Choice of technology for herbicide-resistant transgenic crops in India: Examination of issues†

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Herbicide resistance is the major trait that has been engineered into crops and herbicide-resistant crops (HRCs) occupy the largest area under transgenic crops in the world. The relevance of HRCs in Indian agriculture, however, has been debated due to socio-economic and technical reasons. In this article we examine the scientific issues that will need careful consideration before taking a decision on this matter.

Keywords: Herbicide resistance, herbicide-resistant crops, resistant weeds, technology, transgenic crops.

HERBICIDE-resistant transgenic crops (HRCs) constitute nearly 72% of the 81 m ha under transgenic crops[1]. Since the advent of large-scale cultivation of transgenic crops in 1996, HRCs have maintained the lead in terms of area coverage. HRCs were readily accepted in developed countries, where weed-control strategies almost always rely on the use of herbicides. The relevance of HRCs on small and fragmented farm holdings of India is, however, contentious. The proponents advocate that the new technology is scale-neutral and its benefits should be made available to Indian farmers. The other section firmly believes that HRCs are not suitable to our conditions and pose serious threat to the employment and livelihood opportunities of the poor and marginal farmers and farm labourers, and will adversely impact environment, ecology and biodiversity. Caught between these two extreme views, the Government of India is approaching this issue cautiously and has not placed HRCs on its priority list of traits to be modified through genetic engineering approaches[2] (Draft Biotechnology Policy). In this article, we examine various issues surrounding commercialization of HRCs and highlight some technical aspects that have not received deserved attention so far. We hope that this article will stimulate objective and informed discussions on this topic.

Weed problem in Indian agriculture

Weeds are a problem in Indian agriculture, as elsewhere in the world. Weeds compete with crops for moisture and nutrients. Loss of yield due to weed infestation is variable and is more pronounced in crops grown under rainfed conditions. Some parasitic weeds draw water and nutrients from crop plants and can inflict severe damage. Further, weeds serve as alternate hosts to pathogens and also harbour pests. Control of weeds during early stages of crop growth, when the young seedlings of crop plants are unable to compete with hardy weeds, is crucial for capturing yield potential. For this reason, labour demand for weeding operation is high during early phase of crop cycle and manual weed control over large areas is not feasible from the point of labour supply and monetary costs. Some weeds that are wild relatives of crop plants are difficult to distinguish from crop plants at early stages and pose challenge for manual weeding. Under these situations, chemical weed control is relevant for realizing higher productivity and production.

Herbicides: types and usage

In India, about 6000 tons of herbicides are currently used for weed control, mainly in irrigated crops (about 77% on wheat and rice) and on plantations (about 10%)[3]. However, herbicides form only 12% of the pesticides used on crops in India. A wide variety of weeds (perennial and annual) are generally encountered in crop fields. However, specific weeds predominate different cropping systems and zones. Both broad spectrum/non-selective and selective herbicides are in use. Continuous use of some herbicides has led to development of resistant weeds and has exacerbated weed problems. For example, in rice–wheat cropping system of Punjab and Haryana, *Phalaris minor* has developed resistance against isoproturon[4–6].

Herbicides that kill plants by inhibiting specific vital functions do not distinguish between crop plants and weeds. Such non-selective herbicides are generally ap-

†These are authors' personal views and do not reflect official position on this matter.

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plied before sowing/emergence of crop plants and their residual effects may affect crop performance. There is limited flexibility in the schedule of their application and their use requires caution. However, some crop plants enjoy naturally endowed resistance to specific herbicides. For example, 2,4-dichlorophenoxyacetic acid (2,4-D) kills only broad-leaved weeds and can be used as a selective herbicide in monocot crops like rice, wheat and maize. Similarly, maize is resistant to atrazine and simazine[7]. It is important to recall that although a large number of chemicals have been approved for weed control, their widespread and continuous use is not desirable owing to their toxicity and long-term effects on the environment.

