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GM Rice: Will This Lead the Way for Global Acceptance of GM Crop Technology?

by

Graham Brookes and Peter Barfoot
PG Economics, UK

Abridged version of the June 2002 PG Economics Report made available to ISAAA for publication

No. 28 - 2003

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NOTE TO READERS

The reader should note that this report, published in 2003 is an abridged version of the original PG Economics report, completed in June 2002. This version has not been updated since 2002 and therefore some of the information presented (e.g., relating to biotechnology developments in rice) may not be fully representative of the current state of developments.

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INTRODUCTION

Rice is the most important cereal crop grown globally and is of paramount importance as a staple human food source in many areas of the world.

The use of GM technology in global agriculture is, however, currently controversial. This is largely a result of the expression of strong anti-GM technology sentiment by interest groups concerned about possible health and environmental effects. This has resulted in the use of ingredients, derived from plants containing GMOs, being largely eliminated from foods manufactured for direct human consumption in some developed economies, notably in Europe. This anti-GMO sentiment has also more recently focused attention on the use of GM ingredients in livestock production systems via incorporation of GM derived oilseeds and cereals in animal feed. This raises questions about how international markets for GM and non-GM derived crops will develop and has contributed to a slow down in the application of GM technology *per se*. This has implications for crops like rice, which are of vital importance to many developing economies.

Key drivers for the application and adoption of rice GM technology come from two main sources: the delivery of higher yielding, disease resistant and lower cost rice production and the provision of nutritionally enhanced rice. This points to the technology potentially playing a major role in improving nutrition and enhancing food security in developing countries. It will also influence rice crop production and price competitiveness *vis-a-vis* the global cereals sector.

Due to the importance of rice in the developing world and the significant part played by the public sector in providing new rice crop technology, the drive to apply GM technology to rice may well result in faster acceptance of the technology in rice than would be the case for other crops. Rice, therefore has the potential to act as a catalyst to the wider adoption and acceptance of GM crop technology.

The report is divided into four key parts covering the global importance of rice, rice biotechnology developments, current and future economic, strategic issues, market dynamics and conclusions.

Part 1: Global importance of rice
This part provides a description and analysis of global rice production, trade and consumption. It also places the importance of rice in the global context relative to other cereals.

Part 2: Rice biotechnology developments
This part focuses on the likely future role (and influence) of new GM technology. It covers genetically modified traits being developed.

Part 3: The future: economic and strategic issues and market dynamics
This part covers global production, consumption/demand and trade to 2012, GM

technology adoption by 2012, impact of GM technology on production, prices, trade patterns, the nature and size of GM versus non GM derived rice market segmentation, requirements for traceability and identity preservation and competitiveness implications for developing country versus developed country producers and exporters.

Part 4: Summary and conclusions

This part focuses on bringing parts one to three together to analyse and draw conclusions about the consequences of the introduction of GM rice on international markets.

1. GLOBAL IMPORTANCE OF RICE

1.1 Global Rice Plantings

World plantings of rice are estimated to be just over 151 million hectares in 2001/02 (Table 1). This is broadly similar to plantings over the last five years and is 3% higher than the global area planted 10 years ago. Whilst the global area has been relatively stable in recent years, there have been some significant changes in areas planted in some of the main rice producing countries. By far the largest single change has been, a 4 million hectare fall in plantings in China since 1991/92. Other countries experiencing important decreases in the area planted to rice over the last 5-10 years have been Japan and South Korea where the rice areas have decreased by 0.38 million hectares and 0.12 million hectares respectively. Counter balancing these declines, have been additional plantings of over 2.3 million hectares in India (the country with the largest area devoted to rice: 44.5 million hectares) and 1.7 million hectares in Myanmar[1]. Other countries where there have been significant increases in the areas planted to rice since 1991/92 are Vietnam, Bangladesh, Indonesia, Thailand and the Philippines.

[1] Formerly Burma

Table 1. World Rice Areas Planted 1997/98 to 2001/02 (Million Hectares)

	1991/92	1997/98	1998/99	1999/00	2000/01	2001/02
Bangladesh	10.20	10.26	10.12	10.71	10.90	10.90
China	32.76	32.13	31.57	31.64	30.30	28.59
India	42.21	43.47	44.80	44.97	44.79	44.50
Indonesia	10.69	11.14	11.72	11.96	11.61	11.70
Japan	2.08	1.95	1.80	1.79	1.77	1.70
South Korea	1.18	1.05	1.06	1.07	1.06	1.06
Pakistan	2.03	2.32	2.42	2.51	2.38	2.25
Philippines	3.33	3.84	3.17	4.00	4.04	4.09
Myanmar	4.81	5.41	5.46	6.21	6.30	6.50
Thailand	9.11	9.91	9.51	9.98	9.76	9.80
Vietnam	6.39	7.10	7.36	7.65	7.67	7.50
USA	1.20	1.26	1.32	1.42	1.23	1.33
Others	20.96	21.46	21.99	20.99	20.39	21.38
Total	**146.95**	**151.30**	**152.30**	**154.90**	**152.20**	**151.30**

Source: USDA, FAO

1.2 Global Rice Production

World rice production was forecast to be about 586 million tonnes in 2001/2002. This is broadly stable relative to production levels in the last few years although it represents a 2% increase (+12 million tonnes), relative to production levels in 1997/98 (but a slight fall on production in 1999/00 and 2000/01). Global production, is however, about 12% higher than levels about 10 years ago[2].

Across the main rice producing countries there have been some important changes over the last 5-10 year period. Production has increased in some of the leading rice producers. In India, the world's second largest producer, output has increased by 19% (nearly 21.5 million tonnes) since 1991/92. There have also been significant increases in production over the same period recorded in Bangladesh, Vietnam, Thailand, Myanmar, Philippines and Indonesia since 1991/92 (Table 2). In contrast, production levels have fluctuated in China and fallen in Japan over the same period.

In most of the countries where production has increased, the rate of production increase has been higher than the rate of increase in areas planted. This points to production increases being due to a combination of increased plantings and yield improvements, although

[2] The annual average global production level for the three years 1990/91-1992/93 was 524 million tonnes.

Table 2. World Rice Production 1991/92 to 2001/02 (Paddy: Million Tonnes)

	1991/92	1997/98	1998/99	1999/00	2000/01	2001/02
Bangladesh	27.40	28.30	29.78	34.60	37.63	38.25
China	183.80	200.70	198.71	198.48	187.91	180.00
India	112.00	123.82	129.01	134.56	127.32	133.51
Indonesia	48.20	49.24	50.40	52.92	51.90	52.39
Japan	12.00	12.53	11.20	11.47	11.86	11.33
South Korea	7.40	7.37	6.80	7.07	7.20	7.45
Pakistan	4.90	6.50	7.01	7.74	7.05	5.61
Philippines	9.10	9.98	10.27	11.96	12.52	13.26
Myanmar	12.60	15.34	16.00	17.00	18.57	17.00
Thailand	20.40	23.50	23.62	25.00	25.61	25.00
Vietnam	22.20	28.93	30.47	31.71	31.02	31.21
USA	7.20	8.30	8.37	9.34	8.66	9.66
Others	57.90	59.69	63.96	65.45	61.95	61.13
Total	**525.10**	**574.20**	**585.60**	**607.30**	**589.20**	**585.80**

Source: USDA, FAO

yield improvements have been responsible for most of the increases.

1.3 Trade and Consumption

Table 3 summarises the global export market for rice over the last ten years. In 2001, about 24 million tonnes of milled rice were exported, equivalent to 6% of global production[3] of rice. The volume of rice exported onto world markets has been fairly stable over the last 2-3 years although relative to ten years ago, there has been almost a 90% increase[4]. This increase in exports reflects the underlying increases in production and hence, export availability, in many of the leading rice producing countries. For example, the two largest rice producing countries China and India exported respectively 1.17 million tonnes and 0.89 million tonnes more in 2001 than in 1991[5]. The largest exporters of rice in 2001 were, nevertheless, not the largest rice producing countries but

[3] The global production of about 585 million tonnes paddy is equivalent to about 393 million tonnes of milled rice (source USDA Rice Situation & Outlook, November 2001)

[4] 1998 also proved to be a high point for trade, mainly as a result of production shortfalls (El Nino effect) in some important rice producing countries (eg, Indonesia).

[5] It is, however, relevant to note that export volumes from China have widely fluctuated over the last 10 years. No underlying trend is apparent other than variability of both export availability and production.

Table 3. World Rice Exports 1991-2001 (Milled: '000 Tonnes)

	1991	1997	1998	1999	2000	2001
Argentina	75	530	559	674	332	350
Australia	450	641	547	667	617	613
China	689	938	3,734	2,708	2,951	1,859
Egypt	159	201	426	320	500	725
EU	391	372	346	348	308	350
Guyana	54	286	249	252	167	175
India	711	1,954	4,666	2,752	1,449	1,600
Myanmar	176	15	94	57	159	668
Pakistan	1,297	1,982	1,994	1,838	2,026	2,400
Thailand	3,988	5,216	6,367	6,679	6,549	7,521
Uruguay	260	640	628	681	642	750
Vietnam	1,048	3,327	3,776	4,555	3,370	3,560
USA	2,199	2,304	3,174	2,644	2,847	2,640
Others	703	412	1,088	766	929	1,330
Total	**12,200**	**18,818**	**27,648**	**24,941**	**22,846**	**24,541**

Source: USDA

Thailand, Vietnam, the USA and Pakistan, which exported 7.52. 3.56, 2.64 and 2.4 million tonnes respectively in 2001. Exports from all of these leading export nations increased over the last ten years. Exports from Vietnam have increased three-fold and exports from Thailand and Pakistan have virtually doubled. US exports rose by about 20% over the ten year period. In addition, a number of significant new export players have entered the global rice market since the early 1990s. Of particular note has been the rise in export volumes from Egypt, Myanmar and Uruguay all of which exported 0.5-0.7 million tonnes more rice in 2001 than they exported in 1991.

On the import side, the number of countries importing significant quantities of rice is far higher the number of mainstream exporters. Table 4 summarises the most important global importers of rice over the last ten years. The main importing countries are in South East Asia (Indonesia and the Philippines, Malaysia), the Middle East (Iran, Iraq, Saudi Arabia) and Africa (Nigeria, Senegal and Ivory Coast). In almost all of these countries the volume of rice imported has risen significantly over the last ten years.

Table 5 highlights that:

- 88% of global rice consumption is in Asian countries;
- Asian countries account for about a third of global rice imports;
- African countries account for only 4% of rice consumption but 29% of rice imports;
- North America (the USA, Canada and Mexico) account for 1% of rice consumption and 5% of imports;
- The EU (and EFTA[6] countries) accounts for 0.5% of consumption and 3% of imports;
- The significant increase in the volume of rice traded globally during the 1990s has been due to several factors. These include weather-related production shortfalls in some major rice consuming countries such as China, the Philippines and Bangladesh, increasing populations in most SE Asian countries, rising income levels[7], greater political stability in some traditional rice importing countries (e.g., Iran) and the impact of trade policy reforms (notably the Uruguay Round WTO Agreement and the Mercosur trade agreement in South America) which has begun to open up some previously highly protected markets.

Overall, developing countries, especially in Asia dominate the consumption of rice, with developed economies accounting for a very small share (no more than 5% of total consumption or less than 10% if Middle

[6] European Free Trade Area: Norway, Switzerland, Iceland, Cyprus and Malta

[7] In countries where rice is not considered to be a staple food (eg, the USA, EU), increased rice consumption is generally associated with increased income levels. In contrast, in countries where rice has traditionally been considered as a staple food product (many developing countries and all countries in South East Asia), rice consumption tends to decrease as income levels rise (as wealthier consumers increasingly consume alternatives).

Table 4. World Rice Exports 1991-2001 (Milled: '000 Tonnes)

	1991	1997	1998	1999	2000	2001
Indonesia	192	808	5,765	3,729	1,500	1,300
Nigeria	296	731	900	950	1,200	1,600
Iraq	268	744	630	779	1,274	1,000
Saudi Arabia	559	660	775	750	992	900
Philippines	91	814	2,185	1,000	900	1,170
Iran	599	973	844	1,313	1,100	1,000
Senegal	434	575	600	700	637	850
Japan	34	546	468	633	656	700
Malaysia	367	645	630	617	596	600
Ivory Coast	169	470	520	600	450	700
Brazil	772	845	1,555	781	700	500
North Korea	194	272	250	159	400	550
South Africa	360	573	529	514	525	500
Others	7,865	10,162	12,290	12,416	11,916	13,171
Total	**12,200**	**18,818**	**27,648**	**24,941**	**22,846**	**24,541**

Source: USDA, Eurostat

Table 5. Global Imports and Consumption of Rice by Main Regions of the World ('000 Tonnes Milled Equivalent) 1999/2000

Region	Imports	Consumption
North America	1,098	4,486
Latin America	1,952	14,913
EU & EFTA	650	2,130
Former Soviet Union	475	1,293
Central/Eastern European countries	352	386
Middle East	4,025	6,435
Africa	6,394	15,807
South Asia	855	116,797
Other Asia	5,720	238,039
Oceania	400	706
Total	**21,921**	**400,992**

Source: USDA, FAO, University of Arkansas

Eastern, Central/Eastern Europe and the former Soviet Union are included). On the import side, developed countries have a greater relative importance accounting for about 10% of global imports (if the Middle East, Central/Eastern Europe and the former Soviet Union are included this share rises to about 30%).

