of GM with non-GM varieties of the same crop or a different crop. Hence, if African countries exporting to the EU adopt productivity-enhancing GM crops, they risk losing their markets in the EU. Given that absolute segregation of GM and non-GM crops is both difficult and expensive to achieve on a commercial basis, African countries eschew the adoption of GM crops, thus forgoing improvements in their agricultural productivity (even developed countries are stressed: the EU closed the border to Canadian exports of flax and American exports of corn, rice, and soybeans recently after detecting trace amounts of traits not approved in the EU). The failure to adopt GM crops in the EU also feeds back into global investment decisions: one result is lower investment into the adaptation of GM crops suited to agronomic conditions in developing countries, especially tropical crops.

This latest move away from science-based regulation in the EU will have wide-ranging effects beyond the EU itself, effects that will complicate international efforts to achieve global food security. While numerous GM-adopting nations have positively responded to the challenge of the FAO, the EU continues to ignore the impact of their domestic choices on this crucial global issue. The EU has secure food supplies and is ignoring the cost its politically motivated technology choice has on food insecure consumers and countries. The EU has failed in its responsibility to its own citizens and to those in developing countries by ignoring science and evidence.

Concluding Remarks

While the opportunity to use GM technologies in the EU seems to be lost, there is a bigger opportunity that the world cannot afford to waste. A host of new plant breeding techniques and technologies are poised to enter the crop variety development sector. They offer an exciting opportunity to reverse the trend to weaker yield growth. While many of these new technologies and techniques do not involve cross-species manipulations, there is a movement afoot in the EU, especially in many of the MS that have exercised the opportunity to renationalize decision about GM crops, to outright reject these technologies. This knee-jerk reaction to a real opportunity to accelerate crop productivity, lower the ecological footprint of food production, and improve the lot of many food-insecure farmers and families around the world is a shame. The burden of increasing global food security cannot be in the hands of the few GM crop-adopting countries, led by Argentina, Australia, Brazil, Canada and the USA, but must be shared equally between all industrialized countries. The commercialization of new, higher yielding crops needs all leading food producers to engage. The EU cannot abrogate its duty to use its wealth and resources on behalf of humanity.

Resources

[i] www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/How_to_Feed_the_World_in_2050.pdf

[ii] www.ictsd.org/bridges-news/bridges/news/eu-confirms-provisional-agreement-on-national-gmo-bans

[iii] http://ec.europa.eu/research/biosociety/pdf/a_decade_of_eu-funded_gmo_research.pdf

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Letter

Enhancing Plant Disease Resistance without R Genes

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Crop plants encounter constant biotic challenges, and these challenges have historically been best managed with resistance (R) genes. However, the rapid evolution of new pathogenic strains along with the nonavailability or nonidentification of R genes in cultivated crop species against a large number of plant pathogens have led researchers to think beyond R genes. Biotechnological tools have shown promise in dealing with such challenges. Technologies such as transgenerational plant immunity, interspecies transfer of pattern recognition receptors (PRRs), pathogen-derived resistance (PDR), gene regulation, and expression of antimicrobial peptides (AMPs) in host plants from other

plant species have led to enhanced disease resistance and increased food security.

Lombardo *et al.* recently reviewed new approaches to implementing R genes for insect and herbicide resistance in plants [1]. Similar approaches are also relevant for pathogen resistance in plants. Here, we summarize alternative approaches to engineer disease resistance in plants. In addition to genome editing [2] and antisense technologies [3], several other promising technologies have also emerged as potential instruments for countering the limitations of R gene-mediated resistance in plants against pathogens and insect herbivores. Technologies such as transgenerational epigenetics (TE) in plants could be employed to improve some traits in a shorter period of time. TE can be defined as an epigenetic change that persists across one or more subsequent generations. TE can also be utilized to manage plant pathogens, insect herbivores, and other abiotic stresses such as mechanical injuries. The TE blockage in the expression of some particular genes in response to environmental stimuli, due to either DNA methylation or histone modifications, may accelerate the plant's ability to restrict pest/pathogen development [4]. When outside stimuli induce such blockages in plant gene expression, loss of expression may be permanent in that generation and passed to the next generation in the same state through seeds. Plants thereby pass on the perceived environmental threats of both biotic and abiotic stresses to offspring.

