



## Literature Review on Genetic Use Restriction Technologies

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## **Abstract**

The purpose of this paper is to conduct a literature review to survey current technical and related literature on genetic use restriction technologies (GURTs). Topics covered include the nature of current or proposed GURTs, the potential benefits of GURTs, the risks and potential costs associated with GURTs, and a comparative study between GURTs and hybrid seed technologies. Since the initial patent for ‘terminator technology’ was granted in 1998, the issue of GURTs has been complex and divisive, with different stakeholders embracing widely opposing views. There are several strong arguments that have been put forward, both in favour and against the implementation of these types of technologies. Potential benefits include intellectual property rights protection, stimulation of private research and development, genetic diversity enhancement, transgene containment and production purposes. Potential risks and costs associated with GURTs include outcrossing of terminator genes, reduced access and increased cost of genetic material for breeders, greater necessity of regulating and field monitoring of new GURT technologies, liability for environmental damage, health risks, increased cost of seeds for farmers, greater corporate control over agriculture, and a further narrowing of agrobiodiversity. Until the results of peer-reviewed research on the environmental, social, economic and political impacts of GURTs are publicly available, it is recommended that a precautionary approach regarding implementation of GURTs be followed.



# Table of Contents

Abstract.....	i
Table of Contents.....	ii
1. Introduction.....	1
2. Current status of genetic use restriction technologies.....	1
2.1. Trait based GURTs.....	1
2.2. Variety based GURTs (sterile seed technology).....	2
3. Benefits of GURTs.....	3
3.1 Private seed companies (plant breeders).....	4
3.2 Farmers.....	5
3.3 Governments.....	6
3.4 Society.....	6
4. Risks of GURTs.....	7
4.1. Risks of transgene escape.....	7
4.2. Other risks and costs of GURTs.....	8
4.2.1 Private seed companies (plant breeders).....	8
4.2.2 Farmers.....	8
4.2.3 Governments.....	9
4.2.4 Society.....	9
5. Comparison of GURTs and hybrid seed technology.....	10
6. Summary and conclusions.....	11
7. References.....	12
Appendices.....	14



## **1. Introduction**

The purpose of genetic use restriction technologies (GURTs) is to restrict access to genetic materials and their associated traits. This type of technology was developed to ensure that new seed varieties could be protected against ‘unauthorized’ use. Although originally patented as a “technology protection system” for arable crops (United States Patent and Trademark Office 1998), this type of system could potentially be applied to any organism type, such as trees, livestock or fish (Visser et al. 2001). The topic of GURTs has been a very controversial one, with strongly divergent stakeholders, since the first patent for this technology was granted in 1998 (e.g., Service 1998; Mahajan 1999; Pendleton 2004). Strong arguments can be made both in favour and against the utilization of these types of technologies, depending on socio-economic, political and environmental context.

The purpose of this paper is to conduct a literature review to survey current technical and related literature on the complex issue of GURTs. This information will be used by the Canadian Foodgrains Bank to prepare a discussion guide for further debate on the merits and risks of GURTs for farming, both in developing countries and in Canada. The main body of this literature review is divided into several different sections. In Section 2, the nature of current or proposed genetic use restriction technologies, with particular attention to ‘sterile seed technologies’, is reviewed. In Section 3, the potential benefits of, and those who might benefit from GURTs, are investigated. In contrast, the risks and potential costs associated with GURTs are examined in Section 4. In Section 5, a comparative study is made between GURTs and hybrid seed technologies, with emphasis from the point of view of their application in developing countries by small farmers. Finally, Section 6 represents a brief summary of key points and major findings from this review, and Section 7 is the bibliography.

## **2. Current status of genetic use restriction technologies**

There are currently two main classes of GURTs: trait based and variety based GURTs (Visser et al. 2001; Eaton et al. 2002; Pendleton 2004). Trait based technologies (T-GURTs) regulate the expression of a particular trait; whereas variety based technologies (V-GURTs) restrict the use of an entire variety by blocking its reproduction. There is often a blur in distinction between the two types of GURTs and the molecular mechanism employed in both is very similar (Federation of German Scientists 2006). Although this review will focus on V-GURTs, both types of technologies will be discussed below.

