Developing Workable Regulatory Frameworks for the Environmental Release of Transgenic Plants

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Abstract

The development of transgenic crops has spurred the development of regulatory frameworks in countries hoping to provide safe access of these crops to growers, and foster the development of transgenic crops in their own countries. Regulatory frameworks have emerged that are based on process or on final product, with regulatory responsibilities divided between government and sometimes non-government bodies. While the implementation of regulatory programmes, legal frameworks and regulations may differ from country to country, the information that informs the risk assessments that underlie the safe deployment of transgenic crops share numerous common elements and thus provide extensive opportunities for regulatory streamlining and shared or harmonised approval processes.

This paper describes the common factors considered by regulatory authorities in the environmental risk assessment of transgenic plants and identifies potential areas where efficiencies can be achieved in the science review steps b sharing or cross utilising scientific expertise, data elements and common elements of the scientific review. Although the outcomes of the environmental risk assessment of a genetically engineered plant are linked to a country's protection goals, the common elements of the scientific data review can be portable and sharing can achieve efficiencies in the expenditure of time resources and data generation.

Keywords: biosafety, data requirements, environmental risk assessment, genetically modified crops, regulatory frameworks, regulatory harmonisation, transgenic plants

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Riassunto
Lo sviluppo di colture transgeniche ha stimolato la messa a punto di quadri normativi nei paesi in cui si è cercato di fornire un accesso sicuro a queste colture da parte dei produttori, e di favorire lo sviluppo di colture transgeniche nei loro paesi. Sono cosi emersi quadri normativi che si basano sul processo o sul prodotto finale, con la responsabilità di regolamentazione divisi tra governo e, talvolta, organismi non governativi. Mentre l'attuazione dei programmi normativi, dei quadri giuridici e regolamentari possono differire da paese a paese, le informazioni sulle valutazioni del rischio che stanno alla base della distribuzione sicura delle colture transgeniche condividono numerosi elementi comuni e quindi forniscono ampie possibilità di snellimento normativo e la condivisa o armonizzata approvazione dei processi.

Questo articolo descrive i fattori comuni considerati dalle autorità di regolamentazione nella valutazione del rischio ambientale delle piante transgeniche e identifica le potenziali aree in cui si possono ottenere efficienze nelle fasi di riesame della scienza mediante la condivisione o l'utilizzazione incrociata di competenze scientifiche, di elementi di dati e di elementi comuni della revisione scientifica. Anche se i risultati della valutazione del rischio ambientale di una pianta geneticamente modificata sono legati a obiettivi di protezione di un paese, gli elementi comuni della revisione scientifica dei dati può essere portabile e la condivisione può portare a livelli di efficienza nell'utilizzo delle risorse di tempo e di generazione di dati.

1. INTRODUCTION

It has been nearly three decades since the first transgenic[IV] crops, intended for commercial cultivation, entered regulatory processes. The application of molecular biological tools has allowed plant breeders to rapidly introduce traits that would have been difficult or impossible via more traditional breeding techniques. The production of improved varieties is the primary goal of plant breeding and many of the traits first introduced such as insect, herbicide and disease resistance or stress tolerance are still primary breeding objectives. The application of modern biotechnology broadens the scope of genetic changes that can be introduced into plants to achieve these breeding objectives, although it does not inherently result in plants that are less safe than those produced by more conventional techniques (NAS USA, 1987; NRC USA, 1989). This concept is implicit in some regulatory approaches, most notably Canada, where regulatory oversight is based on the potential risk posed by the new trait, rather than the means by which it was introduced. To date, the general scientific consensus is that the method used to produce a new plant variety (either conventional breeding techniques or genetic engineering) is not necessarily an effective predictor of the plant's environmental impact, although new proteins may raise unique food or feed concerns. Nevertheless, the development of plant varieties developed with the use of recombinant DNA technologies has led to the construction of governmental/institutional regulations around the world that are applied specifically to assessing the safety of such plants.

In 1993, the Organisation of Economic Co-operation and Development (OECD) published general principles applicable to larger-scale production and commercialisation of genetically engineered plants. According to the OECD (1993):

> *"Safety in biotechnology is achieved by the appropriate application of risk/safety analysis and risk management. Risk/safety analysis comprises hazard identification and, if a hazard has been identified, risk assessment. Risk/safety analysis is based on the characteristics of the organism, the introduced trait, the environment into which the organism is introduced, the interaction between these, and the intended application..... Risk/*

IV The terms "genetically modified" (GM), "transgenic", "genetically engineered" (GE) and "living modified" (LM) are used in different legal instruments around the world. It is useful (and deliberate) in this document, to essentially use them interchangeably.

safety analysis is conducted prior to an intended action and is typically a routine component of research, development and testing of new organisms, whether performed in a laboratory or a field setting..... Risk/ safety analysis is a scientific procedure which does not imply or exclude regulatory oversight or imply that every case will necessarily be reviewed by a national or other authority."

Inherent in all current regulatory frameworks for transgenic plants is the concept of conducting a risk assessment prior to environmental release. The risk assessment involves the identification of a potential hazard, an evaluation of the likelihood of the hazard occurring, and a determination of the potential exposure to the hazard in the environment. The risk assessment may also consider benefits as part of the process, depending on the regulatory framework. Risk management strategies and risk communication are also considered as part of the overall risk analysis. The risk assessment is based on science and is applied case-by-case. The type and quality of data that is acceptable for the risk assessment can be outlined in regulation either based on national norms or based on internationals guidance. In general, most countries will make reference to data quality as being of acceptable scientific quality, often referring to the quality of data expected by scientific publications. While there is certainly a need for having scientifically sound, verifiable data, it is worth noting that the objectives of a risk assessment of a transgenic plant for commercial release are not the same as those of scientific research. While both activities are hypothesis driven forms of structured, empirical inquiry, the objective of the risk assessment is to address the relative safety of a product intended for release, rather than an exhaustive and ongoing quest for knowledge. Regulators often speak of "need to know vs. nice to know". This statement from regulators articulates the need to determine what data is necessary and sufficient for a decision on safety. Since regulators generally have formal scientific training, the separation between curiosity driven research and structured inquiry for risk assessment can be problematic. This problem may arise in countries that rely on arm's-length scientific advisory boards rather than full time regulators to undertake risk assessments of transgenic plants. The information that can usefully support a risk assessment for a product may include data that does not necessarily achieve the usual standards for a peer reviewed scientific publication such as information from grower groups, agriculture extension personnel, and grower experiences.

