GREENPEACE Briefing

Environmental and health impacts of GM crops - the science

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This briefing gives an overview of scientific evidence regarding the environmental and health risks of genetically modified crops.

Environmental impacts

Most genetically modified (GM) crops awaiting EU authorisation for cultivation are either herbicide-tolerant or pesticide-producing (or both). The environmental effects of these crops are increasingly well documented, often from experience in North and South America, where they are principally grown.

I. GM pesticide-producing crops kill specific pests, by secreting toxins known as Bt, which originate from a bacterium. Peer-reviewed scientific evidence is mounting that these GM crops are:

- **Toxic to harmless non-target species**. Long-term exposure to pollen from GM insect-resistant maize causes adverse effects on the behaviour[1] and survival[2] of the monarch butterfly, America's most famous butterfly. Few studies on European butterflies have been conducted, but those that have suggest they would suffer from pesticide-producing GM crops[3,4,5,6]. These studies are all based on one type of toxin, Cry1Ab, present in GM maize varieties Bt11 and MON810. Much less is known about the toxicity of other types of Bt toxin (e.g. Cry1F, present in the GM maize 1507). Cry1F is highly likely to also be toxic to non-target organisms[7], but requires separate study.

- **Toxic to beneficial insects**. GM Bt crops adversely affect[8] beneficial insects important to controlling maize pests, such as green lacewings[9, 10,11,12]. The toxin Cry1Ab has been shown to affect the learning performance of honeybees[13]. The environmental risk assessment under which current GM Bt crops have been assessed (in the EU and elsewhere) considers direct acute toxicity alone, and not effects on organisms higher up the food chain. But these effects can be important. The toxic effects to beneficial lacewings came through the prey they ate. The single-tier risk assessment has been widely criticised by scientists who call for a more holistic assessment[14,15,16,17].

- **A threat to soil ecosystems**. Many Bt crops secrete their toxin from their roots into the soil[18]. Residues left in the field contain the active Bt toxin [19, 20, 21, 22] The long-term, cumulative effects of growing Bt maize are of concern.[23]

EU risk assessments so far fail to foresee at least two other impacts of Bt maize:

- **Risk for aquatic life.** Leaves or grain from Bt maize can enter water courses [24, 25, 26] where the toxin can accumulate in organisms[27] and possibly exert a toxic effect[28]. This demonstrates the complexity of interactions in the natural environment and underlines the shortcomings of the current risk assessment.

- **Swapping one pest for another.** Several scientific studies show that new pests are filling the void left by the absence of rivals initially controlled by Bt crops[29, 30, 31, 32]. Plant-insect interactions are complex, are hard to predict and are not adequately risk assessed.

II. GM herbicide tolerant (HT) crops are generally associated with one of two herbicides: glyphosate (the active ingredient of Monsanto's herbicide Roundup used with Roundup Ready GM crops, also sold by Monsanto), or glufosinate, used with Bayer's Liberty Link GM crops. Both herbicides raise concerns, but many recent environmental studies have focussed on glyphosate, which is associated with:

- **Toxic effects of herbicides on ecosystems.** Several new studies suggest that Roundup is far

less benign than previously thought[33]. For example, it is toxic to aquatic organisms such as frog larvae[34] and there are concerns that it could affect plants essential for farmland birds[35]. Wider impacts may exist. Glyphosate is associated with nutrient (nitrogen and manganese) deficiencies in GM Roundup Ready soya, thought to be induced by its effects on soil microorganisms[36].

- **Increased weed tolerance to herbicide**. Weed resistance to Roundup is now a serious problem in the US and South America[37] where Roundup Ready crops are grown on a large scale [38, 39.] Increasing amounts of[40] glyphosate or additional herbicides[41] are needed to control these 'superweeds', adding to the toxicity of food and the environment.