### **2.1. Trait based GURTs**

In the case of T-GURTs, one or more genes conferring a single trait are switched on or off through application of chemical inducers (Visser et al. 2001; Pendleton 2004). Therefore, T-GURTs are not intended to affect the viability of seeds, which is in contrast to V-GURTs, which result in sterile seeds. Traits of interest that could be controlled by T-GURTs include male sterility, pest resistance, stress tolerance, nutrient production, seed germination or flower development (Gupta 1998; Pendleton 2004). The goal of this technology is to protect intellectual property (i.e., the ‘value-added’ transgenic trait of

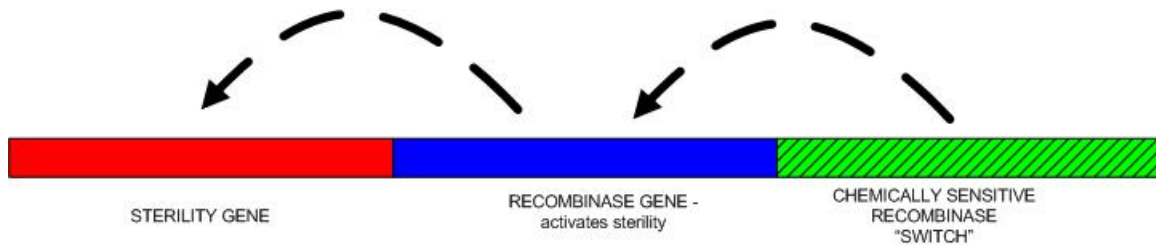
interest) of plant breeders in newly developed varieties by restricting access through a biological mechanism (Eaton et al. 2002). These traits could be activated when needed by induction chemicals. For example, insecticidal genes (e.g., Bt) under the control of an inducible promoter could remain inactivated until an insect pest outbreak justified the application of a chemical to induce the formation of gene products toxic to insects. The inducer chemical would, of course, be under the control and licensing of the seed company; however, the ultimate ‘trigger’ of this technology could be under the control of producers (Pendleton 2004).

## **2.2. Variety based GURTs (sterile seed technology)**

The original patent for V-GURTs (US Patent 5,723,765) entitled “Control of plant gene expression” was granted jointly to the United States Department of Agriculture (USDA) and Delta and Pine Land (D&PL) Company of Mississippi in March 1998 (United States Patent and Trademark Office 1998). See Appendix 1 for an abstract of this patent. Although this patented technology was originally developed for tobacco and cotton, it could potentially be applied to all seed-propagated crops (Lehmann 1998). This technology results in a change in the genetic makeup of a plant cell, whereby plants regenerated from this cell will develop non-viable seeds, which will not germinate in the next generation. Therefore, farmers who use seeds protected by this technology will be able to grow and harvest a first crop, but will not be able to save (‘brown bag’) seeds from this crop to plant in the future. Although, there were originally plans for a corporate merger between D&PL and Monsanto following this patent, this merger eventually failed (Pilger 2002), largely in response to public pressure against Monsanto not to introduce this germination control technology (Masood 1998; Niiler 1999). However, the USDA decided to pursue the commercialization of this technology (Kaiser 2000).

Briefly, this system, also known as “terminator technology”, is based on the transfer of a combination of three genes (Gupta 1998; Lehmann 1998; Pendleton 2004). These genes are: 1) a gene coding for a toxic substance (terminator or lethal gene), which is linked to a blocking sequence preventing the activation of the terminator gene, 2) a recombinase gene (CRE/LOX) containing the information for a protein which cuts the blocking sequence linked to the toxic gene, and 3) a repressor gene with the code for a protein which suppresses the recombinase gene and which is controlled by an external stimulus (Figure 1; see Appendix 2 for more detailed diagram). Without the application of an external stimulus (i.e., chemical trigger such as the antibiotic tetracycline) the repressor gene is normally switched on; therefore, the recombinase gene is switched off so that the blocking sequence of the terminator gene remains intact. Thus, under normal conditions (absence of chemical trigger) the crop remains fertile. However, once the chemical trigger is released, the repressor gene is switched off allowing for the recombinase gene to be switched on, which in turn removes the blocking sequence from the terminator gene, resulting in lethal gene expression. Toxins produced by the activated terminator gene destroy the embryo, thereby rendering the seeds sterile. In this way, seeds could be produced and increased commercially in the absence of the chemical trigger, but when sold to farmers the seeds would be treated with the chemical. All other aspects of plant growth would remain unaffected, because the toxic effects stimulated by chemical treatment only occur during the later stages of embryo development, thus not adversely affecting final yields (Lehmann 1998).