The decision to regulate is the first step in a regulatory framework, while the development of enabling regulations and guidance to applicants normally follow as the next steps. Regulations will prescribe a process to market and articulate principles of transparency and consultation. The degree of transparency depends on the level of intellectual property protection in the jurisdiction and how confidential information is protected. For example, in Canada the exact location of field trials for transgenic crops is confidential, although information on traits, crops and general locations is publicly available. This reflects the view that applicants are responsible for security on their field trial sites, ensuring that plant material is controlled. Other countries, such as Australia and the UK, publish field trial locations. Public involvement will also vary from country to country but generally public consultation is an inherent part of the promulgation of regulations, with stakeholder involvement taking place in various steps in the process.

The regulatory framework should communicate clear and transparent information requirements for the risk assessment to applicants and stakeholders. Clear communication of these requirements will enhance public confidence in the robustness of the risk assessment, assure that applicants have clear expectations, assure equal treatment for all applicants and reduce delays delivering new technologies into the marketplace. This document discusses the issues generally identified as important for the risk assessment and presents a comparison of pre-market information requirements related to the product-specific environmental risk assessment of transgenic plants that have been published in both regulations and guidance documents by regulatory authorities in Australia, Canada, UK, the European Union, Japan, and the USA, as well as those contained in Appendix II of the Canada-USA Bilateral on Agricultural Biotechnology and Annex 3 of the Cartagena Protocol on Biosafety (Table 1). These countries were selected as a representative, but by no means exclusive or complete, sample of country-specific approaches to the risk assessment of genetically engineered plants. Food and feed safety and requirements for post-market monitoring, labelling, handling and storage of transgenic plants are all outside of the scope of this document.

Table 1. Documents used in this review for the comparison of pre-market information requirements related to the product-specific environmental risk assessment of transgenic plants.

Source	Documents
Office of the Gene Technology Regulator (OGTR), Australia	Gene Technology Regulations 2001 (Statutory Rules 2001 No. 106 as amended). Available at http://www.comlaw.gov.au/Details/F2011C00732. Risk Analysis Framework for License Applications to the Office of the Gene Technology Regulator (2nd edition) 2005 Available at: http://www.ogtr.gov.au/internet/ogtr/publishing.nsf/Content/raf-3/$FILE/raffinal4.pdf
Canadian Food Inspection Agency (CFIA), Canada	Seeds Regulations, Part V (Release of Seed). Available at http://laws-lois.justice.gc.ca/eng/regulations/C.R.C.%2C_c._1400/index.html. Regulatory Directive Dir94-08: Assessment Criteria for Determining Environmental Safety of Plants With Novel Traits. Available at http://www.inspection.gc.ca/english/plaveg/bio/dir/dir9408e.shtml.
Canada-USA	Canada and United States of America 2001. Bilateral Agreement on Agricultural Biotechnology, Appendix II: Environmental Characterization Data for Transgenic Plants Intended for Unconfined Release. Available at http://www.aphis.usda.gov/brs/canadian/appenannex2e.pdf.
Department for Environment, Food and Rural Affairs (DEFRA), UK	Schedule 1 of the Genetically Modified Organisms (Deliberate Release) Regulations 2002. Available at: http://www.legislation.gov.uk/uksi/2002/2443/schedule/1/made
European Union	Directive 2001/18/EC of the European Parliament and of the Council of 12 March 2001on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2001:106:0001:0038:EN:PDF Commission Decision 2002/623/EC of 24 July 2002 establishing guidance notes supplementing Annex II to Directive 2001/18/EC of the European Parliament and of the Council on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC. Available at http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2002:200:0022:0033:EN:PDF
Ministry of Agriculture, Forestry and Fisheries (MAFF), and Ministry of the Environment (MOE), Japan	• Act on the Conservation and Sustainable Use of Biological Diversity through Regulations on the Use of Living Modified Organisms (Act No. 97 of 2003). • Regulations Related to the Enforcement of the Law Concerning the Conservation and Sustainable Use of Biological Diversity through Regulations on the Use of Living Modified Organisms • The Guidance of Implementation of Assessment of Adverse Effect on Biological Diversity of Type 1 Use of Living Modified Organisms (Above Japanese documents are available for download from http://www.bch.biodic.go.jp/english/law.html)
Animal and Plant Health Inspection Service (APHIS), USA	Biotechnology Permits – 7 Code of Federal Regulations part 340 (7 CFR 340). Available at http://www.aphis.usda.gov/brs/pdf/7cfr340.pdf. Guide for Preparing and Submitting a Petition for Genetically Engineered Plants, November 5 1996. Available at http://www.aphis.usda.gov/brs/pdf/usergen8.pdf.
Secretariat of the Convention on Biological Diversity	Cartagena Protocol on Biosafety to the Convention on Biological Diversity. Available at http://bch.cbd.int/protocol/text/

2. ENVIRONMENTAL RISK ASSESSMENT

Determining the scope and purpose of the environmental risk assessment of a transgenic crop is a key first step before undertaking the risk assessment of a transgenic plant. Guidance in these areas is typically captured in the central objectives, usually described in acts or implementing regulations that must be addressed by the applicant to assess the environmental safety of a transgenic event. It is here that governments will articulate social values and the aspects of the environment that are most valued. Policy frameworks will inform protection goals and other enabling acts, such as those that describe the protection of species at risk. Ideally, the presence of an overarching policy framework guides the process of risk analysis and regulation by informing the key areas of consideration, and guides the risk assessor and regulator with respect to what will constitute acceptable risk. As an example, the 1993 Canadian Regulatory Framework for Biotechnology, which was renewed in 1998 (available at http://www.biostrategy.gc.ca/CMFiles/1998strategyE49RAI-8312004-5365.pdf,) describes key principles for how products of biotechnology will be regulated and certain key principles are articulated. The Framework principles affirm the use of science-based safety assessments and risk management with the goals of protecting human health, animal health, and the environment, while contributing to the prosperity and well-being of Canadians. This approach guides regulators to create an enabling environment for biotechnology that strikes a balance between the necessary caution in regulation while still allowing innovation to proceed. A key principle in the framework is the use of existing legislation for regulatory oversight rather than a specific gene act. For example, regulations governing the environmental release of transgenic plants were promulgated using the Seeds Act. The decision to regulate products using existing acts, places products derived using biotechnology in the same context as other products produced using more conventional means and takes advantage of existing expertise and knowledge.

