Environmental Dangers of Insect Resistant *Bt* Crops

Of the 68 million hectares of genetically engineered (GE, also called genetically modified, GM) crops grown throughout the world in 2003, 18% (12 million hectares) were varieties developed to be resistant to insects[1]. Most such crops are created by inserting a synthetic version of a gene from the naturally occurring soil bacterium, *Bacillus thuringiensis* (*Bt*), so that the plants produce their own *Bt* toxins to destroy pests.

Insect resistant GE *Bt* maize (corn), cotton and potatoes have already been grown extensively on a commercial scale, particularly in the USA, and several other *Bt* crops are under development (e.g. oilseed rape, rice and tomatoes). However, there is strong evidence that the rush to commercialise *Bt* crops will have serious environmental consequences.

Impact on non-target beneficial organisms

In its natural form, *Bt* has been used by farmers practising organic and other sustainable growing methods since the 1950s as a spray to kill pests without damaging non-targeted insects or other wildlife. However, the *Bt* toxins produced by insect resistant crops such as Monsanto's GE maize, e.g. MON810 are significantly different and have been shown to be harmful to beneficial predator insects.

Natural *Bt* sprays have little effect on non-target organisms because the bacterial "pro-toxin" is in an inactive state and only becomes toxic when processed in the gut of certain (targeted) species of insect larvae. In contrast, many insect resistant plants contain an artificial, truncated *Bt* gene and less processing is required to generate the toxin. It is therefore less selective, and may harm non-target insects that do not have the enzymes to process the pro-toxin, as well as the pests for which it is intended (Fig. 1).[2]

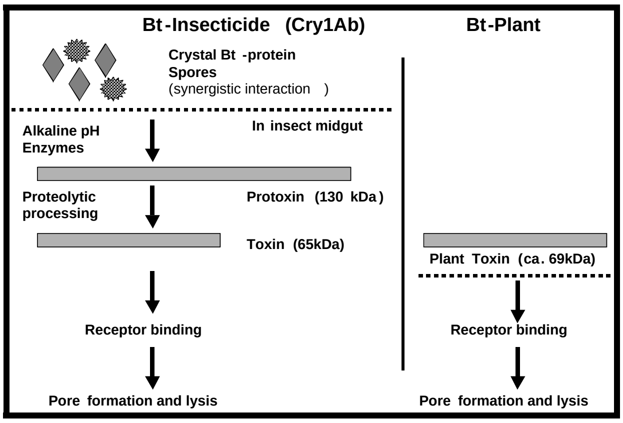

Fig. 1 Differences Bt-insecticides and GE Bt-plants[2].

GE *Bt* plants could be harmful to non-target organisms if they either consume the toxin directly in pollen or plant debris, or indirectly by feeding on pests that have ingested the toxin. This could cause harm to ecosystems by reducing the numbers of important species, or reduce the numbers of beneficial organisms that would naturally help control the pest species.

Most of the current *Bt* crops (containing the Cry1Ab or Cry1Ac gene) are GE to be toxic to certain species of moths and butterflies (Lepidoptera). Larvae of non-target moths and butterflies may inadvertently ingest the *Bt* toxin whilst feeding on plants growing nearby *Bt* crops. The impact of pollen from *Bt* maize on larvae of the monarch butterfly (*Danaus plexippus*) in North America is the most well-known example of this phenomenon[3]. Pollen from *Bt* maize (Syngenta's Bt176) caused the monarch butterfly controversy. This strain of *Bt maize*, Bt176 has, or is, being phased out. Bt176 was also found to be toxic to larvae of the Eurasian peacock butterfly (*Inachis Io*)[4].

Long-term exposure to *Bt* pollen from two *Bt* maize types, MON810 and Bt11, has recently been found to cause adverse effects on larvae of the monarch butterfly, even though these strains of *Bt* maize contain less *Bt* in their pollen than Bt176. Although no short-term effects (4-5 days) were noted[5], longer-term studies (2 years) found over 20 % fewer monarch larvae reached the adult butterfly stage when exposed to naturally deposited *Bt* pollen[6]. Many species of butterflies and other insects are already under threat[7] from factors such as climate change and loss of habitat. Increased stress from exposure to *Bt* pollen could further threaten certain species.