Independent researchers complain about the lack of seed material made available for tests on environmental effects[42] and are seriously concerned because those finding adverse effects face persecution by the pro-GM industry.[43]

A decade of research fails to acquit GM crops

Contrary to GM industry spin, the publication "A decade of EU-funded research"[44] prepared by the Directorate-General for Research of the European Commission, does not provide scientific evidence on the environmental safety of GM plants. The vast majority of research referred to under the chapter Environmental Impact of GMOs is mostly about the development of GM crops with plant protection traits and has very little to do with assessing the environmental impacts (for example on soil health or on butterflies and moths) of the pesticide-producing and herbicide-tolerant GM crops awaiting an EU authorisation. The few projects that do examine environmental safety raise concerns.

Effects on health

We simply do not know if GM crops are safe for human or animal consumption. This is reflected in the ongoing scientific controversy surrounding their safety assessment.

Independent scientific studies on the safety of GM crops for animals or humans are severely lacking[45, 46, 47, 48] and there is a tendency for studies conducted by researchers with affiliations to the GM industry to give favourable results to GM crops.[49]

GM crops do have the potential to cause allergenic reactions, more so than conventional crops[50, 51]. In Australia, for example, GM peas were found to cause allergenic reactions in mice[52]. GM peas also made the mice more sensitive to other food allergies.

Since the introduction of GM Bt (Cry1Ab) crops, both applicant companies and the European Food Safety Authority (EFSA) have assumed that the Cry1Ab toxin degrades rapidly in the human digestive system and is safe for human consumption.[53] However, new studies show there is a lack of degradation in the human gut. This warrants further investigation as it may imply this toxin has a greater potential to cause allergenic reactions than first thought.[54]

Another recent study found the Cry1Ab Bt toxin in the blood of pregnant women and their foetuses showing that it can cross the placental boundary. This raises health concerns, although the implications of this uptake and transference across the placenta are not yet known.[55]

There are potential health risks associated with herbicides used with GM crop cultivation. Studies indicate Roundup may be toxic to mammals [56] and could interfere with hormones[57]. Evidence on the toxicity of the herbicide glufosinate is so strong[58] that it will have to be phased out across Europe.[59]

Almost all commercialised GM crops either produce or tolerate pesticides[60]. While pesticides are tested for two years prior to European approval, the usual duration of safety tests for GM crops is just 28 days, with the longest tests at 90 days, including for pesticide-producing GM plants.

Genetic modification: an unpredictable and risky method

There are fundamental reasons why GM organisms should not be released into the environment. Genetic engineering inserts DNA sequences into a plant's genome in a crude fashion, often causing unintended deletions and rearrangements of the plant's DNA. Unexpected and unknown fragments of genetic material have been found in commercial GM crops such as RR soya and MON810. Inserted genes can affect the

complex regulation of the genome, which is still poorly understood. Thus, scientists are not able to predict exactly how inserted DNA will interact in the plant's genome. GM crops therefore have the potential to produce unintended novel proteins or altered plant proteins, raising concerns about their potential to cause allergies (most allergens are proteins). This makes GM crops prone to unexpected and unpredictable effects.

References

[1] Prasifka, P.L., Hellmich, R.L., Prasifka, J.R. & Lewis, L.C. 2007. Effects of Cry1Ab-expressing corn anthers on the movement of monarch butterfly larvae. Environ Entomolology 36:228-33.

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

[3] Lang, A. & Vojtech, E. 2006. The effects of pollen consumption of transgenic Bt maize on the common swallowtail, *Papilio machaon* L. (Lepidoptera, Papilionidae). Basic and Applied Ecology 7: 296—306.

[4] Darvas, B., Lauber, E., Polga´r, L. A., Peregovits, L., Ronkay, L., Juracsek, J., et al. 2004. Non-target effects of DK-440-BTY (Yieldgard) Bt-corn. First Hungarian–Taiwanese entomological symposium, 11–12 October 2004, Budapest Hungarian National History Museum (p. 5).

[5] Felke, V.M. & Langenbruch, G.A. 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 Pflanzen, 55: 1-7.

