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ORIGINAL PAPER

Genetic modification for disease resistance: a position paper

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Abstract This Position Paper was prepared by members of the Task Force on Global Food Security of the International Society for Plant Pathology. An objective approach is proposed to the assessment of the potential of genetic modification (GM) to reduce the impact of crop diseases. The addition of GM to the plant breeder's conventional toolbox facilitates gene-by-gene introduction into breeding programmes of well-defined characters, while also allowing access to genes from a greatly extended range of organisms. The current status of GM crops is outlined. GM could make an additional contribution to food security but its potential has been controversial, sometimes because of fixed views that GM is unnatural and risky. These have no factual basis: GM technology, where adopted, is widely regulated and no evidence has been reported of adverse consequences for human health. The potential benefits of GM could be particularly valuable for the developing world but there are numerous constraints. These include cost, inadequate seed supply systems, reluctance to adopt

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A Position Paper of the Task Force on Global Food Security is a factual summary of the principal aspects of a topic, from the perspective of plant pathology, to present a position from which the merits and drawbacks of particular issues that arise within that topic can be rationally discussed.

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unfamiliar technology, concern about markets, inadequacy of local regulatory systems, mismatch between research and growers' needs, and limited technical resources. The lower cost of new gene-editing methods should open the practice of GM beyond multinational corporations. As yet there are few examples of utilization of GM-based resistance to plant diseases. Two cases, papaya ringspot virus and banana xanthomonas wilt, are outlined. In the developing world there are many more potential cases whose progress is prevented by the absence of adequate biosafety regulation. It is concluded that there is untapped potential for using GM to introduce disease resistance. An objective approach to mobilizing this potential is recommended, to address the severe impact of plant disease on food security.

Keywords Genetic modification · Genetic engineering · Plant breeding · Food security · Disease resistance · Developing countries · Biosafety

Initial statement

The ISPP Task Force on Global Food Security recognizes the potential of genetic modification (GM) to reduce the impact of plant diseases on the productivity, safety and quality of crops in agriculture, horticulture and forestry, and advocates an objective approach to the assessment of that potential.

Definition

Genetic modification (GM), also known as genetic engineering, is here defined as alteration of the genetic material of a plant through human intervention using methods other than cross-fertilization. The products of genetic modification are referred to here as genetically modified (GM) plants.

Food security, plant diseases and the value of plant breeding

Global crop production needs to be substantially increased to meet the demands of a growing population. Of the population of more than 7 billion people, some 800 million do not have enough to eat today. The vast majority of these people live in developing countries (FAO 2015). By 2050, the global population is expected to exceed 9 billion (US Census Bureau 2015). It has been estimated that some 15 % of global food production is lost to plant disease (Oerke and Dehne 2008). In developing countries losses might be much higher. Plant pathologists cannot ignore the juxtaposition of these figures for food shortage and the damage to food production caused by plant pathogens.

The impact of plant diseases is exacerbated by increasing globalization and trade, which facilitate the spread of pathogens and the emergence of new plant diseases, and by the need for crops to be grown more intensively as global population grows with only limited opportunities for increasing the area of cultivated land.

Management of plant diseases can be effected through crop husbandry and phytosanitary measures, through the use of pesticides, and through plant breeding. But these measures have limitations: for example the diversity of pesticides is declining under more rigorous regulatory control, and resistance to pesticides is increasing. New disease management methodologies are needed in compensation.

Genetic improvement of crop plants by selective breeding presents a particularly cost-effective and easily adopted means of disease management, as the only action required of the grower is to use appropriate seed or other planting material (Evenson and Gollin 2003).

Genetic improvement of plants has been practised since the beginning of agriculture through selection of improved variants, occurring either spontaneously or amongst the progeny of cross-breeding, or sometimes through treatment to induce mutations. The normal multiplication processes of crops then allow stocks of improved cultivars to be built up.

Conventional plant breeding, which is the basis of nearly all modern crop cultivars, has been typified as "crossing the best with the best and hoping for the best". For all its limitations and despite the typical uncertainty of what genetic change is actually responsible for the improved performance of its products, plant breeding retains its importance and acceptance as a key element in crop husbandry (Tester and Langridge 2010). It is taken for granted as a central and safe man-made contribution to food security and has a special importance in the development of cultivars with improved resistance to crop pests and diseases.