**Figure 1: Simplified V-GURT activity**



Besides the mechanism described above for the original patent, there are a number of other variations of the same basic theme that can be applied to interfere with reproduction in V-GURT. The system described above pertains mainly to pure line seed production in self-pollinated crops; however, in the case of hybrid seed production an alternate strategy utilizing different gene components in each hybrid parent could be used (Gupta 1998; Lehmann 1998; Pendleton 2004). In this system, the first hybrid generation (grown by the farmer) would be sterile because the lethal gene and recombinase would be brought together in this generation (Gupta 1998) and a chemical trigger would not be necessary (Lehmann 1998). In another system, tetracycline or another chemical trigger could also be used to inactivate the terminator trait instead of being used to activate the trait (Visser et al. 2001; Pendleton 2004). Another strategy for V-GURT pertains to vegetatively reproducing crops (e.g., roots, tubers and some ornamentals), wherein, unwanted growth during storage can be prevented by inactivating a certain gene, but growth can be restored when needed by activating a second gene (Visser et al. 2001). Indeed, several companies have been pursuing a number of different patents on technology that is similar to the original terminator technology (Kaiser 2000).

### **3. Benefits of GURT**

There are several potential benefits, costs and risks associated with GURT (Table 1). This section will focus on the benefits, whereas the following section (Section 4) will focus on the risks associated with the deployment of GURT. Potential benefits include intellectual property rights protection, stimulation of private research and development, genetic diversity enhancement, transgene containment and production purposes (Gupta 1998; Lehman 1998; Visser et al. 2001; Eaton et al. 2002; Goeschl and Swanson 2003; Lence et al. 2005). The degree of potential benefits derived from GURT depends on social group (i.e., private companies, farmers, government or society in general). Positive impacts of GURT on each group will be discussed below. It should be noted that these groups are not necessarily mutually exclusive.

Table 1: Genetic use restriction technology (GURT): potential economic benefits, costs and risks (Modified from Eaton et al. 2002).

	Benefits	Costs	Risks
Farmers	Increased productivity from improved genetic inputs due to increased research and development (R&D) investment	Increased input costs from seed purchase	Misuse of monopoly powers by breeders  Reduced seed security and access to genetic improvements (marginalized farmers)
Breeders (especially private sector)	Increased share of research benefits from new products	Increased cost for access to genetic resources of other breeders	
Governments	Reduced investment requirements in breeding  Fewer enforcement costs for plant variety protection (PVP)	Complementary R&D investment requirements Establishment and enforcement of new regulatory requirements	
Society	Increased agricultural productivity		Reduced genetic diversity in fields

### **3.1 Private seed companies (plant breeders)**

It has been suggested that the absence of intellectual property rights results in diminished private research and development (R&D) in plant breeding (Goeschl and Swanson 2003; Pendleton 2004; Lence et al. 2005). For example, more private research has traditionally been conducted on crops for which hybrids are feasible (e.g., corn and sorghum) compared to those for which they are not (e.g., wheat and rice) (Goeschl and Swanson 2003). Therefore, GURTs represent a novel mechanism for capturing returns from innovation in the plant breeding industry, in a similar manner to more conventional hybridizing techniques. The GURT mechanism greatly improves the plant breeder's capacity for rent capture, potentially increasing private investment into agricultural R&D and, hence, a higher rate of innovation in the plant breeding industry (Goeschl and Swanson 2003). Breeding companies hope to protect their investments in improved varieties, thus, GURTs may present a better form of insurance (i.e., a biological one) against the free use of genetic innovations than patents, plant breeders' rights or licenses (Visser et al. 2001; Pendleton 2004; Burk 2004). GURTs would allow better enforcement of property rights (Lence et al. 2005). Apart from the sterile seed technology of V-

GURTs, it is also possible that T-GURTs protecting value added traits in newly released commercial varieties could be applied to virtually all crops (Visser et al. 2001). Plant breeders and seed companies, thus stand to make substantial intellectual and financial gains through implementation of GURTs.

The potential for transgene escape may also be reduced through sterile seed technology (Gupta 1998; Visser et al. 2001; Eaton et al. 2002). This would be beneficial for seed companies because it would decrease the probability of corporate liability for environmental contamination or health risks due to escaped transgenes (Pendleton 2004), but would also reduce the chances of competitors or farmers accessing proprietary genetic material through volunteer or feral crop plants.

