GREENPEACE Briefing
April 2005

Rice at Risk

Genetically engineered bacterial blight resistant rice: An unnecessary and risky experiment with the world's most important staple food crop

Scientists in China are proposing the commercial release of genetically engineered (GE) rice which is resistant to bacterial blight disease. The rice is based on an introduced *Xa21* rice gene, which has been isolated from African wild rice.

If the rice is approved for commercial release, it will be the first time that the world's most important staple food has been genetically engineered and will mean a radical increase in the exposure of the human diet to genetically engineered organisms. Exposing such a large number of people to the risks of GE food in a direct way, and on an unprecedented scale is a very high risk proposal, for which there is no obvious justification.

This paper outlines some of the risks of GE bacterial blight resistant rice, explains why it is unnecessary, and describes alternative, less risky options for solving the problem of bacterial blight in rice crops.

Risks of GE Bacterial Blight Resistant Rice

International experts have agreed that genetic engineering is a crude and imprecise technology that can create unexpected effects regardless of the source or type of gene that is introduced. The UN Food and Agriculture Organization/World Health Organization Codex Guidelines on GE food safety[1] confirm the unpredictability of the method.

The GE process can result in multiple copies of genes being inserted, genes may be in the forward or reverse orientation and, there may be fragments of genes from the vector also transferred. Deletions and rearrangements have also been seen. These mutations induced by the GE process may occur at the site of insertion or be genome wide[2]. Such effects occur regardless of the source of the gene and the method of genetic engineering. They are inherent to the process of genetic engineering.

The implications of this crude technology include:

- the possible disruption of the plant's own genes and their abnormal functioning – this could lead to the production of unexpected toxins or anti-nutrients that could affect the plant's fitness to survive in the environment;
- increases or decreases in the activity of plant's owns genes through the introduction or disruption of control genes – this could increase or decrease the levels of naturally occurring toxins, allergenic proteins or other important substances produced by the plant;
- silencing (inactivation) of genes in subsequent generations if multiple copies exist.

---

[1] FAO/WHO 2003. Codex Alimentarius Guideline for the conduct of food safety assessment of foods derived from recombinant-DNA plants CAC/GL 45-2003 ftp://ftp.fao.org/es/esn/food/guide_plants_en.pdfFAO/WHO 2002.

[2] Wilson, A. Latham, J. & Steinbrecher, R. (2004) Genome scrambling – myth or reality? Transformation-induced mutations in transgenic crop plants. EcoNexus technical report. EcoNexus, Brighton, UK.

There are numerous examples that show unexpected and unpredictable effects in GMOs. These include:

- Researchers at Monsanto who were trying to increase the content of carotenoids (a chemical which is used to form vitamin A in oilseed rape (canola) found that vitamin E and chlorophyll levels in the seeds were dramatically and inexplicably reduced[3];
- Other researchers trying to genetically engineer the carotenoid pathways in tomatoes found over-expression of the gene caused unexpected dwarfism in the plant[4];
- Monsanto's GE Roundup Ready soybeans have suffered unexpected crop losses in hot, dry weather due to stem splitting caused, most probably, by increased lignin[5]. The soybeans' phytoestrogen levels are also 12-14 % less than in conventional soybeans, which may mean that soy-based products derived from Roundup Ready soybeans would be less useful as sources of phytoestrogens[6];
- Levels of a potato toxin (glycoalkaloid) increased and decreased unexpectedly in separate genetic engineering experiments when engineered with different genetic inserts that were not intended to alter the toxin content[7];
- A study that compared the behaviour of a GE herbicide tolerant plant (Arabidopsis thaliana) with a herbicide tolerant Arabidopsis thaliana plant that was not produced by GE showed unexpectedly that the GE plant had a dramatically increased ability to donate pollen to nearby wild-type mothers compared to the non-GE plant[8];
- Unexpected alterations in GE rice phenotype and agronomic performance have been reported.[9]

GE bacterial blight resistant rice could also have unexpected and hidden effects that could have an ecological impact or be unsafe for human consumption. Many of these effects may also be influenced by environmental conditions. Allowing commercial growing and consumption of GE rice is a high risk game.

