THE GMO REVOLUTION

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Imagine that safe, effective medicines were banned because they had been developed using biotechnology. Insulin would still be obtained from the pancreas of pigs.

Imagine that the use of certain laundry detergents was not permitted, because they contain products derived from genetically modified bacteria. It would not be possible to wash clothes properly in a cold wash cycle.

Imagine that certain countries were to ban the cultivation of genetically modified crops (GMOs). This is the daily reality.

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FOREWORD

Yes, dear reader, a potato on the cover of this book. What else could we have chosen? Belgians love their potatoes; but more relevantly, since the organization of field trials with genetically modified (GM) potatoes and the accompanying commotion, the potato has inadvertently become the symbol of the debate surrounding genetically modified plants; at least in Belgium. We will also discuss the potato in this book, but make no mistake: this book is not about the controversies surrounding GMOs. This is not a "dream or nightmare" book that will merely contribute to a further polarization of the debate. This is a positive book that provides insights into how GMOs can help find solutions to the agricultural problems that we are faced with today. This book will also introduce you to lots of different crops: from rice to corn, from banana to papaya.

Will GMOs banish world hunger? No.

Are GMOs the only suitable solution? Absolutely not.

GM crops primarily symbolize an important evolution in plant breeding. An evolution that is based on modern plant biotechnology; a new scientific discipline which originated in Belgium at the University of Ghent and which examines the genetic basis of plant characteristics. This knowledge forms the basis for a range of new strategies for crop improvements. In other words: modifying crops to suit human needs. A higher nutritional value for example, or improved taste, better yield or an easier way of cultivating and processing the crop.

Why is that so important? It is indisputable that global agriculture is facing significant challenges. Firstly, the climate is becoming less predictable. Drought or excessive rainfall is making it virtually impossible to cultivate land efficiently in certain agriculturally active regions. Moreover, even small increases in temperature can already have a significant impact on the yields of certain crops. For example, wheat and barley yields in Europe could be 20% lower by 2040 as a result of global warming. Secondly, we need to reduce the impact of agriculture on the environment. This implies changing the way in which we use fertilizers in order to protect the environment and using fewer pesticides to guarantee the safety of farmers and consumers, as well as to spare beneficial insects. However, pesticides and fertilizers form the foundations of modern food production. Abruptly removing these two pillars would automatically result in reduced food production. A third challenge is the increasing standards of living, associated with an increased demand for meat. We hope that Western society will evolve towards a diet that incorporates less meat, but who are we to deny emerging economies such as Brazil and China the consumption of meat? Furthermore, the conversion of plant-based proteins to animal proteins in meat is extremely inefficient. Double the amount of plant-based feed is required for one kilogram of chicken meat, while the production of one kilogram of pork requires six kilograms of animal feed. The production of plant-based proteins will therefore need to increase in certain regions. In summary, there will be less arable land available for agriculture, harvests will be less secured, but production levels will have to increase...

This problem can only be tackled by combining all available insights and technologies: an integrated agricultural model combining the best features of conventional agriculture with the ecological insights from organic farming but with attention for and the integration of new technology. The problems are too complex to simply glorify or rule out a single technology, such as the targeted genetic modification of crops through GM technology.

The main aim of this book is to show that GM crops can help resolve some of the current and future problems in agriculture. In other words, this is not a book about the GMO debate. However, we do not want to ignore the significant resistance to GMOs in Europe and in the rest of the world. In the epilogue, philosopher of science Stefaan Blancke shares his vision on the resistance to GMOs and explains why people have an intuitive aversion to and distrust of GMOs.

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Wim and Jo

There is no greater mystery than DNA. An incredibly small structure that contains all the information to build a complete organism and to allow it to function properly, whether it is a bacterium, a plant or a human being. It is intriguing how such a sophisticated storage system could have emerged at the start of life on Earth. The fascination for the DNA molecule is not limited to the biology scene. For example, computer specialists have noted the powerful simplicity of this storage form. Scientists searching for new opportunities for compact storage of large quantities of data are now looking to DNA as a possible solution. This is biotechnology at its best: implementing biological knowledge to achieve something useful.