To police the unauthorized use of agro-biotechnology, seed companies must currently send agents out into farmers fields, which along with ensuing lawsuits, can be a costly process (Burk 2004). With enhanced transgene containment through GURTs, seed corporations would save on costs of monitoring farmers' fields for any unauthorized use of copyrighted genetic material or transgene escapes that must be mitigated.

### **3.2 Farmers**

Potential gains for farmers through implementation of GURTs may be related to improved yields as a result of increased R&D on crop varieties by private seed companies (Lehmann 1998; Eaton et al. 2002; Goeschl and Swanson 2003). From arguments already stated in the sub-section above, it can be surmised that plant breeders will have greater motivation to develop new and improved varieties of crops for which hybrids are impracticable. For instance, with application of GURTs, it is expected that R&D will increase for self-pollinated crops such as wheat, rice and cotton (Visser et al. 2001). Farmers, thus, may profit in the long-term from these innovations because more productive varieties will become available as breeding efforts increase. For example, the vast majority of improved varieties have been from hybridized crops, with an average annual yield growth of 2.18% over the long-term for hybrid crops compared to a value of 1.58% for non-hybrid crops in developed countries (Goeschl and Swanson 2003). Thus, for many farmers, the surplus of increased yields compensates for having to buy new hybrid seeds every year (Lehmann 1998). The utilization of GURTs potentially could bring non-hybrid yield increases in line with those of hybrids. Furthermore, incentives to breed new varieties may enhance genetic diversity in many important crops, thereby providing further long-term benefits associated with biodiversity (e.g., pest resistance) to farmers (Lehmann 1998).

Apart from long-term yield and biodiversity effects, use of GURTs may offer some short-term practicable applications for farmers as well. Terminator technology could effectively eliminate the problem of genetically modified (GM) crop volunteers in farmers' fields (Pilger 2002) and reduce potential for outcrossing with, and increasing the fitness of, weedy relatives (Gupta 1998; Visser et al. 2001). Controlling GM volunteer weeds such as herbicide resistant crops can add expense to farmers' operating costs, since alternative, often more expensive, herbicides may be required for their control. Another possible agronomic benefit associated with terminator technology is that, because the seeds are sterile in V-GURTs, the problem of crop sprouting would not be an issue with this type of technology (Pilger 2002). In addition, farmers may want to restrict the

expression of a trait only to a specific phase in the development of the plants or animals or during biotic or abiotic stress (Visser et al. 2001). For instance, T-GURTs may allow a stress response to occur only when really needed, because stress responses can require a great deal of resources and may diminish the quality of the processed product. An example of a stress response is a response (e.g., chemical production) to insect pest attack in plants. Alternatively, V-GURTs may be utilized to manage successful reproduction of farm animals in order to maintain the integrity of adapted crossbreeds, produced from mating between local and high-yielding commercial breeds (Visser et al. 2001).

### **3.3 Governments**

Governments may benefit from GURTs through reduced investment requirements in breeding and fewer enforcement costs for plant variety protection (Eaton et al. 2002; Pendleton 2004). Governments could, thus, use GURTs as justification to decrease funding to agriculture R&D and biosafety/copyright infringement enforcement programs. Governments are often under political pressure to reduce spending and cut taxes, therefore, political points could be gained by reducing expenses in these areas. If implementation of GURTs results in yield gains and benefits to farmers, then governments can gain politically with policies that support GURTs.

### **3.4 Society**

Society in general, which includes consumers and the environment, may derive some benefits from GURTs. Society, as a whole, may benefit from GURTs as a result of increased agricultural productivity (Eaton et al. 2002). Pendleton (2004) stressed the importance of the private sector's role in providing adequate food for the world's burgeoning population. Arguments can be made that GURTs will foster an environment of increased innovation, which is needed to develop technology capable of increasing yields to meet global demands (Goeschl and Swanson 2003; Lence et al. 2005). However, forecast model simulations conducted by Goeschl and Swanson (2003) suggested that the most advanced countries stand to benefit the most in terms of productivity gains from GURTs, while less advanced countries stand to gain the least over the medium to long term (i.e., over 20 years). Historically, the general public (especially in developed countries) has benefited greatly from inflated agricultural productivity. For instance, the average Canadian now spends less than 10% of his or her income on food (Kirkpatrick and Tarasuk 2003), and this 'cheap food' policy can, arguably, be attributed to over-production of commodities, which drives down prices, in addition to the effects of subsidies. This was confirmed in a model investigating the impacts of intellectual property protection (IPP) in the seed industry by Lence et al. (2005), who found that while generally producers might lose from innovations, increased benefits to consumers outweighed producer losses resulting in total overall welfare increases with IPP.