The Contamination Threat

If GE rice is planted commercially, it will lead to the contamination of other rice crops and may also contaminate wild rice. Although rice is largely self-pollinating, pollen is strongly influenced by wind speed and direction and can travel up to 100 metres.[10] Gene flow (cross breeding) has been detected

---

[3] Shewmaker, C.K., Sheehy, J.A., Daley, M., Colburn, S. & Yang Ke, D. (1999) Seed-specific overexpression of phytoene synthase: increase in cartenoids and other metabolic effects. *The Plant Journal*, **20**, 401-412.

[4] Fray, R.G., Wallace, A., Fraser, P.D., Valero. D., Hedden, P., Bramley, P.M. & Grierson, D. (1995) Constitutive expression of a fruit phytoene synthase gene in transgenic tomatoes causes dwarfism by redirecting metabolites from the gibberellin pathway. *The Plant Journal*, **8**, 693-701.

[5] Coghlan, A. (1999) Splitting headache – Monsanto's modified soybeans are cracking up in the heat. *New Scientist*, 20th November, p.25.

[6] Lappé, M.A., Bailey, E.B., Childress, C.C. & Setchell, K.D.R. (1998/1999) Alterations in Clinically Important Phytoestrogens in Genetically Modified, Herbicide-Tolerant Soybeans. *Journal of Medicinal Food*, **1**, 241-245.

[7] Documented in Kuiper, H.A., Kleter, G.A., Noteborn, H.P.J.M. & Kok, E.J. (2001) Assessment of the food safety issues related to genetically modified foods. *The Plant Journal*, **27**, 503-528. Table 6.

[8] Bergelson J., Purrington C.B., Wichmann G. (1998): Promiscuity in transgenic plants, Nature 3 September, p. 25

[9] Schuh, W., Nelson, M.R., Bigelow, D.M., Orum, T.V., Orth, C.E., Lynch, P.T., Eyles, P.S., Blackhall, N.W., Jones, J., Cocking, E.C. & Davey, M.R. 1993. The phenotypic characterisation of R2 generation transgenic rice plants under field conditions. Plant Science 89: 69-79.
Shu, Q-Y, Cui, H-R., Ye, G-Y., Wu, D-X., Xia, Y-W., Gao, M-W. & Altosaar I 2002. Agronomic and morphological characterization of Agrobacterium-transformed Bt rice plants. Euphytica 127: 345-352.
Wu, D.X. Shu, QY., Wang, Z H., Cui, HR. & Xia, Y. W.. 2002. Quality variations in transgenic rice with a synthetic cry1Ab gene from *Bacillus thuringiensis*. Plant Breeding 121: 198-202.

[10] Song, Z.P Lu, B-R & Chen JK. (2004). Pollen flow of cultivated rice measured under experimental conditions. *Biodiversity and Conservation* 13(3): 579–90.

at 43 metres.[11] Therefore, some degree of cross pollination of neighbouring non-GE rice is almost certain. Other possible sources of contamination include:

- Previous crops of rice: Growing multiple crops of rice, sometimes as many as three and half crops in a year, is not uncommon. Rice seeds that fall in the field during harvesting can germinate during the next cropping cycle. If a non-GE crop is planted following a GE crop, there is potential for contamination in the second crop.
- The soil seed bank: Rice seed can remain in the soil seed bank for two years or more before it germinates.
- Seed saving and seed exchange.
- Spillage during transport.

The uncontrolled spread of GE rice is particularly risky in Asia, the centre of origin of rice. Wild species with which cultivated rice (*Oryza sativa*) can hybridise (crossbreed), are widely distributed. *Oryza rufipigon* and *Oryza nivara* can cross breed with cultivated rice, and progeny of such crossbreeding events (hybrids) occur in the field. These wild species are sometimes found as weeds in rice production areas. Because rice is largely self-pollinating, outcrossing rates to these wild species are relatively low, up to about 2-3%.[12,13]

When wild and cultivated rice are found in the same regions, the production of hybrids between cultivated and wild rice is considered inevitable over time. Therefore, the introduction of traits such as disease resistance into GE rice will inevitably transfer to wild varieties, which may improve the competitiveness of these wild rice varieties and could lead to their emergence as more problematic weeds.

