Transforming Agriculture
The Benefits And Costs Of Genetically Modified Crops

Prepared For

The Canadian Biotechnology Advisory Committee
Project Steering Committee on the Regulation of Genetically Modified Foods

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1.0 Introduction

Richard Gray

BACKGROUND

Scientific advancements in molecular biology have resulted in new and controversial biotechnologies that allow much greater scope for the genetic manipulation of life forms. Among the most controversial is transgenics, a biotechnology that allows the transfer of genes between species. The use of transgenic processes — often referred to as genetic modification — to produce new crops has spawned considerable public debate over the costs and benefits of these crops. Those who are strongly opposed to genetic modification (GM) argue that these new life forms pose a threat to food safety, the environment, and the social structure of agriculture. Those who come down in favour of GM crop production argue that these technologies present minimal risks, and have the potential to create more plentiful, high-quality food at a lower cost to the environment, and to the benefit of farmers, consumers, and society in general. Among such strongly held opposing views on GM technology, it is often difficult for the public to find objective information.

The purpose of this report is to examine a number of important issues that are related to GM technology and to summarize what is known about these issues to this point. A general economic framework will be used, examining the social costs and benefits related to each issue. Each chapter relies on the available literature. On some issues the economic framework is fully developed, and studies have calculated the costs and benefits; in such cases, the authors rely on the scientific literature for their analysis. On other issues there is a limited amount of conceptual work, and empirical measurements of the effects do not yet exist; in these cases, the authors provide a conceptual framework to identify where impacts are potentially significant and require further examination.

This report is organised into nine chapters, each with different authors. This chapter provides an introduction, some definitions, and the general framework used to identify and evaluate the issues. Chapters 2 through 8 systematically address specific issues related to GM technologies. Chapter 9 summarizes the report and identifies outstanding issues that will need to be addressed by the industry and by policy makers.

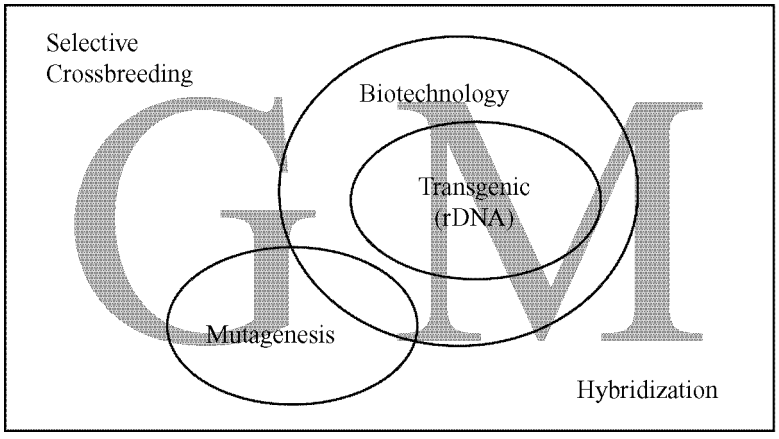
DEFINITIONS

The following definitions are used throughout this report:

> A *Genetically Modified Organism*, or GMO, is any organism that contains recombinant DNA; that is, in which DNA has been transferred from one organism to another.
>
> *Genetic Modification* is the process of creating a GMO.
>
> A *GM product* is a product produced from a GMO.

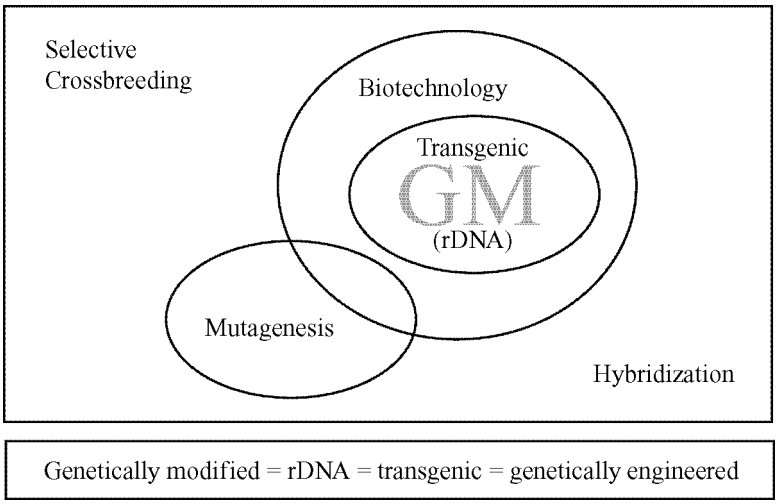
These definitions have been adopted principally because of their widespread use in the popular media. It is important to be aware, however, that the scientific community has a much broader conception of genetic modification, one that differs considerably from narrow popular definitions. Figure 1 depicts the scientific community's view that there are many processes that can bring about genetic modification. Traditional methods of genetic modification include selective crossbreeding and hybridization. Other methods include interspecies and intergeneric protoplast fusion, in vitro gene transfer techniques, somaclonal selection, haploid doubling, and mutagenesis (McHughen, 2000). In the scientific sense, virtually all agricultural crops have been genetically modified over time. Rather than using the term "GMO," then, the scientific community prefers "genetically engineered," "genetically transformed," "rDNA technology," "gene splicing," or simply "transgenic."

Figure 1: Scientific View of "Genetic Modification"



The narrower definition of genetic modification used in this paper is illustrated in Figure 2. It refers specifically to the form of biotechnology which is at the centre of the policy debate.

Figure 2: The Popular Use of "Genetic Modification"



THE COST-BENEFIT APPROACH

This report discusses the potential costs of and benefits to be gained from GM crops. Economists recognise that these are both private and social. Private costs and benefits are those which can be fully accounted for in market prices. When there are no distortions in the marketplace, the benefits that a product provides to consumers who buy and consume it will be reflected in its price. Similarly, firms incur costs in producing goods and services. These costs are incorporated into the price they charge for their products. A higher price therefore reflects the additional costs that a firm incurs in producing a good.

Sometimes, however, markets fail. When this happens, the market price does not accurately reflect all the relevant costs and benefits arising from the production and consumption of a good. Non-market externalities arise from market failure; the market under-provides goods or services with external benefits (also known as positive externalities). Among health-care services, for example, vaccines that combat communicable diseases benefit not only the person who is vaccinated but others who do not pay for the benefit. Or an individual may pay to have a tree planted in her front yard; the tree provides an aesthetic benefit for the community, yet she is not paid for it. Conversely, the market over-provides goods and services that generate external costs (negative externalities). A pulp mill may pollute a body of water, for instance, causing hardship for those who live downstream. The mill is creating a negative externality if those who are negatively affected are not adequately compensated by the pulp mill. These

external costs are said to occur outside the market. Both negative and positive externalities are sometimes referred to as spillover effects (Gray et al, 2001).

When market failure occurs, the equilibrium market outcome is inefficient, leading to losses in social welfare. As a result, when making an evaluation of a GM product, it is important to identify these non-market externalities so that they can be considered in the assessment of the good's desirability. Market failure provides the rationale for government intervention to correct the failure through taxation, subsidisation, regulation, the public provision of goods, and/or direct legislative action. Whether intervention is desirable will depend on the nature and size of the externality and the costs associated with it. Economic analysis has a critical role to play here. Will policy intervention to correct market failure result in a net gain to society? Which is the appropriate policy intervention, given the market failure identified? Cost-benefit analysis is an important tool for evaluating the desirability of policy intervention.

Three key steps are involved in cost-benefit analysis. First, the relevant costs and benefits, both private and external, must be identified. Second, a value must be placed on those costs and benefits. Finally, an overall assessment must be made as to whether there are net social welfare gains or losses over time. This report focuses primarily on the first of these steps, although it summarizes research — when such research is available —that addresses the second step. It most cases, however, it is too soon to move to step two. The report therefore seeks to identify both gaps in our knowledge and the research necessary to enable a more formal quantification of costs and benefits in the future.

ORGANIZATION OF THE REPORT TO IDENTIFY COSTS AND BENEFITS

The genetic modification of crops is a new technology with a great number of potential costs and benefits. These impacts accrue at different stages in the marketing chain, including variety sales, farm production, marketing, and consumption. Moreover, the parallel links throughout the non-GM marketing chain can be positively or negatively affected by the introduction of a GM crop. In addition to the effects on domestic marketing chains, there are effects on other countries as well, through trade and research and development costs. Finally, there are important environmental costs and benefits.

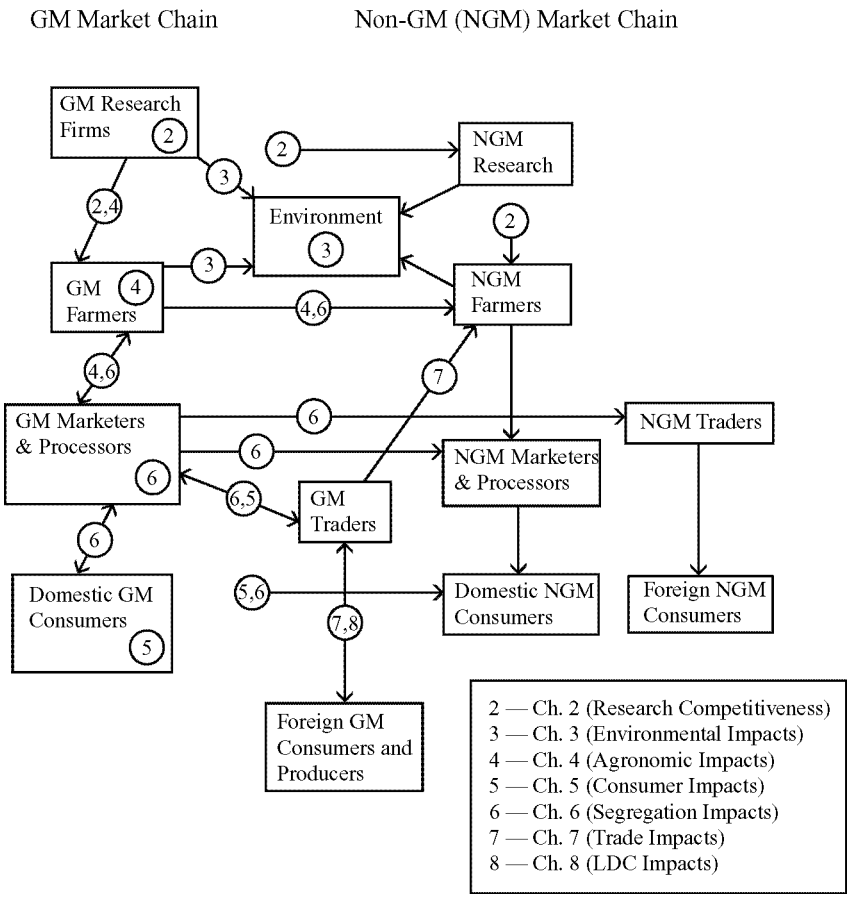
The approach taken in this report is to somewhat arbitrarily divide the costs and benefits into seven chapters that address certain aspects of the larger set of GMO-related issues. Chapter 2 assesses the impacts on GM technology of the structure and control of the crop genetic research industry. Chapter 3 reviews the environmental costs and benefits associated with GM breeding and farm production. Chapter 4 assesses the agronomic impacts of GM technology on farmers, both those growing GM and non-GM crops. Chapter 5 deals with the cost and benefits to consumers of GM and non-GM products. Chapter 6 addresses the segregation costs that may be required to keep GM products separate from non-GM products throughout the marketing chain. Chapter 7 explores the

issues related to the international trade of GM and related non-GM products. Chapter 8 examines the impacts on less-developed countries. Finally, Chapter 9 provides a brief summary of the report and some general conclusions.

An important objective in compiling this report was to provide a range of opinions and perspectives on the economic costs and benefits of GM crops. Inevitably, there are areas of overlap, and even contradictory perspectives, among the chapters. This merely reflects the current state of knowledge and complexity of the issue. The discussion of related issues across different chapters indicates that these benefits and costs affect society on a variety of fronts. Environmental effects, for example, are important not only in their own right; they may also affect consumers' perceptions of the technology and producers' agronomic decisions. Contradictory opinions among the chapters are also a direct reflection of the lack of consensus in society regarding the potential costs and benefits of GM crops and the need for further research to assess more accurately the potential effects.