1.5 Global Use of Rice

As indicated above, trade accounts for the equivalent of 6% of global rice production. In terms of usage, direct consumption as a staple human food product is by far the main use of rice, accounting for 88% of total usage. Use in animal feed accounts for only 3% of total global usage, the same share as seed use (Table 6).

1.6 Rice Versus Other Cereals

Table 6 summarises the supply balances and uses of the main cereal crops grown globally in 1999. The key points to note are:

- Trade accounts for the lowest share equivalent of production in rice relative to other cereals –6% for rice relative to 22% for wheat and barley respectively and 13% for maize and sorghum respectively;
- Animal feed usage accounts for the greatest share of usage of barley, maize and sorghum (66%, 64% and 50% respectively);
- Wheat is the nearest cereal to rice in terms of usage profile, with 72% of supplies used as a direct human food resource. An important proportion of sorghum is also used as staple food product (40% of total usage);
- The use of cereals as an industrial (including food manufacturing) feedstock is greatest for barley and maize and lowest for rice and wheat.

1.7 Rice Prices

Table 7 shows trends in some of the main, globally traded milled rices over the last 9 years. The main feature of note has been the 30%-40% decrease in price since 1998/99 that has been experienced by all of the three primary sources of globally traded rice. Despite these significant decreases in price, global production (and trade) has been maintained at a fairly consistent level since 1998.

Table 6. World Supply Balances and Usage: Main Cereals 1999/2000 (Million Tonnes)

	Rice	Wheat	Barley	Maize	Sorghum
Production	403	585	128	606	60
Imports	27	130	28	79	8
Exports	27	134	29	82	7
Stock change	-11	-2	6	4	1
Total supply	**392**	**579**	**133**	**607**	**62**
Feed use	12	92	87	387	31
Seed use	12	34	9	6	1
Food manufacturing	4	6	22	54	2
Food use	344	416	8	113	25
Waste & other uses	20	31	7	47	3

Source: FAO
Note: rice figures are in milled equivalents

Table 7. Indicative World Milled Rice Prices: 1003-94 to 2001/02 ($ Per Tonne Bagged)

	US long grain (Texas)	US medium grain (California)	Thailand 100% B	Thailand 15% brokens	Vietnam 5% brokens
1993/94	439	451	294	243	n/a
1994/95	314	375	290	270	n/a
1995/96	414	445	362	335	n/a
1996/97	450	415	338	303	n/a
1997/98	415	396	302	275	269
1998/99	369	470	284	261	257
1999/00	284	454	231	185	202
2000/01	272	313	184	167	165
2001/02	232	273	184	159	184

Source: USDA
Notes: 2001-02 is for the 9 month period August 2001-March 2002
N/a= not available

2 RICE BIOTECHNOLOGY DEVELOPMENT

This part reviews who is active in rice biotechnology and presents our forecasts for the possible availability of GM rice traits to Asian farmers.

2.1 Patent Review

A review of patents identified 307 rice biotechnology patents from 404 different organisations listed as patent assignees. DuPont/Pioneer has by far the greatest number of patents at 68, twice the number of both Monsanto and Syngenta at 33 and 32 patents respectively. Other important patent assignees include Aventis Crop Science (now Bayer Crop Science with 19 patents), the Japanese public sector, under the NORQ grouping of nine different organisations, and Japan Tobacco.

2.2 Field Trial Review

In terms of field trials Table 8 summarises developments up to early 2002.

2.3 International Programmes

There have been a number of international programmes that have underpinned rice biotechnology. These include the Asian Rice Biotechnology Network (ARBN) (two core funding sources, the Asian Development Bank (ADB) and the German governments (BMZ)), the Rockefeller Foundation supported projects and training, Rice Genome Projects and the Golden Rice initiative. The latter initiative is an example of how the public and private sector have perceived the market for transgenic rice and the wider market opportunities and constraints of developed and developing country markets.

Scientists, based at the Swiss Federal Institute of Technology, inserted three genes into rice that make the plant produce beta-carotene (pro-vitamin A). However, Syngenta holds the rights to golden rice for commercialisation in appropriate markets and is helping the Humanitarian Board of the Golden Rice Project to transfer the technology to developing countries by complying with the existing bio-safety assessment and environmental risk assessment laws and regulations. The GM rice will be crossed with local varieties using traditional breeding methods, and health and safety tests will be conducted. The target is to make the technology available free to farmers earning less than $10,000 a year from the crop, a figure far exceeding the average income of poor farmers. Farmers will also be able to save seeds from their crop for future plantings because rice is a self-pollinating plant.

2.4 Company Profiles

Details on the lead commercial organisations active in rice biotechnology are given in Table 9.

2.5 IRRI

IRRI is a non-profit agricultural research and training centre established to improve the well-being of rice farmers and consumers,

Table 8. GM Rice Field Trials by Territory

Country	Field trials
United States	Over the period 1997 to 2002 there were 173 notifications for GM Rice field trials in the USA (notifications do not necessarily mean that a field trial took place it indicates intention and potential availability of GM rice seed). Monsanto and Aventis dominated notifications/evaluations, accounting for over 80% of all trials notifications. Both companies have concentrated on herbicide tolerance but Monsanto has also evaluated technology to enhance crop yields.
Europe	Only 8 trials of GM rice have been conducted in Europe, the majority in Italy and targeted at glufosinate tolerance - the lead organisation has been Aventis (now Bayer). The European Commission is also funding a collaborative project involving 8 leading plant biotechnology public institutions aimed at developing transgenic European rice varieties resistant to rice blast and other fungal diseases.
Japan	The first trials on GM rice in Japan were in 1993 on isolated trial plots. Trial numbers have increased to 11 isolated field trials in 2001 and 7 in open field trials in 2000. The lead developers have been the National Agricultural Research Center (NARC) (Rice Blast Resistance), Monsanto (Glyphosate Tolerance) and Japan Tobacco (Low protein for sake brewing).
South America	The only trials of GM rice in South America have been in Brazil and Argentina by Aventis in 1998 and 1999 targeted at glufosinate tolerance.
India	Four organisations are reported to have undertaken GM rice trials (they may have been in controlled environments) indicating ability to transform and regenerate GM rice plants. Several Indian organisations are part of the Asian Rice Biotechnology Network and will be initiating GM rice field trials.
Australia	Three organisations undertook GM rice trials in 2001 across a range of traits - CSIRO (5 trials), University of Southern Cross (4) and Charles Stuart University (1).
SE Asia	In the Philippines the Philippine Rice Research Institute (PhilRice) is planning to conduct three field trials in Barangay Maligaya, Nueva Ecija and IRRI to evaluate Xa-21 resistance to nine types of bacterial blight disease. In China hybrid Bt rice was field tested in Wuhan in 1999 and 2000. A review of the published papers and participation in international programmes indicates that more field trials have been undertaken covering a range of traits - Bt-genes, Xa-21-gene and Rice Dwarf Virus coat-protein.

Table 9. Company Profiles on Lead Commercial Organisations

Company		
Aventis	First company to develop GM rice varieties ready for commercialisation. Started in the mid-90s using the PAT gene to confer tolerance to glufosinate ammonium. Since 1997/98 Aventis conducted 60 GM rice field trials in the US, 6 in South America, 5 in Europe and 2 in Japan. APHIS has de-regulated glufosinate tolerant rice based on field trial data, feeding trial data and other scientific data. FDA review of the Aventis CropScience food safety data was completed in 2000. Aventis is pursuing the necessary governmental reviews in the key importing countries. Has also conducted field trials in the US in 2000 (1 acre) and 2001 (5 acres) on altered carbohydrate metabolism.	Aventis has put in place the following resources to breed and market transgenic rice: • In 1999, AgrEvo acquired Brazil's 'leading rice breeding programme' from Granja 4 Irmaos S.A., the country's largest rice seed producer; • In 2000 it was reported that Aventis CropScience was evaluating the rice and corn seed business in the Philippines; • In February 1999, Aventis CropScience expanded into India, with the acquisition of the Proagro Group of seed companies (the second largest seed group in the country), which produces hybrid corn, rice, oilseed rape, cotton, sunflower, grain and fodder sorghum, millet and vegetables.
Bayer	Bayer has had no specific projects directed at rice biotechnology (see Aventis CropSciences above).	Bayer has not seen the acquisition of seed companies as a vital precursor for deriving added value from GM crops. Its acquisition of Aventis CropSciences will give it access to rice breeding programmes.
BASF Plant Science GmbH	ExSeed Genetics undertook a GM rice field trial in the US in 2001 with altered starch quality and content. ExSeed are using rice mostly as a proxy for maize. Rice is not a key crop for BASF.	No direct rice-breeding expertise identified.
Dow AgroScience	Has capabilities to genetically engineer rice, as well as at least one gene in development to improve rice yields. However, Dow's focus is primarily on corn, cotton, sunflower and canola.	Dow does not appear to have any in-house capability or activity in rice breeding.

continued ...

Table 9. Cont'd. Company Profiles on Lead Commercial Organisations

Company		
Dupont (Pioneer)	DuPont was reported to have originally placed a fairly high priority on wheat and rice GM product development before the Pioneer takeover. The DuPont rice biotechnology group was researching rice genomics and rice diseases resistance (rice blast). This research is now reported to have been largely "put-on-the-shelf" although Pioneer is continuing to use rice as a model/proxy for maize in its genomics programme. Rice is now considered a "secondary" crop compared with maize (the primary crop for research and commercial development).	Pioneer began breeding hybrid rice in India in 1988. The principal target being the high yielding, predominately irrigated areas of India. The main breeding objectives are improved yield, food quality, straw strength and disease resistance. Pioneer was the first organisation to commercialise rice hybrids in India in 1993 and it has an active programme of new hybrids based on proprietary inbreds. We understand that Pioneer is not conducting any rice biotechnology research in India. In 1992 Pioneer's India production, sales and marketing operation became part of a 50:50 joint venture with the Southern Petroleum Industries Corporation (SPIC) as SPIC PHI Seeds Ltd. In January 2001 Pioneer purchased SPIC's share of the JV and now wholly owns the operation.
Monsanto	Monsanto has made the greatest number of notifications to field trial GM rice in the USA (68), the majority (50), targeted at glyphosate tolerance with 11 specific to agronomic traits, 2 to fungal resistance, 2 to product quality traits and 3 specific to markers. However, in 1999 to 2001 all their GM rice trials have been on glyphosate tolerance, which is in pre-commercial testing. Has conducted several GM rice (herbicide tolerance) field trials in Japan (1999-2001) and developed its own rice genome map.	In the US Monsanto has no rice breeding capability. In the US market there are several small rice breeders, co-operative and semi-public/university rice breeders, with the leading independent rice breeder being RiceTec. Following Monsanto's acquisition of Cargill, it has access to rice breeding germplasm and capabilities in the Philippines (it also has rice seed market presence). Monsanto's acquisition of Mahyco in India, a leading rice breeding company, has also given the company a rice seed market presence here.

continued ...