The concepts of "DNA" and "genes" have become familiar to young and old over the past few years. They even have crept into our daily speech, for example, by replacing the phrase "it's in the blood" by "it's in the genes". Yet, knowledge about DNA is still relatively new. Mendel observed the existence of hereditary material only in the 19^{th} century, when he crossed peas with different coloured flowers in an abbey in the Czech Republic. He discovered that specific characteristics from the parents are not randomly passed on to the next generation, but follow certain rules. Mendel's findings formed the basis for the internationally recognized laws of inheritance that bear his name. At the time, new scientific ideas received a half-hearted welcome at best and many great thinkers only obtained the recognition that they deserved posthumously. The same fate befell Mendel's ideas. Fortunately, Mendel's findings were rediscovered at the start of the 20^{th} century. His groundbreaking knowledge created the opportunity for the targeted crossing of plants. Before this period, people already tried to modify crops to suit human needs, but this almost exclusively involved the selection of plant varieties and traits that had developed spontaneously. This all changed as a result of Mendel's biological insights. However, the big breakthroughs only occurred following the development of new technologies in the 20^{th} century. Starting with the discovery of the structure of DNA in 1953 by Watson and Crick and the isolation of the first genes, knowledge about DNA and about how living organisms function at a biological level increased exponentially. The characteristics that passed on from parent to child were suddenly given a name: genes. And the impact of the minuscule, abstract structure that is DNA has become visible in our daily lives.

It is sometimes disenchanting to think that DNA, the basis of all life, is actually nothing more than a storage form for information. For some people this may go one step further – emotionally – than the fact that humans and apes have a common ancestor. To put it bluntly, nature is basically just a workshop using a large DNA construction kit. Over the course of evolution, certain species have acquired certain components of this construction kit to improve their functioning. After all, Darwin taught us that better adapted species have a greater chance to survive and reproduce. However, it was not always about adding components. Species also need to use the information efficiently. Genes that appeared redundant because they were rarely or never used, were lost. For example, one of our distant ancestors lost the ability to produce vitamin C. The intake of vitamin C from food was adequate, so there was no need to maintain the own production. A gene contains the information for a certain characteristic, the species in which the gene is present is of minor importance. There are no "human genes", "tomato genes" or "scorpion genes" for a specific characteristic. At a biological level, there is but one universal language. A language that uses an alphabet consisting of only four letters: A, C, T and G. Simplicity is the ultimate sophistication.

Some species are very clever in their use of this universal language. Consider plant-parasitic nematodes; tiny worms that live at the expense of plants. They burrow a path through plant roots in order to feed on the nutrient-rich liquids from the innermost part of the plant root. However, the plant does not offer enough of certain essential nutrients – such as vitamin B6 – so the nematode must obtain these nutrients elsewhere. Adopting the motto "if you want something done right, do it yourself", plant-parasitic nematodes have acquired all the genes needed for the production of vitamin B6 from another organism; a bacterium in this case. Animals have lost the ability to produce vitamin B6 over the course of evolution. However, these worms have recovered the genetic information, because they needed it. Plant-parasitic nematodes appear to be masters of such DNA exchanges. The nematodes need to break down plant cell walls as they burrow through plant roots.

However, as is the case for vitamin B6 production, the genetic information to produce enzymes that break down cell walls is not present in the animal kingdom. Once again, plant-parasitic nematodes have recovered these genes from bacteria: genetic modification at its best and without human intervention.

Insects do it as well. Certain plants – with manioc (cassava) being the best known example – produce cyanide to repel herbivores. Cyanide is a powerful toxin that affects all animals, including humans. However, certain butterflies and mites can drink the plant sap without any ill effects. These insects have a gene that enables them to detoxify the cyanide; a gene that they have acquired from bacteria and built into their own DNA. Another example is the soil bacterium *Agrobacterium tumefaciens*. This bacterium infects certain host plants in nature and then inserts a fragment of its own genetic material into the host plant's DNA. This bacterial DNA fragment contains the information for substances the bacterium needs to feed on as well as for the production of plant hormones that induce the multiplication of the infected plant cells. These multiplying plant cells are visible from the outside as a so-called crown gall. *Agrobacterium* uses a nifty trick to force a plant to produce food for it. To achieve this, the bacterium inserts the required genetic information – let's say the recipe – into the host plant's DNA. *Agrobacterium* does have the genes, but lacks the machinery and therefore outsources the production. All these forms of genetic modification developed naturally and spontaneously. As it is, nature is not concerned about the exchange of DNA across species boundaries.

PROGRESS THROUGH BIOLOGICAL KNOWLEDGE

Biotechnology is the use of biological processes and/or organisms to manufacture products intended to improve the quality of human life. What if biotechnology were not permitted in medicine? This is hard to imagine. Insulin, required for the treatment of diabetics, would then still need to be obtained from the pancreas of slaughtered pigs. Pig insulin does help patients with diabetes, but it differs from human insulin. Furthermore, it makes people reliant on the supply from abattoirs and there is a slight risk of transmitting diseases from pigs to humans. Fortunately, a much better method has been developed using biological knowledge. Nowadays, patients receive injections of human insulin that is produced by bacteria and yeasts. Scientists have unravelled the genetic information responsible for the production of human insulin and have inserted this information into these microorganisms. These genetically modified bacteria and yeasts are cultured in large fermentation tanks. This results in an endless supply of disease-free insulin that is virtually identical to human insulin.