The interactions between the chapters and the contribution each chapter makes to a myriad of issues are depicted in Figure 3. The boxes in Figure 3 represent parts of the marketing chains in which the impacts originate and/or are incurred; the arrows represent the direction of the effect; and the numbers indicate which chapter deals with each effect. It can be seen, for example, that the environmental impacts discussed in Chapter 3 are directly related to GM research as discussed in chapter 2, and are affected by the rate at which farmers adopt GM crops, as determined by the agronomic impacts discussed in chapter 4. Similarly, the agronomic impacts discussed in chapter 4 affect GM farmers directly, but they also have implications for non-GM farmers and GM marketers and processors. The segregation issues discussed in Chapter 6 have direct implications for the agronomic decisions of GM farmers and non-GM farmers (Chapter 4), for domestic GM consumers (Chapter 5), for international trade (Chapter 7), and so on.

Figure 3: GMO Impacts and Report Organization



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2.0 Biotechnology and Industry Concentration

Murray Fulton and Kostastinos Giannakas[1]

THE ISSUE

In the past ten years the seed and pesticide industries have seen a substantial number of mergers and acquisitions, an increase in vertical and horizontal integration, and an increase in the importance of multinationals, particularly in the seed industry. These structural changes have occurred at the same time that the legal framework of intellectual property rights (IPRs) has been substantially strengthened and as transgenic technology has been used to develop new products (Lindner, 1999).

The purpose of this chapter is to examine the reasons for the structural changes that are under way in the seed and chemical industries, to determine the degree to which market power is present in the seed and chemical industries, and to explore the importance of this market power for activities that are carried out in these industries.

IMPLICATIONS AND CONCLUSIONS

The structural changes under way in the seed and chemical industries are owing to a number of factors. Some of these factors are common to all industries and have no specific link to biotechnology, but intellectual property rights and the nature of biotechnology products are important in understanding the structural changes. The horizontal mergers and acquisitions that have occurred in the seed and chemical industries can be directly linked to the R&D costs and to regulatory costs, with greater expenditures in these areas leading to greater concentration. The increased vertical linkages in the industry are linked to the product complementarity increasingly present between seed and chemical products, as well as to the difficulty in enforcing the ownership of certain types of intellectual property. In other cases, the rise of better-defined intellectual property rights has been a factor in the joint ventures and strategic alliances that have occurred.

The large firms in the seed and chemical industries clearly have market power, with the degree of market power remaining relatively unchanged over the past ten to fifteen years. The key impact of market power is on the distribution of the benefits of the new technology being introduced. For instance, greater market power on the part of the innovator in the soybean complex leads to fewer benefits for farmers using the herbicide-

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resistant technologies and less benefit for the groups processing soybeans. These losses, however, are almost completely offset by gains to the innovator (Moschini *et al*, 2000).

The distributional impact is important because it raises questions about which groups are likely to benefit from the introduction of the new technology, which in turn raises questions about the adoption and/or acceptance of the new technology. When market power is present, for example, both consumers and producers may be less willing to adopt new developments in biotechnology because of the smaller share they obtain of the benefits (Moschini, 2001 Giannakas, and Fulton).

Notwithstanding these results, relatively little is known about the impact of concentration, and substantially more research is required. In particular, little is known about the trade-off that is inherently in place around IPRs and concentration. At their most basic level, IPRs convey a monopoly, albeit for a limited period of time and for a limited product, to the company or individual possessing the intellectual property. IPRs provide the incentive for innovation and encourage the diffusion of new technologies (Lesser, 1998). Thus, there is always a need to ensure that a proper balance is achieved between the benefits and costs of IPRs. To date, the research on this question has not been undertaken.

THE CHANGING STRUCTURE OF THE AGRICULTURAL BIOTECHNOLOGY INDUSTRY

The first step in determining the structure — including concentration — of an industry is to define the relevant market. As Stigler (1982) laments, economists have neglected market definition both in theory and empirical applications. The usual approach is to define the limit of a market as a break in the chain of substitutes by considering cross elasticities of demand and supply. Legal definitions of relevant markets have emerged in the U.S. Department of Justice Merger Guidelines (Shy, 1996), and in a similar set of Canadian Merger Guidelines (Competition Bureau, 1997).

Determining the relevant markets for seed and pesticides is difficult. In some cases, the relevant market is quite wide, and may apply to a range of seeds or a range of pesticides. For instance, for a farmer with no defined crop rotation and climatic conditions that allow the growing of a large number of crops, the relevant market for seed would encompass a number of different crop seeds. Similarly, the relevant market for pesticides may be quite large if a wide variety of chemicals can deal with the pests a farmer needs to control. In other cases, the relevant markets may be small; in some cases, there may be no substitute product that will deal with a particular pest problem. In addition, with the introduction of plant biotechnology, the seed and chemical products are increasingly difficult to separate. The tying of seeds and chemicals — a good example is Monsanto's Roundup Ready™ seeds and Roundup™ — means that the seed and the chemical markets can no longer be treated as separate (Hennessy and Hayes, 2000).

Notwithstanding these observations, the available data are generally at a highly aggregate level. The use of this aggregate data generally understates the level of concentration present in an industry, since the substitution possibilities that are available to most farmers will be much less than what is implied by the aggregate data (for a good analysis of the effect of the use of aggregate data on the estimation of market power, see Sexton, 2000). Thus, the largely aggregate data presented below generally understates the degree of concentration present in the seed and chemical industries.

Horizontal Structure — Mergers and Acquistions

Table 1 (see page 26) presents world sales of the top ten pesticide and seed firms for 1997 and 1999. As the numbers in Table 1 indicate, both the seed and pesticide industries are concentrated. The pesticide industry is particularly concentrated, with a CR4 of 47%. Longer-term time series data on the structure of the chemical and seed company are difficult to obtain. In one of the few published papers to provide this kind of data, Ollinger and Fernandez-Cornejo provide CR4 data for the United States pesticide industry over the period 1972-1989. During this period, the CR4 oscillates, moving from a high of 50% in 1973 to a low of 37% in 1982, then rising to 48% in 1989. These values are consistent with the values presented in Table 1. When attention is shifted to the plant biotechnology market, where seeds and pesticides are combined, an even higher level of concentration emerges, with three companies accounting for the entire market.

Although detailed data is not available for the 1990s, there is evidence that industry structure in the seed and chemical industry is dynamic. One of the major structural changes that has occurred over the past five years in the seed and chemical industries is a consolidation of companies through mergers and acquisitions. Table 2 (see page 27) outlines selected mergers and acquisitions that have occurred among the major seed and chemical companies. Figures 1 and 2 (see pages 28 and 29) provide additional information on the changing structure of one of the seed and chemical companies, Monsanto, who alone has made over twenty strategic alliances, mergers, joint ventures, and acquisitions with life science, seed, chemical, and biotech companies.

Figure 3 (see page 30) illustrates that this merger and acquisition activity is the latest in a series of merger and acquisition waves. As Kalaitzandonakes and Hayenga (2000) note, firm entry in the crop biotechnology industry peaked in the early 1980s, with production innovation continuing throughout the 1980s. The first generation of products — transgenic plants that provide resistance to certain chemicals or certain insects — emerged in the early 1990s. Consolidation began shortly thereafter. Oehmke *et al* (1999) also discuss the cyclical pattern in mergers in the biotechnology industry.

As noted above, aggregate market figures mask the much higher concentration that exists in specific markets. For example, in 1998, Monsanto and Pioneer-HiBred (now owned wholly by DuPont) controlled 15% and 39% of the seed corn market, respectively. These same two companies controlled approximately 24% and 17%, respectively, of the

purchased soybean seed market. For cotton, two companies, Delta & Pine Land and Stoneville, had 71% and 16%, respectively, of the seed market (Kalaitzandonakes and Hayenga, 2000). In Canada, there were approximately thirteen million acres of canola planted in 1999. About ten million of those acres were seeded to herbicide-tolerant varieties. Three companies — Monsanto, AgrEvo, and Cyanamid — controlled this latter market (Fulton and Giannakes, 2000).

The determination of the relevant market is not always done on the basis of output markets. As Brennan *et al* (2000) point out, the Federal Trade Commission has used innovation competition to assess the impact of mergers. Examining competition in innovation is designed to focus attention on the impact of a merger on innovative activity (e.g., does R&D activity rise or fall in the merged firm? Are there consequences for the efficiency of R&D expenditure?). Using data on field trials under way each year, Brennan *et al* calculate a CR4 ratio at the R&D stage. Activity at this stage is highly concentrated, with the four largest firms having 87% of the field trials in 1988. The CR4 ratio declined to a low of 63% in 1995, then rose steadily over the next few years to reach 79% in 1998. This substantial concentration at the R&D stage is matched by a substantial concentration in terms of the number of patents held. The top four firms held 41% of the corn patents (up to 1996), 53% of the soybean patents (up to 1997), 77% of the tomato patents (up to June 1997), and 38% of the Bt patents (up to 1998) (Brennan *et al*, 2000).

It is important to recognize that concentrated markets do not necessarily imply the presence of market power. Baumol, Panzar, and Willig (1992) stress that firms will not be able to exercise market power if the market is contestable. A contestable market has all the desirable properties of perfect competition — cost minimization and prices as low as possible while still covering costs (zero economic profits). Moreover, this result is obtainable with only a few firms, so that highly concentrated markets can end up with the same characteristics as perfectly competitive markets.

The key requirements for market contestability are: (1) potential entrants must not be at a cost disadvantage to existing firms; and (2) entry and exit must be costless. For entry and exit to be costless, there must be no sunk costs. Sunk costs are expenditures that cannot be recouped once they are incurred; examples include expenditures made to obtain regulatory approval, expenditures on advertising, and expenditures on R&D. If there are no sunk costs, potential entrants can use a hit-and-run strategy in which they enter an industry, undercut the price of the incumbents, reap the profits, and exit before the incumbents have time to retaliate. In anticipation of entrants acting in this manner, the incumbents forestall entry by keeping price at average cost. The consequence is that, even in an industry that is highly concentrated, prices can be kept at or near competitive levels.

If sunk costs are present, however, firms entering an industry are unable to exit again without losing a portion of their investment. As a result, hit-and-run strategies are much less profitable and incumbents are able to keep price above average cost. Thus, with sunk

costs, markets are not contestable and market power is once again an issue. As will be discussed below, sunk costs appear to be a key feature of the seed and chemical markets.

Vertical Structure — Mergers, Joint Ventures, and Strategic Alliances

In addition to becoming larger through growth and horizontal integration, the major agrochemical companies have restructured themselves in other ways. One of the major moves is to become life-science companies that contain pharmaceutical, biotechnology, agricultural biotechnology, seed, and chemical components. A further element of this internal restructuring is increased vertical integration — e.g., the combining of seed, chemical, and biotechnology activities in the same company — and the increased use of strategic alliances.

To provide an illustration of the increased vertical linkages, Figure 2 shows the companies that Monsanto has acquired over the past ten years. The pink filling indicates that the firm was primarily a biotech firm, yellow implies that the firm was a seed company, and a combination of the two colours denotes that the firm was involved in both. Figure 3 shows Monsanto's joint ventures, research and development partnerships, and licensing agreements with other companies in the agricultural biotechnology sector. Of course, the strategies followed by Monsanto are not unique; other life-science companies are restructuring themselves in similar ways.

It should also be noted that the major firms involved in agricultural biotechnology are multinationals. Historically, many countries have had their own local seed companies that have, over the years, developed seed for a specific geographical market and operated sales and distribution systems. These seed companies are increasingly being purchased by multinationals as a source of seed material in which to insert the genes for herbicide or insect resistance (Kalaitzandonakes and Hayenga, 2000). As examples, in 1997, Monsanto acquired a 30% share of the Brazilian corn seed market with the acquisition of Sementes Agroceres. With its 1998 purchase of Cargill's international seed division, Monsanto now controls over half the Argentine maize seed market. In 1998, Dow AgroSciences acquired Morgan Seeds, Argentina's second-largest corn seed company, and Brazil's Dinamilho Carol Productos Agricolas, another key South American corn firm. Phytogen (majority owned by Dow Agrosciences) acquired a major cottonseed breeding program in the Chaco Province of Argentina. In 1998, Mexico-based agribusiness giant, Empresas La Moderna (ELM) bought two South Korean vegetable seed companies, and Nath Sluis (agricultural biotech company) of India (RAFI, 2000). The multinationals are, for the most part, purchasing local seed companies rather than licensing the genes to them. For sales and distribution, in contrast, the multinationals are often relying on local, independent seed companies to carry out these functions.