Table 9. Cont'd. Company Profiles on Lead Commercial Organisations

Company		
Monsanto		The Asian rice seed market is of interest to Monsanto as it is reported to view the introduction of hybrid seed (and its associated move towards direct seeding rather than transplantation), as a market opportunity for its herbicide business in key markets (notably Japan).
Syngenta	The Syngenta/Myriad Genome map provides a clear indication of Syngenta's genomic activities and its policy towards collaborations. The Syngenta/Myriad Genome map provides a clear indication of Syngenta's genomic activities and its policy towards collaborations. In January 2001, the Torrey Mesa Research Institute and Myriad Genetics announced the completion of the Rice Genome sequence. The Syngenta Rice Genome Map is the first virtually complete map of a crop plant and contains information that determines the makeup of rice.	Syngenta has discussed the availability of its rice genome map with IRRI. Rice germplasm development has been undertaken in both Syngenta predecessor companies. Orynova is a joint venture between Zeneca Ltd. and Japan Tobacco for the development of rice seeds and traits, which operates independently from Syngenta. A rice germplasm development program is also underway in India.
Applied Phytologics Inc.	API has the capability to produce a range of GM rice lines expressing therapeutic proteins (e.g., human lysozyme, human lactoferrin). It has selected rice for such development and located in central California (one of the main rice growing region in the USA).	The company is perceived to have no plans to develop its technology outside the USA.
Crop Design	CropDesign is using rice extensively for its screening programme for rapid trait development. It can readily transform rice and modulate expression of genes to produce transgenic rice plants within 11 months.	The company has no rice breeding capability or facilities. The company is reported to have stated that in 80% of the rice growing territories intellectual property rights will be virtually unenforceable.

continued ...

Table 9. Cont'd. Company Profiles on Lead Commercial Organisations

Company		
Ceres	Extensive genomics work in rice - used as a proxy for corn and wheat.	No direct capability
Orynova NV	As part of the Orynova joint venture Japan Tobacco contributed its proprietary Agrobacterium-mediated gene transformation technology for rice, transgenic low-glutelin rice and inbred rice varieties. Research programmes focuses on improved quality and yield, and on input traits such as disease and insect resistance.	Orynova has well-established relationships with public and private breeders in Japan. It is involved with the Golden Rice initiative coordinated through the Humanitarian Board and under development at IRRI.
Paradigm Genetics	Has worked on rice transformation and regeneration. Also analysing genes that confer disease and nutritional characteristics.	It has no internal interest in rice breeding and perceives rice to be a crop with very limited opportunity for the development of commercial products.

particularly those with low incomes. It is dedicated to helping farmers in developing countries and undertakes research, breeding and information/technology dissemination. IRRI is part of the Asian Rice Biotechnology Network (ARBN) and sees the ARBN as a pipeline for disseminating information and resources to the NARS. Through training workshops and shuttle research, ARBN and IRRI provide experience in high-throughput technologies, microarray, and bioinformatics that can enhance breeding programmes, including those using GM technology. IRRI is also well positioned to take advantage of the opportunities in GM rice given its unique collection of "introgression lines" (that carry a wide range of unique chromosome segments implanted from commercial varieties and wild rice) and its collection of rice germplasm – it can supply material to other research institutions to assist them in their GM rice research and breeding programmes.

2.6 China: Rice Biotechnology and Breeding

China has three major national-level research institutes focusing on breeding and biotechnology in the rice crop. These are the China National Rice Research Institute (CNRRI) in Zhejiang, the National Hybrid Rice Engineering Technical Centre (NHRETC) in Hunan and the Institute of Genetics and Developmental Biology (IGDB) in Beijing. These institutes are at the leading edge of

China's rice research activities. Their activities are often mirrored at a provincial level within agricultural universities or plant breeding companies, although the three national institutes lead the way and have the most capability in terms of resources and scientific expertise.

2.7 Summary of Traits Under Development

Table 10 summarises our forecasts for the possible availability of GM rice traits reaching the Asian farmer.

Table 10. Projected Release of Traits in GM Rice (2203-2012)

		2003-2005	2006-2008	2009-2012
Herbicide resistance				
	Glyphosate	***		
	Gluphosinate	***		
Disease resistance				
	Bacterial Leaf Blight (Xa21)	***		
	Rice Blast (Chitinase)	*	**	**
	Rice Blast (PR5)	*	**	**
Virus resistance				
	RHBV (Rice hoja blanca virus)	*	**	**
	RTSV (Rice tungro spherical virus)	*	**	***
	RYMV (Rice Yellow Mottle virus)		*	**
	RRSV (Rice ragged stunt virus)		*	**
Insect resistance				
	Brown Plant Hopper		**	***
	Yellow Stem Borer/Lepidopteran insects (Bt)	***		
Nutrition				
	Vitamin A (psy, crtI, lyc)	*	***	
	Iron bioavailability (ferritin, phytase and metallothionin)	*	***	
	Iron bioavailability (IRT1, NAS)		**	***
	High quality protein (Asp1)		**	***
Abiotic Stress				
	Submergence		**	***
	Salt and drought tolerance		**	***
Yield				
	NMS/Novel hybrids		**	***
	Carbohydrate quality/content		*	***
	Panicle development/numbers		**	***

"*" = 30-50% likelihood
"**" = 50-80% likelihood
"***" = >80% likelihood

3 THE FUTURE: ECONOMIC AND STRATEGIC ISSUES AND MARKET DYNAMICS

In this Part of the report, we focus on the future – for the period 2002 to 2012.

3.1 General Market Environment

In order to place the future development of the markets for GM rice within the context of the global market, this sub-section briefly considers the future general direction of global rice production and some of its key factors of influence.

3.1.1 The current baseline and driving forces

3.1.1.1 Factors affecting rice consumption: population and income levels & relative prices

As rice is primarily consumed as a direct human food, changes in global rice consumption are largely determined by changes in population and income levels and to some extent the price of rice relative to the main global alternative 'cereal staple food' source of wheat.

Global consumption of rice is currently about 405 million tonnes (milled equivalent) per year and has been increasing at an average annual rate of over 2% for the last 20 years (global consumption about 20 years ago was 280 million tonnes, milled equivalent). However, this rate of increase has slowed to about 1.5% per year over the last 5 years. The main reasons for this continued, but slowing rate of increase in global consumption are associated with population and income changes in Asian countries. In almost all of the countries in the Asian region, the population has continued to grow, albeit at a decreasing growth rate and hence the demand for rice has increased in line with population expansion. This rate of consumption growth has, however been partially offset by decreases in the consumption per head as average income levels have risen. Thus in many of the economies of the Asian region rice consumption per head falls as income levels rise (i.e., in economic parlance rice is an inferior good in these countries)[8]. This feature of market development probably applies to countries such as Thailand, Japan, South Korea and Taiwan. Overall, the interaction of population and income changes has resulted in different forces for changes to consumption levels. On the one hand population increases have contributed to increases in the level of total consumption whilst positive income changes have contributed negatively to consumption. Lastly the economic recession that hit many Asian economies in the late 1990s will have contributed to slowing the rate of decline in consumption per head that would otherwise have occurred.

Looking at the possible impact of the global 30% plus decrease in the average price of

[8] In contrast in non Asian countries such the USA and the EU where rice consumption has traditionally not been high (relative to Asian countries), rice consumption tends to increase as income levels rise.

milled rice since 1998, this may have contributed positively to global rice consumption levels. As rice and wheat are the main cereals consumed directly for human food it is reasonable to assume that the two grains compete to some extent in some markets. Rice tended to trade at a ratio of 2.5 or 3 to 1 relative to wheat in the period 1996-98 but since 1998 the ratio has fallen to under 1.5 to 1 (ie, whilst both global rice and wheat prices have fallen since 1998, the fall in the price of rice has been greatest). Despite this improvement in the competitiveness of rice relative to wheat, there appears to be only limited evidence of rice consumption having increased because of positive substitution for wheat. In countries where the vast majority of rice consumption occurs, wheat has not generally been made available by the governments of countries with import requirements and there is/has been only limited tradition of wheat being regarded as a staple food. Only in sub-Saharan Africa has the relative cheapness of rice (relative to wheat) possibly contributed to higher consumption levels (and imports) since 1998[9]. It is also important to recognize that whilst world prices of rice have fallen relative to wheat prices on global markets, in many traditional rice consuming countries, the retail prices of different cereals have only limited relationships with world prices. Prices are affected by national producer support mechanisms for different crops, consumer subsidies, import duties, transport costs and processing costs, all of which can mask/offset global price movements.

3.1.1.2 Government policies

Government policies in many of the major rice producing and trading nations have and continue to play important roles in influencing the level of rice production. Some of the key producing and exporting countries are examined further below.

US

US policy has been driven by the 1996 Farm Act. In respect of rice, there are a number of policy support mechanisms including a commodity loan (US rice farmers can take out such a loan and at the end of the marketing season (or during) can repay the loan or keep the loan and surrender the rice commodity in lieu of taking the $127.95/tonne loan rate). In addition, farmers receive payments known as production flexibility contracts (PFCs) and 'market loss assistance'. Farmers can also (alternatively) receive a loan deficiency payment (LDPs) that is equal to the difference between the above $127.95/tonne commodity loan rate and the prevailing county level market price (assuming it is lower). The idea behind LDPs is to provide an equivalent to the alternative of placing the crop under loan and then repaying it at a lower repayment rate based on market prices (when market prices are below loan rates).

Overall, these payments received accounted for 46% of total farmer revenue in 2000/01. These support payments are widely perceived to have made rice an attractive crop for many

[9] In countries such as Nigeria there has been greater historic use and import of wheat and wheat flour for feeding the population.

producers, during a period of relatively low market prices. Consequently this support has probably played an important role in contributing to the increase in plantings and production of rice over the last five years. The 2002 Farm Bill will broadly maintain the level of support for rice at pre 2002 levels and is not expected to result in significant changes in rice plantings over the next 10 years (relative to the area planted forecast by the USDA).

Thailand

There has been no major policy factor of significance in Thailand where the level of support for agriculture is generally very low. Decision taking on planting at the farm level is very much influenced by the market. The government has generally provided some form of floor price to the market for rice at which it will buy up produce in times of low prices. This support mechanism has, however been of greater relevance in the last 2-3 year (times of significant reductions in world prices) and in 2001 government 'support' (known as mortgage) prices have been set at between $16 and $30/tonne above prevailing domestic prices of about $105-$109/tonne.

China

Chinese government policies have had an important impact on rice production. Government intervention in the mid 1990s resulted in expansion of grain production (including rice) up to 1999 (for rice from about 183 million tonnes in the early 1990s to about 200 million tonnes by 1999). There has also been control of volumes of grain and rice in domestic markets.

Chinese recent policy has, however been to allow domestic prices to fall towards world levels so as to facilitate enhanced global competitiveness on accession to the WTO in 2001. This has contributed to the recent decreases in rice plantings and production highlighted in Part 1. Policy has also focused on encouraging farmers to plant rices with higher quality characteristics.

India

Policy has played a major role in influencing the level of production in India. The government regulates the (retail) prices of essential foods including food grains like rice (and energy, fertiliser and water). It uses procurement prices and has open market sales programmes as measures that try to stabilize domestic prices. For rice, a procurement or buying in price is set every year as a floor to the market for farmers and in 2002 the support price for rice varieties was between $108.8/tonne for common varieties rising to $115/tonne for grade A varieties. Farmers are not required to sell their paddy rice to the government at the 'support' price but may well do so if market prices fall below the support price levels. In 2000/01 for example 19.1 million tonnes were sold to the government.

The Indian government also exercises some control over the domestic market for rice by requiring rice millers to sell a proportion of their output to the government (agency) at set 'levy' prices. These levy prices vary by state and are linked to the support price for paddy rice and milling costs. For 2002 the levy price (in Punjab) is $192.8/tonne for common varieties and $203.1/tonne for grade A rice. This rice is then made available to domestic consumers at significantly lower (subsidized) prices.

Overall, government support for rice growing has contributed significantly to the expansion in the area planted and production of rice in India over the last ten years.

Pakistan

Pakistan government policy towards rice is essentially to encourage increases in production through yield improvement and to provide a floor or support price to farmers for both 'IRRI' and basmati varieties. These support prices are adjusted annually in line with perceived costs of production. Despite the setting of these support prices they have been well below prevailing market prices because since the mid 1990s, no rice has been bought up by the government.

The support prices in 2001 were 425 rupees/40kgs and 350 rupees/40kgs paddy respectively for Super and 385 varieties (equal to about $212 and $175 per tonne equivalent).

Myanmar

During the 1990s the Myanmar government targeted significant expansion of its rice production sector through both area expansion (e.g., encouraging all rice areas to grow two rice crops per year) and improvement in yields. Support is provided via the setting of minimum procurement prices and a requirement for farmers and millers to sell a proportion of the output to the government. The procurement prices are widely perceived to be below the cost of production although this has been somewhat offset by the provision of subsidized inputs. Whilst this policy has probably contributed negatively to expansion of the sector, the attraction of market prices for rice (rice farmers can sell the majority of their crop on the open market rather than to the government) has been the main driving force for expansion in the sector[10]. In addition, the requirement to sell a proportion of each farmer's crop to the government has fallen and by the late 1990s it was equal to only about 12% of output.