GM as a tool for plant breeding

The plant breeder's toolbox traditionally contained devices for effecting hybridization between stocks of promising plant material for cross-breeding, and systems of selection of improved variants among progeny for multiplication. The versatility of the toolbox has been greatly increased by the tools of genetic modification (GM). GM facilitates gene-by-gene introduction into breeding programmes of well-defined characters, while also allowing access to genes from a greatly extended range of organisms since there is no reliance on compatibility in hybridization. Not only is the pool of available variation enormously increased (notably for resistance to pathogens) but far greater precision is achievable in the introduction of each desirable genetic trait, without other unwanted genes. Furthermore the release of unwanted variation through genetic recombination that is an inherent feature of hybridization is avoided. Consequently the time needed to breed improved cultivars bearing specific traits is shortened. It should be recognized, however, that the cost to a breeder of acquiring GM capability is likely to be significant. GM as defined here includes the use of gene-editing tools such as CRISPRs (Ledford 2015).

The current status of GM crops

GM crops were first used in agriculture in 1996 when 1.7 million hectares were planted (James 2015). There has been an increasing trend since then, to a total of 180 million hectares in 2015, principally of four crops: soybean, maize, cotton and oilseed rape (canola). Of the 28 countries in which GM crops have been deployed, 20 are developing countries. The principal traits introduced into GM crops up to 2015 are tolerance of the herbicide glyphosate, and resistance to insects from *Bacillus thuringiensis*. New GM crops of the principal four species and also potato, beans, eggplant, papaya, squash, sugar beet, eucalyptus, poplar and apple are now being developed with these characters, and with drought tolerance, disease resistance, salt tolerance, nitrogen use efficiency, speed of ripening, storage quality, nutritional versatility and other characteristics. Field trials of GM potato are being conducted in Bangladesh, India, Indonesia and Uganda to assess their resistance to late blight, caused by *Phytophthora infestans*. Reservations about the safety of GM crops continue to limit their use, notably in Europe where a majority of the Member States of the European Union have opted to prohibit their cultivation (European Commission 2015).

Benefits and risks

There is a strong case for exploring the use of such potentially valuable tools which present new possibilities to meet the challenge of food security, extending the widely valued practice of plant breeding. Nevertheless, the potential of GM for crop improvement has been the subject of much controversy, sometimes based on fixed views that GM is unlike other tools in being unnatural and inherently risky. Thus it has been argued that the widespread use of GM to introduce insect resistance derived from the bacterium *Bacillus thuringiensis* (Bt) into crops brings with it the risk of selection in insect populations for the capacity to thrive in the presence of the genetic resistance. Furthermore this could apply to non-target insects as well as those that are the target of the breeding programme. Such risks have been ascribed to the use of GM but are in fact a consequence of deploying the trait, not the technology used to introduce it.

The choice of traits for introduction by GM should be made with due consideration for the consequences of their deployment. There seems however to be no factual basis to support the contention that GM technology per se is more likely than conventional plant breeding to create dangerous new phenotypes. Indeed the reverse can be argued, since GM should allow far greater control over genetic change than conventional breeding.

As a precaution against risk, the use of GM technology is officially regulated in most countries, at the laboratory level and in the deployment of the products of GM in agriculture. Such regulation may need to be rationalized, for example in some countries where it precludes research on GM or the deployment of research outputs, or in others that lack robust objective oversight. However, the value of appropriate and proportionate regulation of GM is widely recognized.

No evidence has been reported of adverse consequences for human health from consuming the products of crops developed using GM technology (World Health Organization 2014; Suzie et al. 2008; National Academies of Sciences, Engineering, and Medicine 2016). This fact is based on a substantial and growing body of scientific publications. There is a case for adoption of a system of objective collection, evaluation and dissemination of such evidence as a precaution against misleading assertions of risk.

Concerns have been raised about the impact of GM on the environment, though these are often associated with the introduced trait rather than with the use of GM to introduce it. However, there is also evidence of environmental benefit, for example through reduced pesticide use and (with herbicide-tolerant cultivars) conservation tillage (Sanvido et al. 2007).

Evidence-based evaluation

Decision making on the use of GM, like decision making on any other technology for plant disease management, should be based on scientific evidence through critical and independent evaluation of potential cost/benefit on a case-by-case basis, taking into consideration economic, social and environmental issues. There is not yet an accepted structure for such evaluation, which should be rigorously science-based, and should preferably involve the public in its development and use. Such a structure would facilitate evidence-based decisions.

GM in the developing world

The potential benefits of GM-based cultivars in disease management could be considerable in the developing world. There are however many constraints to be overcome (Adenle et al. 2013), including:

– The high cost of development and deployment of GM-based cultivars. Because costs must be recouped, developers focus on major traits in globally significant crops.[1**]

- Inadequate capacity of local seed supply systems to multiply GM seed.
- Growers' reluctance to adopt an unfamiliar technology that may be costly, may require seed to be sourced externally, and may evoke unfounded perceptions of risk.
- Concern among growers that GM produce may be difficult to sell, for example to EU countries.
- The challenge of establishing regulatory systems, and deploying GM in farming systems that differ from those in developed countries where the technology was developed.
- Discrepancy between the priorities of donor-funded research and the needs of growers.
- Limited local research capacity to identify pathogens and their variants as targets for development of GM cultivars.
- The need to manage GM introductions to minimize potential build-up of pathogen virulence and avoid accidental transfer of traits to weed species.
- The risk to GM developers of legal liability for accidental introduction of GM material into food chains designated as non-GM.
- The need for effective seed production and distribution systems to avoid proliferation of poor quality or fake GM products.