[6] Felke, M., Lorenz, N. & Langenbruch, G-A. 2002. Laboratory studies on the effects of pollen from Bt-maize on larvae of some butterfly species. Journal of Applied Entomology 126: 320–325.

[7] Lang, A & Otto, M. 2010. A synthesis of laboratory and field studies on the effects of transgenic Bacillus thuringiensis (Bt) maize on non-target Lepidoptera. Entomologia Experimentalis et Applicata 135: 121–134.

[8] Obrist, L.B., Dutton, A., Romeis, J. & Bigler, F. 2006. Biological activity of Cry1Ab toxin expressed by Bt maize following ingestion by herbivorous arthropods and exposure of the predator *Chrysoperla carnea.* BioControl 51: 31-48.

[9] Andow, D.A. and A. Hilbeck. 2004. Science-based risk assessment for non-target effects of transgenic crops. Bioscience 54: 637-649.

[10] Obrist, L.B., Dutton, A., Romeis, J. & Bigler, F. 2006. Biological activity of Cry1Ab toxin expressed by Bt maize following ingestion by herbivorous arthropods and exposure of the predator *Chrysoperla carnea.* BioControl 51: 31-48.

[11] Harwood, J.D., Wallin, W.G. & Obrycki, J.J. 2005. Uptake of Bt endotoxins by non-target herbivores and higher order arthropod predators: molecular evidence from a transgenic corn agroecosystem. Molecular Ecology 14: 2815-2823.

[12] Lövei, G.L. & Arpaia, S. 2005.The impact of transgenic plants on natural enemies: a critical review of laboratory studies. *Entomologia Experimentalis et Applicata* 114: 1–14, 2005.

[13] Ramirez-Romero, R., Desneux, N., Decourtye, A. Chaffiol, A., Pham-Delègue, M.H. 2008. Does Cry1Ab protein affect learning performances of the honey bee. *Apis mellifera* L. (Hymenoptera, Apidae)? Ecotoxicology and Environmental Safety 70: 327–333.

[14] Andow, D.A. & Zwahlen, C. 2006. Assessing environmental risks of transgenic plants. Ecology Letters 9: 196-214.

[15] Snow, A. A., Andow, D.A., Gepts, P., Hallerman, E. M., Power, A., Tiedje, J. M. & Wolfenbarger, L.L. 2005. Genetically engineered organisms and the environment: current status and recommendations. Ecological Applications, 15: 377–404.

[16] Andow, D.A. & A. Hilbeck. 2004. Science-based risk assessment for non-target effects of transgenic crops. *Bioscience*, 54: 637-649.

[17] Knols, B.G.J. and M. Dicke. 2003. Bt crop assessment in the Netherlands. Nature *Biotechnology* 21: 973-974.

[18] Saxena, D., Flores, S. & Stotzky, G. 2002. Bt toxin is released in root exudates from 12 transgenic corn hybrids representing three transformation events. Soil Biology and Biochemistry 34: 133-137.

[19] Flores, S., Saxena, D & Stotzky, G. 2005. Transgenic Bt plants decompose less in soil than non-Bt plants. Soil Biology and Biochemistry 37: 1073-1082.

[20] Stotzky, G. 2004. Persistence and biological activity in soil of the insecticidal proteins from *Bacillus thuringiensis*, especially from transgenic plants. Plant and Soil 266: 77-89.

[21] Zwahlen, C. Hilbeck, A. Gugerli, P. & Nentwig, W. 2003. Degradation of the Cry1Ab protein within transgenic *Bacillus thuringiensis* corn tissue in the field. Molecular Ecology 12: 765-775.

[22] Zwahlen, C. Hilbeck, A. Gugerli, P. & Nentwig, W. 2003. Degradation of the Cry1Ab protein within transgenic *Bacillus thuringiensis* corn tissue in the field. Molecular Ecology 12: 765-775.

[23] Icoz, I. & Stotzky, G. 2008. Fate and effects of insect-resistant Bt crops in soil ecosystems. Soil Biology & Biochemistry 40: 559–586.