Environmental risk assessments for *Bt* crops do not require long-term exposure studies to non-target organisms and it has been suggested that longer periods of exposure would improve the risk assessment[8]. The case of the monarch butterfly shows it is vital these studies are performed.

Changes in populations of both pests and of natural enemies have been documented in *Bt* cotton. Data from China show that use of *Bt* crops can exacerbate populations of other secondary pests, including aphids, lygus bug, whitefly, Carmine spider mite and thrips[9]. Studies there have shown significant reductions in populations of the beneficial parasites *Microplitis sp*. (88.9% reduction) and *Campoletis chloridae* (79.2% reduction) in *Bt* cotton fields[10]. In the US, impacts of *Bt maize* on field populations of *Coleomegilla maculata*, a beneficial predatory insect commonly found in corn fields have been found[11]. A certain type of the *Bt* toxin (Cry1Aa) has been shown to be toxic to the silkworm (*Bombyx mori*)[12].

Green lacewings (*Chrysoperla carnea*)– have been shown to be affected by *Bt* crops in the laboratory[13]. Lacewings are beneficial insects that play an important role in the natural control of crop pests. The toxic effects of *Bt* crops on lacewings are via the prey that they ate, which in turn had been ingesting the *Bt* crop. This illustrates that the *Bt* toxin can affect organisms higher up the food chain. However, the environmental risk assessments for *Bt* crops include only single species studies, which would not detect any effects on organisms higher up the food web. This approach has been highly criticised and scientists have suggested that the effects of *Bt* crops need to be studied at multiple levels of the food web[14].

"Single-species studies of non-target effects represent a narrow approach to assessing the positive and negative ecological impacts of non-target effects. Understanding the ecological consequences of non-target effects also depends on accurately identifying what physical and biological processes a transgenic organism may alter, and understanding what impacts these alterations have on ecosystems."
Ecological Society of America (2004)

The disturbing conclusion is that *Bt* toxins from GE plants can kill non-target species and be passed higher up the food chain, an effect that has never been observed with the *Bt* toxin in its natural form.

Impact on Soil Health

Soil organisms play a crucial role in soil health. Therefore, it is necessary to understand how different agricultural practices affect them. *Bt* crops may be problematic for long-term soil health, as they express proteins that are known to be toxic to certain insects and are suspected of being toxic to a range of non-target organisms as well, including earthworms[15]. An unknown number of species make up the soil food web and could be affected by *Bt* – yet tests have been conducted on very few, in very few soil types and ecosystems.

If, under field conditions, the *Bt* deposited in the soil by these crops has an impact on soil organisms – bacteria, fungi, insects, earthworms – there will necessarily be downstream effects. If *Bt* crops kill or otherwise reduce the activity of any of these soil organisms, they will disturb the web of relationships necessary for carrying out essential ecosystem functions, such as decomposition and nutrient cycling.

Bt crops secrete the toxin from the root into the soil[16] and *Bt* crop residues left in the field contain the *Bt* toxin. The *Bt* toxin can persist in soils for over 200 days, particularly if there is a cold winter period[17]. Therefore, *Bt* proteins are likely to be present in the soil, not only throughout the growth of the crop, but also long after the crop is harvested. This raises the possibility of the accumulation of *Bt* toxins in the soil[18].

Further studies are needed to determine whether the persistence of *Bt* would cause problems for non-target organisms and the health of the soil ecosystem. This highlights the need for long-term studies on the impacts of *Bt* crops.

Resistance problems

An additional environmental hazard of insect resistant crops is that targeted pests could develop resistance to the effects of *Bt*. This is because constant exposure to the *Bt* toxin produced by these plants encourages the survival of individual pests which have a genetic immunity to *Bt*. Over time, this could lead to the proliferation of resistant individuals to the extent that *Bt* would no longer be effective against the majority of the targeted pest population.