Examples of GM-based disease resistance

To date, there are few examples of utilization of GM-based resistance to plant diseases. Two cases are outlined here. A basis for evaluating other prospects has been discussed (Collinge et al. 2016).

In Hawaii in the 1990s, the increasingly severe effects of papaya ringspot virus (PRSV) were addressed by development of GM papaya cultivars with resistance based on the introduction of coat protein (CP) genes from mild strains of the pathogen (Tripathi et al. 2008; Fermin et al. 2010). Approval for their cultivation in Hawaii was granted by US Government agencies. Their resistance to PRSV was substantial and has enabled production of papaya to continue in Hawaii, where it had been threatened. The GM produce is widely sold locally and exported. Like any other kind of resistance, it may be rendered less effective by the emergence of virulent strains of the pathogen. But as its efficacy is greater when the introduced CP gene is derived from locally damaging strains, there is scope for adapting the GM crop to the local pathogen challenge. Papaya cultivars with CP and other GM-based forms of resistance to PRSV are now available for cultivation in other regions. Their utilization is limited mainly by reluctance to adopt GM technology.

Some other cases are less successful (Tripathi et al. 2009). In East Africa the banana crop may be seriously affected by banana xanthomonas wilt (BXW) caused by the bacterium *Xanthomonas campestris* pv. *musacearum*, which has spread invasively since 2001. Yield may be reduced by 90 % within a year of infection. This is a new disease and is of critical economic and social importance in Uganda where banana is the staple crop. Banana cultivars show no resistance to the disease, so the International Institute of Tropical Agriculture (IITA), with national and African partners, developed GM bananas expressing the Hrap or Pflp genes from *Capsicum annuum*. These exhibited strong resistance to BXW in laboratory tests. The most resistant lines were planted in a Confined Field Trial (CFT) after approval from the National Biosafety Committee. They are however unable to progress further because official biosafety regulation has not been established in Uganda. Attempts to pass new legislation have been stalled by campaigns suggesting health risks and the likelihood of market collapse.

There are many such examples of experimental GM-based lines in developing countries that are prevented from progressing beyond the CFT stage by the need for effective biosafety regulation, which would allow evidence-based consideration of benefits and risks (Bailey et al. 2014).

Conclusion

The ISPP Task Force on Global Food Security considers that there is untapped potential for using GM to introduce resistance to more pathogens in a wider variety of crops. The Task Force advocates an objective approach to assessment and application of the potential of GM, as one means of addressing the severe impact of plant disease on food security.

More detailed treatment of the topic can be found here (Bennett and Jennings 2014; Qaim 2015; Collinge 2016; National Academies of Sciences, Engineering, and Medicine 2016).

[1 **] At present, the costs are such that the choice of GM for disease management in developing countries should be critically compared with alternative strategies for cost effectiveness. The products of commercial investment may however be locally available: for example the African Agricultural Technology Foundation introduces genes donated by multinationals into African varieties and provides farmers with assistance in using them (Delmer et al. 2003). The lower cost of new gene-editing methods should open the practice of GM beyond multinational corporations, reducing the constraint to focus on major crops and increasing the scope for small companies and academic researchers to develop GM cultivars (Ledford 2015).

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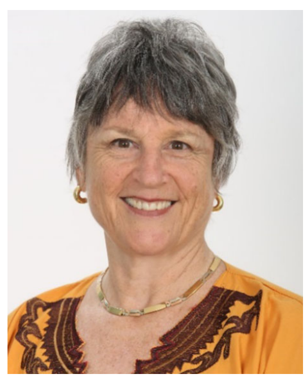

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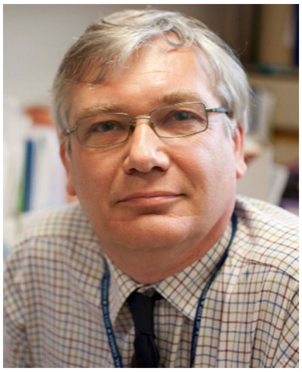

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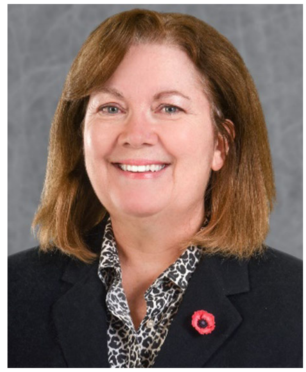

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