Such hybrids may also swamp natural wild varieties and possibly lead to their extinction. This extinction can happen in two ways; – through demographic swamping and genetic assimilation. In swamping, the population of wild plants shrinks in size because crop-wild hybrids are less fertile. Small populations and rare species can be lost. In genetic assimilation, crop genes replace the genes in wild species through continual hybridization.

Although *Oryza rufigpon* is not present in central China, and is not a problem weed in rice fields, it does occur in the southern provinces of Guangdong, Guangxi, Hainan and Yunnan and it is considered endangered.[14] Therefore, the introduction of GE rice could lead to negative impacts on this species and add to the already established need to protect these populations from gene flow from cultivated rice.[15,16]

The swamping of one species of wild rice by genes from cultivated rice is considered to have caused its extinction in Taiwan.[17] The loss of wild species of rice would threaten the conservation of natural biodiversity and represent a serious loss of genetic resources. This could jeopardise breeding and food security in the future as breeding efforts depend on diverse genetic resources.

Loss of effectiveness through decreasing resistance

---

[11] Song, ZP, Lu, B-R. Zhu YG, & Jchen, K. (2003). Gene flow from cultivated rice to the wild species *Oryza rufipogon* under experimental field conditions. New Phytologist 157: 657-665

[12] Chen, L.J. Lee, DS, Song, ZP, Suh, HS. & Lu, B-R. (2004) Gene flow from cultivated rice (O*ryza sativa*) to its wild and weedy relatives. Annals Bot 93: 67-73.

[13] Lu, B-R. (2004) Gene flow from cultivated rice: ecological consequences. ISB News Report. Available at: http://www.isb.vt.edu <28th October 2004>

[14] Gao, L (2004) Population structure and conservation genetics of wild rice *Oryza rufipogon* (Poaceae): a region-wide perspective from microsatellite variation Mol Ecol 13: 1009–1024.

[15] Song, ZP, Lu, B-R. Zhu YG, & Jchen, K. (2003). Gene flow from cultivated rice to the wild species *Oryza rufipogon* under experimental field conditions. New Phytologist 157: 657-665

[16] Song Z P, Xu, X. Wang,B. Chen JK & Lu, B-R. (2003) Genetic diversity in the northernmost *Oryza rufipogon* populations estimated by SSR markers. Theor Appl Genet.107(8):1492-9.

[17] Kiang, YT, Antonovics J. & Wu L (1979). The extinction of Wild Rice (*Oryza perennis formosana*) in Taiwan. J Asian Ecol 1: 1-9.

It is well known that the cultivation of single resistance gene varieties will eventually lead to a breakdown in resistance[18], and can result in the appearance of more virulent strains[19]. The bacteria *Xanthomonas oryzae* pv *Oryzae* (*Xoo*) that causes bacterial blight is highly adaptable[20], and therefore may soon overcome the single GE resistance mechanism.

The likely loss of effectiveness of the bacterial blight resistant rice will mean that rice farmers are highly unlikely to derive any long term benefits from its introduction. As the next section explains, the GE bacterial blight resistant rice will not even provide short-term benefits and is simply not necessary.

GE bacterial blight resistant rice is not needed

The push to introduce GE bacterial blight resistant rice is a distraction from the real priorities of agricultural research and poses unnecessary risks. This rice is unnecessary :- bacterial blight is not a major agricultural problem in China, bacterial blight resistance can be achieved through conventional (non GE) means, and there are other (non-breeding) methods of dealing with the disease.

Bacterial blight is not a major agricultural problem in China

In the International Rice Research Institute's (IRRI) only published assessment of research priorities for biotechnology, Robert Herdt, Director of Agricultural Sciences with the Rockefeller Foundation outlined research priorities for rice. At the time, and according to Herdt, bacterial blight affected 8.1% of the rice growing area in Southeast Asia causing $57.5 million in crop losses - and nearly $100 million in South Asia. Yet, for Herdt, conventional approaches to the disease were already "effective and sustainable" and "biotechnology approaches seem likely to be ineffective." In his ranked ordering of agricultural problems with potential for biotechnology applications, bacterial blight is near to the bottom.[21]

In China, Ministry of Agriculture statistics show that bacterial blight is no longer a major disease for rice with the total area of infection at less than one million hectares over the last five years, representing only around 1-2% of the total rice growing area (Table 1).

The Ministry has not conducted any national bacterial blight infection forecast in the past two years since the disease is no longer considered to be a serious, nationwide problem.