Vietnam

Rice production has increased rapidly over the last ten years in Vietnam mainly as a result of economic reforms initiated by the government during this period. Liberalisation of the agricultural sector began in the 1980s with the provision of security of tenure to farmers and the freedom of farmers to sell their output on open markets (rather than to the government at prices below market levels). There has also been considerable investment in infrastructure and development projects.

Within the rice market, the government annually sets a base price at which it will buy rice off the market (to support market prices). This was about $85/tonne in 2001. The government also provides assistance for private temporary storage of rice during times of surplus. In 2001 the government bought in over 1 million tonnes of rice to support domestic prices.

[10] In 1995 the free market price was reported to be three times the cost of production.

Japan

The Japanese agricultural sector has traditionally operated within a highly protected and supported environment where agricultural support prices for commodities such as rice were considerably higher than comparable, external world price levels. However, faced with a rising cost of agricultural support, surplus production of some commodities and WTO commitments made in the Uruguay Round, the Japanese government has initiated reforms to its agricultural support programme in recent years. In the rice sector a Rice Farming Income Stabilisation Programme was introduced in 1998. Within this rice farmers receive some support if market prices fall below a standard price (average of last 3 years prices), equal to 80% of the difference between the standard price and prevailing market prices. A rice diversion programme also operates whereby farmers can receive additional 'diversion' payments for transferring land out of rice cultivation and into other crops such as fruit trees, vegetables, fodder or fallow.

Overall, this change of policy initiated in the late 1990s has contributed to the decline in area planted and production of rice during the last few years in Japan.

3.1.1.3 Investment in new technology

This has played a significant role in contributing to the increase in global production in all of the main producing regions. This includes the adoption of newer, higher yielding varieties, improved agro-chemicals and greater use of fertilisers in some growing regions. Adoption of new technology, in particular newer, higher yielding hybrid, rice varieties has been and continues to be an important component of government policies towards the rice production sectors in most of the countries. IRRI, the Chinese government and research bodies in Pakistan and India are all heavily involved in plant breeding programmes to deliver higher yielding rice varieties (such as 'Super rice' varieties at IRRI and in China that are targeting commercial yields of 10 tonnes/ ha minimum together with improved disease resistance).

3.1.1.4 WTO

The Uruguay Round Agreement of the WTO in 1994 marked a watershed for global trade in agricultural produce and has started the process of liberalization of global markets. This is of particular relevance to the rice sector because of the historic high levels of support and protection afforded to a number of the major rice producing nations in countries. Commitments to limit the level of Aggregate Monetary Support (AMS) provided to domestic agriculture, on minimum market access and to reduce import protection have begun to play important roles in shaping the environment within rice is produced and marketed across the world. The main contribution of the WTO to date to changes in the rice sector has been through the pressure it has exerted on domestic policy orientation in countries such as China, Japan and South Korea. As indicated above (sub-section 3.1.1.2) the WTO has acted as a catalyst to policy reform that has favoured lower levels of support to the sector in these countries and hence contributed to decreased plantings and production. The minimum access commitments have also begun to open some markets up to limited import competition that were previously largely excluded by the imposition of prohibitive import duties. For example, Japan, where rice imports were subject to import duties of nearly 800% and into which there is now a duty-free import quota for 683,000 tonnes of milled rice. Although these minimum access commitments[11] are not significant in the context of the volumes of rice produced and globally traded, they are set to become of greater importance in the future, especially when China's accession to WTO membership is taken into consideration – China will after the first five years of accession be required to permit 5.3 million tonnes of rice imports at an import duty level of 1%, as compared to the prevailing import duty rate of 71%.

3.1.2 The future general environment

3.1.2.1 General and underlying economic environment

Drawing on USDA long term forecast assumptions about the world economy, the outlook for the world economy over the next 10 years is one of initial continued slow down followed by strong growth in almost all regions of the world. World real GDP growth is projected to average about 2.7 percent annually in 2001-2005, compared with 2.6 percent in the previous decade and then increase to an annual growth rate of 3.3% between 2006 and 2011. Global economic growth will be driven by a recovery from the Asia financial crisis as well as strong and sustained growth in the former Soviet Union, Africa, and Latin America. There will also be a significant narrowing of the differential between the high growth regions such as Asia and the lower growth regions of Latin America, Africa, and the transition economies.

UN forecasts for world population growth are for a projected increase of 1.2 percent a year over the next ten years, a slight (0.2%) decline from the previous decade. Almost all of this is expected to occur in developing countries with growth rates in developed countries at less than 0.4 percent per year. The highest growth rates are expected in Sub-Saharan Africa at 2 percent per year. Populations in developed economies are projected to grow by less than 0.5 percent per year, with the slowest rates in Japan and the European Union. Overall, the number of people in the world is expected to increase at a declining rate, to 6.9 billion in 2011.

Because of differing rates of population growth, GDP gains translate into per capita income growth at differing rates. The highest forecast growth rate in per capita income is in China, which has both very high GDP growth rates and also low population growth rates. The lowest per capita income growth rates are in Africa and the Middle East. This pattern toward a slowing of population growth rates and

[11] These are commitments to allow duty-free or reduced duty imports within a quantitative limit into countries like Japan. There are, however, not requirements to import.

increasing per capita income growth rates is likely to have an important impact on agricultural trade over the coming decade as rising income leads to demand for more high value products (notably livestock products) and less demand for basic products – rice being a basic staple commodity in most countries and therefore likely to experience a decrease in consumption per head (counterbalanced by increases in absolute consumption levels through population increases).

3.1.2.2 Policy effects

This influence is likely to continue to play an important role on the global area and production of rice mainly because of the importance of rice to domestic food security in many countries. Essentially existing policy trends can be expected to continue over the next ten years in countries such as India, Pakistan, Thailand, Vietnam and China. In these countries underlying support to the sector will continue to be provided via some form of support or 'floor' pricing and varying degrees of involvement in government procurement. However, underlying moves to freer trade and more market orientation in countries like Vietnam and Myanmar are to be expected. In China WTO membership has already triggered less state involvement and support to the sector and this is likely to expose the rice sector to greater reliance on market influences, especially as the Chinese market is opened up to greater import competition. Similarly the policies of reduced levels of support in Japan and South Korea will continue and should result in a continued trend to reduced planted areas (see section 3.1.2.5). In the US, existing policies based on the 1996 Farm Bill will continue to shape US support to the sector. The 2002 Farm Bill will probably result in a broadly similar level of support for rice relative to the pre 2002 level. Lastly in the EU, the policy environment in 10 years time is likely to be one of significantly lower levels of support to the rice production sector. The main trigger for this has been the 'Everything but Arms' Agreement with the least developed countries that will allow duty-free access to the EU market for developing country origin rice by 2009.

In the sub-sections below these policy directions are taken into consideration when looking at the likely future direction of production and demand for rice.

3.1.2.3 Prices

As indicated in sub-section 3.1.1 global rice prices have been weak since 1998 and fell by about 30%, mainly because of a combination of additional production volumes coming onto world markets at a time of weakening global demand (economic downturns, especially in South East Asia and improved production volumes in some of the main importing countries like Indonesia). Over the next ten-year period, the environment of low prices (relative to historic trends) is expected to persist for most of the period, even though a slow and steady recovery in price levels is forecast. Thus it is likely to take to the latter half of the decade before world rice prices recover to levels that prevailed in the mid/late 1990s. The rationale for the expected recovery in prices, is based on levels of demand (see sub-section 3.1.2.4 below) in key consuming and importing countries rising (in line with population increases) and driving prices upwards. The USDA, for example, forecasts a world price for paddy rice in 2011 of $79.52/tonne relative to the world average paddy price of $60.63/tonne in 2001/02. Even with continued output and productivity gains in exporting countries, commodity prices and export earnings are projected to strengthen in the baseline because of steady growth in import demand.

3.1.2.4 Global demand

Drawing mainly on the forecasts in sub-section 3.1.2.1 above relating to population and GDP growth projections, the level of global demand for rice is expected to increase, but at a slower rate than which occurred during the 1990s. Global demand for/consumption of rice is expected to increase from about 580 million tonnes (paddy equivalent) in 1999 to 660 million tonnes (paddy equivalent) in 2012[12]. Over this period the level of global trade in rice is also expected to increase from about 34 million tonnes (paddy equivalent) in 2001 to 45-50 million tonnes in 2012.

Table 11 provides a summary of the likely demand/consumption requirements over the next ten years in some of the key consuming countries. It highlights a continued increase in demand for (and consumption of) rice in all of the main rice producing and consuming countries, with the exception of Japan and South Korea. In all of the main 'developing' countries, where consumption is forecast to increase this largely reflects expected increases in the populations of these countries. Although the level of rice consumption per head is expected to decrease in line with improvements in the level of income in these countries the rate of increase in population will more than offset this trend. In contrast in Japan and South Korea, where the population is not expected to increase at the rates in other SE countries, the increasing trend away from consumption of the staple rice, will result in a net decrease in the level of demand for rice by 2012.

3.1.2.5 Production and supply availability on world markets

The production and availability of the necessary volumes of rice required to meet the levels of demand projected above are forecast to come from continued expansion in production in most of the primary producing countries.

The primary source of increased production is expected to come from yield improvements rather than any increase in the global area planted to rice, with the total area planted to rice expected to remain at about the 152 million hectares level (any increase in the area planted in countries like Vietnam will be offset by decreases elsewhere). Global rice production is therefore forecast to increase to about 672 million tonnes (paddy equivalent), relative to current levels of about 585 million tonnes (paddy equivalent). In terms of trade, about 44-45 million tonnes (paddy equivalent) of rice are likely to be traded in 2012, an increase of

[12] These forecasts have been made by PG Economics using forecasts made by the USDA and the University of Arkansas as points of reference.

Table 11. Forecast World Rice Demand/Consumption 2000-2012 (Million Tonnes Paddy Equivalent): Key Players

	1999	2012
Bangladesh	38.5	44.5
China	203.4	217.0
Egypt	4.0	5.35
India	121.1	149.2
Indonesia	52.8	62.8
Japan	13.6	11.9
South Korea	7.5	6.9
Pakistan	3.9	4.7
Philippines	12.5	15.6
Myanmar	13.8	15.5
Thailand	13.3	14.1
Vietnam	23.3	28.3
USA	5.3	7.2
Others	67	77
Global Total	**580**	**660**

Source: PG Economics forecasts using USDA and University of Arkansas base comparisons

about 10-12 million tonnes (+30%) when compared to recent levels. Relative to production, the volume of trade will be 6.7% of global production in 2012 compared to 6% currently.

3.1.2.6 Forecasts 2012: summary of key features

The forecasts presented above point to the world market for rice being broadly in balance in 2012 (a small surplus of production relative to demand of 12 million tonnes paddy equivalent). However, in using these forecasts it is important to recognise that the forecasts are heavily dependent upon the assumptions used for a) demand/consumption changes and b) production changes. In summary, the forecasts assume the following:

- The global area planted to rice will remain fairly stable - given the lack of significant amounts of additional, suitable land available for rice cultivation in the main producing countries, and limited availability of additional water;

- Global demand/consumption will increase at a compound rate of marginally under 1% per year to 2012;
- Global production will increase at a compound rate of marginally over 1% per year to 2012. This will come from yield increases.

What is vital to recognise from these assumptions is the sensitivity of the global supply and demand balance for rice to small changes in these assumptions. Table 12 provides some indications of the sensitivity of these assumption changes and highlights that only small positive changes to the rate of consumption increase relative to the baseline assumptions (largely driven by small increases in the rate of population growth in developing countries) may potentially result in significant global shortfalls in production. In addition, possible shortfalls between demand and supply could result from lower than the baseline projected increase in yield (e.g., if the historic rate of increase in rice yields were to slow down).

3.2 Impact of GM Technology

In sub-section 3.1 above, the forecasts relating to global rice production do not take into consideration the potential impact of GM

Table 12. World Supply and Demand for Rice 2012: Sensitivity Analysis (Million Tonnes Paddy Equivalent)

	World demand	World production	Shortfall (-)/ surplus (+)
1999/2000	584	585	+1
2012: 1% pa increase in consumption and 1% pa increase in production	660	672	+12
2012: 1% pa increase in consumption and 0.5% pa increase in production	660	625	-35
2012: 1.5% pa increase in consumption and 1% pa increase in production	708	672	-36
2012: 2% pa increase in consumption and 1% pa increase in production	755	672	-83
2012: 2% pa increase in consumption and 0.5% pa increase in production	755	625	-130

technology. The forecasts effectively assume a continuation of past trends in yield improvements, based on developments in conventional technology. However, GM technology represents a fundamental change to the technology change issue and may provide scope for important (and above trend) advances to rice production husbandry and productivity. This sub-section examines some of these issues in more detail.

