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That wasn't meant to happen! GM Soya's tales of the unexpected

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The proponents of GM crops often refer to the 'precision' of the GM technique. Claims about the testing of crops produced by this technique make a point of saying how the testing is 'rigorous', 'extensive' and 'thorough'. One of the obvious ways to test how well the regulatory system is at spotting the unintended and unpredictable impacts of genetic modification is to look at the longest standing and most widely planted (largely in USA and Argentina) GM crop – Roundup Ready soya.

Monsanto's GM **Roundup Ready** (RR) soya, designed to be tolerant of the broad-spectrum herbicide **glyphosate** (Roundup), was approved for planting in the USA in 1994 and first grown commercially in 1996. That year it was also granted import (but not planting) approval in the EU and Japan.

Farming and Roundup Ready soya

Farmers have adopted RR technology eagerly because it greatly simplifies weed management, allowing the use of other herbicides besides glyphosate to be reduced or cut out altogether. However, RR soya requires more herbicide in total than conventional soya, and the evolution of glyphosate-resistant weeds makes the reintroduction of other herbicides likely. More seriously for the farmers, it is now becoming clear that far from increasing yields and profitability as Monsanto have suggested, RR soya yields are in practice lower than those of conventional varieties. Yields could be between five and ten per cent lower under most circumstances, and as much as 19 per cent in some studies.

There are a number of reasons for this yield reduction, but none have ever been adequately investigated, or at least publicised, by Monsanto prior to the commercialisation of RR soya. A brief survey of these possible explanations can tell us much about the uncertainties that still surround the effects and reliability of GM technology.

Roundup tolerance and its biochemical impacts

Although Roundup was developed by Monsanto as early as 1970, and RR soya grown commercially from 1996, it was not until 2001 that Monsanto scientists claimed that the herbicide's biochemical mode of action was now almost fully understood.

Glyphosate works by targeting an enzyme called **EPSPS**, which forms part of the **shikimate pathway**, part of plant metabolism which is responsible for the synthesis of a number of key amino acids – the building blocks of proteins. These play a critical role in normal cell function, plant growth, and disease and stress response. Glyphosate kills plants by binding to EPSPS and inhibiting the manufacture of amino acids. The genetic modification in RR plants replaces the gene that codes for EPSPS with a version derived from bacteria which prevents

EPSPS from absorbing glyphosate, leaving the shikimate pathway working largely as normal.

However, since the gene that is modified serves as a control switch to this key biochemical pathway, it is unsurprising that the modification should give rise to other unintended effects. EPSPS fulfils many important regulatory functions, including the plant's defence responses to pest feeding and other stresses. In some circumstances (for example after application of glyphosate or under pest-induced or physical stress), the synthesis of amino acids may be distorted and these functions impaired.

A study conducted by Monsanto in 1992, prior to regulatory approval of RR soya in the USA, allegedly found that there were no compositional differences between RR and conventional soya – although their published report (1995) did not include any actual data. It was not until 2001 (by which time RR soya had been grown commercially for five years) that the results of this study surfaced. While they do demonstrate equivalence for 40 out of 50 characteristics investigated, they also show that RR soya exhibits a significant drop in levels of both phenylalanine (see below) and **lectins**, proteins that have insecticidal properties. The fall in lectin levels may explain why RR soya shows increased vulnerability to some common insect pests. It is unclear why Monsanto did not consider these differences significant enough to highlight in their 1995 report on the study.

Unfortunately, most studies have measured levels of key regulatory substances at harvest time, rather than considering what is actually going on while the plants are growing and reacting to pests and other stresses. Even a short period with reduced levels of these substances may open a window of opportunity for pests and diseases, which can then build up to levels where the plants have to invest so much of their resources to combat them that yields are greatly reduced. Clearly this has severe implications for farmers who have invested in RR technology in the belief that it will give higher yields.

Other unintended effects

Stem splitting

During hot spring weather, farmers in the southern USA noticed that the stems of RR soya split open, exposing the plants to infection. Subsequent independent laboratory tests comparing the hardiness of RR soya with that of conventional varieties showed that as maximum soil temperature increased, so the RR plants became stunted, until in soils reaching 45ºC the RR soya showed stem splitting and yield reductions up to 40 per cent. The researchers also discovered that the RR varieties produced higher levels of **lignin** (a tough woody form of cellulose), and concluded that this was responsible for making the stems brittle. Lignin levels were markedly higher even at normal temperatures, but the increased brittleness of the stems made them especially vulnerable to hot, dry conditions.