Table 1. Bacterial blight occurrences in China 2000-2004[22]

	2000	2001	2002	2003	2004*
Total rice acreage (x 10,000 ha)	2,996	2,881	2,820	2,651	-
Areas affected by BB (x 10,000 ha)	50.27	72.13	51.20	38.80	43.40
Areas affected by BB (x 10,000 mu)	754	1,081.95	768	582	651
% affected by BB	1.68%	2.5%	1.82%	1.46%	-

*2004 BB figure is based on forecast by Ministry of Agriculture, China.

Bacterial blight resistance can be achieved through conventional breeding

---

[18] Meung, H., Zhu ,Y.Y., Revilla-Molina, I., Fan, J.X., Chen, H.R., Pangga, I., Cruz, C.V. & Mew, T.W. (2003).Using genetic diversity to achieve sustainable rice disease management. Plant Disease, 87: 1156-1169.

[19] Wang, C., Su, C, Zhai, H. & Wan, J. (2005). Identification of QTLs underlying resistance to a virulent strain of *Xanthomonas oryzae* pv. *oryzae* in rice cultivar DV85. Field Crops Research 91: 337–343.

[20] Vera Cruz, C.M., Bai, J., On, I., Leung, H., Nelson, R.J., Mew, T-W. & Leach, J.E. (2000). Predicting durability of a disease resistance gene based on an assessment of the fitness loss and epidemiological consequences of avirulence gene mutation. Proceedings of the National Academy of Sciences 97: 13500–13505.

[21] Herdt, Robert W. "Research Priorities for Rice Biotechnology," in *Rice Biotechnology,* G.S. Khush and G.H. Toenniessen (eds.), Alden Press Ltd., London, 1991, pp. 19-54.

[22] Shiwen, Dr. Huang, "Integrated Pest Management in Sustainable Rice Production," from Proceedings of International Conference on Sustainable Rice Production (2004); Official website of Ministry of Agriculture, http://www.agri.gov.cn/index.htm.

The Xa21 gene can be, and has been, introduced into rice by conventional breeding methods[23] and marker assisted breeding[24]. There is no need to use genetic engineering and no need to take any of the risks that are inherent with the process of genetic engineering. Even if developing bacterial blight resistant rice was considered a priority, conventionally bred rice lines that have the Xa21 genes exist. Similarly, molecular marker assisted breeding techniques can be further used to speed up the development of conventional rice varieties or hybrids that are resistant to bacterial blight.

Marker-assisted breeding is often viewed as accelerated conventional breeding. In seed development and breeding programmes it can be used to select the plants for further breeding programmes because they contain a genetic marker. Marker-assisted breeding does not change the DNA of the plant in the same disruptive and unpredictable way as genetic engineering.

Marker-assisted breeding can also be used to select and breed rice varieties that have several resistance genes[25]. This ability to breed in several resistance genes[26], is more likely to give longer-lasting resistance against disease[27] and makes marker assisted breeding a far superior technique to genetic engineering without the associated risks.

Other methods of controlling bacterial blight in rice

Breeding resistance to bacterial blight into the rice is only one way of solving the problem of bacterial blight. Other methods, based on farming practices, may also offer promising solutions.

Genetic diversity in rice has been reduced over the past few decades. This tendency towards genetic uniformity results in an increased frequency of disease epidemics[28]. Therefore, increased diversity of rice varieties planted could aid the control of bacterial blight. Interplanting of varieties in Yunnan has been shown to be effective in reducing rice blast[29]. It is possible they could also be useful in controlling bacterial blight.

The sequential release of resistant varieties has been successful in controlling rice diseases. As one variety become susceptible, another is released in rotation so the disease does not overcome all the resistant varieties[30].

Another option may be the use of biocontrol agents. Certain strains of a soil bacterium (*Pseudomonas fluorescens*) are known to suppress bacterial blight, but this has yet to be explored in detail[31].

---

[23] Khush, G.S., E. Bacalangco, and T. Ogawa. 1990. A new gene for resistance to bacterial blight from *O. longistaminata*. Rice Genetics Newsletter, 7:121–122 http://www.gramene.org/newsletters/rice_genetics/rgn7/v7p121.html

[24] Chen, S., Lin, X.H., Xu, C.G. & Zhang, Q. 2000. Improvement of Bacterial Blight Resistance of 'Minghui 63', an Elite Restorer Line of Hybrid Rice, by Molecular Marker-Assisted Selection. Crop Science 40: 239–244.

