pepper	Virus resistance
Tobacco	Disease resistance
Tobacco	Insect resistance

Source: National Program, China; Compiled by Clive James

Selected transgenic plants for which field trials were permitted are listed in Table 12. More than 40 transgenic plants in total have been permitted for field trials. They can be commercialized. In fact, low allergen rice has been commercialized, but the needs for it are so small that it was grown in a small scale. Most of transgenic crops have not been grown in large areas in Japan like in USA, Canada and China. However some of transgenic plants are or will be commercialized; bluish purple carnation produced by Suntory Inc. is one of successful products by gene engineering of flower colour. Kirin Brewery Inc. succeeded to produce viroid resistant potato and chrysanthemum introduced with gene of RNA decomposing enzyme specific for double strand RNA. Transgenic chrysanthemum is going to be commercialized.

Two important systems of transformation were established in Japan: One is the transformation of monocots mediated with Agrobacterium by Japan Tobacco [3]. By this system, rice, the main crop in Asia, can be transformed by using Agrobacterium and this system has been applied to production of many transgenic rice and other crops of monocot.

The other new and useful system is MATV (multi-auto-transformation vector) system. In this system, *ipt* gene (cytokinin systhesizing gene) as a marker gene and R/RS system (yeast site specific recombination system), which removes selection marker gene, are used, resulting in obtaining transformant without marker gene [2]. This system was established by Nippon Paper Company and will be useful for multiple introduction of genes as well as for biosafty and public acceptance because of production of transgenic plants without marker gene.

Production of salt tolerant plants have been succeeded in some laboratories in Japan. In Prof. Takabe's lab, Nagoya University, salt tolerant rice was produced, which can grow in saline water of one third of concentration of sea water, by introduction of betA gene encoding glycine-betain synthesizing enzyme. Many other transgenic plants are tried to produce in many laboratories in Japan.

Production of useful substances in a large scale has been actively investigated by Mitsui Chemicals

Table 10. Seven Countries Introduced Eleven New Transgenic Crops in 1998

Country	Crop	Trait	Hectares
China	Cotton	Insect Resistance	63,000
Spain	Corn	Insect Resistance	20,000
Argentina	Corn	Insect Resistance	17,000
South Africa	Cotton	Insect Resistance	12,000
USA	Corn	Herbicide Tolerance/Insect Res.	12,000
USA	Soybean	Oil Quality	10,000
Argentina	Cotton	Insect Resistance	8,000
South Africa	Corn	Insect Resistance	3,000
France	Corn	Insect Resistance	2,000
Mexico	Cotton	Herbicide Tolerance/Insect Res	1,000
USA	Papaya	Virus Resistance	200
Total			**151,200**

Source: Clive James, 1998.

Table 11. Global area of Transgenic Crops in 1996 and 1997: **By Country** (millions of hectares/acres)

Country	1996			1997			Increase 1996-97		
	Ha	Acres	%	Ha	Acres	%	Ha	Acres	Ratio
USA	1.5	3.6	51	8.1	20.1	64	6.7	16.5	5.6
China	1.1	2.8	39	1.8	4.5	14	0.7	1.8	1.6
Argentina	0.1	0.3	4.0	1.4	3.5	11	1.3	3.3	13.0
Canada	0.1	0.3	4.0	1.3	3.3	10	1.2	3.0	9.2
Australia	<0.1	0.1	1.0	0.1	0.1	<1.0	<0.1	<0.1	1.6
Mexico	<0.1	<0.1	1.0	<0.1	<0.1	<1.0	<0.1	<0.1	10.0
Total	2.8	7.0	100	12.8	31.5	100	9.9	24.5	4.5

Source: Compiled by Clive James.

Table 12. Selected transgenic plants permitted for field trial by Biosafety Committee in Japan

Plant	Institution involved	Trait	Year of permission
tomato	NIAR	TMV resist.	1992
petunia	Suntory Inc.	CMV resist.	1994
rice	NIAR, NARC	rice stripe(RSV)resist.	1994
rice	NIAET, PBT Inc.	RSV resist.	1994
melon	NARC, NIAR	CMV resist.	1996
rice	Mitsui Chem.	low allergene	1995
rice	Inst. Breed. Rice Inc.	low protein	1994*
potato	Hokkaido Green Bio Inst.	virus resist.	1994*
soybean	Japan Monsanto	herbicide resist.	1996
tomato	Kagome Inc.	high pectin	1996
carnation	Suntory Inc.	bluish color flower	1997
cauliflower	Takii Seed Inc.	herbicide resist.	1997*
rape	NIVT	herbicide resist.	1998*
chrysanthemum	Kirin	viroid resist.	1998*
rice	JT	low protein	1999*
rice	NIAET	herbicide resist.	1999*
papaya	Mac Inc.	virus resist.	1999*

*permitted for environmentally isolated field trial

Inc., which could produce shikonin in *Lithospermum erythrorhizon* suspension cultures. This was the first industrial success of production of useful substance in the world.