A similar application is used in the dairy industry. If biotechnology were not permitted in cheese production, there would be a severe shortage of chymosin; the enzyme required during the first step in the production of cheese to make the milk curdle. Originally, chymosin (rennet) was obtained from the fourth stomach compartment (rennet bag) of freshly slaughtered calves. Calf chymosin has become a scarce and relatively expensive product. A small Dutch biotech company isolated the genetic information for chymosin production from the DNA of calves and inserted it into yeast. The genetically modified yeast cells produce a pure chymosin that has been used for decades to make cheese. The cheese is vegetarian, in contrast to the traditional product obtained from calf stomachs and is also *Kosher* as it no longer involves the mixing of dairy with an "animal product", namely the animal-derived chymosin.

Imagine if some countries would not allow the use of certain laundry detergents, because they contain products derived from genetically modified organisms. That also seems unlikely. Certain enzymes have been added to laundry detergents for decades in order to improve their function. Proteases are added to breakdown proteins, while lipases ensure that oils and fats are degraded. These enzymes take over part of the role of the soap, but far more efficiently and in a different manner. As a result, the laundry is cleaned more quickly, can be washed at a lower temperature and less detergent is required. Furthermore, the enzymes are rapidly biodegraded. A third of the global turnover of industrially produced enzymes is contained in laundry products. Most of these enzymes are produced by genetically modified bacteria, fungi and yeasts. The demand for enzymes in laundry detergents is particularly high in Europe, where people want to wash at the lowest possible temperature. Without biotechnology and without genetically modified organisms doing the laundry would be much less environmentally friendly.

What if biotechnology were not permitted in the paper industry? Paper is available in all colours, but white remains the most commonly used. In the past, manufacturers used environmentally harmful chemicals such as chlorine in order to remove the natural, slightly brown colour from paper pulp. A natural method has since been developed, thanks to mushrooms. Oyster mushrooms, to name but one, can live on wood because certain enzymes enable them to breakdown wood molecules. One such enzyme is laccase, which breaks down the molecules responsible for the brown colour of paper pulp. The genetic information of laccase was obtained from mushrooms and inserted into the DNA of yeasts. These yeasts are cultured on a large scale for the industrial production of laccases, which are used – among other things – to produce chlorine-free bleached paper.

It is unimaginable that countries would ban the use of insulin, cheese rennet, laundry detergents or chlorine-free bleached paper because they were developed using biotechnology. On the other hand, certain countries do want to restrict biotechnological applications in agriculture. Governments are banning the cultivation of genetically modified crops, i.e. plants that were given additional information by means of biotechnology so that they more closely meet people's needs.

European citizens have come out on the streets, protesting against biotech crops. However, we cannot ignore the fact that the technology of genetic modification – GMO technology – offers many benefits, for both people and the planet.

BENEFITS FOR THE ENVIRONMENT, FARMER AND CONSUMER

Agriculture has an enormous impact on the environment. From the moment our distant ancestors decided to put the finding and capturing of fruits and tubers on a back burner and put more energy into growing plants themselves, nature came under strain. Natural ecosystems were ploughed, the original vegetation was removed and plants were sown or planted in an unnatural manner, namely at a high density. The first mini-monocultures were born.

But it didn't end there. In nature, it is all about the survival of the fittest: weeds overgrow edible crops, while insects and fungi grab the remainder of the energy-rich food. The first farmers soon realized that further intervention in the ecosystem was required to guarantee sufficient production. It was a tough and slow learning process, which meant that it took until the middle of the previous century before a large part of the population obtained certainty on the availability of food. Before that time, food shortage was the rule rather than the exception. For example, before the Second World War, eating meat more than once a week was definitely not the norm. The remarkable improvement in food production is thanks to the so-called "Green Revolution"; a period that is characterized by the development of fertilizers and crop protection products and that coincides with the breeding of plant varieties that respond optimally to fertilizers.

Agriculture forms the basis for the successful existence of humans, but the flipside is the impact of (over)fertilization and crop protection on the environment. This impact can be reduced again thanks to new technologies – including genetic modification – and we can start thinking about sustainable food production with maximum focus on the environment. Moreover, this can be achieved in a much more efficient way than previously and applications that used to be unthinkable come within reach. Natural resistance to fungi and insects can be engineered into the modern agricultural crops, meaning that the use of pesticides can be reduced drastically. Trees can be genetically modified to make the environmentally harmful process of paper production more environmentally friendly. Bio-fuels that are produced from sustainably farmed non-food crops can result in a decreased dependence on fossil fuels. By using biotechnology in agriculture, we can reduce the ecological footprint caused by the production of food, textiles and other plant-related products.