3.2.1 Assumptions relating to GM technology adoption in rice to 2012

Drawing on Part 2 (our assessments of probabilities for the release of GM rice traits, based on scientific and technical parameters), Table 13 refines these forecasts for the leading traits, after taking into consideration, political, economic and intellectual property right factors of influence.

Table 13. Projected Time Periods for the Probable Farm Level Use of GM Rice to 2003-2012

Company	Period in which greater than 80% probability of availability to growers	Comments/Assumption
Herbicide tolerance	2004-05	Ready for release in 2002 but held back largely by political/ regulatory approval processes. Availability for use is assumed to start from 2004-2005. It is assumed that the technology will reach the farm level in China and India first by the biotechnology companies (Monsanto & Aventis) seeking collaborations with breeders and obtain approval from national authorities. The technology will become available at the farm level and its cost effectiveness will then drive uptake. This will then act as a catalyst for regulatory approval and uptake in other important rice growing countries in the region. It is also assumed that no licence fees or premia on seed costs are charged and hence this will not act as a barrier to adoption - a similar scenario to the release of herbicide tolerant soybeans in Argentina.
Disease (fungal) resistance	2005-06	Bacteria leaf blight is a major problem for growers. The research of the Xa21 gene is well advanced, shows broad spectrum resistance to all races and is endogenous to rice.

continued ...

Table 13. Cont'd. Projected Time Periods for the Probable Farm Level Use of GM Rice to 2003-2012

	Period in which greater than 80% probability of availability to growers	Comments/Assumption
		It is assumed that IP rights can be agreed and IRRI, through the network of international breeding stations disseminates parental transgenic material to breeders. Regulatory approval is first granted in China and widespread adoption in China occurs. Its efficacy and positive yield impact will then drive uptake across China and into other countries. Wider regulatory approval may not be initially forthcoming in some countries (e.g., possibly Thailand) but the clear benefits of the technology will drive uptake (which may include unapproved plantings in some countries where the regulatory approval process moves slowly).
Insect resistance	2005-06	Insect resistance using Bt genes is a well established/proven method of insect control. The introduction of Yellow Stem Borer/Lepidopteran pest resistance will result in more secure and higher yields and reduced use of insecticides. It is assumed that, through a combination of gene discovery and collaboration, breeders in China and India will release Bt transgenics in rice to growers. The technology will become available at the farm level in these countries and its cost effectiveness will then drive uptake. This will then act as a catalyst to uptake in other important rice growing countries in the region. It is also assumed that no licence fees or premia on seed costs will occur in China but that there will be some room for commercial incentives in more market oriented economies.
Nutritionally enhancement	2007-08	The portfolio of 'Golden Rice' genes provides a combination of enhanced vitamin A and improved iron bio-availability, both of which are important to improving the nutrition and well being of populations in many developing countries. It is assumed that through a co-ordinated approach by the Golden Rice Humanitarian Board, regulatory approval and interaction with national breeding programmes will result in the material being made available through the CGIAR and national breeding programmes.

3.2.2 Impact of GM technology on rice production

Drawing on the earlier assumptions for GM adoption, Table 14 illustrates the potential impact of the mainstream (agronomic) GM rice traits on global production of rice.

Key points to note from Table 14 (plus some additional analysis) are:

- Assuming the equivalent of 40% global adoption and a 10% net positive effect on yields by 2012 this would result in an additional 23-29 million tonnes of rice production relative to baseline (non GM adoption) production forecasts. This is equivalent to about 5.86 million hectares of rice (3.9% of forecast 2012 plantings). If adoption levels were 50% then the production increase would be an additional 25-33 million tonnes;
- If the positive yield impact was extended to an average of +15% (at 40% adoption levels) the positive

Table 14. World Supply and Demand for Rice 2012: Sensitivity Analysis with Adoption of Some Key GM Traits (Million Tonnes Paddy Equivalent)

No application of GM technology	World demand	World production	Shortfall (-)/ surplus (+)
1999/2000	584	585	+1
2012: 1% pa increase in consumption and 1% pa increase in production	660	672	+12
2012: 1.5% pa increase in consumption and 1% pa increase in production	708	672	-36
Application of GM technology: positive impact on yields +10%			
2012: baseline 1% pa increase in consumption and 1% pa increase in production	660	701	+41
2012: baseline 1.5% pa increase in consumption and 1% pa increase in production	708	701	-7

Notes/assumptions

1. Adoption levels in 2012. It is assumed that a global average adoption level of 40% occurs in 2012. This is broadly based on 50% adoption in mainstream producing countries such as China, Vietnam, India, Indonesia, Philippines and lower levels of adoption (20-30%) in Thailand, USA, Japan, and South Korea.
2. Positive yield assumptions include net effect on production of herbicide tolerance, insect and fungal resistance genes. The assumed 10% yield improvement is in addition to the forecast yield increases using conventional technology

impact on global production would be +42 million tonnes, the equivalent of 8.41 million hectares or 5.5% of the forecast global planting area in 2012;

- If current baseline assumptions for growth in demand for rice by 2012 are used, a 40% adoption rate for the GM rices examined above would result in the potential for reductions in the global area planted to rice of 4% (+10% yield responses assumed), freeing up this area for alternative uses and reducing pressures on demand for the increasingly scarce resource of water in many rice producing countries;
- If the more pessimistic assumption for growth in demand for rice is assumed (+1.5% compound increase in demand pa over the next 10 years), then the adoption of the GM rices referred to above would largely eliminate the global supply deficit at a 10% positive yield impact.

3.2.3 Impact on prices

In seeking to assess the impact of a new technology such as biotechnology on the price of rice, it is important to recognise that the impact depends on the nature of the GM technology: whether you are assessing the impact of a cost reducing trait like herbicide tolerance or fungal resistance or a quality (value enhancing) trait.

a) Quality traits

Where the trait is a quality one, the primary aim of the technology is to create a new and improved product, which has added value to purchasers down the supply chain. As such, the intention is to produce and sell a better, differentiated rice than can be derived from conventional seed, for which purchasers will be willing to pay a premia. To date there are very few examples of GM quality traits commercially available (only high oleic soybeans in the US), although it is likely that by 2012, a number of others, both in oilseeds and other crops, possibly including rice can be expected to be commercially available and in production.

The effect of this category of GM rice becoming commercially increasingly available by 2012 will be to create additional segments within the total rice market, which are distinct from mainstream 'commodity' rice. In each of these segments, the likely price premia that the rice containing a quality trait will command, relative to 'commodity' rice, will be directly related to the degree of value added created plus the additional costs of initiating the identity preservation systems required. Where such quality traits are developed and commercialised by the private sector, examination of existing quality segments of cereal and oilseed markets (based on non GM technology) suggests that the price premia will be within a range of +5% to +20% over commodity-traded rice. Nevertheless, it is important to acknowledge that the only GM quality trait rice that will probably be commercially available by 2012 (e.g., nutritionally enhanced rices) are being developed to meet human dietary deficiencies in developing countries. Such developments are likely to be bought to the production base in countries by international institutions and governments in order to improve the welfare of domestic populations. As such, the commercial pressures to derive a return on the R&D investment will be less than those if a private company were bringing the trait to the market place and the 'new quality trait' rice is unlikely to trade at any premia up to the farm level (ie, in the seed market). Additional costs will, however exist in the post harvest (on-farm and downstream) distribution chain because of the need to segregate/identity preserve the quality trait rice from mainstream rices. These additional costs will ultimately have to be borne by some part of the supply chain and re-couped via the charging of higher prices for the quality-traited rice. The likely price premia relative to mainstream rices will ultimately depend upon the level of costs associated with segregation. Existing examples of these costs in grain crop supply chains suggest that a price premia of 5%-10% may develop. This assumes that nutritionally enhanced rices are not more expensive to grow or are lower yielding than conventional varieties. If they are then higher premia than this range will be required.

b) Agronomic traits

Assessing the impact of agronomic, cost saving technology such as herbicide tolerance or fungal resistance on rice prices is difficult. Current and past prices reflect a multitude of factors including the introduction and adoption of new, cost saving technologies. However, disaggregating the effect of different variables on prices is far from easy, and in the case of the impact of a single example of cost saving technology, it is virtually impossible. Whilst this means that it is not possible to be precise about the likely future impact of agronomically improved GM rice that will be available in the next 10 years, the following comments and assessments can be made.

a) The real price of food products has fallen consistently over the last 50 years. This has not come about 'out of the blue' but from enormous improvements in productivity by producers. These productivity improvements have arisen from the adoption of new technologies and techniques.

b) Cost reducing GM technology has been commercially available for over five years in crops like soybeans. Whilst such examples are not directly comparable with the hypothetical impact of the technology on rice, they do offer some pointers to the possible magnitude of impact. The magnitude of the benefits accruing from GM herbicide tolerant soybean adoption in the US were broadly estimated to be within a range of \$28-\$40/ha (\$15-\$25/ha additional profitability to the farmer net of technology fee). Against this background, in 2002, GM (herbicide tolerant) soybeans accounted for nearly three-quarters of production in the US and nearly 90% of the Argentine crop. This means that GM soybeans now effectively influence and set the baseline price for commodity traded soybeans in each country. Also, as both are two of the leading three exporters on global markets, it is also reasonable to infer that GM soybeans also play a significant role in setting the world price for soybeans (and derivatives). Given that GM (herbicide tolerant) soybean varieties offer significant cost savings to growers (see above), it is likely that some of the benefits of the cost saving will be passed on down the supply chain in the form of lower real prices for commodity traded soybeans. Thus, the current baseline price for all soybeans, including non-GM soya is probably at a lower real level than it would otherwise (in the absence of adoption of the technology) have been.

Building on this theme of the impact of the technology to lower real soybean prices, Moschini et al (2000) estimated that in 1999 the global post farm 'consumer' benefit of the technology was about $318 million and the impact on global prices was between –0.5% and –1%. Also under varying assumptions about whether there are yield benefits to be derived from herbicide tolerant soybeans, this work estimated that:

- Under the assumption of global adoption of the technology and no yield benefit to farmers, the total consumer benefit rises to about $900 million and soy/derivative prices falls by between 2% and 2.6%;
- Under the assumption of global adoption of the technology and a 5% yield benefit to farmers, the total consumer benefit rises to about $1,350 million and soy/derivative prices fall by between 5.6% and 6.1%.

The reader should note the simplifying nature of some of the assumptions used in the analysis and therefore extreme caution should be used in drawing conclusions from this analysis. What the analysis does show, however, is that some of the benefit of the cost reducing technology has probably already resulted in lower real prices for commodity soybeans, meal and oil. The effect has probably been greatest on the global price of soybeans but has also affected meal and oil prices. It also highlights the impact of increasing adoption levels for herbicide tolerant soybeans (and other cost reducing GM advances that will be commercialised over the next ten years). As the level of adoption rises, then the value of the total post farm 'consumer' benefit will increase further, and hence contribute to further real reductions in the commodity traded price of GM derived soybeans, meal and oil.

In respect of GM cost reducing rice, it is reasonable to assume that significant adoption of herbicide tolerant, fungal and insect resistant rice should result in some real reductions in the price of commodity traded rice in the main producing countries and on global markets.

3.2.4 Impact on trade patterns and requirements for traceability, segregation and identity preservation

Leaving aside the impact of GM quality traits (see c) below), the widespread adoption of GM agronomic traits has already, in the case of GM herbicide tolerant soybeans, added a new dimension to global trade. In 2002 it is possible to group the major soybean, meal and oil exporting countries into GM derived and non GM derived sources. The GM derived countries comprise those major exporting countries where herbicide tolerant soybeans have been permitted for commercial planting (the US and Argentina). The non GM exporting countries comprise the other exporting countries, where GM soybeans are currently not legally permitted for planting and essentially comprise Brazil plus India. On the demand side the main import markets where demand for non GM derived material has become a distinct part of the markets are in the EU and Japan (also developing in other parts of Asia like South Korea). The rest of the global market can effectively be classified as largely indifferent to the technological origin of the soybeans or derivatives used.

The key question to ask as applied to the rice sector is whether similar developments may occur in the rice sector once GM agronomic traits become available ? Providing an answer to this question requires two important tasks a) looking briefly at how existing GM crop markets like soya may develop over the next ten years and then b) examining the extent to which these are likely to develop in the rice sector.

a) The benchmark: future developments in trade patterns for existing GM (agronomic) crops- the case of soybeans

In 2002 the balance of global available supplies traded on world markets (beans and meal added together and converted to bean equivalents) was about 75 million tonnes GM derived and 30 million tonnes non GM derived[13]. On the demand side, the current, total annual requirements (beans and meal added together and converted to bean equivalent) in the main countries where there is a distinct demand for non GM derived material are about 45 million tonnes[14] (the EU 37.5 million tonnes and Japan 7.5 million tonnes).