When a scope and context have been set, more specific guidance on the risk assessment is achieved through an elaboration of the key issues. This includes the information and data requirements used to support an environmental risk assessment that are usually specified in regulations and/or guidance documents. The scale of the release will determine the level of detail required. For example, field trials are generally an opportunity for an applicant to generate the information to support a risk assessment and as such, the regulatory requirements are focused on risk management of the trial rather

than the submission of data. There is a strong consensus between countries as to the hazards that may be associated with the unconfined release of transgenic crop plants. Country-specific variation in pre-market information requirements is apparent, however, in the level of detail provided by the regulator to the applicant on the parameters that should be measured to evaluate these risks. For example, Canada's Regulatory Directive Dir94-08 is more explicit than the USA's 7 CFR 340(c), which stipulates the data and information requirements with a petition to deregulate a transgenic plant. In the Canada case, the use of guidelines provides a mechanism to give developers guidance while retaining flexibility. In Canada and other jurisdictions, changing regulations can be difficult but guidelines can be revised as familiarity and scientific knowledge increase, the technology advances and its products become more diverse.
Specific guidance can also encompass the inclusion of defined experimental protocols, either in guidance documents or other regulatory documents, that the applicant is either recommended or required to follow in generating data to address specific information requirements. Defined protocols can provide regulators with consistent data sets and provide a mechanism for comparing the relative impacts of a transgenic plant. For example, the toxicity of the expressed toxins from different insect pest-protected plants could be compared with respect to pest range, toxicity and non-target effects. These comparisons allow for greater portability of data and assure greater consistency in regulatory approaches. Issues can arise however, if an endpoint for hazard/risk assessment is not well defined, for example a protocol to look for residual effects from a transgenic crop could require general surveillance of the following crop in the subsequent growing season. Without specific hypothesis-driven outcomes, any results would be, at best, difficult to interpret and at worst, contradictory and confusing. In addition, defined experimental protocols might decrease the flexibility typically afforded to scientists in the discovery and evaluation phases of product development, fail to address emerging technologies or no longer be relevant with respect to emerging technologies.

A review of the various regulations and guidance documents listed in Table 1 suggests substantial areas of agreement in the broad descriptions of types of information that have been most commonly considered when countries have performed environmental safety reviews for transgenic plants. These are considered in greater detail below. However, there may often be significant differences between specific reviews, based upon the relevant circumstances of individual cases and/or the laws and regulations under which the reviews and decisions are being made. The specific data sets reviewed may vary depending

upon the specific characteristics of the plant and introduced trait as well as the environment of use. Thus, most reviews are still, in actuality, conducted on a case-by-case basis, thereby allowing for the consideration of a greater or lesser number of criteria that can be articulated in broad descriptions of the types of information most commonly considered in government-performed environmental risk/safety assessments.

3. INFORMATION ELEMENTS FOR AN ENVIRONMENTAL RISK ASSESSMENT (ERA)

The characteristics of the transgenic plant under review must be known to conduct an environmental assessment. Information on the host organism, the donor organism, the properties of the new trait and the phenotype of the transgenic plant usually constitutes the basic framework for the environmental risk assessment.

In broad terms, the ERA considers the potential effects of the release of the transgenic plant on biodiversity. In this regard, highly domesticated crops will pose different questions for this consideration than, for example, forestry tree species or previously undomesticated plant varieties intended for uses such as biofuels. For the latter types of transgenic plants, the possibility of affecting the biodiversity of natural populations either directly through invasion and competition, or indirectly through the transfer of undesirable traits may need to be considered. For genetically engineered crops, the considerations are most pertinent when applied to the managed ecosystem, since domesticated crops do not usually persist well outside of managed ecosystems. However, when considering the introduction of such crops either in centres of origin or for those that retain weedy traits, such as canola (oilseed rape), the potential to invade and/or persist in unmanaged habitats is evaluated. For transgenic crops, the most relevant considerations with regard to biodiversity is the evaluation of the incremental risks associated with replacing a conventional crop variety with a genetically engineered one.

Generally, the ERA of transgenic plants identifies and evaluates the risks associated with the release and cultivation of these plants in comparison with a conventional counterpart. The counterpart used is generally the most closely-related unmodified version of the transgenic plant. In some cases, the most closely-related comparator may itself be a transgenic plant, such as a subsequent transformation of an already commercialised transgenic plant.

Generally, for comparative assessments, other similar varieties of the same species will also be considered as part of the environmental safety assessment to help inform normal variability of tested characteristics and to predict the behaviour of the new transgenic trait(s) in other varieties.

Amongst those countries with established regulatory programs for ERA of transgenic plants, there are common safety concerns that are considered to be important and are addressed on a case-by-case basis prior to commercialisation of a transgenic plant. The ERA will normally include information on the molecular characterisation and stability of the genetic modification. Documents such as the OECD consensus document on the molecular characterisation of a transgenic plant (OECD, 2010) provide guidance on the wide variety of elements that countries consider and on how they can be used in the environmental safety assessment. Molecular characterisation data can be useful in calculating potential toxicity levels and characterising potential pathways to harm, but genotypic data is not necessarily predictive of potential risks considering the inherent variability in plant genomes (FAO, 2009). Just as the DNA rearrangements, deletions and insertions that are documented consequences of traditional breeding (e.g. Udall *et al.*, 2005; Nicolas *et al.*, 2007; Batista *et al.*, 2008; Anderson *et al.*, 2010) do not necessarily raise concerns; the perturbations at the molecular level that can occur as a consequence of genetic engineering are not necessarily indicative of a hazard, especially without a phenotypic change. This fact is especially relevant when considering the extensive data that can be generated from conducting genomic analyses. Applying this type of data is difficult, and at this time, its relevance to risk analysis of transgenic plants or related regulatory functions is uncertain. Common considerations emerge with respect to hazards associated with the environmental interactions. Generally these concerns include: gene transfer to related plants, including wild weedy relatives; changes in weediness potential; secondary (indirect) and non-target adverse effects; and enhanced capacity to harbour or vector plant pests. These are covered in more detail below.

3.1. The host organism

The basis for determining the environmental safety of a transgenic plant intended for unconfined release is the comparative risk assessment. In order to proceed with this approach, one must be familiar with both the biology of the plant itself, as well as the agricultural or silvicultural practices employed in its cultivation. This concept of familiarity is a key approach used in identifying and evaluating environmental risks that may be associated with the release of

a transgenic plant, and also in informing management practices that may be needed to mitigate recognised risks. Familiarity considers the biology of the plant species, the trait, and the agricultural practices used in the production of the crop.