[25] Joseph, M. Gopalakrishnan, S., Sharma, R.K., Singh, V.P., Singh1, A.K., Singh, N.K., & Mohapatra, T. 2004. Combining bacterial blight resistance and Basmati quality characteristics by phenotypic and molecular marker-assisted selection in rice. Molecular Breeding 13*,* 1–11.

[26] Joseph, M. Gopalakrishnan, S., Sharma, R.K., Singh, V.P., Singh1, A.K., Singh, N.K., & Mohapatra, T. 2004. Combining bacterial blight resistance and Basmati quality characteristics by phenotypic and molecular marker-assisted selection in rice. Molecular Breeding 13*,* 1–11.

[27] Meung, H., Zhu ,Y.Y., Revilla-Molina, I., Fan, J.X., Chen, H.R., Pangga, I., Cruz, C.V. & Mew, T.W. (2003).Using genetic diversity to achieve sustainable rice disease management. Plant Disease, 87: 1156-1169.
Gnanamanickam, S.S., Brindha Priyadarisini, V., Narayanan, N.N., Vasudevan, P. & Kavitha, S. (1999). An overview of bacterial blight disease of rice and strategies for its management Current Science 77: 1435-1443.

[28] Mew, T., Leung, H., Savary, S., Cruz, C.V. & Leach, J. (2004). Looking ahead in rice disease research and management. Critical Reviews in Plant Sciences, 23: 103-127.
Meung, H., Zhu ,Y.Y., Revilla-Molina, I., Fan, J.X., Chen, H.R., Pangga, I., Cruz, C.V. & Mew, T.W. (2003).Using genetic diversity to achieve sustainable rice disease management. Plant Disease, 87: 1156-1169.

[29] Meung, H., Zhu ,Y.Y., Revilla-Molina, I., Fan, J.X., Chen, H.R., Pangga, I., Cruz, C.V. & Mew, T.W. (2003).Using genetic diversity to achieve sustainable rice disease management. Plant Disease, 87: 1156-1169.

[30] Meung, H., Zhu ,Y.Y., Revilla-Molina, I., Fan, J.X., Chen, H.R., Pangga, I., Cruz, C.V. & Mew, T.W. (2003).Using genetic diversity to achieve sustainable rice disease management. Plant Disease, 87: 1156-1169.

[31] Gnanamanickam, S.S., Brindha Priyadarisini, V., Narayanan, N.N., Vasudevan, P. & Kavitha, S. (1999). An overview of bacterial blight disease of rice and strategies for its management Current Science 77: 1435-1443.

Conclusion

If GE bacterial blight resistant rice is approved for commercial release, it will be the first time that a staple food has been genetically engineered. On average, rice provides 30% of calories and 19% of protein intake in China[32]. In other countries, such as Bangladesh and Cambodia, rice can provide around two thirds of both calorific and protein intake. Rice also forms an important part of the diet at all ages, including for babies where rice flour and gruel are used during weaning.[33] The importance of rice in the diet means that the decision to introduce GE rice should not be made lightly.

Genetic engineering is a crude and un-precise method and poses unknown risks to the environment and human health. Once the commercial growing of GE rice is allowed, GE contamination of conventional, organic and wild rice will be inevitable in Asia. Over time contamination will lead to loss of markets and undermine or threaten the availability of non-GE rice. If GE rice seed became contaminated this would seriously limit options in the future should any unexpected problems arise, as the situation may have become irreversible.

There is no demonstrable need for GE bacterial blight resistant rice. It is a high-risk experiment with one of the world's most important staple food crops. Greenpeace urges the Chinese government to ban the release of GE bacterial blight resistant rice.

---

[32] Rice Today, September 2002. Rice Facts. Essential food for the poor. http://www.irri.org/publications/today/pdfs/1-2/facts1-2.pdf <28th October 2004>

[33] Ministry of Health and Welfare, Japan (1999) Guideline for weaning (revised edition) Pediatrics International 41 (1): 115 - doi: 10.1046/j.1442-200x.1999.01037.x