FACTORS THAT AFFECT HORIZONTAL INDUSTRY STRUCTURE

Numerous factors are behind the wave of horizontal mergers and acquisitions that has characterized the seed, chemical, and agricultural biotechnology industries over the past ten years. Some of these factors are common to all industries and have no specific link to these particular industries. Thus, the mergers and acquisitions in the seed and chemical industries are, at least in part, a result of the need to consolidate costs and rationalize industry capacity, a desire by the management of the firms involved to extend their sphere of influence, and a wish by some firms to pre-empt other firms from taking over valuable assets (Shy, 1996).

There are at least two factors, however, that pertain specifically to the seed, chemical, and agricultural biotechnology industries. The empirical and the theoretical literature both suggest that the following factors are important in understanding the mergers and acquisitions that have occurred: (1) intellectual property rights and R&D expenditures; and (2) the regulatory requirements that governments have introduced before the products of the R&D activity can be marketed.

On the empirical side, Ollinger and Fernandez-Cornejo (1998) examine sunk costs and regulation in the U.S. pesticide industry. Using data over the 1972-89 period, they find that research costs and pesticide regulation costs negatively affect the number of companies in the industry, and that smaller firms are affected more strongly by these costs than are larger firms. Research and regulation costs also encourage foreign-based firms to expand into the U.S. market, and to force less-profitable, innovative firms to exit the market. Ollinger and Fernandez-Cornejo also point out that their results on the impact of regulatory costs generally match those found in other industries.

On the theoretical side, the argument is typically cast around sunk costs and the economies of scale and scope that sunk costs tend to create. As Sutton (1991) outlines, the presence of sunk costs means that, for firms to be profitable, price needs to be raised above marginal cost, typically by reducing the amount of competition (i.e., the number of firms). Sutton identifies two types of sunk costs: exogenous and endogenous. Exogenous sunk costs are those such as regulatory costs that are beyond the control of the firms in the industry. Endogenous sunk costs, in contrast, are firm-level strategic variables, such as advertising and R&D. Firms choose their expenditures on these costs depending on the characteristics in the market (e.g., the size of the market, the nature of the competition) and the nature of costs in the firm (e.g., the nature of economies of scale and scope).

The rest of this section examines the connections between IPRs, R&D expenditures, regulatory costs, and economies of scale and scope. The nature of IPRs used in agriculture is examined first. A discussion of IPRs, economies of scale and scope, and sunk costs, as well as their impact on industry structure, then follows.

Intellectual Property Rights

Prior to the 1980s, there were few property rights associated with agricultural products, and consequently few incentives for private firms to invest in research. As a result, the public sector played a large role in plant breeding during this period. Beginning in the early 1980s, governments around the world have taken actions to establish property rights over life forms and the processes used to develop life forms.

In the context of agricultural biotechnology, an IPR grants a company limited ownership over either the use of a technology used to create an organism or the genetic information in an organism. Four major types of IPRs are used in agriculture: patents, Plant Breeders' Rights (PBRs), trade secrets, and trademarks. Of these, patents and PBRs are the most important. PBRs, which apply to plants only, are a form of protection granted to plant breeders that allows them to exclude others from producing or commercializing material of a specific plant variety for a period of fifteen to thirty years. The PBRs system has traditionally allowed unauthorized use of protected varieties for two purposes: research or breeding, and reseeding by farmers (the so-called farmers' privilege). The research or breeders' exemption allows third parties to use the protected variety to create new varieties and/or to conduct scientific research. Under the farmers' privilege, farmers can retain seeds from the production of the protected variety for re-sowing on their own land. Thus, PBRs are not effective for protecting engineered genes in a plant (Lesser, 1995).

Patents are a temporary and partial monopoly granted to the inventor by society. In Canada, the length of patent duration is twenty years following application. The partial nature of the monopoly is determined by the scope of the patent or the degree of difference required before a related development is not covered by the patent. For a patent to be granted, the invention must also be novel. In exchange for the partial monopoly, society receives a disclosure of the invention. Disclosure not only permits competition when the patent lapses; it also provides a storehouse of technical knowledge that would not otherwise exist. Unlike PBRs, under patent law all unauthorized use of patented material, including on-farm seed saving of patented plant varieties, is prohibited. Gene patents are presently possible in Canada (Lesser, 1995).

The limited monopoly inherent in IPRs is granted to companies and individuals to encourage innovation and the development and diffusion of new products and technologies to undertake research and to invest in intellectual property. From a public policy perspective, IPRs thus represent a trade-off between the short-run effects of resource misallocation because of the presence of market power and the long-run benefits from greater R&D (Gallini and Trebilcock). The establishment and strengthening of property rights in agriculture has certainly led to an increase in private investment in agricultural research (Moschini and Lapan). For example, private canola research in Canada has increased from less than $1million per year in 1970 to over $85 million in 1998 (Gray *et al*, 1999). This large influx of investment has increased research output with over forty new varieties of canola being produced each year.

IPRs, Sunk Costs, and Economies of Scale and Scope

Sunk costs and the economies of scale and scope they often create are major factors in propelling industries toward concentration. Economies of scale exist when average costs fall as more output is produced, while economies of scope exist when the total cost of producing two outputs together is less than the cost of producing the two outputs separately. Since economies of scale and scope mean that larger and diversified firms have lower average costs, there is clearly an incentive for firms to get large (Fulton, 1997; Lesser, 1998; Hayenga,1998). Indeed, those that do not get large are vulnerable to being driven out of the market by larger and more cost-efficient firms. Of course, there is a limit to how large firms can get. While development and production costs may fall with an increase in the size of the firm, other costs rise, particularly those associated with administration. Nevertheless, economies of scale and scope clearly create pressures for consolidation.

Sunk costs often create economies of scale and scope because sunk costs are generally created as a result of investment in non-rival goods. Unlike rival goods — such as materials, labour, and energy — which can only be used in one place, by one person, and at one time, non-rival goods — such as R&D, advertising, and regulation expenditures — can be used in more than one place, by more than one person, all at the same time. This feature of non-rival goods — namely, that they can be used over and over again — means that output can be increased without having to increase all inputs. As a consequence, economies of scale and scope are created (Romer, 1990; Fulton, 1997).

Intellectual property, of course, is a good example of a non-rival good. Indeed, ideas generally are considered non-rival goods. It is widely believed that many of the high-technology industries, including the biotechnology and information industries, are subject to increasing returns. Romer postulates that this is a result of the distinction between physical goods and ideas. Ideas are not scarce, so any industry based primarily on the trade of intellectual property will not face diminishing returns in its primary resource, the idea.

An example illustrates the connection between intellectual property and economies of scale and scope. Suppose a biotechnology firm has some intellectual property, such as a technological advancement that provides a unique understanding of a particular biological process or a particular gene that has been isolated. In both of these cases, this intellectual property can be used over and over again as the firm expands its activities. If the company wishes to develop seeds for a new crop, it will not have to invest again in the research that isolated the gene and that provided the unique understanding of a key biological process. While the development of a new seed will require additional lab and greenhouse space, labour, and materials, the expenditure on the technological advancements do not have to be made again.

A similar result occurs if the firm needs to invest substantially in obtaining regulatory approval for a seed: while the production of additional units of the seed will require additional costs, the regulatory expenditures do not have to be made again. Once again,

large companies typically have an advantage, since they are able to spread the costs of obtaining regulatory approval over more output. Thus, the greater the regulatory requirements in an industry, the more concentrated the industry is expected to be.

Intellectual property may also create economies of scope. If the unique understanding of a key biological process can be used in the production of an entirely different product, then the production of both products together will be less than if the products were produced separately. Similarly, once a specific gene has been isolated — for instance, a gene that confers a resistance to a particular herbicide — it can then be put in a number of crops. Once again, the production of a number of products together will be less than if the products were produced separately.

To recap, R&D expenditures and regulatory costs are both sunk costs and a source of economies of scale and scope. Since economies of scale or scope mean that larger and more diversified firms have lower average costs, there is clearly an incentive for firms to get large. As firms get larger, concentration in the industry rises.

FACTORS THAT ENCOURAGE INCREASED VERTICAL LINKAGES

A number of factors encourage increased vertical linkages in the agricultural biotechnology industry. These factors can be divided into supply side and demand side factors. The supply side factors are mostly linked to intellectual property rights (IPRs), while the demand side factors are linked to the substitutability and complementarity of biotechnology products.

Demand Side Factors: Complementarity and Substitutability in Agricultural Biotechnology

To date, agricultural biotechnology has focused on the creation of crops that are resistant to particular insects (e.g., corn, cotton, and potatoes) and herbicides (e.g., corn, soybeans, cotton, and canola). With new genetic coding, seeds have become both complementary and substitute products for chemicals. For instance, Roundup Ready™ soybean seeds are complementary products to the glyphosate in Roundup™ and are substitute products for the herbicides traditionally used to control weeds in soybean crops.

There is some evidence that the direct market effects of product complementarity and substitutability are economically significant. For instance, in the United States, the adoption of herbicide-tolerant soybeans was associated with small increases in yields and variable profits, and significant decreases in herbicide use. The adoption of herbicide-tolerant cotton in 1997 was associated with an increase in yields and variable profit, but was not associated with significant changes in herbicide use (ERS 1999a, 1999b). Of course, looking at total herbicide use masks the fact that the introduction of herbicide-tolerant crops means that the demand for certain herbicides increased, while demand for others declined.

As Just and Hueth (1993) point out, strong demand complementaries mean that a single firm producing both chemical and biotechnology products can be more profitable than can separate firms producing these products. A single firm can be more profitable producing both these products because it can price the products so that the use of the complementary product is encouraged. Thus, demand complementaries appear to be important factors in explaining the amalgamation of seed and chemical companies.

Demand substitutability is also an important factor in determining industry structure, although the impact is on industry consolidation rather than on vertical linkages. Demand substitutability is a key element in what is known as an escalation strategy. An escalation strategy is one in which a company spends large amounts on R&D to achieve a dominant role in the market — i.e., the firm tries to leap-frog its competitors to become the dominant firm. Escalation can be a profitable strategy when there is a high degree of substitutability with competitors' products on the demand side and there are scope economies on the supply side (Sutton, 1998).

Both these factors are present in the agricultural biotechnology industry. On the supply side, the isolation of a gene that provides particular advantages and which can be inserted into a number of crops means there are economies of scope. There are also clear scope economies associated with the enabling technologies that are required to use these genes. On the demand side, herbicide and insect-resistant seeds and the accompanying chemicals are clearly a substitute product for traditional seeds and herbicides and pesticides (Hayenga, 1998). As the theory suggests, the combination of these two factors does appear to be linked with escalation strategies. One example of a firm that appears to be following this escalation strategy is Monsanto (see Figure 2), although Dow and others are following somewhat similar strategies.

Supply Side Factors: Intellectual Property Rights

The way in which organizations and contractual arrangements are structured is also influenced by IPRs. Intellectual property rights create pressures for either greater vertical integration or strategic alliances and contracting, depending on the nature of the intellectual property and the rights associated with it.

If IPRs are well defined, then transaction costs — costs associated with negotiating, specifying, monitoring, and enforcing contracts — are usually fairly low (Merges, 1998). As a result, contracting and strategic alliances are now more likely. Independent companies can efficiently and effectively operate alongside each other, each focusing on their specialty and at the same time having access to the intellectual property of other firms through contracts, licenses, or joint venture agreements.

However, if IPRs create opportunities for exploitation, or if the intellectual property is associated with intangible assets (which are inherently difficult to monitor and enforce in contracts), then the transaction costs may be fairly high. In this case, IPRs are expected to make vertical integration more likely. For instance, the opportunity for exploitation may

arise if IPRs give one or two companies the ability to exert considerable market power vis-à-vis the companies they trade with. This market power may deter other companies from investing in new technologies or developing new products. To remedy the situation, the companies with the market power may decide to vertically integrate and take over R&D and market development.