One of the most useful reference tools when conducting an environmental safety assessment of a genetically engineered plant is a detailed monograph describing the biology of the species under review. Specifically, it can be used to identify species-specific characteristics that may be affected by the novel trait so as to permit the genetically engineered plant to become "weedy", invasive of natural habitats, or be otherwise harmful to the environment. It can also provide details on significant interactions between the plant and other life forms that must be evaluated in the risk assessment. Typically such a document includes the following (OECD, 2005):

- Taxonomic description (common name, scientific name)
- Consumption and uses of the crop plant
- Centres of origin and genetic diversity for the plant species
- Regional/national breeding, seed production, and agronomic practices
- Reproductive biology of the crop plant, including details on pollination, mechanisms for dispersal of pollen and seed, and any other means of gene escape
- Weediness characteristics
- Distribution and ecology of sexually compatible species, including any evidence of weediness
- Details on the genetics of the cultivated crop, its progenitors and any sexually compatible species
- Occurrence and viability of intraspecific, interspecific, and intergeneric hybrids
- Common diseases and pests
- Potential interactions with other organisms such as pollinators, mycorrhizal fungi, animal browsers, birds, soil microbes and soil insects

The degree of information related to these characteristics that is required in different jurisdictions is compared in Figure 1. The characterisation of the host organism is an important step in the overall characterisation of a transgenic plant. From the figure it is apparent that there is common agreement across the representative guidance chosen that the taxonomy should be well defined. There is some divergence on the importance of considering normal agronomic practices but this may reflect either the focus of the competent authority

(environment versus agriculture), or this aspect may be captured at another point in the consideration of the transgenic crop. The key life history traits of the host organism, such as reproductive biology, potential for hybridisation and weediness, are incorporated in all of the guidance. [Note, for all figures, an "X" indicates that the information or data requirement is included within the regulatory or guidance documents published by that competent authority. An "I" indicates that while the information or data requirement listed may not be explicitly included within regulations or guidelines, it may be a parameter that is encompassed within a broader category. For example, for Figure 1, the number of days to onset of flowering, number of days for flowering and number of days until maturity may be used as indicators of rate of reproduction].

Information / Data Requirement	**Australia**	**Canada**	**Canada-USA Bilateral**	**Japan**	**UK**	**USA**	**Cartagena Protocol on Biosafety**
Common name, scientific name (including subspecies, cultivar)	X	X	X	X	X	X	X
Use and/or distribution in the country of proposed release	X	X	X	X	X	X	X
Centres of origin, genetic diversity and cultivation	X	X	X	X			X
Breeding and seed production practices		X	X	I			
Agronomic practices		X	X	X	X		
Reproductive biology	X	X	X	X	X	X	I
Weediness characteristics	X	X	X	X	X	X	I
Potential for intra- and inter-specific hybridisation	X	X	X	X	X	X	I
Occurrence of sexually compatible species	X	X	X	X	X	X	I
Interactions with other life forms[1]	X	X	X	X	X		I

Figure 1. Description of the Host Organism. Reproduced with permission.

[1] Pollinators, mycorrhizal fungi, animal browsers, birds, soil microbes, and soil insects. May also include any toxic or allergenic effects on humans.

Detailed consensus documents or monographs about the biology of specific crop plant species have been prepared by inter-governmental organisations like the OECD, as well as national regulatory authorities. A list of available biology documents is provided in Table 2.

Table 2. Online available "Biology documents"[1]

Crop	OGTR	CFIA	MoEF/ DBT	OECD
Ananas comosus var. comosus - Pineapple	✓			
Abelmoschus esculentus L. - Okra			✓	
Beta vulgaris (L.) - Sugarbeet		✓		✓
Betula pendula Roth - European White Birch				✓
Brassica napus (L.) - Oilseed rape/ Canola	✓	✓		✓
Brassica rapa (L.) - Oilseed rape/ Canola		✓		
Carica papaya - Papaya	✓			✓
Capsicum annuum Complex Chilli Peppers, Hot Peppers and Sweet Peppers				✓
Gossypium spp. - Cotton				✓
Cucumis, Cucurbita – Cantaloupe, Squash				
Dianthus caryophyllus (L.) - Carnation	✓			
Glycine max (L.) Merr. - Soya bean		✓		✓
Gossypium hirsutum - Cotton	✓		✓	
Helianthus annuus (L.) - Sunflower		✓		✓
Hordeum vulgare L. - Barley	✓			
Larix sp. – N. American larches				
Lens culinaris Medikus - Lentil		✓		

Linum usitatissimum (L.) - Flax		✓		
Lolium sp. – Ryegrass & Fescue	✓			
Lycopersicon esculentum - Tomato				
Medicago sativa (L.) - Alfalfa		✓		
Musa L. - Banana	✓			✓
Oryza sativa - Rice	✓		✓	✓
Picea abies (L) Karst. - Norway Spruce				✓
Picea glauca (Moench) Voss - White Spruce				✓
Picea mariana [Mill.] B.S.P. - Black Spruce				✓
Pinus banksiana – Jack Pine				✓
Pinus contorta – Lodgepole Pine				✓
Pinus monticola (Dougl.ex D. Don.) - Western White Pine				✓
Picea sitchensis [Bong.] Carr. - Sitka Spruce				✓
Pinus strobus (L.) - Eastern White Pine				✓
Populus (L.) - Poplars				✓
Prunus sp.- Stone fruits				✓
Pseudotsuga menziesii - Douglas Fir				✓
Rosa x hybrida - Rose	✓			
Saccharum spp. hybrids - Sugarcane	✓			
Solanum tuberosum subsp. *tuberosum* - Potato		✓		✓
Torenia x hybrida	✓			
Trifolium repens (L.) - White Clover	✓			
Triticum aestivum - Bread Wheat	✓	✓		✓
Triticum turgidum – Durum Wheat		✓		
Zea mays – Maize/Corn	✓	✓	✓	✓

[1]Sources: Office of the Gene Technology Regulator (OGTR), Department of Health & Ageing, Australian Government, Risk Assessment References (http://www.ogtr.gov.au/internet/ogtr/publishing.nsf/Content/riskassessments-1); Canadian Food Inspection Agency (CFIA) Biology Documents, Companion Documents for Directive 94-08, Assessment Criteria for Determining Environmental Safety of Plants with Novel Traits (http://www.inspection.gc.ca/english/plaveg/bio/dir/biodoce.shtml); Ministry of Environment and Forests (MoEF)/Department of Biotechnology (DBT), Indian Government, Series of Crop Specific Biology Documents (http://igmoris.nic.in/); Organisation for Economic Co-operation and Development (OECD), Consensus Documents for the Work on Harmonisation of Regulatory Oversight in Biotechnology: http://www.oecd.org/document/60/0,3746,en_2649_34385_46720508_1_1_1_1,00.html

3.2. The donor organism

Information about the natural history of the donor organism is most relevant when the organism is a pathogen or produces allergens or displays environmental toxicity. This concern is captured in most regulatory guidance (see Figure 2), but in practice the toxicity or allergenicity of the expressed gene product in the transgenic plant is more relevant, particularly for proteins that are either subject to extensive post-translational modification or rely on post-translational modification for activity. Organisms that produce proteins which have allergenic potential, such as trypsin inhibitors for example, can raise additional concerns since post-secondary modifications can enhance allergenicity, especially for those who are already predisposed to allergic reactions to proteins from the donor organism (for example, Prescott et al., 2005).