Genetic engineering of herbicide tolerance

Before the emergence of plant genetic engineering, options for selective crop protection against herbicides were limited. Specific herbicides could be used in the crops that were naturally resistant to the herbicide. In rare cases, resistance could be induced in crop varieties through mutations[8,9]. For example, monocots are naturally resistant to triazine and hence triazine could be used as selective herbicide in monocot crops to control dicot weeds. Developments in plant genetic engineering and knowledge of biochemical action of herbicides on plants spurred innovative approaches to engineer crops to withstand herbicides. These strategies usually involve isolation and introduction of a gene from another organisms, mostly bacteria, which is able to overcome the herbicide-induced metabolic blockage. For example, tolerance to the herbicide glufosinate (Basta®) is conferred by the bacterial gene *bar*, which metabolizes the herbicide into a non-toxic compound[10]. Glyphosate (another most popular herbicide) resistance is achieved by the introduction of either *Agrobacterium* gene *CP4* that codes for a glyphosate-insensitive version of the plant enzyme, EPSP-synthase, or *gox* gene from *Achromobacter*, which codes for glyphosate oxidoreductase in the breakdown of glyphosate[11]. A number of other genes have been identified that can alleviate the herbicide action through various ways (such as detoxification, sequestration, etc.) and thus confer resistance to the plants carrying them. Thus genetic engineering technology has made it possible to tailor crop varieties to resist specific herbicides by introducing relevant genes. Consequently, the range of selective herbicides has now greatly expanded, wherein specific genotypes and varieties can be conferred resistance rather than generic crops displaying resistance to specific herbicides. These developments have provided the herbicide companies new opportunities to promote their herbicides through development and marketing of genetically engineered HRCs.

Technical issues about HRCs

Effects of introduction of HRCs on biodiversity have been widely discussed[12]. It is now shown that introduction of HR soybean has not adversely impacted genetic diversity of soybean varieties. HRCs have promoted conservation tillage in the US and thus may have reduced soil erosion. Because of effective control of weeds, the population of bees and butterflies was lower in fields with HRCs[12]. It should be noted that good weed management practices would check weeds and thus lead to reduced population of insects and animals that are dependent on weeds.

Introduction of HRCs may lead to a paradigm shift in approach to the breeding of crop varieties. In this connection, it is instructive to examine the story of HR soybean in the US. Monsanto introduced transgenic soybean resistant to the herbicide glyphosate in the US in 1996. Just after approval for the commercial release, companies refused to enter their glyphosate-resistant soybean in common variety trails, where conventional herbicides were employed for weed control. Their contention was that since the transgenic varieties were not resistant to conventional herbicides, benefits of the transgenic HR soybean would be realized only when glyphosate is used for weed control. This led to the introduction of separate trails for HR transgenic soybeans, which did not allow proper comparison between transgenic and conventionally bred cultivars, that was the basis of choice of farmers for glyphosate-resistant soybean[13]. Following the widespread adoption of HR soybean by farmers, most soybean breeders had to incorporate this trait into their varieties for remaining in business. That meant taking sublicense from Monsanto for the use of their patented *CP4* gene for breeding glyphosate-resistant varieties.

A similar situation is currently witnessed in India with respect to *Bt*-cotton. The demand for *Bt*-cotton hybrids has forced almost all major seed companies marketing seeds of cotton into developing *Bt*-transgenic cotton hybrids. For a quick entry into the transgenic arena and to remain in competition, companies have entered into sub-licensing agreements with Mahyco/Monsanto to use the MON 531 transgenic event, approved by the regulatory authorities, into their own genotypes through backcross breeding. Public-sector breeders have also geared up to produce *Bt*-cotton hybrids and varieties through their own initiatives and efforts.

What lessons can we learn from the above with respect to HRCs? There is little doubt about the effectiveness of the herbicides (glyphosate and glufosinate for which transgenics are currently available) in controlling weeds when used in conjunction with HRCs. Therefore, in crops where herbicides are being currently employed in weed control (and where transgenic HRCs will be primarily targetted) HRCs will be quickly accepted. Currently, the patent rights for the relevant genes rest with specific companies and they would be keen to capture the market for HR varieties. Soon, breeders in both public and private sectors may be compelled to incorporating the resistance trait into their varieties, lest they are left out of competition. Unlike *Bt*-cotton, where many *Bt* genes can be sourced to bypass patent rights, finding new genes and approaches to overcome patent protection for developing HRCs will be difficult in the short run. The consequence of this will be similar to what has happened in the US for HR soybean.