[24] Rosi-Marshall, E.J., Tank, J.L., Royer, T.V., Whiles, M.R., Evans-White, M., Chambers, C., Griffiths, N.A., Pokelsek, J. & Stephen, M.L. 2007. Toxins in transgenic crop byproducts may affect headwater stream ecosystems. Proceedings National Academy Sciences 41: 16204–16208.

[25] Douville, M., Gagne, F, Blaise, C. & André, C. 2007. Occurrence and persistence of *Bacillus thuringiensis* (Bt) and transgenic Bt corn cry1Ab gene from an aquatic environment. Ecotoxicology and Environmental Safety 66: 195–203. Cambers, CP., Whiles, M.R., Rosi-Marshall, E.J., Tank, J.L., Royer, T.V., Griffiths, N.A., Evans-White, M.A. & Stojak, A.R.. 2010. Responses of stream macroinvertebrates to Bt maize leaf detritus. Ecological Applications 20:1949–1960.

[26] Cambers, CP., Whiles, M.R., Rosi-Marshall, E.J., Tank, J.L., Royer, T.V., Griffiths, N.A., Evans-White, M.A. & Stojak, A.R.. 2010. Responses of stream macroinvertebrates to Bt maize leaf detritus. Ecological Applications 20:1949–1960.

[27] Douville, M., Gagne, F., André, C. & Blaise, C. 2009. Occurrence of the transgenic corn cry1Ab gene in freshwater mussels (*Elliptio complanata*) near cornfields: evidence of exposure by bacterial ingestion. Ecotoxicology and Environmental Safety 72: 17–25.

[28] Bøhn, T., Primicerio, R., Hessen, D.O. & Traavik, T. 2008. Reduced fitness of *Daphnia magna* fed a Bt-transgenic maize variety. Archives of Environmental Contamination and Toxicology DOI 10.1007/s00244-008-9150-5.

[29] Men, X., Ge, F., Edwards, C.A. & Yardim, E.N. 2005. The influence of pesticide applications on *Helicoverpa armigera* Hübner and sucking pests in transgenic Bt cotton and non-transgenic cotton in China. Crop Protection 24 319–324.
Deguine, J-P., Ferron, P. & Russell, D. 2008. Sustainable pest management for cotton production. A review. Agronomy for Sustainable Development 28: 113–137
Wang, S., Just, D.R. & Pinstrup-Andersen, P. 2008. Bt-cotton and secondary pests. International Journal of. Biotechnology, 10: 113–121.

[30] Cloutier, C.; Boudreault, S. & Michaud, D. 2008. Impact of Colorado potato beetle-resistant potatoes on non-target arthropods: a meta-analysis of factors potentially involved in the failure of a Bt transgenic plant. Cahiers Agricultures 17: 388-394.

[31] Catangui M.A. & Berg R.K. 2006.Western bean cutworm, *Striacosta albicosta* (Smith) (Lepidoptera : Noctuidae), as a potential pest of transgenic Cry1Ab *Bacillus thuringiensis* corn hybrids in South Dakota Environmental Entomology 35 1439-1452.

[32] Faria, C.A., Wäckers, F.L., Pritchard, J., Barrett, D.A. & Turlings, T.C.J. 2007. High susceptibility of Bt maize to aphids enhances the performance of parasitoids of lepidopteran pests. PLoS ONE 2: e600. doi:10.1371/journal.pone.0000600.

[33] For a full review of glyphosate, see: Greenpeace and GM Freeze 2011. Herbicide tolerance and GM crops: why the world should be Ready to Roundup glyphosate. GRL-TN-03/2011. www.greenpeace.org www.gmfreeze.org

[34] Relyea, R.A. 2005. The impact of insecticides and herbicides on the biodiversity and productivity of aquatic communities. Ecological Applications 15: 618-627.
Relyea, R.A. 2005. The lethal impact of roundup on aquatic terrestrial amphibians. Ecological Applications, 15: 1118–1124. Relyea, R.A., Schoeppner, N.M. & Hoverman, J.T. 2005. Pesticides and amphibians: the importance of community context. Ecological Applications, 15: 1125–1134.