The vertical structure of an industry can also be affected by the presence of intangible assets. Intangible assets are those factors that are important to a transaction, but difficult to specify and measure. Transferring a new biotechnology process from one company to another, for example, may involve more than simply specifying the steps that are required. Often the precise timing of the steps, or subtle nuances in how the steps are performed, can affect the results in important and significant ways. In these situations, licensing the new process to another firm may be relatively ineffective, and the other firm may be unwilling to pay for the technology under a license agreement. In such situations, vertical integration is often a solution. The purchase of local seed companies by multinationals is one example of a strategy that is consistent with this theory. It would be difficult to license a new gene to a seed company; the seed company would generally not have the expertise to use the technology. Licensing the seed from the seed company is also difficult, since it opens the multinational firm up to problems of license renegotiation and license infringement down the road.

The need to deal with intangible assets is also an important factor in the creation of multinational firms. As Caves (1996) argues, multinational firms often develop because the mother company is unable effectively to license an important technology to a company in another country. To make use of the technology, the mother company sets up a subsidiary in the other country, thus creating a multinational.

Quality assurance factors are also important in determining industry structure. Agriculture is increasingly moving away from commodities and toward various forms of identity preservation (Boehlje, 1996). Quality assurance will become more and more an issue as food companies develop specialized products, and as the quality of the final product is increasingly linked to the crop grown on the farm, the manner in which it is grown, or the manner in which it is transported and processed. When quality and/or the identity of a product can easily be determined, independent firms linked by contracts are likely to emerge as a dominant institutional form (Barzel, 1999). When quality is difficult to determine, other organizational forms — such as those that rely more on personal relationships and reputation than on legal contracts — may be required to deal with monitoring problems. Thus, at least for a period when the quality of genetically modified products is difficult to determine, personal relationships and reputation are likely to emerge as an institutional mechanism between farmers and seed and chemical companies (or between farmers and grain marketing and processing companies).

EXPECTED RESULTS OF CONCENTRATION

Market concentration in the agricultural seed, chemical, and biotechnology industry is relatively high, and appears likely to remain that way for some time. Is this structure having an impact on the pricing of agricultural biotechnology products or on other aspects of the behaviour of agricultural biotechnology companies?

Analyzing the behaviour of seed, chemical, and biotechnology companies is difficult, and no studies can be found to date that explicitly examine the pricing behaviour of firms in these industries. Despite this lack of information, several conclusions can be drawn from the literature.

First, sunk costs appear to be a key feature of the seed and chemical industries. Research costs and pesticide regulation costs have been found to negatively affect the number of companies in the industry, with the smaller firms more strongly affected by these costs than larger firms (Ollinger and Fernandez-Cornejo, 1998). The importance of sunk costs suggests that the seed and chemical industries are not contestable, and, given the relatively high degree of concentration, that market power is likely to be an issue.

Second, the basic premise of the current literature is that non-competitive pricing is the rule in the seed, chemical, and biotechnology products industry. For example, in the two papers to date on the impact of biotechnology products on producers, consumers, and life science companies, Falck-Zepeda *et al* (2000) and Moschini *et al* (2000) both assume that the observed pricing of the biotechnology products (Bt cotton and Roundup Ready™ soybeans, respectively) is reflective of some degree of market power. Falck-Zepeda *et al* find that 26% of the total benefits accrue to the gene developer and the germ plasm supplier because of their market power, while Moschini *et al* find that 45% of the total benefits in their base case are captured by the innovator.

Third, the explicit recognition of market power is important when examining the impact of changes in an industry, such as the introduction of biotechnology innovations. In a general discussion of market power, Sexton (2000) shows that even relatively small amounts of market power can have significant impacts on the distribution of welfare benefits among the various players in a sector. Sexton's results show that even when the overall welfare loss from market power is very small, the losses to consumers and producers can be large. In fact, these groups can suffer losses even when there are substantial efficiency gains to the other sectors of the industry because of higher concentration. Sexton also points out that even small amounts of market power can substantially reduce the incentives for producer groups to undertake advertising or agronomic R&D.

Similar results to Sexton's are found in Moschini *et al* (2000). They show that biotechnology innovation in the soybean complex resulted in substantial benefits to the entire industry. While the presence of market power did not reduce the overall benefits of the herbicide-resistant technologies, it did significantly alter the distribution of these benefits. For example, in their study, the surplus that accrued to the innovator when market

power was present (an amount equal to 45% in the base case) was almost completely offset by a loss to consumers and producers.

The incorporation of market power also affects the distribution of market power between consumers and producers. Moschini *et al* show that when market power is zero, consumers receive 150% of the total consumer and producer benefits generated in the home country — the country in which the innovation was created (producers in the home country lose because the wholesale adoption of the technology in the rest of the world decreases prices). When market power is high, consumers receive 460% of the total consumer and producer benefits.

Thus, the examination of market power becomes a critical factor in understanding the distribution of benefits among the innovator, consumers, and producers. The distributional impact is important because it raises questions about which groups are likely to benefit from the introduction of new technology; this in turn raises questions about the adoption and/or acceptance of new technology. In the presence of market power, both consumers and producers may be less willing to adopt or accept new developments in biotechnology because of the smaller share they obtain (Moschini, 2001; Giannakas and Fulton).

Moschini *et al* further point out that the benefits captured by the innovator are a significant part of the benefits received by the home country. When market power is zero, the home country receives only 22% of the total benefits, whereas when market power is high the home country receives 58% of the benefits (assuming the innovation is adopted around the world). Thus, the encouragement of a highly concentrated innovating sector within its borders could become part of a strategic trade policy for a country wishing to maximize the benefits it receives from biotechnology.

Fourth, the recognition of market power is important when examining the pricing practices of seed and chemical firms. Fulton and Giannakas argue that Technology Use Agreements (TUAs) are a form of differential pricing: farmers pay a set fee for the right to use the seed, as well as paying the per-unit cost of the chemical to which the seed is resistant. The need to pay a set fee regardless of how much chemical is used makes TUAs a form of price discrimination; farmers that purchase only a small amount of chemical effectively pay a higher per-unit price for the chemical than do farmers purchasing a large amount. Price discrimination does not emerge in perfectly competitive industries; attempts to introduce a fixed fee would be met with an undercutting of the fee by the other firms. Thus, the use of TUAs suggests that pricing is non-competitive, a point also made by Hennessey and Hayes (2000).

Price discrimination could also be carried out across geographical regions, since farmers in different locations likely have a different willingness to pay for a seed and chemical package. Evidence from the United States and Canada suggests that differences do exist in willingness to pay. Whereas herbicide-resistant technology is being adopted widely in some areas, for example, it is being adopted less widely in others. On the Southern Seaboard, over three-quarters of soybean production is from herbicide-tolerant

varieties; in contrast, the Northern Crescent region has much lower adoption rates for soybeans than the other regions (ERS 1999a, 1999b). The adoption rate in Canada for herbicide-tolerant soybeans is also relatively low, and there is evidence that the cost of alternative weed- or insect-control packages and agronomic characteristics vary by region and by farmer (Carpenter and Gianessi, 1999; Klotz-Ingram *et al*, Fulton and Keyowksi, 1999).

Despite the difference in the willingness to pay, the price of biotechnology products appears to be similar across the United States and across Canada. This lack of price discrimination is likely a result of a desire to limit arbitrage within these markets. Evidence for this conclusion comes from the observation that, on the international front, the same firms do practice price discrimination. Lindner (1999) provides an example in the case of cotton, where the TUA fee was set substantially higher in Australia that in the United States. In a well-publicized case, the U.S. General Accounting Office provided evidence of how Roundup Ready™ soybeans are priced significantly lower in Argentina than in the United States.

In conclusion, there is some evidence that the pricing of biotechnology products is non-competitive. Since companies appear to be limited in their ability to price discriminate among producers within the North American market, the rate of adoption is different depending on the region and the agronomic characteristics of farmers. On an international level, however, there is evidence of price discrimination.

Finally, the recognition of market power is important in understanding other aspects of the behaviour of firms in the seed and chemical companies. In an examination of the behaviour of life science companies, Hennessey and Hayes (2000) attempt to infer the structure of the market from the strategic decisions made by the life science companies with respect to the tying of seed and chemical products. The starting point of their analysis is that the presence of tying strategies — the linking of the sale of seed and chemicals — means that seed and chemical companies have market power. Hennessey and Hayes provide evidence that the behaviour of Monsanto up to the 1998 crop year is consistent with Monsanto having a monopoly in Roundup Ready™ technology, all the while facing substantial competition in the chemical (glyphosate) market. After 1999, the behaviour of Monsanto is more consistent with a model in which Monsanto is involved in a duopolistic seed market and a relatively competitive chemical market.

SUMMARY AND CONCLUSIONS

In the past ten years, the seed and pesticide industries have seen a substantial number of mergers and acquisitions, an increase in vertical and horizontal integration, and an increase in the importance of multinationals, particularly in the seed industry. These structural changes have occurred at the same time that the legal framework of intellectual property

rights (IPRs) has been substantially strengthened, and as transgenic technology has been used to develop new products (Lindner, 1999).

The structural changes under way in the seed and chemical industries are owing to a number of factors. Some are common to all industries and have no specific link to biotechnology. For instance, the mergers and acquisitions in the seed and chemical industries are, at least in part, a result of the need to consolidate costs and rationalize industry capacity, a desire by the management of the firms involved to extend their spheres of influence, and a wish by some firms to pre-empt other firms from taking over valuable assets.

Intellectual property rights and the nature of biotechnology products are also important in understanding the structural changes that have occurred. The horizontal mergers and acquisitions in the seed and chemical industries can be linked to the R&D costs, economies of scale and scope, and to regulatory costs. The increased vertical linkages in the industry are linked to the product complementarity that is increasingly present between seed and chemical products, as well as to the difficulty in enforcing certain types of intellectual property. In other cases, the rise of better-defined intellectual property rights has been a factor in the joint ventures and strategic alliances that have taken place.

The large firms in the seed and chemical industries clearly enjoy some market power, although the degree of market power appears to have remained relatively unchanged over the past ten to fifteen years. One conclusion that can be drawn is that the key impact of market power is not on the total economic surplus (i.e., the size of the pie), but rather on the distribution of the surplus (or pie) (Sexton, 2000). Moschini *et al* (2000) provide evidence of this outcome in the agricultural biotechnology area. In a study of the soybean complex, they show that increased market power by the seed and chemical industry leads to fewer benefits for farmers using the herbicide-resistant technologies and less benefit for the groups processing soybeans. However, these losses are almost completely offset by gains to the biotechnology companies. Thus, while the overall benefits were not unduly affected by the exertion of market power, the distribution of these benefits was substantially affected.

Notwithstanding these results, relatively little is known about the impact of concentration, and substantially more research is required. In particular, little is known about the trade-off that is inherently in place around IPRs and concentration. At their most basic level, IPRs convey a monopoly, albeit for a limited period of time and for a limited product, to the company or individual possessing the intellectual property. IPRs provide the incentive for innovation and encourage the diffusion of new technologies (Gallini and Trebilcock; Lesser, 1998). Thus, there is always a need to ensure that a proper balance is achieved between the benefits and costs of IPRs. To date, the research on this question has not been undertaken.