Recently Mitsui Chemicals succeeded to produce taxol using *Taxus* suspension culture in a large scale. Nitto Denko Inc. has produced cell clusters of ginseng in a large scale. It is one of cell clusters of commercially succeeded examples in the area of production of useful substances on plant biotechnology.

4. Korea

In Korea, mass propagation of many species including woody plants through cell and tissue culture techniques, mass production of secondary metabolites by cell culture systems and production of transgenic plants by genetic engineering are being actively conducted at laboratory and even industrial levels. For detail of status of plant biotechnology in Korea, the reference [1] can be referred.

5. Myanmar

Myanmar is a country which has a big potential of agricultural production. However, agribiotechnology is still not well developed. They need technical as well as financial support from developed countries.

Crop improvement is attempted in rice, which is the major crop in Myanmar, corn, potato, peanut, broccoli and others by anther culture and F1 hybrid vigor. Tissue culture techniques are applied to micropropagtion of peanut, sesame, broccoli and orchids.

Screening for stress tolerance is conducted through callus and protoplast culture. Screening of salt tolerant rice is extensively carried out in salinity-prone areas.

In Myanmar, there is a drought-prone area of ca. 3 million ha, where peanut and sesame are of vital importance. Tissue culture of these crops for selection for drought tolerance is being carried out. However, they need advanced techniques of molecular biology for improvement of crops [6].

6. Taiwan

Main commercialized plant biotechnology is mass production of seedlings of useful plants, in particular, orchids, by using micropropagation. The procedures of production have been industrialized. Production of orchid seedlings is a big business in biotechnology of Taiwan.

As regards transformation and production of transgenic plants, many researches on various plants and traits are carried out in universities and national institutions. For example, attempts to produce virus resistant papaya, insect tolerant (Bt) broccoli, brown plant hopper resistant rice, tuberose of new flower colors and other transgenic plants are conducted.

7. Thailand

Thailand has started research works on plant biotechnology. The National Center of Genetic Engineering and Biotechnology (BIOTEC) and labs in various universities have played a key role in developing plant varieties resistant to plant pest through genome manipulation and modification. Target plants are rice, papaya, tomato, chili, other vegetables and cotton by conferring genes such as viral coat protein and Bt toxin. Several species have been tested and it is expected that the National Biosafty Committee will grant increasing numbers of field trials. Production of seedlings of ornamental plants is also active in Thailand.

8. Vietnam

In Vietnam, main activity in plant biotechnology is also production of seedlings of crops and tropical ornamental plants at present. Target plants are potato, banana, many species of ornamental plants and others. Production of virus free potato seedlings is active in particular, and is conducted even in a small home of farmers who are making a good business.

Vietnam government established National Biotechnology Institute (NBI) with their own fund in 1995 where they started studies on transgenic rice, banana, cassava, other crops and vegetables. In other national institutes such as Agricultural Genetics Institute (AGI) and universities such as Agriculture College No. 1 and National University of Hanoi, similar researches are carried out. Researches on improving crops by using gene engineering have started.

Perspectives of plant biotechnology in Asia

Overviewing the status of plant biotechnology in Asia, micropropagation of many species including crops and ornamental plants is well developed in most countries. It is contributing to agricultural production in Asia. As regards transgenic plants having new or better functions, however, China is the only country to have commercialized transgenic crops. Research works in laboratories and field trials of transgenic plants have been actively conducted in China, Japan, Korea, Singapore, and Taiwan, and many important findings, which can be applied to biotechnology, have been reported. Other countries have also started such works. This trends will be expanded in next few years. Expansion of area of growing transgenic crops will continue more and more in China, and other countries, including Japan, Korea, Thailand, Taiwan, Malaysia, Indonesia and others, will permit more transgenic crop for field trial and commercialization. Rice is the most important crops in Asia, but the transgenic rice has not been grown in a large areas of field. It is expected that transgenic rice such as bacterial blight, rice borers and fungal resistant rice will be grown in a large areas of fields in Asian countries in next century.

Development of plant biotechnology in developing countries in Asia is constrained by limited number of qualified plant scientists and deficiency in fund source for necessary equipments and reagents. It is also one of constraints for development of plant biotechnology in developing countries that they have not established biosafety regulation. Biosafety is very important for public acceptance and future progress of plant biotechnology. Thus, developing countries need support and help for these difficulties. Laboratory works in Japan and Korea are at rather high levels, but markets of agriculture are small in both countries and application of laboratory works to agribiotechnology in fields is limited. Therefore, Japan and Korea should transfer accumulated knowledge, experiences and techniques to developing countries and develop their own plant biotechnology practically in agriculture of Asia. In this way, Japan and Korea can make great contribution to rescue human beings from the crisis of biosphere in the 21st century.

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