Chapter 16
Will the Public Ever Accept Genetically Engineered Plants?

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Abstract Compared to transgenic herbicide- or insect-resistant plants, pathogen-resistant ones are rarely found in the field. There are several economic reasons for this, but an additional cause is the scientific and public debate about potential risks and a low attractiveness for consumers to buy these plants and their products. This paper gives a short overview of traits theoretically available or already on the market and describes the concerns raised that reduce their market opportunity. Finally it proposes solutions on how to proceed in the future to allow a rational dealing with the technology.

16.1 Transgenic Pathogen Resistant Plants

Since the beginning of their existence plants and pathogens survive by ongoing development of sophisticated strategies to either attack or defend. In plant breeding, humans try to pyramid as many defense strategies as possible in crops in order to combine a healthy growth with a minimal input of pesticides and with optimal yield. Theoretically, this can be achieved using pathogen resistant plants. Nevertheless, since in classical breeding complete genomes are mixed, stacking of many beneficial genes without retaining deleterious ones is complicated and analysis of high numbers of crossings and descendants is unavoidable. In spite of the development of molecular markers, which reduce these numbers drastically, it is still an enormous challenge. In addition, classical breeding is restricted to defense genes present in sexually compatible cultivars. Hence several attempts have been made to enhance crop resistance to pathogens via genetic engineering which enables scientists to exploit the whole gene pool of the world.

Most of the defense genes transferred up to now originate from plants, but in many cases donor and recipient are not sexually compatible like for instance rice and maize. According to Collinge et al. (2008) out of twenty eight examples for transgene encoded disease resistance only 8 of the donors were sexually compatible

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to the recipient. Only for these a transfer via conventional breeding would be possible. All other donors were non compatible plants, viruses, insects, fungi or bacteria. The establishment of plant resistance using these resources is therefore strictly dependent on gene transfer.

So far forty five different cultivars have been successfully transformed to receive pathogen resistance. However, only virus resistant squash and papaya are cultivated in the USA and some other countries and virus resistant pepper and tomato in China (James 2014). The transgenic papaya was developed and commercialized by the University of Hawaii and is now approved for consumption in Japan (Dec 2011) and China (Dangl et al. 2013). This seems surprisingly little considering that herbicide and insect resistant plants are grown worldwide with great success. In 2013, transgenic plants, most of them herbicide or insect resistant, covered 175 million ha worldwide (ISAAA 2014). In the USA, about half of the total land was used for GM crops (USDA 2014). E.g. no pathogen resistant soybean variety is on the market (Hudson et al. 2013) although more than 81 % of the worldwide production is transgenic. So up till now, transgenic pathogen resistant plants play no visible role. This is especially surprising considering that crop losses due to bacteria, fungi and viruses account for about 16 % yield loss over all major crops (wheat, rice, maize, potato and soybean for the period 2001–2003) (Oerke 2006). An overview of the status of transgenic pathogen-resistant plants is shown in Table 16.1. Numbers of field trials for pathogen resistant plants are also much lower than those of herbicide and insecticide tolerance. 2616 total field releases of transgenic plants with virus/fungal resistance have been conducted in the USA until September 2013. This has to be compared to 6772 releases of plants with herbicide tolerance, 4809 with insect resistance, 4896 with improved product quality and 5190 with agronomic properties (USDA 2014). One interesting example of a commercially potent, virus resistant plant is a virus resistant bean, created by the Brazilian Agricultural Research Corporation (EMBRAPA). Beans are very important crops in South and Middle America and are mostly produced by small farmers. The golden mosaic virus causes severe yield loses (40–100 %). Descendants of one single transformant (event) showed resistance up to 93 %, hence this might be a real breakthrough for the small farmers (Bonfim et al. 2007). The bean is approved in Brazil und expected to appear on the market in 2014/2015.

16.2 Reasons of Why so Few Transgenic Pathogen Resistant Plants Exist in Agriculture

There seem to be several reasons for the minimal use of transgenic pathogen resistant plants in the world. In many countries, economic concerns might be of most importance. In Europe, political and public concerns are dominant while scientific concerns seem to matter less.

Table 16.1 Approval and cultivation of transgenic, pathogen resistant plants worldwide. (Source: ISAAA/TransGEN/Hudson et al. 2013)