In the US, the Environment Protection Agency (EPA) have complex requirements for *Bt* refugia (planted areas of non-*Bt* crops), which are required to slow down the build up of insect resistance to *Bt*. However, there are concerns that the current refugia requirements (20 % of the area planted with *Bt* crops) may not be sufficient[19] and may not be rigorously enforced. Refugia may not be practical on small farm holdings in Europe and elsewhere, which are very different to the large field sizes in the US. This problem has been identified with *Bt* cotton in both India[20] and China[21].

There is doubt that the refugia will be fully effective. It has also been shown that resistance of the major *maize* and cotton pest, *Helicoverpa zea* (bollworm or earworm), to *Bt* could develop rapidly[22] if the acreage of *Bt* maize increases in the US corn belt. GE contamination of non-*Bt* maize refugia, caused by cross pollination, could undermine refugia, as pest insects will still be exposed to *Bt* in the refugia[23].

There is overwhelming scientific data to support concerns of insect pest resistance[24]. If widespread resistance were to occur, the insect resistant properties of the GE crops would become ineffective. The application of new and even more toxic chemical pesticides would therefore be almost inevitable. Furthermore, increased resistance would pose a serious threat to sustainable and environmentally friendly agricultural methods.

Emergence of Superweeds?

Insect-resistance in GE crops (e.g. *Bt* crops) is considered by scientists to be a fitness-enhancing gene, and thus likely to increase in frequency and spread throughout local populations[25]. Such an increase in fitness raises the potential for wild relatives to become problem weeds or swamp the existing wild population[26]. For example, studies with oilseed rape (*Brassica napus*) have shown that the *Bt* gene can be passed on to a wild, weedier relative (*B. rapa*)[27].

The *Bt* gene could have broad ecological impacts following its spread throughout the population (introgression), through:

- persistence of the *Bt* protein in the soil, with toxicity to soil organisms
- toxicity to non-target herbivores, predators and parasites (natural enemies of affected pests)
- the development of resistance to *Bt* in affected pests

Impact on sustainable farming methods

The use of naturally occurring *Bt* toxins in foliar sprays has provided organic and other environmentally conscious farmers with an invaluable weapon against harmful pests for several decades. *Bt* pesticides kill targeted pests without harming beneficial predator insects[28] and the toxins have no known detrimental effect on mammals or birds.

Because of its effectiveness and safety compared to the pesticides it displaces, *Bt* is probably the single most important insecticide ever discovered. If pests develop resistance to its effects, however, organic farmers will be deprived of a powerful pest control mechanism and other users may switch to more environmentally damaging pesticides. Organic pest control methods could also be jeopardised by the destruction of beneficial predator insects, such as the green lacewing, which are essential to environmentally friendly pest management.

Greenpeace is opposed to the release of GE organisms because of the irreversibility of such releases and the potential of GE organisms to cause serious harm to the environment.

For *Bt* crops the environmental dangers include:

- **effects on non target organisms, including indirect and long-term effects;**
- **effects on soil health;**
- **build up of insect resistance to Bt and the impacts on sustainable farming practices and**
- **the threat of wild relatives acquiring traits, giving them an ecological advantage.**

References

1 James, C. 2003. Global Review of Commercialized Transgenic Crops: 2003. ISAAA Briefs No. 30. Ithaca, NY: ISAAA. http://www.isaaa.org/

2 Hillbeck, A. 2001. Transgenic host plant resistance and non-target effects. In: *Genetically engineered organisms: assessing environmental and human health effects.* Letourneau, D.K. and B.E. Burrows [eds.] Boca Raton, FL: CRC Press. Hilbeck, A., M.S. Meier and A. Raps. 2000. Review on non-target organisms and *Bt* plants. Report prepared for Greenpeace International, Amsterdam, EcoStrat GmbH, Ecological Technology Assessment & Environmental Consulting, Zurich, Switzerland.

3 Losey, J.E., L.S. Raynor and M.E. Carter. 1999. Transgenic pollen harms monarch larvae. *Nature* 399: 214; Hanson-Jesse, L.C. and J.J. Obrycki. 2000. Field deposition of *Bt* transgenic corn pollen: lethal effects on the monarch butterfly. *Oecologia* 125: 241-248; Sears, M.K., R.L. Hellmich, D.E. Stanley-Horn, K.S. Oberhauser, J.M. Pleasants, H.R. Mattila, B.D. Siegfried, and G.P. Dively. 2001. Impact of *Bt* corn pollen on monarch butterfly populations: A risk assessment. *Proceedings of the National Academy of Sciences* 98: 11937-11942.