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Table 1: World Sales of Top Ten Pesticide and Seed Companies

Company	1997 Pesticides	1997 Seed	1999 Seed	1998 Plant Biotech
	millions $			
DuPont (Pioneer) USA	2,518	1,800	$1,850	
Pharmacia (Monsanto) USA	3,126	1,800	$1,700	88 %
Syngenta (Novartis) Switzerland	4,199	928	$ 947	4 %
Groupe Limagrain (France)		686	$700	
Grupo Pulsar (Seminis) Mexico		375	$531	
Advanta (AstraZeneca and Cosun) UK and Netherlands	2,674	437	$416	
Sakata (Japan)		349	$396	
KWS AG (Germany)		329	$355	
Dow USA	2,200		$350	
Delta & Pine Land (USA)			$301	
Adventis Group (Hoechst/Rhone-Poulenc)	4,554			8 %
Bayer	2,254			
American Home Products	2,119			
BASF	1,855			
Sumitomo	717			
Agribiotech		425		
KWS		329		
Takii		300		
Total World Sales	30,900	23,000	24,700	
CR4	47 %	23 %	21 %	100 %
CR10	85 %	32 %	31 %	100 %

Source: Brennan et al*; RAFI (2000)*

Table 2: Major Mergers and Acquisitions By Selected Chemical and Seed Companies

Company	Date	Action
MONSANTO	March 1996	Increase equity stake in DeKalb Genetics
	April 1996	Acquired plant biotech assets of W.R. Grace & Co.
	September 1996	Acquired Asgrow Agronomics from Epmresas La Moderna
		Acquired Holden's Foundation Seeds, Inc., Corn States Hybrid
	January 1997	Service, and Corn States International
		Completed purchase of all outstanding shares of Calgene Inc.
	May 1997	Acquired Sementes Agroceres S.A. (Brazilian corn seed)
		Acquired Plant Breeding International (Cambridge)
		Acquired international seed business of Cargill Inc.
	November 1997	Purchased remaining 55% of DeKalb Genetics
	July 1998	Merger of Monsanto and Pharmacia-Upjohn to form Pharmacia
	October 1998	Corporation.
	December 1998	
	April 2000	
DOW AGROSCIENCES	January 1996	Dow Elanco acquired 31% of shares in Mycogen
	December 1996	Dow Elanco receives controlling interest (51.8%) in Mycogen with purchase of shares from Pioneer Hi-Bred
		Dow Chemicals acquires the 40% share of Dow Elanco from Eli
	May 1997	Lilly and Company (Dow Elanco now wholly owned by Dow Chemicals. Becomes Dow Agrosciences)
		Purchase of Sentrachem (South African chem. Co)
		Extension to 63% ownership of Mycogen
	December 1997	Acquired remainder of Mycogen
	March 1998	Mycogen then purchases both Hibridos Colorado Ltda. and FT
	September 1998	Biogenética de Milho Ltda. In the same month Mycogen
	November 2000	acquires Cargill Hybrid Seeds from Cargill International
NOVARTIS AG	December 1996	Novartis formed via merger between Ciba-Geigy and Sandoz
		Purchased Merck &Co.'s crop protection business
	May 1997	Purchase of Oriental Chemical Industries' crop protection
	May 1998	division
		Purchase of Seoul Seeds Co. Ltd.
	1998	Purchase of Agritrading (Italian seed co)
	August 1998	Acquired 50% equity in Wilson Seeds Inc. (owned by Land O'
	1998	Lakes)
		Novartis and Zeneca Agrochemicals merge to form Syngenta
	October 2000	
AGREVO (AVENTIS CROPSCIENCE)	1994	Formation of AgrEvo via merger between Hoechst and Schering
		Purchase of Plant Genetics Systems (Belgium)
	August 1996	Purchase of Nunhems (vegetable seed)
	1997	AgrEvo acquires India-based Proagro
	February 1999	AgrEvo merges with Rhône Poulenc Agro to form Aventis
	December 1999	CropScience

DUPONT	September 1997 April 1998 October 1999	Acquires 20% of Pioneer Hi-Bred International Seeds Acquires Hybrinova S.A. (wheat breeder) Acquires remainder of PHI.
ZENECA AGROCHEMICALS	1997 December 1997 October 2000	Acquires Mogen International Acquires Ishihara Sangyo Kaisha Ltd. (fungal control) Novartis and Zeneca Agrochemicals merge to form Syngenta

Figure 1: Mergers and Acquisitions By Diversified Biotechnology Firms
Source: Kalaitzandonakes and Hayenga

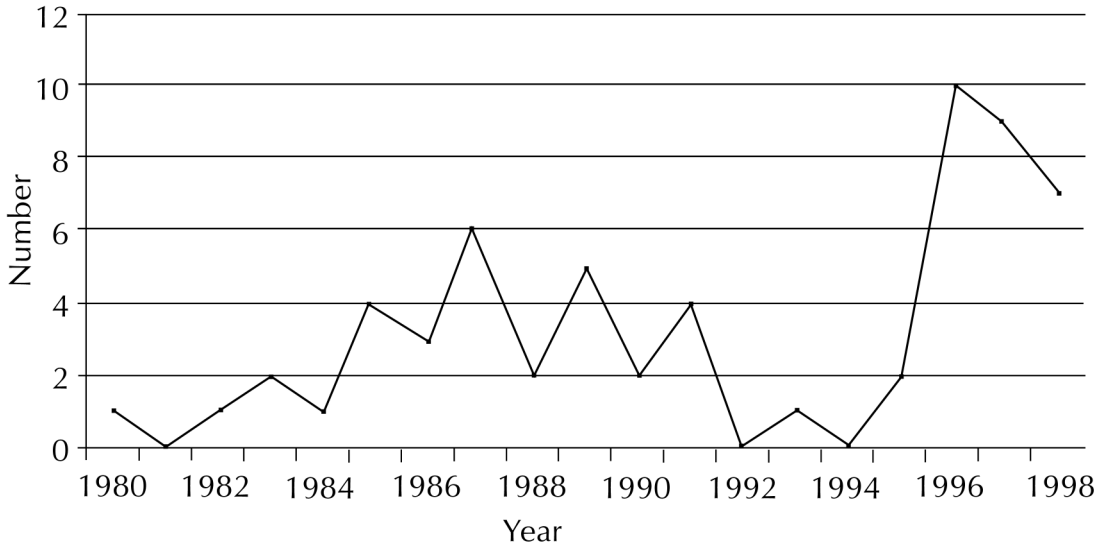


Figure 2: Monsanto Acquisitions, 1990–1999
Source: Gray

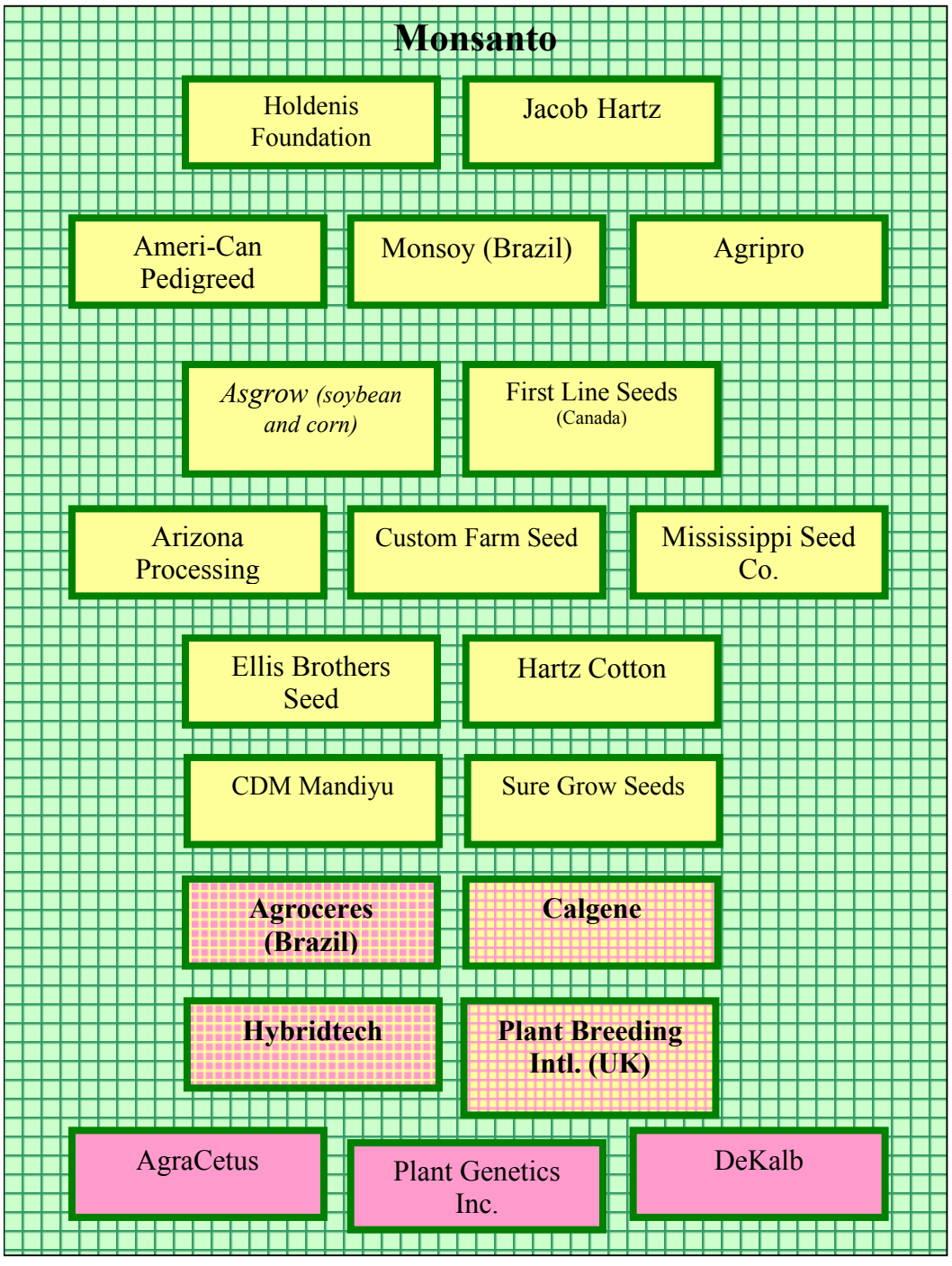
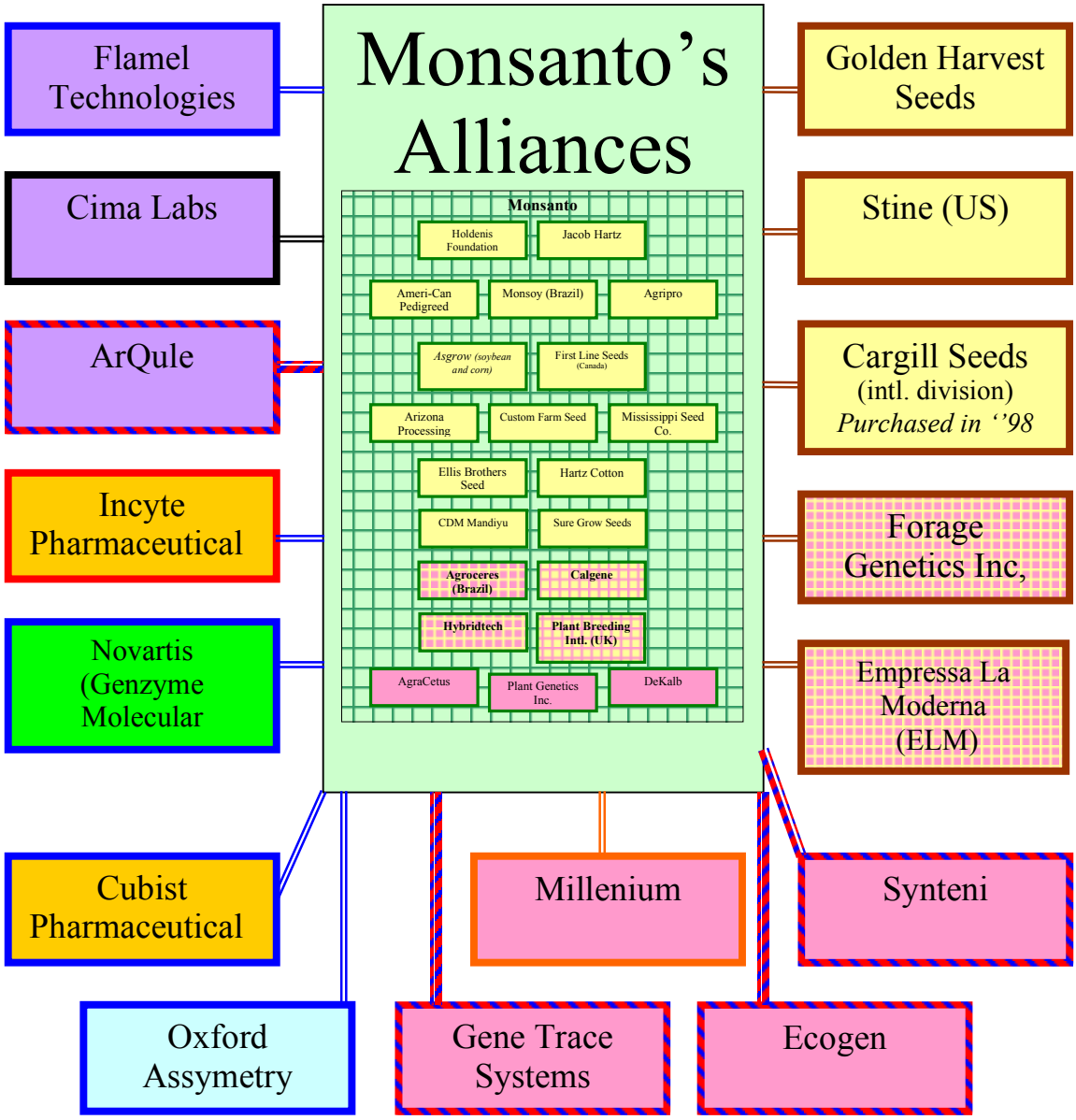


Figure 3: Monsanta's Strategic Alliances, 1990 to 1999.
Source: Gray.