Culture	Trait	Approval	Cultivation
Apple	Fungal/bacterial resistance	–	–
Apricot	Virus resistance	–	–
Avocado	Fungal resistance	–	–
Banana	Fungal/bacterial/virus resistance	–	–
Barley	Fungal resistance	–	–
Broad bean (*Vicia faba*)	Fungal resistance	–	–
Carrot	Fungal resistance	–	–
Cassava	Virus/bacterial resistance	–	–
Chestnut	Fungal resistance	–	–
citrus fruits	Fungal/virus/bacterial resistance	–	–
Cocoa	Fungal/virus resistance	–	–
Coconut	Virus resistance	–	–
cowpea (*Vigna unguiculata*)	Fungal resistance	–	–
Eggplant	Fungal resistance	–	–
Grape vine	Fungal/virus/bacterial resistance	–	–
Grapefruit	Fungal/virus/bacterial resistance	–	–
Hop plant	Fungal resistance	–	–
Kidney bean (*Phaseolus vulgaris*)	Virus/fungal resistance	Brazil	Starting 2014
Kiwi	Fungal resistance	–	–
Lettuce	Fungal/virus resistance	–	–
Lupine	Virus resistance	–	–
Mango	Fungal/bacterial resistance	–	–
Melon	Virus resistance	–	–
Oat	Virus resistance	–	–
Olive	Fungal resistance	–	–
Papaya	Virus resistance	USA 2, China 1, Canada 1, Japan 1	USA, China
Pea (*Pisum sativum*)	Fungal/virus resistance	–	–
Peanut	Fungal/virus resistance	–	–
Pear	Bacterial resistance	–	–
Pepper	Virus resistance	China	Cultivated In China

Table 16.1 (continued)

Culture	Trait	Approval	Cultivation
Persimmon	Fungal resistance	–	–
Pineapple	Virus resistance	–	–
Plum	Virus resistance	USA 1	USA 1
Potato	Fungal/virus/bacterial resistance	USA/ Canada	Not now
Raspberry	Virus resistance	–	–
Soybean	Virus/fungal resistance	–	–
Squash	Virus resistance	USA/ Canada	USA
Strawberry	Fungal resistance	–	–
Sugar beet	Virus resistance	–	–
Sunflowers	Fungal resistance	–	–
Sweet potato	Virus/fungal resistance	–	–
Taro	Fungal resistance	–	–
Tobacco	Virus resistance	–	–
Tomato	Virus resistance	–	Cultivated in China
Water melon	Virus resistance	–	–
Wheat	Fungal resistance	–	–

Economic Causes The approval process required to develop permitted pathogen resistant plants is often too costly to make it viable for any business to pursue. Unfortunately, pathogen resistance is much more complex compared to herbicide or insect resistance. Since there are several kinds of organisms causing disease (bacteria, fungi, viruses, oomycetes) no single gene is expected to protect against all of them. In addition, the pathogen's strategies to exploit the plants resources are quite divergent. Hence the diversity of defense genes is huge, ranging from chitinases, virus repressor genes and viral coat proteins, bacterial (Bt-toxin) and viral toxins (KP4) to RNAi (Collinge et al. 2008). Unfortunately, most plants suffer from the constitutive expression of defense genes that quite often causes cell death. Consequently, in order to sustain yield, inducible expression is often necessary, complicating the process further.

The high divergence of pathogens and defense mechanisms also complicates their administrative approval. In Europe 10–50 million € are estimated as final costs for approval of a single event. Compared to a herbicide or insect resistance, the risk assessment of a pathogen resistant plant is much more complex and expensive. Due to the high capability of pathogens to adapt to the plant defense, several different defense mechanisms should be introduced. In addition to the location of these transgenes in the plants genome, potential side effects of each transgene have to be analyzed. Although from a scientific point of view it might be assumed that the analysis of each combination of transgene and cultivar is sufficient (trait specific) the European legislation requests the analysis of each event for approval (event specific). Taking into account that the market for pathogen resistant plants is much smaller compared to insect- or herbicide resistant plants, the chance for a sufficient return of investment seems for the time being too low.

Scientific Causes The most obvious scientific concern is the spread of the resistance gene to wild relatives, giving these hybrids a better chance to survive. Although this could also happen to the resistance genes in classical breeding, and is not regulated there, in transgenic plants it is required to be analyzed when cultivars are used that have sexual compatible wild relatives in the area where the transgenic plants are likely to grow. This is for instance important for pathogen resistant maize in South America, for transgenic canola at river beets where *Brassica oleracea* is found, or for sugar beets at the coastline of Europe where wild beets are growing. Hence intensive out crossing studies have been conducted (www.transgen.de).

Secondly, unwanted effects on non-target organisms have to be taken into account. Stefani and Hamelin (2010) summarize eighty six studies investigating the impact of transgenic fungal resistant crops on target and non-target fungi. No significant changes in the populations of non-target fungi could be detected. Similar results were obtained for fungal resistant trees. Nevertheless, this result cannot be generalized since the studies were mostly carried out under controlled conditions; only eleven were conducted in the field.

The uncontrolled spread of the transgenic plants is quite often named as one of the biggest problems. Nevertheless, as long as crop plants are used that are not able to survive without human support, this risk is restricted to the agricultural area. Here, strict seed thresholds defining the maximum content of transgenic seeds in a conventional seed lot and corresponding thresholds for the labeling of products that contain small amounts of transgenic plants in combination with guidelines that define the distance between fields where conventional or transgenic sexual compatible plants are grown, is sufficient to secure the availability of non GMP products on the market, as long as the demand is high enough to justify the costs of the separation. In case of plants that are able to spread into the wild, more caution has to be taken. It has to be assured that the expression of the transgene does not lead to any advantage compared to the near isogenic lines.