Lignin production is controlled by **phenylalanine**, an amino acid produced by the same shikimate pathway that is modified in RR soya to give resistance to glyphosate. It appears that the modification has also led, unintentionally, to reduced phenylalanine production and consequently increased levels of lignin.

When confronted with this research, Monsanto denied that heat stress had been identified as a problem, claiming (in the face of the farmers' evidence) that the laboratory conditions that had given rise to stem splitting rarely if ever occurred in the field. They backed up this claim with a list of average summer air temperatures for the region, ignoring the fact that the independent research had considered soil temperatures, which can rise much higher.

This unfortunate experience showed that tests under extreme conditions could bring to light significant changes that also exist, less recognisably, under normal conditions. The extreme conditions encountered by the farmers and replicated in the laboratory revealed that RR soya is not 'substantially equivalent' to conventional soya – the key test for the commercialisation of a GM variety.

Increased* Fusarium *colonisation
Field studies conducted on RR soya in Missouri found that plants treated with Roundup showed dramatically increased levels of root colonisation (up to 500 per cent higher) by ***Fusarium***, a genus of soil fungi that can trigger Soybean Sudden Death Syndrome – a growing problem in the American Midwest. Moreover, researchers found that *Fusarium* levels tend to build up in fields treated with Roundup year after year, an increasingly common occurrence as different RR crops become popular.

Effects on nitrogen fixation
Like most plants of the bean family, soya has root nodules containing bacteria that fix nitrogen. This phenomenon is important to the plant's growth and yield potential, particularly when growing in less fertile soils with little available nitrogen. Until 2001 there was an astonishing lack of published research into the possible effects of glyphosate on nitrogen fixation – all the more unfortunate because the bacterium responsible, *Bradyrhizobium japonicum*, is known to be very sensitive to glyphosate. Sure enough, the independent research finally conducted found delayed nitrogen fixation in young soya plants, along with reduced root growth. While the impact on yields was slight in fertile, well-watered soils, less fertile soils and/or drought stress gave yield losses of up to 25 per cent.

Additional and unidentified DNA
Before any GM crop can receive European Union market approval, the applicant must provide a range of information including a formal description of the GM insert. The approval only extends to crops having exactly the genetic arrangement described. However, it has emerged that Monsanto's notification submitted in 1994 did not include an accurate description of the modified gene sequence. In 2000, Belgian scientists using a new method of DNA characterisation found two additional fragments of the modified EPSPS gene that should not have been there.

When Monsanto were informed, they submitted a report to the UK Advisory Committee on Novel Foods and Processes (ACNFP), in which they gave a detailed characterisation of the inserts and the DNA sequence to either side of them – the so-called flanking region. The flanking region next to one insert was labelled by Monsanto as "soybean genomic DNA".

Soon afterwards, however, an independent, peer-reviewed article demonstrated that this alleged "soybean genomic DNA" sequence was not present in the unmodified soya, and in fact could not be matched with any known DNA. Monsanto then stated that the mystery sequence was actually "rearranged" soya DNA – it had presumably been scrambled as an unintended consequence of the original genetic modification, in addition to the insertion of the extra fragments of the EPSPS gene.

Monsanto went on to say that the consequences of this scrambling had been considered as part of a safety assessment on RR soya. The assessment had concluded that it was "agronomically, compositionally and nutritionally comparable to conventional soybeans, except for the RR trait" – this in spite of the studies, by now in the public domain, showing biochemical differences and problems with stem splitting and *Fusarium* infestation.

Conclusion

The evidence shows that contrary to what we might be led to believe, even the 'flagship' product of GM crops displays a variety of problems that appear to stem from the unintended consequences of the GM process. Fortunately none of the identified problems has proved serious, but we must wonder if there are any others, and what problems might be lurking in other GM crops.

Greenpeace believes in the light of the unknown and unpredictable risks, and the availability of an abundance of methods for enhancing agriculture and agricultural biodiversity, we should ban releases of GMOs to the environment.