Availability of such HRCs will, in all likelihood, promote herbicide use even in areas and situations where herbicides are not currently used and may adversely impact employment opportunities of rural poor. It is still unclear as to how private companies will realize profit if HRCs are to be introduced in self-pollinated crops like rice, wheat, soybean, etc. The Seed Act allows use of farmer-saved seeds and farmer-to-farmer exchange of seeds. Hence, once introduced, HRC varieties of self-pollinated crops will continue to spread unchecked. Large-scale cultivation of HRCs and indiscriminate use of herbicides may lead to development of herbicide-resistant weeds, especially if wild relatives of crop plants are growing in the vicinity. There are already numerous examples of development of HR weeds where herbicides are used continuously. The resistance against isoproturon in *P. minor* is a burning example.

Resistance development is widely discussed with respect to *Bt*-transgenics. However, *Bt*-resistance and herbicide resistance are qualitatively different. If insects develop resistance against a particular *Bt*-toxin, alternative *Bt*-toxins with different modes of action or target sites can be deployed. Various strategies such as pyramiding of different *Bt*-genes, and maintaining refugia have been suggested to delay development of resistant insects. Similarly, strategies have been defined to delay development of herbicide-resistant weeds in the case of conventional crop varieties. These include combined or sequential use of herbicides with different modes of action, crop rotation, integrated weed control, etc. In the case of genetically engineered HR varieties, these strategies are less relevant. For example, when the herbicide could be applied at various stages of crop growth, farmers may not opt for integrated weed-control measures. Similarly, when different crops carry engineered resistance to the same herbicide, use of different herbicides may not remain an option. Once the weeds develop resistance, through either acquisition of the gene from the HR variety or by mutation, they will remain resistant against that herbicide. Replacement of the herbicide is the only option in such a scenario. Since development of new and safer herbicides is time- and resource-demanding, development of new herbicides is not likely to keep pace with emergence of HR weeds. A major current concern with the introduction of glyphosate- or glufosinate-resistant transgenic crops is that if the weeds develop resistance, these environmentally benign herbicides will become ineffective and will force use of other less-desirable herbicides for weed control. Already, glyphosate-resistant *Lolium* populations have emerged in Australia[14], USA[15] and South Africa[16], defying the low probability of such a scenario predicted by Bradshaw *et al.*[17]. Further, glyphosate resistance has also been recorded in *Eleusine indica* in Malaysia[18,19], *Lolium multiflorum* (Italian rye grass) in Chile[20] and *Conyza canadensis* (horseweed)[21,22]. In some of these cases novel mechanisms of resistance, not envisaged earlier were discovered[23,24].

The ongoing debate about HRCs is largely focused on their effect on environment and rural employment opportunities. Some of the opposition to HRCs also arises from the prevailing perception that the multinational companies, who hold the rights over herbicide and/or HR technology, are profit-motivated and disregard social issues. We need to recognize the fact that public sector has hardly any presence in the pesticide business and it is inevitable that HRCs and herbicide business will go hand-in-hand. However, this situation should not be the rationale for shunning these products. If they are indeed relevant to us, we should consider adopting them. In the modern technology-driven and -dominated world, private enterprise is assuming a major role in developing and disseminating technologies. The government/public sector is gradually moving to social sectors. While aversion to private enterprise (local or multinational) is not prudent, decisions should be made after an objective assessment of the pros and cons of the choice of technology in relation to relevant broader issues, including socio-economic, ecological and environmental dimensions for specific situations.

Thus, as a technology, herbicide-resistant crops offer opportunity for efficient control of weeds. However, doubts remain about the long-term viability of this strategy, especially the emergence of herbicide-resistant weeds following widespread cultivation of HRCs. In that case, the best herbicides may not be available even for conventional weed control. From the above discussion, it is clear that many aspects of HRCs need to be considered seriously before accepting the widespread introduction of HRCs in India.

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Received 16 November 2005; accepted 5 July 2006