There may also be religious or ethical concerns that pertain to genes from certain sources (e.g. a transgene originating from pig may cause concern for Islamic groups, likewise transgenes originating from any animal for vegetarians).

3.3. Identity of the transgenic plant

Basic information on the identity of the transgenic plant usually includes:

- A description of the taxonomy
- The designation given to the transgenic plant, including all synonyms and a OECD unique identifier (OECD, 2006)
- The pedigree of the transgenic event
- A description of where the transgenic plant will be grown
- A description of the use (and users) of the transgenic plant in the country of proposed release.

Figure 2 describes the information included in the basic description of the transgenic plant, the basic taxonomy, the breeding to produce the final

event and the prospective end uses are included directly or indirectly for the most part, in the representative guidance considered. It is worth noting that both the UK guidance and the guidance under the Cartagena Protocol (the "Protocol") exclude information on the breeding used to derive the final product. This is reflective of the non-product specific guidance contained in the Protocol (which is intended to cover all living modified organisms, not just transgenic crops) and UK documents, rather than the significance of this data element to the risk assessment.

Information / Data Requirement	Australia	Canada	Bilateral Canada-USA	UK	Japan	USA	Cartagena Protocol on Biosafety
Taxonomy	X	X		I	X	X	I
Designation, including all synonyms and OECD unique identifier	X	X		X	X	X	X
Pedigree of the transgenic event	I	X			X	X	
Use (and users) of the transgenic plant in the country of proposed release	X	X		X	X	X	X

Figure 2. **Description of the Transgenic Plant.** Reproduced with permission.

3.4. The properties of the new trait

The introduced trait(s) is often the consequence of the introduction of a new protein but the trait can also result from regulating endogenous gene function using mechanisms such as the expression of small interfering RNA molecules (RNAi) or other deliberated mechanisms to target endogenous genes. In cases where a new protein is not expressed, the characterisation of the intended phenotype will be important, but "off target" or other non-specific effects will need to be considered for the molecular analysis. It may also be useful to ensure that the targeted mRNA is not present to confirm phenotypic data, especially if the

phenotypic change is transitory or subtle such as a yield enhancement or reduction in pollen production. The consideration should still link to a potential hazard, for example if the attempt to reduce pollen production is intended to minimise out-crossing.

For plants that express new proteins, a full characterisation of the new protein is expected, usually including a screen against known toxins and allergens. The physical-chemical properties of the newly-expressed protein(s) can also be useful, where relevant, to show that the protein has been expressed in the plant as expected, and knowledge concerning the safety of the native expressed protein can be applied to the safety assessment of the transgenic plant. Extensive physical-chemical data can be generated on expressed proteins and the relevance will be dependant on whether the data can be applied to the characterisation of the protein in a meaningful way. If the protein is already well known or characterised, this can be very useful data to apply to the safety assessment.

Information about the novel gene product that is generated during molecular characterisation, such as expression levels and any tissue or developmental stage-specificity, can be used to determine the routes and potential for exposure to the novel gene product by interacting grazers, symbionts, parasites, predators, competitors or pathogens. For example, when considering a plant expressed protein, such as an insecticidal protein from *Bacillus thuringiensis*, (Bt), information on the stability and toxicity of the protein can be used to determine the likelihood of exposure to organisms that are not the intended target of the protein (usually referred to as non-target organisms) and to determine routes to potential harms based on tissue expression, the reproductive biology of the plant and the persistence of the newly-expressed protein in the environment. Allergenicity arising from farm worker exposure may be considered by some jurisdictions (see Figure 5).

3.5. Phenotype of the transgenic plant

Information provided on the phenotype of the transgenic plant confirms the expression of the intended traits and may contribute to detecting any unintended traits. In practice, the transgenic plant is compared to non-modified counterparts with respect to characteristics which influence reproductive and survival biology, as well as interactions with other organisms. For example:

- Basic morphology including any abnormalities
- Life span (annual, biennial, perennial)
- Vegetative vigour
- Time to production of mature fruit or seed
- Seed production, seed dormancy, seed germination
- Out-crossing frequency
- Impact on pollinator species
- Pollen parameters
- Fertility acquired or lost
- Vegetative reproduction
- Seed dispersal factors
- Interactions with symbionts
- Adaptations to biotic and abiotic stresses

Any of these parameters would have to be considered on a case-by-case basis. If phenotypic differences are detected, a consideration of whether they represent a realistic pathway to harm is required. Figure 3 illustrates the type of information contained in guidance or regulatory guidance documents from the representative competent authorities. There is a high level of agreement in the respective guidance and regulatory documents, particularly the requirement to address any potential changes in life history traits for the transgenic plant. Phenotypic characterisation is a key step in the process of conducting the comparative risk assessment. It is important to consider the normal range of variation inside a crop type when characterising the phenotype of the transgenic plant. This normal range of variation for the crop type should be considered, along with the closely-related comparator that lacks the new genetic modification when assessing the phenotype of the transgenic crop. This places any potential phenotypic change(s) in the transgenic crop into the context of the crop itself, particularly if there will be additional variety development of the transgenic crop.

Information / Data Requirement	Australia	Canada	Bilateral Canada-USA	UK	Japan	USA	Cartagena Protocol on Biosafety
Growth habit[1]	I	X	X		X	X	
Life-span[2]	I	X	X	I	X	X	I
Vegetative vigour[3]	I	X	X		X	X	I
Ability to overwinter (or overseason)	I	X	X	I	X	X	I
Number of days to onset of flowering; number of days for flowering	I	X	X	I	I	X	I
Number of days until maturity[4]	I	X	X	I	I	X	I
Seed parameters[5]	X	X	X	I	X	X	I
Proportion surviving from seedling to reproduction	I	X	X	I	I	X	I
Outcrossing frequency (intra- and inter-specific)	X	X	X	X	X	X	I
Impact on pollinator species[6]	X	X	X	X	X	X	I
Pollen parameters[7]	X	X	X	I	X	X	I
Fertility[8]	I	X	X	I	X	X	I
Self-compatibility	I	X	X	I	X	X	I
Asexual reproduction[9]	X	X	X	I	X	X	I
Seed dispersal factors[10]	X	X	X	X	X	X	I
Symbionts[11]	X	X	X	X	I	X	I
Stress adaptations[12]	X	X	X	I	I	X	
Add substances to, or subtract substances from, soil.	X				I		

Figure 3. Phenotype of the Transgenic Plant. Reproduced with permission.
[1]e.g., basic morphology of the plant including any abnormalities. [2]Annual, biennial or perennial, noting if this has changed from the non-transformed parental plant. [3]e.g., plant height, crop biomass, etc. [4]e.g., time to the production of mature fruit or seed (suitable for harvesting). [5]e.g., seed production; length of time (days) of seed/fruit production; seed dormancy: Characterise any changes in the ability of the seed to remain viable over time; seedling emergence. [6]e.g., changes in pollinator species visiting flowers and data on changes in flower morphology, colour, fragrance, etc. that may affect interactions with pollinators. [7]e.g., amount of pollen produced, proportion of viable pollen; the longevity of pollen under varying environmental conditions; physical parameters such as stickiness, shape, and weight. [8]e.g., fertility acquired or lost. [9]e.g., vegetative reproduction; ability of the plant material to set roots; parthenocarpy. [10]e.g., characteristics such as seed shattering or dispersal by animals. [11]e.g., vesicular-arbuscular mycorrhizal fungi, rhizobia. [12]to biotic and/or abiotic stresses.