4 Felke, M. and G.A. Langenbruch. (2003): Wirkung von *Bt*-Mais-Pollen auf Raupen des Tagpfauenauges im Laborversuch (Effect of *Bt*-maize-pollen on caterpillars of *Inachis io* in a laboratory assay). *Gesunde Pflanze* 55: 1-7.

5 Stanley-Horn, D.E., G.P. Dively, R.L. Hellmich, H.R. Mattila, M.K. Sears, R. Rose, L.C.H. Jesse, J.E. Losey, J.J. Obrycki and L. Lewis. 2001. Assessing the impact of Cry1Ab-expressing corn pollen on monarch butterfly larvae in field studies. *Proceedings of the National Academy of Sciences* 98: 11931-11936.

6 Dively, G.P., R. Rose, M.K. Sears, R.L. Hellmich, D.E. Stanley-Horn, D.D. Calvin, J.M. Russo and P.L. Anderson. 2004. Effects on monarch butterfly larvae (Lepidoptera: Danaidae) after continuous exposure to Cry1Ab expressing corn during anthesis. *Environmental Entomology* 33: 1116-1125.

7 Thomas, J.A., M.G. Telfer, D.B. Roy, C.D. Preston, J.J.D. Greenwood, J. Asher, R. Fox, R.T. Clarke and J.H. Lawton. 2004. Comparative losses of British butterflies, birds and plants and the global extinction crisis. *Science* 303: 1879-1881.

8 Andow, D.A. and A. Hilbeck. 2004. Science-based risk assessment for non-target effects of transgenic crops. *Bioscience*, 54: 637-649. Ecological Society of America (ESA) 2004. Genetically engineered organisms and the environment: Current status and recommendations. ESA Position Paper http://www.esa.org/pao/esaPositions/Papers/geo_position.htm. Marvier, M. 2002. Improving risk assessment for nontarget safety of transgenic crops. *Ecological Applications* 12: 1119-1124.

9 Cui, J. and J. Xia. 1998. Effects of transgenic *Bt* cotton (with early maturity) on population dynamics of main pests and their natural enemies. *Acta Gossypii Sinica* 10: 255-262.

10 Cui, J. and J. Xia. 1999. Effects of transgenic *Bt* cotton on the population dynamics of natural enemies. *Acta Gossypii Sinica* 11: 84-91.

11 Wold, S.J., E.C. Burkness, W.D. Hutchison, and R.C. Venette. 2001. In-field monitoring of beneficial insect populations in transgenic corn expressing a *Bacillus thuringiensis* toxin. *Journal of Entomological Science* 36: 177-187.

12 Fan, L-J., Y-Y. Wu, H-Q. Pang, J-G. Wu, Q-J. Shu, M-K. Xu and J-F. Lu. 2003. *Bt* rice pollen distribution on mulberry leaves near rice fields. *Acta Ecologica Sinica* 23: 826-833.

13 Hilbeck, A., W.J. Moar, M. Pusztai-Carey, A. Filippini, and F. Bigler. 1999. Prey-mediated effects of Cry1Ab toxin and protoxin and Cry2A protoxin on the predator *Chrysoperla carnea*. *Entomologia Experimentalis et Applicata* 91: 305-316. Dutton A., H. Klein, J. Romeis and F. Bigler. 2002. Uptake of *Bt* toxin by herbivores feeding on transgenic maize and consequences for the predator *Chrysoperla carnea. Ecological Entomology* 27: 441-447.

14 Knols, B.G.J. and M. Dicke. 2003. *Bt* crop assessment in the Netherlands. *Nature Biotechnology* 21: 973-974. Andow, D.A. & A. Hilbeck. 2004. Science-based risk assessment for non-target effects of transgenic crops. *Bioscience*, 54: 637-649. Ecological Society of America (ESA) 2004. Genetically engineered organisms and the environment: current status and recommendations. ESA Position Paper http://www.esa.org/pao/esaPositions/Papers/geo_position.htm

15 Marvier, M. 2001. Ecology of transgenic crops*. American Scientist* 89: 160-167. Zwahlen, C. A. Hilbeck, R. Howald and W. Nentwig. 2003, Effects of transgenic *Bt* corn litter on the earthworm *Lumbricus terrestris*. *Molecular Ecology* 12:1077 –1086.