Key to Figure 3

Company Type	Colour of Box	Agreement Type	Colour of Link
Seed	Yellow	Research and Development	Navy
Agbiotech	Mint Green	Liscensing Agreement	Dark Red
Biotech	Pink	Joint Venture	Orange
Cehmical	Lavender	Equity	Grey
Pharmaceautical	Mustard	Other	Black
Other	Sky Blue		

3.0 Environmental Impacts of Transgenic Crops

Jan Stevens

THE ISSUE

In any examination of genetically engineered crops, one controversial issue that arises is their impact on the environment. The debate is adversarial; activist groups vehemently protest the dangers presented by the release of GMOs while producers and corporations rally just as vigorously in their defence. Informed, knowledgeable discussion on the issue is rare, especially in the popular press. This chapter will strive to present the legitimate environmental issues in a reasonable manner that accurately reflects the scientific knowledge behind biotechnology.

To date, most genetically modified agricultural crops offer herbicide tolerance, insect resistance, and/or virus protection. Briefly, the environmental concerns surrounding these transgenic crops can be expressed in terms of:

- Gene flow / Seed dispersal
- Outcrossing with non-modified plants
- Development of pest resistance
- Adverse effects on non-target organisms

IMPLICATIONS AND CONCLUSIONS

Concerns over the impact of agriculture on the environment are valid and must be addressed. Indisputably, it is the consensus of the scientific community that risk assessment must focus on the characteristics of the plant itself and the environment into which it is to be introduced rather than on the method of genetic manipulation by which it was produced; the product, not the process, must be the focus of investigation. It is, then, of critical importance to note that these environmental issues do not relate exclusively to transgenic crops. Rather, any real or perceived risks pertain equally to traditionally bred plants. The genetic engineering process used to create GMOs, however, has the advantage of being a more precise, faster, and cheaper way of bringing about desired genetic change. The extent and pace of genetic innovation will require, increasingly, that more resources be made available for testing and registration purposes.

Scientific evidence would suggest so far that the environmental impact of genetically engineered crops has been positive. For instance, the environmental advantages of herbicide-resistant crops have clearly outweighed the disadvantages. Besides an overall

reduction in herbicide application, the reduction in tillage and soil erosion is particularly significant. Any problems that have arisen — for example, herbicide-resistant volunteer canola — have been manageable using standard farm management practices. Herbicide resistance is not an issue in unmanaged areas where herbicide is not traditionally used.

The impact of pest-resistant transgenic plants is somewhat more controversial. There are ongoing studies to determine if genetically engineered, insect-resistant plants accelerate the inevitable development of pesticide-resistant insects, but to date, the reliable, constant, and predictable dosages offered by GM crops seem preferable to the often unreliable, inconsistent, and unpredictable consequences of spraying.

Virus-resistant crops are truly in their infancy. No problems have arisen with them, either, but this area will require continuing vigilance on a case-by-case basis.

In Canada, the established regulatory systems have proved to be dependable and well equipped to monitor any potential adverse impacts of agricultural crops, whether transgenic or traditional. As more genetically modified crops are introduced in the near future, it is of paramount importance that sufficient resources be allocated to regulatory agencies. This is especially true since increasingly complex concerns, such as gene stacking and multiple tolerances, will be the next issues with which farmers, industry, and regulators must grapple. The development and introduction of stress-resistant crops will require, further, that regulators not only assess the risks that these crops present, but also that these risks be weighed against the benefits of their release.

BACKGROUND

Genetic Engineering: The Process

The term "genetically modified," or "genetically modified organism," is somewhat misleading. Virtually all agricultural crops have been genetically modified over time by traditional selective breeding methods. Rather than "GMO," the scientific community prefers such descriptions as "genetically engineered"; "genetically transformed"; "rDNA technology"; "gene splicing"; or simply, "transgenic." In this paper, the terms will be used interchangeably.

Very simply, the generally accepted definition of "GMO" is any plant which contains recombinant DNA; that is, in which DNA has been recombined from one organism to another. This is accomplished by identifying a single gene out of the thousands of genes in an organism, manipulating it in the laboratory, then transferring it or introducing it into a host plant cell, and later recovering a complete new organism (Lemaux, 2000b).

There are many traditional methods of genetic modification, including selective crossbreeding and hybridization. Others include interspecies and intergeneric protoplast fusion, in vitro gene transfer techniques, somaclonal selection, haploid doubling, and mutagenesis (McHughen, 2000). These techniques have become increasingly sophisticated

over the years, but they still rely largely on the process of hybridization. Generations of plants must be produced, from each of which the most desirable are taken and bred. The development of an improved plant through traditional means is a time-consuming process, taking up to fifteen years before a crop is ready for the market.

Recombinant DNA technology, on the other hand, offers the advantage of increased precision in the breeding process. Because only one specific, well-characterized gene is spliced into a target plant, the process may take only one or two generations, at most. Valuable time, and costs, are saved in getting a crop to market.

Even if concern over transgenic crops were focused solely on the process rather than the product, there are considerable advantages to the process itself. As Dr. James Cook, a plant pathologist from Washington State University, states, "since traditionally bred crops are accepted as the standard of safety, then crops developed by genetic engineering are at least as safe and are probably safer because of the greater precision of the genetic modifications and knowledge of the protein products and their function" (Cook, p. 38 1999).

Moreover, if a desired trait is not available in a sexually compatible plant, no amount of traditional breeding will yield an improved strain. Genetic engineering, in such cases, becomes the only option. This is also true in instances where the desirable trait *is* available in a sexually compatible plant, but is inextricably linked to an undesirable trait — for example, an unpleasant taste.

Genetically Engineered Crops Currently in Production

Essentially, the products currently in production are the result of herbicide- and insect-resistant crops. They represent what has been called the "first wave" of agricultural biotechnology, and they reflect the developments of ten to fifteen years ago. In terms of genetic engineering, these qualities were relatively easy to develop, as they involved transference of single, easily identifiable genes. In the future, as crops with multiple desirable traits are introduced, today's technology will seem elementary by comparison.

In Canada today, there are forty-three novel foodstuffs,[2] including fifteen corn, eleven canola, five cotton, four potato, three tomato, two squash, one flax, one soya bean, and one wheat (Health Canada, 2000). Of all the "first-wave" GMO crops, of particular importance to Canadian farmers is herbicide-resistant canola. Canola is this country's second largest crop, with 13.7 million acres planted in 1999, and gross revenues almost equal to the revenues from the sale of spring wheat (Canadian Canola Growers Association, 1999). Canola represents Canada's most significant foray into genetic engineering; it is estimated that 55% of canola crops planted in 2000 were modified (Buth, 2000).

[2] The Canadian regulatory system is based on product novelty, not process. So, of these forty-three foodstuffs, not all were the result of genetic engineering. Some, such as imidazolinone-tolerant wheat, were produced by such traditional breeding methods as mutagenesis (CFIA, 1999d).

The most common modified canola is Roundup Ready, which has been genetically altered to tolerate Roundup herbicide (glyphosate) produced by Monsanto. Glyphosate is a broad-spectrum, low-toxicity herbicide that degrades quickly in the soil and is safe for humans and animals. Similar products include Liberty Link canola, which is produced by AgrEvo and is resistant to glufosinate, and Rhone-Poulenc Rorer, which produces bromoxynil-tolerant canola and was grown for commercial production in Canada for the first time in 2000 (Buth, 2000). There are also smart canola varieties that are resistant to Odyssey and Pursuit, but they are not considered to be genetically engineered, as they originated from induced mutations (Canadian Canola Growers' Association, 1999).

Crops designed to be insect resistant also play an important role in Canadian agriculture. Of special interest is corn, which is Canada's third-largest grain crop, after wheat and barley. Corn was grown on almost three million acres in 1999, producing seven million tonnes of grain. It is estimated that 30% of that crop was genetically engineered, either for herbicide resistance or to contain the naturally occurring soil bacterium *Bacillus thuringiensis*, commonly called Bt, or both (Ontario Corn Producers' Association, 2000). Bt plants are designed to express various forms of toxins that kill target insects, especially, in the case of corn, the insidious European corn borer.

Also available are products that are the result of virus-resistant crops, specifically squash and potato. Just as humans are vaccinated for protection against disease, these crops are engineered to develop immunity to viral infections that commonly affect them. Genetic engineering has been particularly valuable in this area, as resistance to many plant pathogens is not available in sexually compatible species. Biotechnology is, in many cases, the only option. Since pest epidemics can devastate entire crops, and thus rural communities in general, biotechnology is a valuable agricultural tool with immense potential. In the future, more virus-resistant crops can be expected.

Herbicide-Resistant Crops

Herbicide-resistant crops are designed to tolerate broad-spectrum herbicides. Thus, it has been reasonable, or at least understandable, for the public to conclude that there will be an ever-increasing amount of herbicide applied to agricultural crops. This, however, is not the purpose — nor has it been the result — of this genetic modification. Rather, these crops allow the application of a single, broad-spectrum herbicide to an established crop rather than the traditional pre-emergence and post-emergence cocktail of up to fifteen conventional herbicides that provides only partial weed control (McHughen, 2000).

There have been other fears surrounding herbicide-tolerant crops. In particular, opponents claim that their introduction will upset delicate ecosystems, that they will reproduce unrestrictedly and be impossible to eradicate. Scientists are "letting the genie out of the bottle." There are also concerns that these plants will cross-breed with nearby weeds, creating "superweeds." Meanwhile, the benefits of the technology are ignored, as well as its potential to improve the environmental impacts of farming, and increase agricultural sustainability generally.

The Gene Flow / Seed Dispersal Concern

The phrase "letting the genie out of a bottle" implies that transgenic plants represent some extraordinary force that is being unleashed into the environment and will become an uncontrollable pest. It implies that genetically engineered pollen or seed will escape, spread throughout the community, and establish itself where it falls. Fortunately, this fear is easy to allay, for it is based on the misconception that genetically engineered plants will behave like non-indigenous plant pests. For example, the kudzu vine, a ubiquitous weed, has been impossible to eradicate since it was introduced to the United States in the 19th century. Similarly in Canada, the major weed problems that reduce crop yields are plant species that have been introduced as ornamentals. Of the top twenty weed species in Saskatchewan, eighteen were introduced, mostly from Europe and Asia, and only two are native plants (Canadian Canola Growers' Association, 1999). These species became pests because they were introduced into an environment to which they are suited and in which they have no natural enemies. Crop plants that have been genetically engineered, however, are merely *reintroduced* "into the same or a similar environment from which they were taken, so they are not analogous to the introduction of nonnative species" (NAS, p. 14 1987). Thus, the comparison of GM crop plants to non-indigenous plants is inaccurate at best. It is important to remember that a trait such as herbicide resistance is a minute modification of an established crop plant, about which there is already a storehouse of knowledge. Because the genetic variation is performed on a plant whose traits are already well known, there is a broad base upon which to predict future behaviour.