The level of demand for non GM derived material will probably increase in the short to medium term and as a result, may push global prices for non GM derived material upwards. This would potentially make the non GM market more attractive to some producing and exporting countries. It could lead to some countries that currently do not permit the planting of GM (herbicide tolerant) soybeans pursuing a deliberate policy of non approval in order to encourage their domestic production sector to service global demand for non GM derived material. The most likely candidates for such a policy are Brazil and India. However, as the act by some governments of not granting approval for planting GM (herbicide tolerant) soybeans, has not stopped a significant proportion of producers in countries like Brazil and Paraguay accessing the technology illegally, it is more likely that the only way in which the market segment demanding non GM derived soybeans, meal and oil can be serviced is via the active policy of a number of individual producers or traders (in specific regions within the main soybean producing and exporting countries) to focus on this market segment. If

[13] Assuming no IP of non GM supplies in GM growing countries.
[14] This relates to total demand, not the sub-demand where non GM derived material is required.

this 'scenario' were to develop then the newly developing trade patterns will be region (within countries) specific rather than country specific. Thus rather than, for example Brazil and India focusing mainly on servicing global demand for non GM derived soybeans, there will be specific regions of Brazil (e.g., the Northern half), India, the US and Argentina that service this market.

Although the market for non GM derived soybeans is currently expanding in the global market, the majority of global demand for soybeans, meal and oil is likely to remain largely indifferent to method of production (GM derived or non GM derived). As such, this market will continue to be serviced by the current, traditional main exporters of the US, Argentina and Brazil.

Overall, we expect that this distinct market for GM versus non GM derived material (based on agronomic traits) to peak in terms of size in the next 1-2 years and will then probably decline in size, as consumer acceptance levels of GM technology *per se* increase[15]. It will, nevertheless continue to represent a niche market by 2012. Within this increasingly segmented global market, we expect the emergence of new players in the marketplace, mostly to service the non GM market. These are likely to be new traders or groups based in specific regions of the main soybean and derivative producing and exporting countries (notably the US, Brazil and Argentina).

b) *Possible trade developments in the markets for GM (agronomic) rice*

The following points are of importance in influencing possible trade developments in the rice sector:

- The nature of the global market for rice has some important differences to the current market for soybeans (and maize). These include i) the majority of soybeans and maize are used as animal feed ingredients whilst the majority of rice is consumed directly as human food, ii) rice is mainly produced and consumed in lower income countries in Asia, with consumption in developed countries accounting for a small minority of total production, iii) trade is a less important part of global use of rice (the equivalent of 6% of production relative to over 20% for wheat, 13% for maize and 30% for soybeans), iv) a greater number of sub-markets and segments (e.g., japonica rices relative to indica rices, aromatic rices (e.g., Basmati, jasmine) than is the case for a crop like soybeans;
- Those with strong anti-GM technology sentiment and the requirement to consume food not derived from GM crops tend to be mostly in higher socio-economic groups and found in the highest income, developed countries;
- In 10 years time, a demand and market

[15] Largely as a result of a) greater familiarity and objective information about the technology, b) the increasing onset of GM value adding traits for which consumers can more easily associate with the (personal) benefits of the technology and c) more relaxed specifications relating to non GM origin and presence amongst retail groups because of the additional and rising costs of supply and the lack of scope for re-couping these costs.

for non GM derived material is likely to exist but probably at a small level. It will be like the current organic market, servicing a niche market in which some consumers have strong views and a desire to avoid any consumption of products derived from GM materials.

Given these factors we do not expect any significant development of any GM versus non GM markets in the rice sector. A non GM market will probably develop when the first agronomic traits are commercialised from 2004/05 but this will be concentrated in the EU and possibly Japan. It is also likely to affect some of the higher quality indica rices like Basmati and jasmine and will mainly impact on the regions/countries that traditionally supply rice to the EU/Japan markets. As both basmati and jasmine rices are currently subject to segregation through the supply chain, any additional requirements about being derived from non GM rice is unlikely to add significantly to the way in which these rices are produced and supplied to markets although additional (probably marginal) costs will be incurred in providing certification (and testing) that these rices have no adventitious contamination with GM rices. It should also be noted that the higher value rices are likely to be less attractive to plant breeders developing GM rice germplasm than mainstream 'IRRI' rices because of the much smaller size of the respective markets.

Thus, the main rice producing countries in which requirements for segregation/Identity Preservation of GM from non GM derived rice is likely to be initiated are:

- The US - an important source of indica rice to the EU market, especially to the Northern EU states where anti-GM sentiment is strongest;
- Thailand – notably because of the importance of jasmine rices (the main rice exported to the EU) and a need to ensure no mixing of GM varieties with rices exported to the EU;
- India and Pakistan, because of the importance of Basmati, which has significant sales into the EU, and the need to ensure no mixing of GM rices with the Basmati.

Nevertheless, no significant change in rice trading patterns is to be expected. Some new players may enter the market specifically to service the non GM market, but this will be a small, niche part of the overall market. We do not foresee the non GM rice market being any greater than 1% of the global market in 2012.

c) Quality traits

We do not expect any commercial development of added value quality traits in rice by the private sector by 2012. Rice is not a priority crop for the development of these traits.

The only development of GM quality traits in rice will probably be the adoption of rices containing nutritional benefits like improved vitamin levels, improved iron availability and higher protein rices. These traits will probably be available from 2007-2008. Production is likely to be largely within countries, with limited trade. Where trade may develop will be between some 'surplus' rice producing countries, with traditional rice importing countries. Such trade, if it develops will also probably be driven by national government import/export contracts and within food aid programmes.

3.2.5 Nature and size of market differences: GM derived and non GM derived rice

A summary of the possible key market differences is shown in Table 15.

Table 15. Summary of Nature and Size of Key Market Developments

GM Derived	Non GM Derived
Agronomic cost saving technology	*Agronomic cost saving technology*
Mainstream part of global rice production that focuses on maximizing production relative to limited availability of additional land and water and continued population	Small part of global market as GM traits come to market in the next 2-3 years, declining in importance to a niche (under 1% of global market by 2012).
Global trade expanding relative to 2002 but still a low share of production compared to other cereals & oilseeds	Main focus on supplies: EU domestic production, US, Japan plus India/Pakistan and Thailand (the latter regions because of the need to ensure separation from their important aromatic rice exports)
Mostly commodity based trading but continuation of segregation along lines of japonica and indica rices and higher value aromatic rices	Nature of demand: some in higher income groups in developed countries – main concentration in EU and Japan
World price of japonica and indica rices = GM derived price	Segregated/identity preserved supply lines 2 levels of IP used: • soft IP (mainly for aromatic rices and based on existing distribution systems supplying these rices, limited to existing certification procedures plus some testing) • harder IP (applicable to indica and japonica rices, strict tolerances, assurances on contamination levels, traceability to origin and testing. Operating in conjunction with/ part of organic market)
Nature of demand: global human food uses Focus of supply: Asia	

continued ...

Table 15. Cont'd. Summary of Nature and Size of Key Market Developments

GM Derived	Non GM Derived
	Prices vary according to type of IP, uses etc: +3%-5% for the softer IP systems (relative to existing aromatic rice price differentials with conventional rices) to +10%-20% for harder IP systems applied to non aromatic rices (relative to the world price of GM derived rice)
GM value added quality traits Unlikely to be developed by private sector whose efforts being focused on other crops (notably oilseeds) Main development will be nutritionally enhanced rices grown and segregated from mainstream rices Price premia to farmers +5% to +10% of farm gate price for mainstream rices (ultimately dependent upon the cost of growing relative to mainstream rices plus segregation/IP costs) Strict IP from farm to mill	*Non GM value added quality products* See above with reference to aromatic rices

3.2.6 Future nature and size of market differences

3.2.6.1 Agronomic (cost saving) GM traits

We see the potential market for GM versus non GM (agronomic traits) rice developing as follows:

- Using the assumptions for GM agronomic trait rices becoming commercially available in mainstream rice producing countries: section 3.2.1, some GM versus non GM rice market will begin to develop in the following 2-3 years (from 2004-05) as fungal and insect resistant varieties are adopted. However, this market is likely to be much smaller and less significant in the rice sector than in other crops (notably soybeans and maize) because of the limited proportion of global rice production that is globally traded and the minor proportion of global rice production and trade accounted for by developed (relative to developing) countries. The market for non GM rice will be initially concentrated in the EU and Japan (plus possibly in some other parts of SE Asia like South Korea, Singapore, Hong Kong). The non GM market will probably be no more than 2%-2.5% of global consumption (about 9.5-10 million tonnes inclusive of aromatic rices which will not be targets of GM technology) and accounting for about 4% of global rice trade in 2004; about 1 million tonnes). On the production side, GM rice will be slowest to be adopted in the main producing regions that have important customer bases in developed country markets and hence reluctance to take up GM technology will probably be concentrated in the Basmati growing regions of India and Pakistan, the fragrant rice growing regions of Thailand, amongst US farmers producing long grain rice (e.g., Arkansas region) that traditionally has a good market in Northern Europe, with EU rice farmers and some elements of the Japanese sector. In contrast, GM (agronomic trait) rices are likely to be subject to greatest adoption rates in the mainstream rice producing (and consuming) countries of Asia – countries where the GM versus non GM issue will be of minor importance relative to issues of food security and welfare of rising populations;

- In the developed economies where a distinct GM versus non GM rice market segment develops, price premia for non GM rice will initially be low because the level of demand relative to supply will be small. Price premia of 2%-5% only will probably appear, reflecting mostly certification and IP systems introduced to provide re-assurance to buyers. In the aromatic rice markets minor additional costs are likely due to requirements for certification that the rice has no adventitious contamination with GM rices;
- These additional costs of servicing the non GM market segments will be absorbed by the supply chain, mostly at the milling part of the chain;
- If GM (agronomic trait) rice is adopted at similar rates to the uptake of GM (herbicide tolerant) soybeans[16], then GM rice will, by 2007-08 be setting the benchmark for world rice prices. As the agronomic traits are cost reducing technology this will effectively create downward pressure on world rice prices and contribute to a widening of any GM versus non GM rice price differential;
- Downward pressure on world rice prices (based on GM rices and their revenue benefits derived from lower costs and higher yields) will place additional pressures on rice growers growing non GM varieties to switch to GM adoption or will require those demanding non GM rices to increase the level of premia paid for non GM rices. This pressure to switch to growing

[16] From zero to 40% adoption of global plantings in five years.

GM varieties is likely to be greatest in Japan and South Korea, where rice farmers will be increasingly faced with competition from imports as WTO market access commitments open these (traditionally highly protected) markets. In the USA the downward pressure on world prices will also place additional pressure on farmers to switch to GM varieties, in order to maintain competitiveness in important export markets (the EU, whilst an important market, accounts for only a small total share of exports), unless buyers are willing to pay more for their non GM rice. Even in the EU pressure to adopt GM rice is likely to build by 2008/09, as import competition intensifies, putting a squeeze on domestic profitability[17];

- Any widening of the GM versus non GM price differential will probably contribute to reducing some of the demand for non GM rice (a reluctance of the supply chain downstream of farmers to pay more for the rice unless they can pass on the additional costs to retailers and ultimately consumers), it will probably lead to re-appraisal by some retail groups as to the real level of demand for such products. Some will then probably drop their demands for non GM origin and be more willing to accept 'any technology origin' rice;
- By 2012, the market for non GM rice will probably have decreased in size, to a very small niche relative to global production and trade. It will mostly impinge on the market segments for aromatic rices and, for mainstream indica and japonica rices, may well become part of the organic segment of the rice market. The size of these markets in total will probably be 0.5%-1% of global production and no more than 1%-1.5% of global trade. Non GM rice will probably trade at 5%-10% premia relative to GM rice.

3.2.6.2 GM quality traits

Likely developments in markets for GM quality trait rices have been discussed in sub-section 3.2.1.