Big advantages of certain varieties lead to an increase of these varieties in the field. Hence it might be assumed that transgenic, pathogen resistant varieties will be preferred by the farmers and thereby reduce the number of different varieties available on the market. However, this holds true for any interesting variety independent on the method with which it was created. Actually, it could be much easier to integrate an interesting trait into several varieties via genetic engineering instead of crossings, but this is only possible if the legislation changes from event specific to a trait specific approval.

In contrast to insect or herbicide resistant plants, the creation of resistance is not of great concern. Resistance of pathogens will occur at some point, no matter which strategy is used to create the resistant plant; this is just a matter of time and evolution. Nevertheless, the pyramiding of resistance genes, which is much easier and more effective using genetic engineering, should prolong the utilization phase of specific traits drastically.

Political and Social Concerns As shown in Brazil, pathogen resistant plants are of importance for small farmers and could support a sustainable agriculture due to the reduction of pesticides. This is of public interest and should therefore—as happened in Brazil—be supported by public money. For several years the development as well as risk assessment of transgenic plants was funded by governments in the whole world. Nevertheless, opposition against this policy arose quite early and with increasing intensity. Several non-governmental organizations and even political parties declared the opposition to genetically modified plants as a primary goal, leading to increasing financial and political support by the public. Unjustified dispraise of scientists conducting risk assessment analysis led to a loss of trust in the independence of science. Politicians expressing their doubts on the governmental assessment system and countless scandals in food and feed production undermined the public faith in security systems. Contradictive scientific studies also caused confusion. For example, a study by Séralini et al. concluded that a herbicide-tolerant maize caused tumors and early death in rats (Séralini et al. 2012). This was widely dismissed by scientists including EFSA (European Food Safety Authority 2012). In November 2013, this article was retracted by the journal concerned (Elsevier 2013). All this supported attacks on field trials, scientists and watchmen by activists without disapproval from the public. Understandably, neither the business nor the governments are now very keen to support the production and cultivation of GMP in Europe.

In addition to the scientific reasons, which are unfortunately less and less part of the debate, ethical and moral concerns influence the public opinion. The integrity of a being and of its genome is often mentioned as an important value, ignoring the fact that genomes always undergo changes due to the mixing in sexual mating, recombination, mutation through environmental factors and jumping genes. These changes are the prerequisite of evolution. The potential dependence on multinational companies is another, and very relevant, concern. Only very few big multinational companies are able to finance and support the approval process necessary, especially in Europe. All applications for approval in Europe have been made by only nine companies. This is much different for instance in the United States, where approval is cheaper and easier and therefore also smaller companies are able to bring their events on the market. Due to the high cost in Europe, the companies join to apply for the approval of one event that is then inbreed into the different varieties.

One last important concern is the fact that high licensing costs make it impossible for small farmers to use transgenic, pathogen resistant plants. The example of the golden rice, where license holders agreed to waive the fee if the income of the farmer is below a certain level, shows that it is possible to solve this problem. In addition, the support of governmental research independent of companies, like in Brazil, would allow more innovations to come to the market with lower licensing fees.

16.3 What has to Happen?

Pathogen resistant transgenic plants have the potential to make agriculture more cost-effective and with less adverse impact upon the natural environment. The following suggestions might contribute to use this potential and to ensure that all people, not just multinationals, can benefit from the technology.

Worldwide, mainly plants with small market potential are problematic. Here, first of all the costs for approval and licenses have to go down while keeping the relevant safety level. In addition, the trait has to reduce the costs for the farmer in order to justify a technology fee. Even then, it might also be necessary to refund the farmer for the environmentally friendly cultivation in order to set enough incentives to saw these seeds. In addition, public acceptance is a prerequisite for the cultivation. This seems only achievable when there is an advantage for the consumer that is directly obvious, which unfortunately seems to be not the case for ecological advantages.

Even then, taking the huge opposition into account, it is unrealistic to think that there will be transgenic pathogen resistant plants on the market in Europe in 10 or even 20 years. Here, scientists should prepare for the time when cultivation of transgenic plants will be needed and possible too, since it takes more than 20 years from the first idea to a safety assessed transgenic variety ready for the market. This is only possible if field trials can be conducted. For instance in 2014, not a single field trial is planned in Germany. This is also due to the high costs of field protection (for fences and watchmen) that exceed the actual research costs. The Swiss government is funding a protected site where all field trails can be conducted (Romeis et al. 2013). This is a good start; nevertheless the site is much too small. Similar attempts have to be undertaken in other European countries or even by the EU.

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