There are also believed to be environmental benefits associated with GURTs. Perhaps the most often cited environmental benefit related to the application of GURTs is the containment of potentially harmful transgenes (Gupta 1998; Visser et al. 2001; Pilger 2002; Pendleton 2004). Supposedly, GURTs could be used for the environmental containment of entire transgenic varieties through use of V-GURTs or for specific transgenes contained in transgenic varieties through use of T-GURTs (Visser et al. 2001). T-GURTs could also be used to contain traits that might pose a health risk to consumers

or farmers. In either case, biosafety risks should be reduced with GURTs; however, with sterile seed technology, there is still a risk of GM pollen escaping and outcrossing with other varieties or weedy relatives (Pendleton 2004). No research has yet to be published on this topic.

## **4. Risks of GURTs**

### **4.1. Risks of transgene escape**

It should be noted that the risks of transgene escape associated with GURTs are poorly understood, because there is, currently, no peer-reviewed published research on this specific topic (Federation of German Scientists 2006). One of the most often cited environmental risks associated with GURTs is the threat of outcrossing or gene flow of terminator genes into crops or populations of 'wild' relatives (Bhatia 1998; Lehmann 1998; Service 1998; Visser et al. 2001; Giovannetti 2003). The movement of genes among crops and their wild relatives is possible through two mechanisms: dispersal in viable pollen or in viable seeds (Daniell 2002; Schiemann et al. 2005). Because sterile seed technology is designed to eliminate production of viable seeds, it is expected that risks of transgene escape through the seed route will be very limited or impossible with GURTs (Lehmann 1998; Rakshit 1998; Pendleton 2004). However, there are still concerns of transgene escape via seeds. For instance, the 100% efficacy of tetracycline (or some other chemical inducer) treatment on terminator seeds is questionable and the recombinase gene (see Appendix 2) could remain inactive in some seeds (Giovannetti 2003). Considering that millions of terminator seeds would need to be treated with a chemical inducer to render them sterile, it is not unreasonable to expect that at least a few seeds will escape the effects of the chemical trigger. Although on a percentage basis the number of unaffected seeds may be extremely small, on an absolute basis, this number could still be potentially large, if hypothetically, sizable volumes of seeds were treated in the same facility. Such escaped seeds would carry the complete genetic complement of the V-GURT, and could go on to germinate to produce both pollen and more seeds carrying the terminator technology trait. Costly fumigation treatments with the chemical inducer to control possible escaped seeds and progeny may be required to mitigate 'contaminated' fields. Furthermore, if a GURT used a variation of the terminator technology exhibiting negative control of a trait (i.e., the trait is expressed unless blocked by an inducer - Visser et al. 2001; Pendleton 2004), then it is possible that terminator trait could be blocked by related compounds that occur naturally or are applied intentionally. Thus, utmost care must be made in selecting highly specific inducers for these types of GURT systems (Visser et al. 2001).

Risks of outcrossing through pollen flow from GURTs appear to be greater than they are through seed dispersal; since plants from chemically induced seeds are not inhibited from producing pollen in the terminator technology. Gene escape through transgenic pollen flow and cross-pollination is unavoidable in many of the world's most important crops, such as wheat, rice, corn, barley, sorghum and sugar beets (Giovannetti 2003). In addition, spontaneous hybridization with wild relatives appears to be a common feature of most crops (Ellstrand et al. 1999). Negative effects of outcrossing from V-GURT varieties on viable seed yields of neighbouring crops are of special concern (Visser et al. 2001; Giovannetti 2003; Pendleton 2004). Pollen carrying a terminator trait could result