16 Saxena, D., S. Flores and G. Stotzky. 1999. Transgenic plants: Insecticidal toxin in root exudates from *Bt* corn. *Nature* 402: 480; Saxena, D., S. Flores, and G.Stotzky, 2002. *Bt* toxin is released in root exudates from 12 transgenic corn hybrids representing three transformation events. *Soil Biology & Biochemistry* 34: 133-137.

17 Tapp, H. and G. Stotzky. 1998. Persistence of the insecticidal toxin from *Bacillus thuringiensis* subsp. kurstaki in soil. *Soil Biology & Biochemistry* 30: 471-476. Zwahlen, C., A. Hilbeck, P. Gugerli & W. Nentwig. 2003. Degradation of the Cry1Ab protein within transgenic *Bacillus thuringiensis* corn tissue in the field. *Molecular Ecology* 12: 765-775.

18 Venkateswerlu G. and G. Stotzky. 1992. Binding of the protoxin and toxin proteins of *Bacillus thuringiensis* subsp. kurstaki on clay minerals. *Current Microbiology* 25: 225-233.

19 Knight, J. 2003. Agency 'ignores its advisers' over *Bt* maize. *Nature* 422: 5.

20 Jayaraman, K.S. 2002. Poor crop management plagues *Bt* cotton experiment in India. *Nature Biotechnology* 20: 1069.

21 Huang, J. and Q. Wang. 2003. Biotechnology policy and regulation in China. IDS Working Paper, Biotechnology Policy Series 4, Brighton: Institute of Development Studies.

22 Gould, F., N. Blair, M. Reid, T.L. Rennie, J. Lopez, and S. Micinski. 2002. *Bacillus thuringiensis*-toxin resistance management: stable isotope assessment of alternate host use by *Helicoverpa zea*. *Proceedings of the National Academy of Sciences*. 99: 16581-16586.

23 Chilcutt, C.H. and B.E.Tabashnik. 2004. Contamination of refuges by *Bacillus thuringiensis* toxin genes from transgenic maize. *Proceedings of the National Academy of Sciences* 101:7526-7529.

24 See, for example, Andow, D.A. 2001. Resisting resistance to *Bt* corn. In: *Genetically engineered organisms: assessing environmental and human health effects.* Letourneau, D.K. and B.E. Burrows [eds.] Boca Raton, FL: CRC Press.

25 Stewart, Jr., C.N., J.N. All, P.L., Raymer, and S. Ramachandran. 1997. Increased fitness of transgenic insecticidal rapeseed under insect selection pressure. *Molecular Ecology* 6: 773-779. Vacher, C., A.E. Weis, D. Hermann, T. Kossler, C. Young, M.E. Hochberg 2004. Impact of ecological factors on the initial invasion of *Bt* transgenes into wild populations of birdseed rape (*Brassica rapa*). *Theoretical and Applied Genetics* 109: 806-814.

26 Haygood, R., A.R. Ives and D.A. Andow 2003. Consequences of recurrent gene flow from crops to wild relatives. *Proceedings of the Royal Society of London B, Biological Sciences* 10.1098/rspb.2003.2426.

27 Halfhill, M.D., R.J. Millwood, P.L. Raymer, and C.N. Stewart, Jr. 2002. *Bt*-transgenic oilseed rape hybridization with its weedy relative, *Brassica rapa. Environmental Biosafety Research* 1: 19-28. Vacher, C., A.E. Weis, D. Hermann, T. Kossler, C. Young, M.E. Hochberg 2004. Impact of ecological factors on the initial invasion of *Bt* transgenes into wild populations of birdseed rape (*Brassica rapa*). *Theoretical and Applied Genetics* 109: 806-814.

28 McGaughey, W.H. and M.E. Whalon. 1992. Managing insect resistance in *Bacillus thuringiensis* toxins. *Science* 258: 1451.