3.6. Gene transfer to related plants

The introgression of genetic material from one plant to another is only possible if the two plants are sexually compatible, sympatric, and if their hybrid offspring are viable. If the introduced gene is detrimental to fitness, it will likely not persist at any significant level. In order to assess potential environmental risks associated with out-crossing from transgenic plants cultivated under normal agronomic conditions, the reproductive biology of the plant and the distribution and density of sexually compatible relatives must be known. Likewise, the impact of the introduced trait, should it be introgressed into other plant species, must be understood. Information about the former may be obtained from reviews on the biology of the plant species, scientific literature (including national or regional plant surveys), extension agronomists, and weed scientists.

Out-crossing with sexually compatible species should be assumed, unless there is sound experimental evidence to indicate otherwise *(e.g.*, the transgenic plant has been rendered infertile). However, the rate of out-crossing may be quite low, especially if the related species do not normally co-occur with the transgenic plant or the flowering periods do not overlap. The rate of out-crossing may be influenced by deliberate changes made to the transformed plant and these may need to be considered. Rates of out-crossing to crop volunteers in agricultural settings may not be easily extrapolated to rates of out-crossing to weedy biotypes of the crop species, where flowering periods and other growth habits may be quite different.

The environmental significance of trait introgression *(i.e.*, the potential environmental hazard) will vary with each plant/trait combination, and is

addressed through the case-by-case assessment of transgenic events. The compatible wild relative(s) should be characterised with respect to weediness in managed ecosystems and/or establishment and spread into unmanaged ecosystems. It should be considered whether:

- the introduced trait is similar to a trait found currently in natural populations of the compatible wild relatives
- the introduced trait will have the potential to increase the reproductive fitness or confer a selective advantage on the wild relative
- the introduced trait will have a significant impact on the establishment and spread of populations of wild relatives

Figure 4 shows the high correlation in the information requirements related to gene transfer with the exception of considerations of horizontal gene transfer where opinions are more divergent.

Information / Data Requirement	Australia	Canada	Canada-USA Bilateral	UK	Japan	USA	Cartagena Protocol on Biosafety
Presence of sexually compatible species in areas where the crop will be cultivated[1]	X	X	X	X	X	X	I
Characteristic(s) of introduced trait that could change the ability of the transgenic plant to interbreed with other plant species	X	X	X	X	X	X	I
Consequences of potential for gene flow from the transgenic plant to sexually compatible species[2]	X	X	X	X	X	X	I
Potential changes in likelihood of HGT to unrelated species.	X			X	X		I

Figure 4. Gene Transfer to Related Plants and/or Unrelated Organisms. Reproduced with permission.

[1]Characterise compatible wild relative(s) with respect to weediness in managed ecosystems and/or establishment and spread into unmanaged ecosystems. [2]Consider whether: the introduced trait is similar to a trait found currently in natural populations of the compatible wild relatives; the introduced trait will have the potential to increase the reproductive fitness or confer a selective advantage on the wild relative; the introduced trait will have a significant impact on the establishment and spread of populations of wild relatives.

3.7. Gene transfer to unrelated organisms

Some but not all regulatory frameworks incorporate a consideration of horizontal gene transfer (see Figure 5). Gene transfer between unrelated organisms occurs through horizontal gene transfer (HGT), the non-sexual exchange of genetic material between organisms belonging to the same or different species. It is a naturally occurring phenomenon that was first demonstrated to occur between bacteria, and whose importance in prokaryotic genome evolution has been inferred from phylogenetic analysis.

The possibility of HGT between plants and bacteria in either the soil or gut, particularly as this relates to the possible transfer of genes encoding antibiotic resistance, has been seen as a hazard associated with transgenic plants. The significance of this concern as a risk depends on the likelihood of HGT occurring and the magnitude of any associated adverse outcome. Europe has identified the potential transfer of antibiotic resistance marker genes as an issue and recommends against their use, particularly if the resistance is to antibiotics that are in medical or veterinary use. Regulation 6(2) of the GMO Regulations in the UK (UK, 2002) specifically references antibiotic resistance markers:

> *"Where the genetically modified organisms contain antibiotic resistance markers, the environmental risk assessment shall include an examination of the particular risks of damage to the environment which may be posed by the deliberate release or marketing of those genetically modified organisms".*

Australia, Canada, the USA and Japan do not single out antibiotic resistance markers for special attention in their regulations, instead they require the examination of all introduced traits in a consistent manner. Australia and Canada do make specific reference to antibiotic resistance markers in their guidance documents. Other countries emphasise a case-by-case approach for all traits, including antibiotic resistance markers.

In assessing the environmental and/or human health consequences of HGT, the frequency of occurrence of this natural phenomenon should not be the only consideration of the risk assessor. The properties of introduced genes, and the existence of favourable selective pressure should these genes be incorporated into other organisms, must also be a biosafety consideration. Although the potential HGT of antibiotic resistance traits from plants to [v]bacteria has both an exceedingly small probability of occurrence coupled with a lack of significant consequences should it occur, this might not be so for other genes. However, caution must also be tempered by the realisation that HGT is a natural process of cross-species gene movement responsible for effecting genetic change, and that genes introduced into transgenic plants are no more likely to be transferred to other organisms than are other plant genes.