in the sterility of the next generation of seeds, but this would not be realized until after these seeds were planted. The reduced seed viability due to terminator pollen contamination may be problematic to farmers who save seed to be planted the next year or for seed growers who must provide high quality seed to customers. The magnitude of these effects will depend on the outcrossing rate of the crop and on the distance between the donor and acceptor plants (Visser et al. 2001). Outcrossing rates vary greatly between crops, from less than 1% in most self-pollinated crops to 15-20% in strongly cross-pollinated crops such as pigeon pea (Bhatia 1998). However, in some cases outcrossing rates can also be high in self-pollinating crops. For example, Lawrie et al. (2006) found that outcrossing rates could be up to 10% for some varieties of wheat in a greenhouse study, and for a field study, Matus-Cadiz et al. (2004) found that outcrossing in wheat can occur over a distance of several meters, but decreased rapidly with distance from the pollen source. However, for insect pollinated crops (e.g., canola) outcrossing can occur over several hundred meters (Giovannetti 2003). Although GURTs should minimize the outcrossing risk of crops with related species (Gupta 1998; Pendleton 2004), there is still concern that the terminator gene may be able to move around and transform within agroecosystems through insects, birds and possibly soil bacteria (Giovannetti 2003). The probability of outcrossing for GM trees and fish is particularly high because of the long distance pollen dispersal in the former and high probability of escapes in the latter (Visser et al. 2001). Technologies utilizing male sterility to contain transgenes could be useful in preventing outcrossing of terminator genes and have already been commercialized in herbicide resistant rapeseed (Daniell 2002).

## **4.2. Other risks and costs of GURTs**

Besides the risk of transgene escape, there are several other potential costs and risks associated with the application of GURTs (Table 1). The level of impact of these technologies depends on the issue and social group of concern.

### **4.2.1 Private seed companies (plant breeders)**

Breeders will have an increased cost of acquiring genetic resources from private breeders (Eaton et al. 2002). With increased intellectual property protection and proprietary of materials it will be very difficult to share resources amongst competing companies and institutions. Thus there will be a reduced atmosphere of sharing genetic resources with the implementation of GURTs and other property rights protection. With less cooperation amongst breeders, there is a possibility of achieving fewer scientific accomplishments because resources will have to be spread around within different companies that may basically be trying to achieve similar goals. There is also a certain amount of risk that companies must take in performing R&D on products, such as GURTs, that may not have political or public approval in the end. There is also the risk of being held liable for environmental contamination or adverse health effects related to terminator transgene escape.

### **4.2.2 Farmers**

GURTs may be potentially detrimental to farmers, especially poor farmers. First, there is the possibility that traditional crops grown adjacent to those with sterile seed technology may suffer reductions in viable seed due to pollen transfer from the latter to the former

(Gupta 1998; Giovannetti 2003). Second, there would be increased input costs associated with GURTs because farmers would have to purchase GURT seeds from the supplier every year. This would be detrimental to farmers' practice of saving seeds, which is especially important, for poor farmers of developing countries (Gupta 1998; Lehmann 1998; Service 1998; Eaton et al. 2002). For example, about 90% of farmers in India save seeds to be replanted (Bhatia 1998) and worldwide, greater than 1 billion people depend on this practice (Service 1998). Sterile seed technology would also be detrimental to crop genetic diversity in traditional farms, where farmers often breed and adapt local landraces of crops and exchange seeds. Inputs of novel genetic material are of great benefit to increase the genetic diversity of these locally adapted varieties; however, this practice would not be possible with utilization of GURTs because novel genetic traits would be under GURT control (Visser et al. 2001). Corporate concentration and increased controls on farmers' autonomy could threaten farmers' food security. Richer countries and richer farmers are likely to gain most of the benefits from this technology (Eaton et al. 2002; Goeschl and Swanson 2003). Thus it appears that GURTs could further marginalize already vulnerable and poor farmers.

#### **4.2.3 Governments**

With application of GURTs governments may have increased expenditures and responsibilities (Eaton et al. 2002). Some governments might be obliged to provide matching R&D investment to those of private companies. With development of GURTs, governments may feel pressured to increase public funding for plant genetic resources that are not copyright protected and have no genetic use restrictions. The uncertainty of the containment of terminator transgenes may necessitate further regulations and monitoring. Governments may also be liable for any ill environmental or health effects due to GURTs. For example, the USDA (along with a private company D&PL) filed for the first sterile seed patent (Appendix 1), so would therefore be partially responsible for any damages accrued through the use of this technology. Allowing the commercialization and release of terminator technology by governments might prove to be an unpopular decision resulting in negative political ramifications (Service 1998; Niiler 1999).