[35] ACRE. 2004. Advice on the implications of the farm-scale evaluations of genetically modified herbicide tolerant crops. http://webarchive.nationalarchives.gov.uk/20080727101330/http://www.defra.gov.uk/environment/acre/advice/pdf/acre_advice44.pdf

[36] Zobiole, L,H,S,, Kremer, R.J., Oliveira, R.S. & Constantin, J. 2011a. Glyphosate affects chlorophyll, nodulation and nutrient accumulation of "second generation" glyphosate-resistant soybean *(Glycine max* L.) Pesticide Biochemistry and Physiology 99: 53-60.
Zobiole LHS, Kremer RJ, Oliveira RS, Constantin J. 2011. Glyphosate affects micro-organisms in rhizospheres of glyphosate-resistant soybeans Journal of Applied Microbiology. 110: 118-127.
Kremer RJ & Means NE. 2009. Glyphosate and glyphosate-resistant crop interactions with rhizosphere microorganisms. European Journal of Agronomy 31: 153-161.
Gordon B. 2007. Manganese nutrition of glyphosate resistant and conventional soybeans (North America). Better Crops with Plant Food 91: 12-13.

[37] Binimelis, R., Pengue , W. & Monterroso , I. 2009. "Transgenic treadmill": Responses to the emergence and spread of glyphosate-resistant johnsongrass in Argentina. Geoforum 40: 623–633.

[38] Nandula, V.K., Reddy, K.N., Duke, S.O. & Poston, D.H. 2005. Glyphosate-resistant weeds: current status and future outlook. Outlooks on Pest Management August 2005: 183-187.

[39] Johnson, W.G., Owen, M.D.K., Kruger, G.R., Young, B.G., Shaw, D.R., Wilson, R.G., Wilcut, J.W., Jordan, D.L. & Weller, S.C. 2009. US farmer awareness of glyphosate-resistant weeds and resistance management strategies. Weed Technology 23: 308–312.

[40] Duke, S.O. 2005. Taking stock of herbicide-resistant crops ten years after introduction. Pest Management Science 61: 211–218.

[41] Monsanto 2008. Management guide for marestail. http://www.monsanto.com/weedmanagement/Documents/Marestail.pdf

[42] Waltz, E. 2009. Under wraps. Nature Biotechnology 27: 880.

[43] Waltz, E. 2009. Battlefield. Nature 461: 27-32.

[44] European Commission, Directorate-General for Research 2010: A decade of EU-funded GMO research.

[45] Vain, P. 2007. Trends in GM crop, food and feed safety literature. Nature Biotechnology Correspondence 25: 624-626.

[46] Domingo, J.L. 2007. Toxicity studies of genetically modified plants: a review of the published literature. Critical Reviews in Food Science and Nutrition, 47:8, 721 – 733.

[47] In 2003. a review of published studies on possible health consequences of GMOs found ten published studies, but 5 of these were performed in collaboration with private companies promoting GM crops. None of these studies reported effects related to GM-material. Conversely, in the 5 independent studies adverse effects were reported: Pryme, I.F. & Lembcke, R. 2003. In vivo studies on possible health consequences of genetically modified food and feed —with particular regard to ingredients consisting of genetically modified plant materials. Nutrition and Health 17: 1-8.

[48] Brown, P., Wilson, K.A.., Jonker, Y. & Nickson, T.E. 2003. Glyphosate Tolerant Canola Meal Is Equivalent to the Parental Line in Diets Fed to Rainbow Trout. Journal of Agricultural Food and Chemistry 51: 4268-4272.

[49] Diels, K., Cunha, M., Manaia, C., Sabugosa-Madeira, B., Silva, M. 2011. Association of financial or professional conflict of interest to research outcomes on health risks or nutritional assessment studies of genetically modified products, Food Policy, 36 197-203.