3.8. Weediness potential in managed ecosystems

Weeds are considered to be a subset of plants that may be considered pests. The term weed is used to describe a plant that is a nuisance in managed ecosystems such as farms or forest plantations. Predicting weediness is difficult but consideration of weedy characteristics such as those developed by Baker (1995) can by useful. Baker (1995) described the ideal characteristics of weeds as including the following:

- Discontinuous germination and long-lived seeds
- Rapid seedling growth
- Rapid growth to reproductive stage
- Long continuous seed production
- Self-compatible, but not obligatorily self-pollinated or apomictic
- If out-crossing, uses wind or unspecialised pollinator
- High seed output under favourable conditions
- Germination and seed production under a wide range of environmental conditions
- High tolerance or plasticity of climatic and edaphic variation
- Special adaptations for dispersal
- Good competitiveness achieved through, for example, allelochemicals or choking growth, and
- If perennial, then with vigorous vegetative reproduction, brittleness at the lower nodes of rhizomes or rootstocks, and ability to regenerate from severed rootstocks

More recent publications (for example, Williamson [1993]) have criticised Baker's weediness list as unreliable but none the less it provides a good starting point for an evaluation of weediness. The ability of the plant to become a weed will of course also be dependant on the receiving environment and whether the traits impart a competitive advantage.

Invasiveness potential is a measure of a plant's ability to successfully colonize an ecosystem, especially when it may also lead to the displacement of other species. Generally, both weediness and invasiveness depend on the selective advantage of many genes functioning in combination, which are unrelated to the genes usually introduced for agronomic reasons. However, traits that enhance tolerance to environmental stresses such as drought, cold or dormancy have the potential to increase the survival and distribution of the plant in managed and unmanaged ecosystems. Additionally, traits which provide for resistance to biotic stresses that play a significant role in the ecology of the plant (*e.g.*, insect or pathogen resistance) could permit the plant to become weedier in invasive agriculture systems and/or invasive outside of the agricultural ecosystem. This consideration is more relevant with regard to plants that are new to domestication or cultivation in the centre of genetic diversity where a trait that confers an advantage may spread more readily outside of cultivation. It is worth noting that the ability to tolerate drought and other forms of abiotic stress has also been introduced through more conventional breeding approaches and these plants can provide useful examples for the risk assessment.

To evaluate if a transgenic plant has altered weediness potential in comparison with its conventional counterpart as cultivated in a managed ecosystem, the following may be examined:

- Dissemination of seed
- Dormancy of seed
- Germination of seed/survival
- Reproductive capacity
- Competitiveness
- Agronomic characteristics *e.g.* time to maturity, disease and pest resistance
- Stress tolerance

3.9. Effects on organisms, including non-target organisms

Potential hazards to organisms including terrestrial wildlife, aquatic animals, plants and beneficial insects are possible, particularly if the gene product is intended to protect the plant against pests or disease. In the case of plants that produce compounds designed to kill particular pests, organisms other than the intended target are referred to as non-target organisms. These concerns are important with respect to overall biodiversity but most regulatory frameworks will also capture concerns for the protection of endangered or culturally important species. The novel gene product itself may cause adverse effects such as toxicity or affect the physiology or behaviour of non-target organisms. Alternately, the novel gene product may lead directly or indirectly to the expression of a toxin or other product that is known to affect metabolism, growth, development, or reproduction of non-target organisms. Threatened and endangered species and beneficial organisms (pollinators, predators, parasites, biological control organisms, soil microbes) present in the area where the crop is to be grown can be identified. Potential routes of exposure include direct ingestion of plant material or ingestion/parasitism of preys/hosts that have fed on transgenic plant material. For transgenic plants that could reasonably be expected to affect soil micro-flora or fauna, a consideration of the potential effects would be appropriate. The choice of appropriate indicator organisms is based on the potential for field exposure to the novel protein/products expressed in transgenic plants, which is dependent on the tissue specificity of expression.

A tiered system approach may be adopted to characterise the risk to non-target organisms (e.g. as proposed by Romeis *et al.*, 2011). If detrimental effects are observed under laboratory conditions, field studies may be required to assess the actual abundance of non-target species under test and control conditions. In the field, insects, for example, are usually exposed to smaller amounts of toxin than the laboratory test dose because of diet choice and other environmental factors within the field setting.

Adverse affects to workers, adults, and children may arise through physical contact or use other than for uses as food, feed, or pharmaceuticals of the transgenic plant or its parts or its raw or processed products. The analysis may include a comparison of the transgenic and non-transgenic counterpart(s) with respect to the likely exposure to toxins, irritants, and allergens.

Figure 5 shows a comparison between the regulatory guidance of the representative countries chosen. The USA does not consider the presence of the gene product in the human diet or incidental exposure since this is considered to be part of the safety assessment of the transgenic crop as a food and conducted by the Food and Drug Administration. Similarly, the guidance given under the Protocol does not consider whether the newly-expressed protein has previously been part of the human diet and this may reflect the scope of the Protocol which excludes food. The consideration of the potential production of toxins and allergens is common to all of the selected regulatory or guidance documents.

Information / Data Requirement	**Australia**	**Canada**	**Canada-USA Bilateral**	**UK**	**Japan**	**USA**	**Cartagena Protocol on Biosafety**
Has gene product been part of the human or animal diet	X	X	X	X	I		
Gene product known to lead directly or indirectly to expression of a toxin or other product that is known to affect metabolism, growth, development, or reproduction of animals, plants, or microbes	X	X	X	X	X	X	I
Potential physiological and behavioural effects to non-target organisms[1]	X	X	X	X	X	X	I
Potential adverse effects on the health of humans[2]	X	X	X	X	X		I

Figure 5 . Secondary and Non-Target Adverse Effects. Reproduced with permission.

[1]Including insect, avian, aquatic, or mammalian species in the areas where the crop will be cultivated, including any new area of cultivation. Threatened and endangered species in the area where the crop is to be grown beneficial organisms (pollinators, predators, parasites, biological control organisms, soil microbes) and other appropriate non-target organisms. [2]Adverse affects to

workers, adults, and children that may arise through physical contact with or use of the transgenic plant or its parts or its raw or processed products, when used for other than food, feed, or pharmaceuticals. The analysis might include a comparison of the transgenic and non-transgenic counterpart(s) with respect to the likely exposure to toxins, irritants, and allergens.

3.10. Other secondary effects

Changes in agronomic practices can result in potential effects on soil integrity, nutrient cycling and weed and pest populations. These changes can be positive or negative. For example in Canada, the widespread adoption of broad spectrum herbicide tolerant crops has led to extensive adoption of minimum disturbance tillage systems (Hoffman, 2008). It is important to identify and describe any new ecosystems where the transgenic plant will be cultivated and to describe any changes in cultivation practices for the transgenic plant (see Figure 6). In particular, it must be indicated if transgenic volunteers may dictate altered management practices for succeeding crops.