It is important also to note that there is no evidence that any crop plant has ever become a weed. The National Academy of Science describes the chances of a crop plant reverting to a weedy condition as "negligible" (NAS, 1987). No crop plant is designed for survival in the wild, but is, as the result of generations of development, dependent on human nurturing to survive. The longer a plant has been cultivated, the less likely it is to become weedy, as these traits will have been deliberately bred out of it for generations. To expect a crop to survive in the wild is analogous to expecting that "a Chihuahua would survive in a pack of wolves" (Trewavas, p. 4 2000). A plant's propensity toward weediness will not be increased merely by gene-splicing a herbicide resistance trait into it, as it is merely one alteration to one of many genes that the plant already possesses.

Nonetheless, the impact of the resistance gene will be felt in agricultural fields, manifested by the emergence of, for example, Roundup-resistant volunteer canola. Volunteers can complicate crop rotations, but they can be controlled through standard management practices. Even though they will not be eradicated by the application of Roundup, they will still be susceptible to Liberty. Alternatively, farmers have been advised to add 2,4-D or MCPA to their Roundup mix in order to achieve an effective chemfallow (Canadian Canola Growers' Association, 1999).

Outcrossing

Outcrossing refers to the cross-hybridization of a crop plant with a weedy relative. The concern here is that herbicide- or pest-resistant crops could breed with nearby weeds, creating what have been called "superweeds." It is a misleading term. A herbicide-tolerant plant that breeds with a weed does not make the weed a greater pest; rather, it makes a weed that is resistant to a specific herbicide. In the wild, the transfer of herbicide resistance is not relevant, as herbicides are not sprayed in unmanaged environments. Because there would be no selection pressure to retain the trait, it would likely disappear in a matter of generations (House of Lords Select Committee, 1999). In an agricultural setting, or in ditches or along roadsides where herbicides are traditionally sprayed, these weeds would be handled by traditional management practices.

Many conditions must be present in order for cross-hybridization to occur in the first place. There must be a wild relative with which the crop plant can breed. Most of the novel plants so far approved for release in Canada — including potatoes, tomatoes, corn, soybean, and flax — do not have wild relatives (CFIA, 1998a). In the event that a wild relative does exist, as is the case for canola and squash, many further conditions must exist in order for outcrossing to occur. The wild relative must be in range of the crop pollen, and it must flower at the time that the crop pollen is available. Fertilization must occur in the wild relative, producing viable seeds. These seeds must then survive and germinate, and the progeny of the hybrid seeds must be fertile or survive vegetatively (OECD, 1993). Even if the progeny is fertile, it still has thousands of crop plant genes, and is unlikely to survive untended.

In the event that the potential for environmental damage is significant, regulatory safeguards prevent the release of a dangerous organism. The Canadian Food Inspection Agency (CFIA) has the authority to discontinue field trials and suspend further development of the plant if it feels so justified. The CFIA derives its authority to deal with plants with novel traits, including those produced through genetic engineering, under the *Plant Protection Act* and the *Seeds Act*. An important part of the CFIA's assessment process involves a thorough investigation of the risks of outcrossing. The "novel trait" — in this case, herbicide resistance — is examined carefully, including an analysis of the presence of weedy relatives to the plant itself, and the significance of that relative in managed and unmanaged ecosystems. Each novel product is examined on a case-by-case basis; if it is determined that the product raises no potential environmental concerns when compared to its traditionally developed counterparts, it will be considered acceptable (CFIA, 1998b).

Have Herbicide-Resistant Crops Reduced Chemical Inputs?

Because the technology is so new — Roundup Ready crops were first grown commercially in 1996 — statistics regarding reduced herbicide application are just now becoming

available. In the United States, the Federal Department of Agriculture (USDA) indicates that the adoption of genetically engineered crops is associated with a decrease in the number of acre-treatments of pesticides — that is, the number of acres treated multiplied by the number of pesticide treatments (Heimlich, 2000). It is more difficult to calculate the reduction in volume of active ingredients. For example, while there was a rise in the amount of Roundup used on United States soybean crops as the adoption of transgenic crops increased, the use of other synthetic herbicides decreased by a greater amount (Economic Research Service, 1999), so there was a significant decrease in *overall* herbicide application. It is important to note, when comparing different mixes of herbicides, that synthetic herbicides are at least three times as toxic as glyphosate and persist in the environment nearly twice as long (Heimlich, 2000).

Concern has been expressed that, if the use of Roundup is increasing because of the advent of GM crops, the weeds will eventually develop resistance to glyphosate. Certainly, the development of herbicide-resistant weeds is a problem with conventional programs. This is because traditional herbicides (including imidazolinone, sulfonylurea, and sulfonamide) all have the same mode of action, inhibiting the ALS (acetolactate synthase) enzyme. Several ALS-resistant weed populations have emerged, limiting the effectiveness of these compounds (Carpenter and Gianessi, 1999). However, glyphosate is *not* an ALS-inhibiting herbicide; it is a post-emergent herbicide that inhibits the protein EPSP synthase. This unique mode of action and lack of residual activity greatly reduce the chance that resistant weeds could appear over time in a weed population (Monsanto, 1998).

An independent Monsanto study indicated that Roundup Ready crops required 10%-40% less herbicide in total. This research also noted that Roundup Ready soybeans had pesticide residue levels one-third the maximum level for conventional soybeans (Monsanto, 1999). The best results were realized by farmers who had previously been experiencing troublesome weeds, such as stork's bill or cleavers, that were difficult to control with traditional methods. Less-significant gains were realized with the easier-to-control weeds, but farmers still appreciated the ease and simplicity of a herbicide-resistant crop (Lemaux, 2000b). Dr. C. S. Prakash estimates that this reduction in herbicide application saved North American farmers U.S. $30 per hectare, and also increased crop yield due to less competition from weeds (Prakash, 1999).

Other Benefits of Herbicide-Resistant Crops

Herbicide-resistant crops were designed to have advantages other than reduced chemical inputs. Most significant is their ability to reduce tillage and lower soil erosion. In a zero-tillage system, seed is placed directly into the soil with a seeder, allowing the soil to remain undisturbed. As Dr. Cook notes, "I can say from working in this area over these two decades that no herbicide has done more than Monsanto's Roundup to allow farmers to move towards the use of no-till farming. The availability of crops with built-in resistance to Roundup only means that more crops can be grown without the use of tillage"

(Cook, p.29, 1999). Farmers also appreciate the flexibility and increased weed control strategies that herbicide-resistant crops afford. They can seed their crops earlier in the spring, thus avoiding periods when certain disease and insect infestation are common. Compared to traditional herbicides, crop injury is dramatically reduced, and there is no carryover to rotational crops. Fewer passes in the field reduce manpower and fossil fuel costs. Weather concerns are allayed, as glyphosate is effective in either wet or dry conditions (Carpenter and Gianessi, 1999). Placing plants closer together, in narrower rows, can increase yields. As Roundup lacks toxicity, farmers prefer to handle it instead of traditional herbicides.

Insect-Resistant Crops

Insect resistance was developed simultaneously with herbicide resistance. It, too, was a relatively simple trait to incorporate, as the most commonly used gene to instill insect resistance is the naturally occurring *Bacillus thuringiensis*. Bt, as it is known, is a natural pesticide that has been widely used since the 1950s in insecticidal powders. It is certified organic, and organic farmers rely on it heavily. Bt toxins are very specific in the species they affect, and exhibit low toxicity to humans and other animals (McHughen, 2000).

Although the agricultural community has always embraced Bt, the fact that it has now been inserted directly into the plant through the process of genetic engineering has raised special concerns — particularly that, because transgenic Bt crops express Bt toxins in their tissue at all times (as opposed to spraying, which is periodic), the development of pesticide-resistant insects will accelerate. Parallel to the term "superweeds," such insects have been named "superpests."

It has also been suggested that the process of genetic modification could have a detrimental impact on the existence of beneficial, non-target insects such as the Monarch butterfly. This concern arose from a preliminary laboratory study that was published as a letter in the scientific journal *Nature.* The exquisite Monarch, already an unofficial symbol of conservation, thus became the "Bambi" of the GM debate. Meanwhile, studies that have outlined the advantages of Bt crops have been largely ignored.

Development of Pest Resistance

Insects have always been remarkably adept at developing resistance to insecticides, and are ever evolving in an effort to assure the survival of their species. As Dr. Cook notes, "This issue is not new to agriculture" (Cook, p.42, 1999). It is commonly accepted that, since resistance-proof insecticides do not exist, it is imperative to stay one step ahead of the insects. So, Bt resistance is to be expected, whether or not Bt crops are used. This is a grave concern to *all* farmers, as well as to governments and regulators. It is a legitimate issue, but it is not a GM issue *per se*; rather, it is a management problem that applies equally to traditional as well as organic agriculture. Resistance must be avoided if possible, as the loss of availability of Bt would have far-reaching consequences.

In Canada, the Canadian Food Inspection Agency (CFIA) has stepped in to help farmers develop insect resistance management (IRM) programs. Compliance is voluntary and that there is no enforcement mechanism in place. Nonetheless, CFIA makes the following recommendations:

- All growers should plant a minimum of 20% non-Bt corn not sprayed with insecticides;
- Non-Bt corn should be planted within one-quarter mile of the farthest Bt corn in a field to provide a refuge where Bt-susceptible moths may exist;
- Non-Bt corn hybrids for use as refuges in a field should be selected for growth, maturit,y and yield traits similar to the Bt hybrid used in the remainder of the field;
- Refuge areas may be planted in blocks on the edges or headlands of fields or in strips across the entire field. When refuge corn is planted in strips across a field, a minimum of six rows should be planted with non-Bt corn alternating with Bt hybrid across the entire field. Refuge created by mixing seed in the hopper is ineffective;
- The Bt Corn Coalition recommends that individual corn producers using Bt technology be responsible to ensure that the minimum 20% refuge occurs on their farm. (CFIA, 1999)

The basis for this IRM plan is the belief that these refugia will allow Bt-susceptible insects to survive and multiply. They will then be available to breed with resistant insects. Assuming, genetically, that pesticide resistance is a simple recessive trait, then it is less likely that two resistant insects will mate and produce offspring that are homozygous, or completely resistant to Bt (CFIA, 1999).

Ongoing studies are addressing the issue of whether transgenic Bt crops will accelerate pest resistance, but so far there is growing evidence of the advantage of Bt crops over Bt spray. The precision of genetic engineering, allows for a much more accurate and consistent dose of the toxin (Shelton, 1999). This makes refugia much easier to study as scientists seek more information about resistance development. As well, farmers avoid the variable dosages that are an inevitable part of spraying; there is no danger of accelerating resistance through an inadequate dosage. Transgenic Bt will not wash off in the rain, and since sprays make contact only with the tops of leaves, there is no danger with Bt plants that pests who feed on the underside of leaves will evade the toxin (Felsot, 2000).

Bt plants attack only those insects that prey upon them, as opposed to sprays, which will attack all susceptible insects in the field (House of Lords Select Committee, 1999). This may also be a factor in determining whether resistance is accelerated or postponed by the use of transgenic Bt crops.

Dr. Milton Gordon, a biochemist from the University of Washington, raises yet another point: whereas sprayed Bt is really a cocktail of different Bt compounds, each of which is encoded by a different gene, Bt crops express only one of these genes. Therefore,

he extrapolates, it would be preferable to develop resistance to only one gene rather than to a cocktail of many. In a letter to the U.S. Subcommittee on Basic Research, he states:

> Talking about *Bacillus thuringiensis* toxin as a single compound is very similar to talking about all of the antibiotics that have been discovered and are now being used in humans as a single compound. If the pathogenic bacteria become resistant to one type of antibiotic, it is possible to switch to another type and still get good results. The same is true of Bt. (Gordon, 1999).

Additionally, the technology of "gene stacking" could make Bt plants even more effective than they are today. This would involve inserting multiple genes, each producing a different form of the toxin, into a single plant variety. Thus, an insect would have to be resistant to each form of the toxin to survive. While current Bt crops produce only a single form of the Bt toxin, it is anticipated that future crops will benefit from multiple-resistance genes (U.S. Subcommittee on Basic Research, 2000).

Adverse Effects in Non-Target Organisms

The furor over the effect of Bt crops on beneficial insects arose out of a study done by John Losey and published in a letter to *Nature* in May, 1999. The study, the result of a single laboratory assay, reported the death of 44% of Monarch larvae that were fed genetically modified Bt maize pollen (Losey *et al*, 1999). Those that were fed ordinary pollen survived. The report was interpreted to mean that genetic engineering caused the death of Monarch butterflies. This is a typical example of how the process of genetic modification is confused with its products.