#### **4.2.4 Society**

There are also potential risks posed to society by introduction of GURTs (Service 1998; Visser et al. 2001; Eaton et al. 2002). Besides a risk of environmental contamination of terminator transgenes, there is also a risk of reduced biodiversity in farmers' fields due further homogenization of crops. Although reduced crop diversity is already a serious issue, it is believed that implementation of GURTs would further aggravate this problem, because with sterile seed technology, farmers would not be have access to novel genetic traits often utilized to increase agrobiodiversity at the local level (Visser et al. 2001). For example, introgression of 'modern' pearl millet varieties into locally adapted landraces in India has been shown to increase genetic diversity of this crop (Yadav et al. 2000; vom Brocke et al. 2002). A narrowing of the genetic pool for crop plants may result in increased vulnerability to pest attack, which could destabilize yields and may result in food shortages (e.g., the Irish potato famine). It is unclear how widespread adoption of GURTs would impact local economies of countries (e.g., India), which rely heavily on the exchange of seed for locally adapted varieties (Rakshit 1998). An over-reliance on

biotechnology and associated inputs rather than on traditional knowledge, diversity and ecological services to maintain production could be harmful to local agroecosystems. While the advent “Green Revolution” has already initiated the erosion of local agroecological capital (Visser 1998), it is expected that GURTs will exacerbate this situation. With the need to purchase new seeds every year under GURTs, it is likely that this technology would be detrimental to local cultures and economies of third world countries where farmers typically save seed. . Similarly, risks may also arise from food aid consisting of GURT seeds distributed for disaster relief, because relief grain supplies are also often used as seed (Eaton et al. 2002). A further question is related to potential impacts on human or animal nutrition associated with sterile seed technology. Since terminator technology (in its original application) results in the destruction of the seed embryo, there is a possibility that this technology could adversely affect the food quality of harvested grain, because the embryo represents a nutritious portion of the seed with the most protein. In the broader context of diet and health (e.g., type II diabetes) the issue of food quality related to GURTs needs to be addressed.

## **5. Comparison of GURTs and hybrid seed technology**

Hybrid technologies have several attributes which make them useful for plant breeding and food production purposes (van Wijk 1994). These include a high yield potential, relative ease of breeding in desirable traits, uniformity in maturity and size, and built-in protection against multiplication. Therefore, hybrids have traditionally been considered one of the most important incentives driving the development of a private seed industry (van Wijk 1994; Goeschl and Swanson 2003; Pendleton 2004), and indeed, one can draw parallels between hybrid technologies and GURTs in this respect. Hybridization has been commercially applied to several major crops including maize, sorghum, rice and a number of vegetables (Eaton et al. 2002).

There are several similarities as well as differences between hybrid seed technologies and GURTs that can be noted. GURTs and hybrid seed technologies are similar in that they both offer some form intellectual property protection to breeders and replanting of seeds is not normally a viable option. Thus with both systems, farmers are discouraged from saving seed and both may be used as use restriction technologies (Gupta 1998; Goeschl and Swanson 2003; Pendleton 2004). However, for GURTs, these characteristics are delivered in a more extreme form, whereby yield loss from replanting GURT seeds is absolute and the reproduction of the seeds for breeding purposes is impossible (Goeschl and Swanson 2003). In the case of hybrid seeds, yield reduction with replanting typically results in a yield depression that is not absolute and, although F<sub>2</sub> generations are inferior to F<sub>1</sub> ones, they can still be grown by the farmer and used for breeding purposes, regardless of poor quality (Visser et al. 2001). It is possible that ‘apomixis’ (seed from vegetative reproduction and not from fertilization) could be applied to some hybrid crops, thereby allowing farmers the possibility to produce seeds for the next growing season that are the same as those of the parents (Visser 1998); however, apomixis is only known to occur in a few crops and this type of technology is relatively undeveloped (Daniell 2002). Currently, like GURTs, hybrid seeds make farmers dependent on purchasing external seeds, which may result in a loss of autonomy and a financial burden on some farmers (van Wijk 1994). In order to be economically feasible, hybrids generally must have 15 to

20% higher yields than open-pollinated varieties to make up for the cost of purchase (Lehmann 1998).