Figure 6 illustrates the data and information related to the outcomes of cultivating the transgenic crop. A number of concerns are common across the representative countries but there are some notable exceptions. The UISA does not specifically examine transgenic crop volunteer control and neither Japan nor the UK considers insect resistance management plans for insect tolerant crops. It is unclear from the regulatory documents why this is so. In the case of transgenic plants developed for resistance (tolerance) to a herbicide or class of herbicides, appropriate strategies that are intended to delay the development of herbicide resistant weeds and avoid significant changes in weed biotypes can be included as part of the regulatory oversight. In Canada, applicants are required to include a herbicide resistance management plan as a condition of commercial authorisation. Similarly, insect resistance management plans can be described for insect resistant crops, to avoid or delay the potential build-up of resistance in insect populations to engineered insecticidal traits.

Information / Data Requirement	Australia	Canada	Canada-USA Bilateral	UK	Japan	USA	Cartagena Protocol on Biosafety
Describe where the transgenic plant will be grown	X	X	X	X	X	X	X
Identify and describe any new ecosystems where the transgenic plant will be cultivated.	X	X	X	X	I	I	X
Describe changes in cultivation practices for the transgenic plant[1]		X	X	X	I	X	X
Discuss if transgenic volunteers may dictate altered management practices for succeeding crops	X	X	X	X	I		
Describe any specific deployment strategies recommended for this transgenic plant[2]	X	X	X	X	I		
Insect resistance management plans	X	X	X			X[3]	
Herbicide resistant crop management[4]	I	X	X	I			

Figure 6. Cultivation of the Transgenic Plant. Reproduced with permission.

[1]Examples may include land preparation, fertiliser usage, weed and pest control, harvest, post-harvest protocols, and other cultivation practices. [2]Deployment strategies may include geographic or temporal factors or integration with other practices. [3]In the USA, this is required by the Environmental Protection Agency. 4In the case of transgenic plants developed for resistance (tolerance) to a herbicide or class of herbicides, describe appropriate strategies that are intended to delay the development of herbicide resistant weeds and avoid significant changes in weed biotypes.

3.11. Unexpected effects

The evaluation of unintended effects is one of the more challenging aspects of risk assessment and this aspect is generally tackled indirectly since it is nearly impossible to postulate and evaluate a full suite of potential effects. Current practice is to rely on a thorough agronomic evaluation of the modified variety to determine if there are significant changes in normal agronomic performance, including changes in significant life history traits. This underscores the importance of the phenotypic assessment wherein significant changes should be evident and cause the risk assessor to go back and investigate potential causality and evaluate whether there is a potential risk. It is worth noting that the presence of the unexpected effect may not present a risk, and even conventional plant breeders are familiar with unexpected outcomes (in fact it has been an important part of crop and variety development). The risk assessor is tasked to evaluate whether there may be any reason to expect the change to lead to an associated environmental harm. There may also be a need to rely on post-marketing reporting mechanisms to identify unexpected environmental effects for transgenic phenotypes that are not be as familiar or well understood and thus not captured in the risk assessment. Many jurisdictions rely on post-approval monitoring to evaluate any potential unexpected changes but monitoring is difficult in the absence of sound baseline information.

4. CONCLUSIONS

Regulatory frameworks provide government oversight on commercial or other activities that raise concerns, whether social, ethical or environmental. The creation of regulatory frameworks to address the potential risks and access the benefits of biotechnology has been, to date, the usual response of governments. Whether the basis of the regulation is process-based, such as Australia or the United Kingdom, or truly product-based like the Canadian approach, there needs to be a sound basis in legislation, with regulations derived from the legal authority. Integral to this process is the application of the concepts of transparency and consultation, and the articulation of a policy framework that describes the goals and social values that underlie the regulations. The policy framework may in some cases make allowances for food security or other emergencies to be incorporated into considerations for eventual release or as a consideration for protection goals. Equally integral to a regulatory framework is a description of the information required to support the safe deployment of the transgenic crop. There is ample guidance with regard to the issues addressed in a risk assessment and the information that

can be applied to address these concerns, and substantial overlap in different regulatory regimes has been demonstrated. This commonality in information requirements is a strong argument for the portability of data and the possibility of applying risk assessments either in whole or in part to a number of regulatory jurisdictions leading to, for example, the possibility of harmonised mechanisms for regional approvals. As countries develop regulatory frameworks, there will be opportunities to take advantage of familiarity and potentially eliminate traits or some aspects of the risk assessment of those traits on a case-by-case basis. The information to inform the risk assessment should be fit for purpose, and sufficient to address hypothesis-driven concerns in order to ensure that the risk assessment fulfils its purpose rather than acting as a barrier to innovation.

The mechanics of the regulatory process may differ with respect to how the functions are conducted inside the regulatory framework and which individuals, whether from government or private institutions, have responsibility. Frequently, the risk assessment and risk management recommendations are separated from the decision-making part of regulation (e.g. Canada, Australia and the UK) in order to separate the more science-based aspects of risk assessment from the broader concerns that take place when deciding on the feasibility and economics of risk management measures and those that can be applied to decision-making. Whatever the breakdown of roles, it is essential that all involved in delivering the regulations have the skills and necessary information to deliver their part. In Canada, those involved in the regulation of transgenic crops have expertise in crop production, crop inspection, plant health and plant risk assessment. In countries with limited resources there is a great deal of value in cross-utilising the experience of those involved in the regulation of crops to the regulation of transgenic crops as part of their duties.

The development of transgenic crops and their commercial release has provided advantages to growers worldwide in providing new management tools, and new possibilities for enhancing yields. Like all technologies there have been benefits and problems. The adoption of agricultural biotechnology has sparked a larger discussion on the environmental impact of agriculture and how the impacts of food production can be minimised, recognising that there is a need to feed burgeoning populations. The environmental footprint of agriculture can be addressed and biotechnology provides one tool in the suite of tools available to growers to address the concerns associated with large scale production systems with high inputs. In Canada, recent reviews have calculated the environmental and economic benefits of the adoption of herbicide

tolerant crops (Smythe et al., 2011). However, along with benefits such as the reduction of pesticide use, the conservation of soil and the reduced costs to growers, there are the potential problems that arise from the loss of very useful herbicides and the evolution of resistant weed biotypes. The potential problems that can arise with the loss of valuable and cost effective herbicide controls is made more acute by the fact that there is declining investment in terms of new herbicide modes of action. Once the efficacy of some of these valuable herbicide tolls has been compromised, there are no ready replacements on the horizon. In the same vein, growers have reaped significant economic benefits from the deployment of insect-tolerant crops and health benefits from reduced exposure to sprayed pesticides, however there are already reports of resistance evolving to these insect-protected crops and the alternative will be a return to less sustainable technologies. The implementation of a regulatory framework will not address all of the risks and challenges posed by transgenic crops but a properly constructed regulatory framework can provide a consistent, adaptable, transparent mechanism to allow the development of transgenic crops (if desired) and their responsible deployment into the environment.

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