The benefits of plant biotechnology exist at all levels in the food production chain, not just at environmental level. For example, innovation can also make the life of a farmer easier and financially more attractive. Developing plants that use fertilizers more efficiently or cereals that obtain their nitrogen needs from the air we breathe, will reduce fertilizer costs as well as the transportation costs to distribute these products in the field. This is in addition to the benefits of a reduced need for pesticides, which together with fertilizers form two significant costs in the production of food. On top of that, plant biotechnology can also help to improve the condition of the soil. Erosion of fertile land is a big problem in agriculture, a problem that becomes worse if the soil is ploughed intensively. The best way to combat erosion is to avoid tilling. Genetically modified crops that facilitate no-till agriculture are more than welcome. Farmers are also very worried about global warming. Drought, floods and increases in temperature are serious problems that require immediate solutions, if we want to maintain our food security. Biotechnology can offer solutions that cannot be achieved using classic plant breeding techniques.

The greatest potential of GMO technology probably lies in crops that multiply by vegetative reproduction, such as banana and cassava. As it is virtually impossible to make crosses within these species, the insertion of new genetic material is severely limited and thus it is extremely difficult to add resistance to diseases and pests. Farmers, primarily in developing countries, have to witness entire plantations being destroyed by fungi and viruses. There is a concerted effort to develop disease-resistant GM banana and cassava plants in these locations. The urgent need for such solutions is demonstrated by the fact that GM field trials in developing countries require security measures. In stark contrast to Europe, where GM field trials are threatened with destruction, security measures are required because farmers want to use these plants in their fields immediately, because they need them.

Whereas the first genetically modified crops primarily benefit the farmer and the environment, the second generation GM crops aim at a more direct advantage to the consumer. The main focus here is on the nutritional value. Plants that produce health-promoting omega-3 fatty acids that could previously only be obtained from fish – and therefore taken up by most people in too low amounts – are being tested in field trials. Gluten-free GM wheat is also an option, although this is still a long way off. The most essential GM crop at the moment is undoubtedly the so-called “golden rice”. Golden rice is a GM rice variety that produces beta-carotene; a substance that our body can use to produce vitamin A. Vitamin A deficiencies occur mainly in developing countries where people live on a diet in which rice is the most important product. Vitamin A deficiency can cause severe health problems in children. This GM rice can literally save millions of children’s lives. Richard Roberts, Nobel Laureate in Medicine, considers it a crime against humanity that the cultivation of golden rice is still not permitted. The remainder of this book will cover the current and future GMO applications in agriculture in more detail and we will discuss why plant biotechnology is an important asset to the environment, farmer and consumer.

2.4 MILLION TONNES OF PESTICIDES

In 2007, a total of 2.4 million tonnes of pesticides was used globally.[1] This is a staggering amount and equivalent to 40,000 trucks carrying a load of 50 m³ or 800 Olympic-sized swimming pools. The United States accounted for 20% of this, about 500,000 tonnes.[1] The most recent figures available for Europe are from 2010.[2] In that year, 280,000 tonnes of pesticides were used, including 108,000 tonnes of fungicides, 103,000 tonnes of herbicides and 36,000 tonnes of insecticides. A small country as Belgium used 4,470 tonnes of pesticides in 2010, the Netherlands 9,180 tonnes.[2] Some crops require vast quantities of pesticides. As anyone living near a potato field may have noticed: potato plants are so susceptible to *Phytophthora infestans* – the pathogen that causes late blight – that they require treatments with fungicides about ten to fifteen times per growth season. During a wet summer, this figure can increase to twenty times in a season, amounting to weekly treatments. Cotton is another example. Cotton farming occupies approximately 2.5% of the world's arable land, but accounts for 16% of the insecticides used worldwide.[3] India for example, the country with the most cotton fields in the world, used nearly 6 grams of pesticides to produce 1 kilogram of cotton in 2001.[4] Most of these are insecticides.

Why are such vast amounts of pesticides used? In nature, every species has to fend for itself. The maize or wheat plants that a farmer sows are also a source of nutrition for many types of insects, fungi and bacteria. Similarly, fertile fields are a favourite place for weeds or unwanted plants, where they compete with the planted crop. Since the dawn of agriculture, the only option available to the primitive farmers was to try to protect the useful crops. Producing food basically means: keeping unwanted species under control. Our ancestors have had to master the ecosystem to ensure that each harvest would produce enough food to feed the group. Weeds were removed manually and insects were eliminated where possible, mostly by removing the larvae by hand.