Hybrid  $F_1$  generations typically result in increased vigour or heterosis (Lehmann 1998; Yadav et al. 2000); whereas this has yet to have been demonstrated for GURT seeds. Instead, GURT crops are claimed to provide other agronomic traits (e.g., disease resistance) that result in increased yields. It is possible, however, to utilize hybrid seed technology in an alternate V-GURT strategy in which different gene components for the terminator system are placed in each hybrid parent (Gupta 1998; Lehmann 1998; Pendleton 2004). In this manner, the  $F_1$  generation would still produce sterile seed; however, it is not known whether this type of system would result in increased vigour for the first hybrid generation, because it is not known to what extent the genetic backgrounds of the parents used for this cross differ in order to create effective heterosis in the offspring. If the parents differ only by the inserted terminator genes, then heterosis would be unlikely to be very great in the  $F_1$  generation of terminator seeds. If this were the case, then the agronomic benefits associated with such a system would be derived solely from transgenic traits and not from any hybrid vigour.

Although, all current GURTs are derived by genetic manipulation, this does not have to be the case for hybrids. Therefore, while GM hybrids do exist, not all hybrids need be GM crops, whereas all GURTs by definition must be GM. Thus non-GM hybrid crops may not have the same market restrictions that GM crops currently have in some jurisdictions. In short, it might be easier for farmers to sell hybrid crops compared to crops grown using GURTs; however, this is unlikely to be an issue for small subsistence farmers in third world countries where most grain is consumed locally and is not intended for international markets.

## **6. Summary and conclusions**

The issue of GURTs is complex, with different stakeholders embracing widely opposing views. There are several strong arguments that have been put forward, both in favour and against the implementation of these types of technologies. There are a number of potential benefits, costs and risks associated with GURTs. Potential benefits include intellectual property rights protection, stimulation of private research and development, genetic diversity enhancement, transgene containment and production purposes. It seems that private seed companies and consumers in general will gain the most, whilst farmers (especially those with smaller holdings in third world countries) will gain the least as a group from the adoption of GURTs. Environmental benefits associated with GURTs may include enhanced containment of transgenes and fewer chemical inputs. However, one of the most often cited environmental risks associated with GURTs is the threat of outcrossing or gene flow of terminator genes into crops or populations of 'wild' relatives. Risks of outcrossing through pollen flow from GURTs appear to be greater than they are through seed dispersal; however, terminator transgene escape through the latter route is still probable. Other potential risks and costs associated with GURTs include reduced access and increased cost of genetic material by breeders, greater necessity of regulating and field monitoring of new GURT technologies, liability for environmental damage, health risks, increased cost of seeds for farmers, greater corporate control over agriculture, and a further narrowing of agro-biodiversity. Although there are many

similarities between GURTs and hybrid seed technologies, it can be argued that impact of former on small scale farmers would be more severe than that of the latter technology, because restrictions associated with GURTs would be more absolute. Overall, it is very difficult to assess the environmental, social, economic and political ramifications of GURTs because there is a lack of peer-reviewed publications with novel research addressing these issues. Until the results of this type of research are publicly available, it is recommended that a precautionary approach regarding implementation of GURTs be followed.

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## Appendices

Appendix 1: Abstract patent for “Control of plant gene expression” (From United States Patent and Trademark Office 1998).

A method for making a genetically modified plant comprising regenerating a whole plant from a plant cell that has been transfected with DNA sequences comprising a first gene whose expression results in an altered plant phenotype linked to a transiently active promoter, the gene and promoter being separated by a blocking sequence flanked on either side by specific excision sequences, a second gene that encodes a recombinase specific for the specific excision sequences linked to a repressible promoter, and a third gene that encodes the repressor specific for the repressible promoter. Also a method for making a genetically modified hybrid plant by hybridizing a first plant regenerated from a plant cell that has been transfected with DNA sequences comprising a first gene whose expression results in an altered plant phenotype linked to a transiently active promoter, the gene and promoter being separated by a blocking sequence flanked on either side by specific excision sequences to a second plant regenerated from a second plant cell that has been transfected with DNA sequences comprising a second gene that encodes a recombinase specific for the specific excision sequences linked to a promoter that is active during seed germination, and growing a hybrid plant from the hybrid seed. Plant cells, plant tissues, plant seed and whole plants containing the above DNA sequences are also claimed.

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Appendix 2: Figure showing genetic basis of 'terminator technology' for pure line seed production in self-pollinated crops (From Gupta 1998).