3.3 Effects on Relative Cereal Ingredient Usage/Competitiveness

As rice is a cereal, it faces some competition from other cereals in some markets where it is utilised. This means that the relative competitive position of rice with other cereals can play a role in influencing usage. More specifically:

- Rice is primarily used as a staple food item for large populations in many countries – 88% of total usage is as a human food source, with only 3% used for feed purposes and 1% subject to

[17] The Everything but Arms trade agreement will allow the duty-free import of rice into the EU from least developed countries from 2009.

further processing 'as human foods'. This contrasts sharply with other cereals. Feed use is the most important use for maize and barley (64% and 69% of total usage respectively) and represents significant usage markets for wheat (16%) and sorghum (50%). The only other cereal for which the main use is as a human food is wheat (72%). Like rice, wheat use as a source of human food is mainly found in countries where wheat is most suitable for growing – temperate climatic regions;

- This importance of rice as a food source largely reflects its suitability for growing in the SE Asian region where no other cereal can grow as well or under such high rainfall conditions. In addition, if the countries of Asia attempted to feed their populations by other cereal means, they would probably fail – population densities would probably be significantly lower than they currently are if rice was not widely available;
- The importance of rice (and wheat) as sources of staple human foods means that in each country where either rice or wheat is mainly grown, the crops compete as a source of human food, only at the margin (rather than as direct competitors). Rice tends to compete with wheat as a source of human food only once basic human food requirements have been met and incomes rise above subsistence levels. Thus rice competes with a variety of other cereals (eg, wheat, durum wheat based products like couscous and pasta) as a human food source in developed economies, although as income rise in developing countries some shifts in consumption patterns away from rice have already been occurred and are forecast to continue - see sub section 3.1;
- In the feed sector, cereals are primarily a source of carbohydrate and fibre, although protein content is also relevant (the primary source of protein being from protein crops/oilseeds). Consequently, most cereal sources are considered to be largely interchangeable from the point of view of feed manufacturers and hence, price tends to be the key determinant influencing which cereals are used. The relatively low level of rice use in animal feed globally largely reflects a) its primary role as a source of human food in countries where alternatives are limited, b) global production of livestock products is more heavily concentrated in temperate climatic regions where other cereals are more readily available to the local feed industries – in SE Asia rice bran is used in the animal feed sector, c) feed standard wheat, barley and maize tend to trade at a discount to rice on world markets. For example the respective average prices for a tonne of feed wheat, maize and milled rice in 2001 were respectively \$105/tonne, \$84/tonne and \$220/tonne.

The application of new technology and new techniques to rice (and other cereal) production systems essentially results in improvements to the competitive position of the beneficiary crop.

The most common way in which crops such as rice have traditionally benefited from technology advances is through yield improvements (e.g., from traditional plant breeding of higher yielding varieties). These technology advances have contributed to increases in the ratio of returns to input costs and have been the major objective of traditional breeding of new varieties for many years. Also in this context, are breeding characteristics such as GM herbicide tolerance and GM fungal resistance, which reduce the costs of growing crops, and hence also improve the ratio of returns to costs.

The key point to note here is that the widespread adoption of a new cost reducing technology such as GM herbicide tolerant or GM fungal resistant rice is contributing to improving the competitive position of rice relative to other cereals. This means that unless the rate of introduction and commercialisation of GM (or conventional) cost saving (agronomic traits) technology to other cereals matches that of rice, over the next ten years, the relative competitive position of rice will improve. Although this report does not cover the adoption and potential commercial availability of similar technology developments for other cereal crops, it does appear that rice will be an important foci for GM agronomic trait development in the next 10 years, with the introduction of herbicide tolerant, fungal resistant and insect resistant traits. This largely reflects the size and importance of the global rice crop to many developing countries. This points to reasonably widespread adoption of GM agronomic traits in rice by 2012 and to the competitive position of rice improving a little relative to other (temperate) cereals that are currently faced with greater levels of public hostility to GM technology adoption (for example, it is probable that herbicide tolerant and fungal resistant rice will be commercially available earlier and adopted more widely than any GM agronomic trait wheat). As a result rice use may increase relative to other cereals in some developing countries largely dependent on imported cereals to feed their populations and in the feed user sectors.

3.4 GM Derived Versus Non GM Derived International Competitiveness Implications

The development of any GM derived versus non GM derived rice markets over the next 10 years (see sub-section 3.2.4 above) is likely to have some impact on different countries and groups which trade in the global marketplace. This sub-section briefly considers some of the main implications.

3.4.1 Users/consumers of rice in markets where the demand for non GM derived material is greatest (e.g., the EU)

3.4.1.1 The rice milling and rice using elements of the food industry

In sub-section 3.2.4 it was emphasised that the price differential between GM derived and non GM derived rice will be borne through the supply chain back from retailers and hence will probably fall on rice millers and food processors/manufacturers.

The net effect of this development, should it occur, will be reduced margins to food manufacturers and rice millers. Where rice ingredient use is small relative to total ingredient use this is unlikely to represent any significant problem to food manufacturers. However, for rice millers, where rice accounts for an important cost component, the implications are possibly more negative, especially as from 2009 EU rice millers will be faced with duty-free import competition from rice originating in least developed countries (countries which may well also have access to and use GM cost reducing technology).

Overall, it is factors other than GM issues (i.e., trade mechanism and policy changes) that are the primary concerns of the competitiveness of the rice milling sector in the EU, although the GM versus non GM issue may constitute a small, additional negative on industry profitability, income generation and employment.

3.4.1.2 Exporters of rice based in countries with markets for non GM derived rice

Success in exporting agricultural and food products onto world markets is heavily dependent on being price competitive. As such, a key element of export competitiveness is having access to raw materials at the lowest possible cost.

The sector of greatest relevance here is the rice milling and exporting industries. This means that where countries have well developed rice milling sectors that are export oriented (e.g., japonica rices from Italy), their ability to compete on global markets is significantly influenced by their ability to access the lowest priced japonica paddy rice available or, alternatively access to export subsidies that offset the difference between uncompetitive local raw material prices and world prices. In the case of rice millers located in the rice growing countries of the EU, the scope for access to and use of export subsidies has already been reduced by the Uruguay Round WTO Agreement and this will be further eroded in the next 'Doha' Round (likely to be implemented from 2005/06 onwards). Couple this with the opening of EU markets to duty-free rice imports from the least developed countries in 2009, it will become vital for EU-based rice mills to have access to the most competitively priced (paddy rice) raw material. As rice derived from GM (agronomic traits) rice will be cheaper to produce than rice derived from non GM rices, it (GM derived) will become the favoured source of paddy rice for millers competing in a highly competitive marketplace, provided markets for (EU milled) rice do not actively show preferences in favour of non GM derived rice. As indicated earlier, the EU is currently developing a market segment that wishes to avoid consuming GM derived products and this is also likely to develop within the rice sector from about 2004/05 when the first GM rices are likely to be grown commercially. This development of a non GM element to the market will push EU-based rice millers, which service the EU market, to source the less competitively priced non GM rice, adding cost to their production systems that they will not easily be able to re-coup (even in the EU market where demand for non GM material will be greatest). If this category of (non GM) rice is also the base material used for milled rice exported (out of the EU) this could adversely affect export competitiveness in markets where consumers are less sensitive or indifferent to the GM versus non GM derived food issue.

The only alternatives available for rice millers and exporters faced with these potential market circumstances will be to a) concentrate on exporting to markets where the demand for non GM rice is strong or b) source GM derived paddy rice for milling. The first of these alternatives is faced with the problem that the market will be a small and largely EU only market and the second alternative leaves EU millers with a problem of being located a long way from the production regions. This will add cost and reduce competitiveness relative to millers based in the main producing regions of these rices – the EU is also unlikely to have approved GM rice for planting when GM rice becomes commercially available in other parts of the world. The most cost effective action for EU millers would therefore be to get local (EU) growers to plant GM varieties and then to segregate the two categories of rice for milling: GM for export and indifferent consumers in the EU and non GM for discriminating EU customers. Inevitably this will add some costs and contribute to some reduced (export) competitiveness.

3.4.2 Suppliers of rice in the main rice producing countries

3.4.2.1 Growers and millers of GM rice

This category of producer/user in countries such as China, India, Thailand, Indonesia, Vietnam and the USA will be producing and selling products that are highly price competitive, both domestically and on world markets. The only market to which their produce will be denied is the market for products derived from non GM material, which will be very small relative to the total volume of global production and trade.

3.4.2.2 Growers and millers of non GM rice

This category of producer/miller is mostly likely to be found in parts of the EU, the USA, Thailand and Japan and will be producing and selling products that are less price competitive on world markets than GM derived rice. Their products will need to service markets where the demand for non GM derived material is strong and where these markets are prepared to pay the necessary additional costs involved in growing non GM rice and undertaking the associated IP systems required to ensure that there is no adventitious contamination of the product on route to markets.

In the immediate period of about 2-3 years after 2004, this market may provide market opportunities for a minority of producers and exporters of rice located in the EU, USA, Thailand and Japan. However, in the longer term, this small market is likely to decrease in importance towards 2012, making it purely a niche market attractive to a small number of growers and millers.

It is also important to recognise that if a major rice producing country (e.g., Thailand) were to prohibit (and enforce) the growing of GM (agronomic trait) rice, it would be denying its rice export industry a competitive advantage in the majority of its export markets.

4 SUMMARY AND CONCLUSIONS

4.1 Global Importance of Rice

1. There has been a broadly stable area of rice planted globally over the last five years although the level of production has increased by 12% relative to the early 1990s. Therefore increases in yield have been the main origin of the higher levels of production.

2. The vast majority of global production and consumption of rice is found in Asia (e.g., 88% of global rice consumption).

3. Only 6% of global rice production is traded globally and three-quarters of this trade is indica varieties. The importance of trade relative to production is much lower for rice than for the other leading cereals (e.g., trade accounts for 13% of global maize production and 22% of global wheat production).

4. The vast majority of rice is consumed directly for human food (88%). This contrasts with other cereals. Food use accounts for 72% of wheat use and only a small share of barley and maize use. Animal feed use is the primary use for barley and maize and is an important usage for wheat. In contrast feed use accounts for only 3% of total rice use.

5. Rice prices are currently at an historic low, having fallen by 30%-40% over the last 10 years.

4.2 Rice Biotechnology Development

6. There are many players in the field of rice biotechnology including public and private organisations. Of the 16 leading organisations, 5 are multinational biotechnology companies, 6 are boutiques/specialist biotechnology companies and the balance are international and national institutions/organisations.

7. For the mainstream (five) multinational biotechnology companies, rice has been an important priority crop for research but in recent years it has been downgraded to a 'second/third' tier crop (in terms of priority for regulatory approval and commercial development). This largely reflects a perceived limited scope for capturing value through the rice crop and hence a reasonable return on investment.

   Nevertheless, considerable investment is being made by commercial organisations and international/national bodies on sequencing the Rice Genome. This makes rice the most genetically understood of all cereal grains and is being used as a model for cereals. Also over the last 10 years there have been considerable amounts of public funding and institutional support in laying the foundations for laboratories in the key rice producing countries to take advantage of modern methods of rice transformation and gene expression.

Public-private partnerships in developing rice biotechnology are making steady progress as illustrated by the Golden Rice Initiative and the formation of the Humanitarian Board for Golden Rice.

8. Successful transfer of biotechnology developments to commercial application requires germplasm, plant breeding capability and seed multiplication. Monsanto and Aventis have relevant capability in some of the leading rice producing countries and IRRI acts as a major source of advanced breeding, germplasm and varieties through its well established network in Asia, Africa and South America. In addition, there are a number of important, national (publicly funded) plant breeding programmes (e.g., in India, China, Vietnam, Malaysia) each of which has proprietary germplasm and access to IRRI's material.

9. Our forecasts for release of GM traits in rice (see Part 2) highlight that four technologies are currently available and ready for advanced breeding, seed multiplication and release to farmers. These are herbicide tolerance, fungal disease resistance (bacterial leaf blight), insect resistance (Bt) and nutritionally enhanced rice (Golden Rice).

4.3 General Market Development

10. The main factors driving rice consumption are population growth and income levels. In general, these forces are 'pulling in opposite directions' in the main rice consuming countries with consumption per head declining as income rises counterbalanced by increases in the absolute level of consumption as populations rise.

11. The main drivers of production are domestic support policies, trade agreements, the development of new technology and the price of rice.

12. The projected nature of the global rice market in 2012 (in the absence of GM development) is for global rice consumption to rise from 584 million tonnes (paddy equivalent) to 660 million tonnes (paddy equivalent) and for global production to increase from 585 million tonnes (paddy equivalent) to 672 million tonnes (paddy equivalent). The planting area is expected to remain broadly stable over the next 10 years.