[50] Bernstein, J.A. et al. 2003. Clinical and laboratory investigation of allergy to genetically modified foods. Environmental Health Perspectives 111:1114–1121.

[51] Freese, W. & Schubert, D. 2004. Safety testing and regulation of genetically engineered foods. Biotechnology and Genetic Engineering Reviews, 21: 229-324.

[52] Prescott, V.E., Campbell, P.M., Moore, A., Mattes, J., Rothenberg, M.E., Foster, P.S., Higgins, T.J.V. & Hogan, S.P. 2005. Transgenic expression of bean alpha-amylase inhibitor in peas results in altered structure and immunogenicity. Journal of Agricultural & Food Chemistry 53: 9023- 9030.

[53] See, Monsanto 2002. Safety assessment of YieldGard insect-protected corn event MON 810. http://www.monsanto.com.ar/nuestros_productos/informacion_tecnica_seguridad/resumenes_seguridad/yieldgard_corn_es.pdf and EFSA 2009. Applications (EFSA-GMO-RX-MON810) for renewal of authorisation for the continued marketing of (1) existing food and food ingredients produced from genetically modified insect resistant maize MON810; (2) feed consisting of and/or containing maize MON810, including the use of seed for cultivation; and of (3) food and feed additives, and feed materials produced from maize MON810, all under Regulation (EC) No 1829/2003 from Monsanto. The EFSA Journal 1149: 1-84, Section 5.1.4.1.

[54] Guimaraes, V., Drumare, M-F., Lereclus, D., Gohar, M., Lamourette, P., Nevers, M.C., Vaisanen-Tunkelrott, M-L., Bernard, H., Guillon, B., Créminon, C., Wal, J-M. & Adel-Patient, K.2010. In vitro digestion of Cry1Ab proteins and analysis of the impact on their immunoreactivity. Journal of Agricultural and Food Chemistry 58: 3222-3231.
Finamore, A., Roselli, M., Britti, S., Monastra, G., Ambra, R., Turrini, A. & Mengheri, E. 2008. Intestinal and peripheral immune response to MON810 maize ingestion in weaning and old mice. Journal of Agriculture and Food Chemistry DOI: 10.1021/jf802059w

[55] Aris A. & Leblanc S. 2011. Maternal and fetal exposure to pesticides associated to genetically modified foods in Eastern Townships of Quebec, Canada. Reproductive Toxicology in press. Available online Feb 18 2011.

[56] Paganelli, A., Gnazzo, V., Acosta, H., López, S.L. & Carrasco, A.E. 2010. Glyphosate-based herbicides produce teratogenic effects on vertebrates by impairing retinoic acid signalling. Chemical Research in Toxicology 23: 1586-95.
Benachour, N. & Seralini, G.E. 2009. Glyphosate formulations induce apoptosis and necrosis in human umbilical, embryonic, and placental cells. Chemical Research in Toxicology 22: 97-105.
Benachour, N., Siphatur, H., Moslemi, S., Gasnier, C., Travert, C. & Seralini, G.E. 2007. Time- and dose-dependent effects of Roundup on human embryonic and placental cells. Archives of Environmental Contamination and Toxicology 53: 126-33.

[57] Richard, S., Moslemi, S., Sipahutar, H., Benachour, N. & Seralini, G-E. 2005. Differential effects of glyphosate and Roundup on human placental cells and aromatase. Environmental Health Perspectives 113: 716–720.

[58] EFSA 2005. Conclusion regarding the peer review of the pesticide risk assessment of the active substance glufosinate. EFSA Scientific Report 27: 1-81.

[59] In 2009, the EU adopted legislation that regulates the authorisation of agrochemicals (Regulation (EC) No. 1107/2009). It sets criteria for the approval of these products, forbidding the authorization and re-authorisation of agrochemicals classified as toxic for reproduction, carcinogenic or mutagenic. Based on these criteria, glufosinate, cannot have its marketing licence, which expires in 2017, extended.

[60] See, e.g. GM crop database http://www.cera-gmc.org/?action=gm_crop_database