Additionally, interspecies transfer of receptors has also shown promise in managing biotic stresses. Broad-spectrum resistance in plants can be developed by transferring pattern recognition receptors (PRRs) between plant species [5]. Engineering broad-spectrum disease resistance through transferring PRRs has shown promise, and the impact is expected to be long-lasting. These PRRs are either receptor kinases (RKs) or receptor-like proteins (RLPs); signals from potential pests/pathogens received by the PRR result in a conformational change in the receptor, leading to the activation of downstream defense signaling genes. Transferring PRRs from related species, or wild relatives, that can perceive a pathogen threat from one plant cultivar or species to another and thereby increasing the level of resistance in a susceptible plant cultivar or species against a specific pathogen.

Genetic engineering and biotechnology can open doors for counteracting infection; one strategy is introducing genes from various sources into plants, which could generate disease resistance with none of the species boundaries that apply to conventional methodologies. The expression of structural viral nucleic acid sequences (e.g., coat protein, movement protein, or replicase protein genes) in plants, known as pathogen-derived resistance (PDR), generally offers a broader range of resistance even to the related viruses. The technique is effective against a low level of inoculums but, as with most viral proteins, this strategy can elicit R gene-driven effector triggered immunity (ETI), causing hypersensitive response (HR), a mechanism leading to rapid cell death surrounding a pathogen infection that limits the pathogen spread [6]. Bioengineering against viral pathogens is particularly important as only around 40 R genes have been identified so far against more than 1000 identified plant viruses. Further, plantibodies have also been developed to protect plants, which could be constructed to focus on any pathogen, sequestering the antigens that are frequently required to complete the infection cycle, thus preventing diseases [7].

Similarly, regulating genes that are not considered to have direct roles in governing host resistance may also lead to enhanced disease resistance against both pathogens and insect herbivores. Downregulating cellulose synthase (*CesA*) increases Arabidopsis resistance to *Botrytis cinerea* [8]. Similarly, disruption of the main brassinosteroid receptor (*BRI1*, *brassinosteroid insensitive 1*) in both *Brachypodium distachyon* and barley enhanced disease resistance against some cereal fungal pathogens [9]. Further, when the rice *heme activator protein* (*HAP*) gene (*OsHAP2E*), which is known to regulate plant growth, development, and stress responses, was overexpressed, it not only enhanced disease resistance to a fungal and a bacterial pathogen but also conferred rice plants resistance to abiotic stresses such as drought and salinity [10].

In addition, generating antimicrobial peptides (AMPs) in plants to fight pathogens has also become an interesting tool to reduce crop losses. AMP chitin-binding capability plays a crucial role in antifungal activity. The AMP antiviral effect depends on different factors, such as the direct interaction with the viral envelope, disrupting or destabilizing it; competition with viruses for the host membrane, preventing the viral connection with particular cell receptors; and prevention of expression of viral genes in the earlier infection stages, affecting the propagation and the viral infection [11]. Interestingly, some endogenous peptides are even perceived as danger signals and a stereotypical defense response is induced in host against the invading pathogens [12]. Technological interventions may lead to greater utilization of such peptides in reducing pathogen progress in hosts.

Recent technological advancements in biological sciences have thus created the future possibility for disease resistance in crop plants to those pathogens against which neither R genes nor available chemicals have been effective. Moreover, overreliance on R genes for disease resistance has become counterproductive in several instances. Therefore, new technologies are desirable as they are proving to be viable, complementary, or supplementary to R genes, environmentally acceptable, and ecologically feasible alternatives to R