13. Global trade in rice is forecast to increase by about 10 million tonnes to 44-45 million tonnes (paddy equivalent). Relative to production the volume of trade will be 6.7% of global production compared to 6% currently. The forecasts above point to the world market for rice being broadly in balance in 2012 (a small surplus). However,

these forecasts are based on both global demand/consumption and production increasing at a compound rate of about 1% per year to 2012. If the rate of change to either production or consumption is altered (e.g., 0.5% additional rate of increase in demand or –0.5% to the rate of production increase) this will result in significant shortfalls in the global supply balance position for 2012. This highlights the vulnerability of the global rice supply/demand position to for example, small negative changes in the level of annual production and the limited nature of security to the global rice balance.

4.4 Impact of GM Technology

14. Our forecasts for the projected timing for commercial, farm level use of some of the leading GM rice developments are summarised in Table 16. These

Table 16. Projected Time Periods for the Probable Farm Level Use of GM Rice 2002-2012

	Period in which greater than 80% probability of availability to growers	Comments/Assumption
Herbicide tolerance	2004-05	Ready for release in 2002 but held back largely by political/ regulatory approval processes. Availability for use is assumed to start from 2004-2005. It is assumed that the technology will reach the farm level in China and India first by the biotechnology companies (Monsanto & Aventis) seeking collaborations with breeders and obtaining approval from national authorities. The technology will become available at the farm level and its cost effectiveness will then drive uptake. This will then act as a catalyst for regulatory approval and uptake in other important rice growing countries in Asia. It is also assumed that no licence fees or premia on seed costs are charged and hence this will not act as a barrier to adoption - a similar scenario to the release of herbicide tolerant soybeans in Argentina.
Disease (fungal) resistance	2005-06	Bacteria leaf blight is a major problem for Asian growers. The research of the Xa21 gene is well advanced, shows broad spectrum resistance to all races and is endogenous to rice.

continued ...

Table 16. Cont'd. Projected Time Periods for the Probable Farm Level Use of GM Rice 2002-2012

	Period in which greater than 80% probability of availability to growers	Comments/Assumption
		It is assumed that IP rights can be agreed and IRRI, through the network of international breeding stations disseminates parental transgenic material to breeders. Regulatory approval is first granted in China and widespread adoption in China occurs. Its efficacy and positive yield impact will then drive uptake across China and into other Asian countries. Wider regulatory approval may not be initially forthcoming in some countries (e.g., possibly Thailand) but the clear benefits of the technology will drive uptake (which may include unapproved plantings in some countries where the regulatory approval process moves slowly).
Insect resistance	2005-06	Insect resistance using Bt genes is a well established/proven method of insect control. The introduction of Yellow Stem Borer/Lepidopteran pest resistance will result in more secure and higher yields and reduced use of insecticides. It is assumed that, through a combination of gene discovery and collaboration, breeders in China and India will release Bt transgenics in rice to growers. The technology will become available at the farm level in these countries and its cost effectiveness will then drive uptake. This will then act as a catalyst to uptake in other important rice growing countries in the region. It is also assumed that no licence fees or premia on seed costs will occur in China but there will be some room for commercial incentives in more market oriented economies.
Nutritionally enhancement	2007-08	The portfolio of 'Golden Rice' genes provides a combination of enhanced vitamin A and improved iron bio-availability, both of which are important to improving the nutrition and well being of populations in many developing countries. It is assumed that through a co-ordinated approach by the Golden Rice Humanitarian Board, regulatory approval and inter-action with national breeding programmes will result in the material being made available through the CGIAR and national breeding programmes.

forecasts take into consideration, political, economic and intellectual property right factors of influence.

4.5 Impact of GM Technology on Rice Production

15. Drawing on analysis presented in Part 3, the following are some of the potential impacts of GM rice by 2012:

- Assuming the equivalent of 40% global adoption and a 10% net positive effect on yields, by 2012 this would result in an additional 23-29 million tonnes of rice production relative to baseline (non GM adoption) production forecasts. This is equivalent to about 5.86 million hectares of rice (3.9% of forecast 2012 plantings). If adoption levels were 50% then the production increase would be an additional 25-33 million tonnes;

- If the positive yield impact was extended to an average of +15% (at 40% adoption levels) the positive impact on global production would be +42 million tonnes, the equivalent of 8.41 million hectares or 5.5% of the forecast global planting area in 2012;

- If current baseline assumptions for growth in demand for rice by 2012 are used, a 40% adoption rate for the GM rices examined above would result in the potential for reductions in the global area planted to rice of 4% (+10% yield responses assumed), freeing up this area for alternative uses and reducing pressures on demand for the increasingly scarce resource of water in many rice producing countries;

- If the more pessimistic assumption for growth in demand for rice is assumed (+1.5% compound increase in demand pa over the next 10 years), then the adoption of the GM rices referred to above would largely eliminate the global supply deficit at a 10% positive yield impact.

4.6 Impact on Prices

16. *Quality traits*: The commercial development of value added traits in rice is not a major priority for the leading biotechnology companies – their focus is much more on oilseeds and other cereals (notably maize). As indicated above, the main quality trait in rice that is likely to be grown commercially is nutritionally enhanced rice, which targets dietary deficiency in developing country populations. As these forms of rice need to be kept segregated from mainstream rice varieties, there will inevitably be some, probably small additional cost involved in supplying these rices to the market. These additional costs will be in the on and post farm part of the supply chain and will result in a small price premia

relative to mainstream rices. Based on evidence of existing (non GM) quality segments of other rice, cereal and oilseed crops, this premia will probably be in the region of 5%-10% (it should be noted that the premia will be higher than this if nutritionally enhanced rices are more expensive to grow than conventional rices, e.g., have lower average yields).

17. *Agronomic traits*: Assessing the impact of agronomic, cost saving technology on agricultural crop prices is difficult because prices reflect a multitude of factors, of which the introduction of new technology is one factor of influence. Also there are no current examples of the commercial application of GM (agronomic trait) rice on which data can be drawn. Nevertheless, some conclusions can be drawn from current examples of the application of GM technology in other crops (notably soybeans). The key point to note about the application of GM cost reducing technology in soybeans is that it has contributed to a lowering of the real price of soybeans traded globally (and within the main producing countries). Estimates made in the USA suggest that global soybean prices may have fallen by between 0.5% and 1% as a result of adoption of herbicide tolerant soybeans by 2000 (this estimate assumes that there are no yield benefits), that the impact on prices would be –2% to –2.6% if there was global adoption and that if there was global adoption of the technology and significant (+5%) yield benefits were also derived, the impact on price would be –5% to –6%.

4.7 GM Versus Non GM Markets: Segregation/IP and Trade Patterns

18. The following points are of importance in influencing these developments in the rice sector:

- The nature of the global market for rice has some important differences to the current market for soybeans (and maize). These include i) the majority of soybeans and maize are used as animal feed ingredients whilst the majority of rice is consumed directly as human food ii) rice is mainly produced and consumed in lower income countries in Asia, with consumption in developed countries accounting for a small minority of total production, iii) trade is a less important part of global use of rice (the equivalent of 6% of production relative to over 20% for wheat, 13% for maize and 30% for soybeans), iv) the global rice trade probably has a greater number of sub-markets and segments (e.g., japonica rices relative to indica rices, aromatic rices (e.g., Basmati, jasmine) than is the case for a crop like soybeans;

- Those with strong anti-GM technology sentiment and the requirement to consume food not derived from GM crops tend to be mostly in higher socio-economic groups and found in the highest income, developed countries.

Given these factors we do not expect any significant development of any GM versus non GM markets in the rice sector. Initially from 2004-05 it may develop to 2%-2.5% of global consumption or 9.5 million tonnes (inclusive of aromatic rices consumed in developed countries), but by 2012, it is likely to be no more than 0.5%-1% of global production (3.4-6.7 million tonnes) and affecting only 1%-1.5% of global trade (0.5-0.7 million tonnes). In effect it will, by 2012 be a small, niche market.

19. The lack of regulatory approval (even for importation) of GM rices in some developed countries is unlikely to hold up the introduction of GM agronomic traits in the main producing countries because of the lack of significance of developed country demand for rice.

20. The non GM market will be concentrated in the EU and possibly Japan. It will also affect some of the higher quality indica rices like Basmati and jasmine and will mainly impact on the regions/countries that traditionally supply rice to the EU/Japan markets. As both Basmati and jasmine rices are currently subject to segregation through the supply chain, any additional requirements about being derived from non GM rice is unlikely to add significantly to the way in which these rices are produced and supplied to markets, although additional (marginal) costs will be incurred in providing certification to demonstrate no adventitious contamination with GM rices.

21. Higher value rices are also likely to be less attractive to plant breeders developing GM rice germplasm than mainstream 'IRRI' rices because of the much smaller size of the respective markets.

22. The main rice producing countries in which requirements for segregation/ Identity Preservation of GM from non GM derived rice is likely to be initiated are:

- The US - an important source of indica rice to the EU market, especially to the Northern EU states where anti-GM sentiment is strongest;
- Thailand – because of the importance of jasmine rices (the main rice exported to the EU);
- Parts of India and Pakistan, because of the importance of Basmati, which has significant sales into the EU.

Lastly in the case of nutritionally enhanced rice, these rice need to be kept segregated from mainstream rice and therefore will be subject to segregation/IP.

Table 17. Winners and Losers

Issue	Winners	Losers
Adoption of GM (agronomic traits) rice	Global users and consumers (lower real prices) and greater security of supply Farmers: reductions in costs of production, higher yields, greater flexibility/convenience, additional revenues The technology innovators (biotechnology companies): sales of allied products to GM seed (notably herbicides) and 'spin off' gains for adoption of GM technology in other crops (see concluding comments) Developing country governments: improved food security and probable reductions in import requirements in traditional importing countries (lower volumes required and imports at lower prices) The environment: less pesticide use	Non adopting farmers: falling prices but no cost savings or yield benefits Technology innovators (biotechnology companies): limited scope for earning returns on GM innovations and for some, reduced sales of agro-chemicals – replaced by GM pest & disease control mechanisms
Adoption of GM quality traits (nutritionally enhanced rice)	Consumers accessing improved products with better nutritional content Developing country governments: improved health and welfare of populations Technology providers (biotechnology companies): demonstration of the utility of the technology leading to 'spin off' gains for wider acceptance of GM crops	None

4.8 Winners and Losers

These are summarised in Table 17.

4.9 Concluding Comments

The information and analysis presented in this report highlights that there are a number of GM rice traits that are either ready for or close to readiness for commercial use. These offer some potentially substantial benefits ranging from the provision of nutritionally enhanced rices for dietary deficient populations in developing countries, to the provision of higher yielding, lower cost rice production. In addition, the technology has the potential to make important contributions to enhanced food security in developing economies.

Nevertheless, the application of GM technology is currently 'stalled' through a combination of reasons including politics, intellectual property rights, regulatory approval processes and opposition to the technology from some international interest groups.

Our analysis and forecasts presented in this report for the global rice market and the development of GM technology points to GM technology playing a significant and growing role by 2012. This clearly assumes that the factors that are currently 'stalling' progress are largely overcome in the next 2-3 years.

We perceive that the driving force for this will come from the adoption of GM rice technology at the national level. Here the largely public sector plant breeding and research bodies in China, Vietnam and possibly India, will drive this based on the desire (of their respective governments) to reap the benefits of the technology for their domestic economies, for population nutritional enhancement and for improved food security. Once GM rice is adopted in countries like China it is likely that the clear benefits of the technology will drive rapid uptake across Asia and political and regulatory opposition is likely to subside 'in the face of the clear benefits'.

Clearly the speed with which this may happen will be influenced by the willingness of those biotechnology companies and research institutes to strike deals over the intellectual property rights held on some of the GM traits. Some traits (notably those being developed independently in countries like China) will not be dependent on this process, whilst others will. Therefore the willingness of holders of Intellectual Property Rights on GM rice to agree favourable 'deals' with international bodies such as IRRI and public sector plant breeding/ research bodies in countries like China, Vietnam, India etc will have a significant influence on the speed of uptake.

As the holders of IP rights on GM rice weigh up the pros and cons of striking such deals (the main negative being the apparent limited nature of commercial incentives within the rice sector), it may be worthwhile for these IP right holders taking a broader look at the issues by examining the wider benefits to be obtained from disseminating GM technology for rice to national and international bodies with little or no restriction or cost to use. Whilst the opportunities to derive commercial benefits from the technology in rice may be low, opportunities from "knock-on" effects in other crops are much more significant. Certainly if GM rice is made widely available across Asia (without undue restrictions on users having to pay significant royalties/license fees), its rapid uptake in the region has the potential to demonstrate across the world the benefits of the technology. In turn this may make a valuable contribution to reducing opposition to GM technology, especially in developed economies. In turn this may contribute to facilitating regulatory approval and uptake of the technology in all crops in these countries – countries in which the scope for deriving reasonable returns on innovations is much higher than in developing countries.

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