Every entomologist recognizes that the death of *Lepidopteran* insects, including Monarch butterflies and the European corn borer, is the expected result of an application of Bt. The concern that Bt will affect insects other than those that are harmful to crops is undoubtedly valid, but it is immaterial whether the Bt is delivered through a transgenic plant or through a traditional spray used by an organic farmer. Either way, the concern still exists, and needs to be addressed. One problem with the Losey study is that the larvae were not fed maize pollen dusted with ordinary Bt. Had Losey done that, he may have been able to report that larvae fed with ordinary Bt pollen also suffered large losses. Unfortunately, it was this lack of a critical control that enabled the public to make the connection between the process of genetic engineering and the death of Monarch butterflies (McHughen, 2000).

Losey's report was a preliminary study of an experiment that was conducted only once, and it did not address the behaviour of Monarch butterflies in the field; rather, the larvae in the lab were force fed the pollen. Entomologists have long understood that Monarch butterflies are unlikely to ingest Bt corn pollen. Monarchs prefer to lay their eggs

on milkweed plants. Milkweed is considered a noxious weed and is routinely eradicated from farm fields. Corn pollen, meanwhile, is extremely heavy and does not drift far from its parent plant. It is therefore unlikely to be found on milkweed, and Monarchs are unlikely to lay their eggs in areas where Bt pollen is present. Larvae do not like to eat pollen, in any case; they much prefer milkweed leaves that have no pollen on them. But in the Losey study, they had no choice. Even if they did like to eat pollen, Monarch migratory patterns suggest that their larvae are not present when corn is shedding pollen, a process which takes place over a short five- to ten-day period (CFIA, 2000; Felsot, 2000; Irwin, 1999; U.S. Subcommittee on Basic Research, 2000).

The furore over transgenic Bt is perhaps misplaced. Any reduction in spraying should be of advantage to beneficial insects. The refugia recommended by the CFIA to delay the development of pest-resistant insects will also benefit non-target insects, as they will provide a buffer zone between the insects and managed agricultural areas. Perhaps public anxiety will moderate when new lines of Bt corn, now in development, are introduced. These new plants have been modified so that Bt is expressed only in the leaves and tissue of the plant, and not in the pollen. Only insects that attack the corn will be affected (Lemaux, 2000a).

As an interesting aside, entomologists report that Monarch populations flourished in 1999 (Branom, 1999; Felsot, 2000, Prakash, 1999; Trewavas, 2000).

Have Insect-Resistant Crops Reduced Chemical Inputs?

Like herbicide resistance, one of the goals of insect-resistant crops is to reduce overall chemical inputs. Again, because the technology is so new, the results are just starting to come in. For some crops — for example, cotton — the reports have been astonishingly positive. It is estimated that, in the United States, there has been a reduction of two million pounds of insecticides that have traditionally been used to control the tobacco budworm, the cotton bollworm, and the pink bollworm that feed on cotton. As a result, yields and returns are expected to increase dramatically (Carpenter and Gianessi, 1999).

The story is much more complicated for Bt corn, however, for it is difficult to measure the overall impact of chemical reduction. This is because of the problems that farmers have traditionally experienced in eliminating the European corn borer. As its name suggests, this insect bores its way into the corn stalk, where it is impervious to Bt sprays. Any spraying for the European Corn Borer is a matter of delicate timing: the insect must be found and destroyed before it has had the opportunity to get into the stalk. Because the window of opportunity is so small, few farmers (about 5%) bother spraying at all (Carpenter and Gianessi, 1999). As a result, prior to the introduction of Bt crops, the European corn borer was largely uncontrolled, and caused massive production losses, ranging from thirty-three to over 300 million bushels per year (Carpenter and Gianessi, 1999).

The advent of Bt corn may not have reduced chemical inputs *per se*, but there have been substantial yield increases in many circumstances. In the United States there were yield advantages of approximately twelve bushels per acre in 1997 and four bushels per acre in 1998 (Carpenter and Gianessi, 1999). Overall, depending on the level of infestation, corn growers can expect a gain from using Bt crops (Carpenter and Gianessi, 1999; CFIA, 1999; Powell, 2000).

Virus-Resistant Crops

In a discussion of herbicide- or insect-resistant plants, the concern is the impact of gene flow from the transgene to the same, or a related, species of plant. With virus-protected plants, however, there is the *additional* concern that the virus will flow to other viral populations. Of particular concern is that the virus resistance transgene will recombine with an attacking virus, creating a virus with modified biological properties (Teycheney, 2000). Potentially, these modified viruses could have greater virulence or a broader host range. To date, this has not happened; neither potato nor squash has been the source of any new virus. In field tests, even crops injected with other viruses have not caused recombination. In Hawaii, a virus-protected papaya plant has been extremely successful and stable over years of testing (McHughen, 2000). As yet unpublished research suggests that fears of viral recombination may not be as serious as once thought, owing to the potential effects of gene silencing (Allison, 2000). In any event, virus-protected plants will have to be considered on a case-by-case basis, weighing the advantages against the risks. The potential for these kinds of crops is vast if it means that previously virus-infested regions can be made arable.

DISCUSSION

It has been shown that transgenic crops have been manageable, so far, using traditional agricultural methods. As biotechnology improves, however, and more and more traits are introduced, there may be increasing potential for environmental impacts. Already there is some concern about "pyramid" effects. In Alberta, for example, canola volunteers have emerged that are impervious to both Roundup and Liberty (AgWest Biotech, 1999). Should such resistances be allowed to "stack," giving rise to weeds that are tolerant to a range of herbicides, fewer conventional management methods would be available to control them. Eventually, farmers could end up using increasingly more herbicides to eradicate these weeds, thus damaging non-target biodiversity (Johnson, 2000).

Strategies have been proposed to minimize the effects of potential gene stacking. For example, farmers may be advised not to plant crops with differing herbicide tolerances adjacent to one another. This approach, however, is largely dependent on the co-operation of farmers. It may be necessary to devise alternate ways of achieving genetic isolation using traditional knowledge about isolating certain conventionally bred crops. There may be some areas in which it is determined that transgenic crops should not be introduced at

all. Further research should be done in the area of genetic isolation, including the potential for "one-use" crops to eliminate the risk of gene flow. These types of crops could be developed in a variety of ways, including male sterility, pollen incompatibility, altered flowering times, and genes conferring negative fitness (frost susceptibility, for example) closely linked to the transgene (Johnson, 2000).

It is critical to remember that herbicide- and insect-resistant plants represent the "first-wave" products of agricultural biotechnology. The "second-wave" crops will have more tangible environmental benefits. Crops resistant to such stresses as drought, frost, and salinity will have the obvious advantage of allowing producers to use previously non-arable land to grow food. However, while herbicide resistance is of no advantage in the wild, where herbicides are not sprayed, frost resistance (for example) is an advantage anywhere. A frost-resistant crop plant could potentially cross-breed with a weedy relative, survive, multiply in the wild, and be the sole survivor of a killer frost. Given all that is known about crop plants, this is unlikely. A frost-resistant weed would still contain thousands of crop-plant genes and be unlikely to survive without human intervention. Still, the advantage that stress resistance gives must be kept in mind. The risks of introducing stress-resistant crops must be weighed against the advantages (House of Lord's Select Committee, 1999).

Fortunately, the Canadian regulatory system examines each plant with a novel trait, including those produced through genetic engineering, on a case-by-case basis, and the CFIA is equipped to assess and monitor any potentially adverse environmental effects. The CFIA does not, however, address the environmental *benefits* that a novel trait may present. The British House of Lord's Select Committee recommends that risk assessments instead be called "environmental impact analyses" that include benefits as well as risks. The Canadian regulatory system could certainly benefit from this approach; at the least, it would be a means of providing the public with more balanced information.

Environmental impact analyses would be especially beneficial when considering the release of virus-resistant plants. As these crops may expose ecosystems to more complicated risk factors, it will be imperative to weigh these risks against the potentially enormous benefits these crops offer. Continued research in the area of viral recombination is essential.

The Canadian regulatory system has also been effective in establishing IRMs for the management of insect resistance development. So far, the high dose/spatial refuge strategy has been successful. Target insects should be monitored for genetic changes that might indicate that resistance to Bt is developing, so that the CFIA can make changes to its IRMs if necessary. Despite the strongest efforts of governments and regulators, however, ultimate resistance to Bt may be inevitable. Alternative organic pesticides should be investigated so as to minimize the potential loss of Bt to organic farmers.

Efforts must continue in examining the effects of Bt on non-target insects. The advantages versus the disadvantages of transgenic Bt must be considered in this regard.

Regulators must determine if, for example, the advantage of periodic spraying outweighs the fact that transgenic Bt destroys only those insects that attack the plant directly. The continued development of plants that express Bt only in their leaves and tissue, but not in their pollen, should be encouraged.

Overall, any analysis of the environmental impact of agricultural crops must focus on the characteristics of the plant itself rather than the method by which it was produced. Environmental concerns apply to traditionally bred and genetically engineered crops alike. Any discussion of transgenic crops should take place in the context of crops in general, keeping in mind that, no matter what the method of production, there will always be management issues with which to contend. Agricultural crops, whether transgenic or conventionally bred, will always pose environmental issues, but genetically engineered crops can reduce overall chemical inputs and provide farmers with economic and environmental advantages. Their rate of success is dependent on each farmer's situation. At the least, they can be a valuable addition to a producer's management system.

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4.0 Agronomic Costs and Benefits of GMO Crops: What Do We Know?

Hartley Furtan and Jeff Holzman

THE ISSUE

The introduction of genetically modified crops has been accompanied by questions regarding the potential production costs and benefits of the new technology. First, what happens to the agronomic conditions on the farm, and what does this mean in terms of profitability? Second, what are the impacts of one farmer growing GMO crops on other farmers in the neighbourhood?

The majority of genetically modified crops currently being grown in Canada feature input-reducing traits, the two most common being herbicide tolerance (HT) and insect resistance. Crops with these traits are designed to reduce input and may provide better yields. The issue of the long-term cost and benefits of such crops has not been fully addressed.

Implications and Conclusions

The first conclusion, drawn from the data presented, is that farmers have rapidly adopted GM canola varieties. This is consistent with the forecast economic benefit, which ranges from $5 to $8 per acre. These benefit forecasts do not account for the convenience factor associated with many GM crop varieties.

The longer-term costs and benefits of GM crop varieties have not been measured, because no data yet exist either to validate or dismiss people's concerns. The remote possibility of increased weed infestation due to GM crops must be weighed against the environmental benefits of releasing less herbicide and pesticide into the environment.

BACKGROUND

What are Genetically Modified Organisms?

Genetically Modified Organisms (GMOs) are developed through a process known as genetic engineering, which involves the transfer of genetic material from one organism to another. Genetic engineering allows genes to be transferred between closely related

organisms, but the process also enables genes to be crossed between entirely different organisms (Feldmann *et al*, 2000).

The process of genetic engineering has allowed researchers to transfer a number of desirable traits into plants, including insect resistance and herbicide tolerance. Transgenic crops with these traits were developed in an effort to improve crop yields and reduce the cost of production. Because of these traits, genetic engineering has been important in developing new crops that potentially increase the profitability of agriculture.

The insertion of the Bt gene into plants to develop insect-resistant crops is another example of genetic engineering. Bt, Bacillus thuringiensis, is a bacterium that induces plants to produce a protein that is toxic to certain insects (Feldmann *et al*, 2000). The pest resistance obtained from the Bt gene provides benefits in terms of increased yields, reduced chemical use, and an increase in quality (such as reduced secondary infections).

Another trait that has been successfully inserted into plants through the use of genetic engineering is herbicide tolerance (HT) — although not all HT crops are GMOs; most crops are resistant to some herbicides that are used to control weeds. Inserting the HT trait into plants provides resistance to specific herbicides; that is, tolerance to herbicides that cannot normally be used on those plants. The most common HT trait inserted into plants is tolerance to the chemical Roundup™. The Roundup Ready™ trait was developed by Monsanto and provides plants with resistance to glyphosate herbicides. The gene has been inserted into varieties of cotton, soybeans, corn, and canola. Similar to the case of the Bt gene, the development of HT technology provides potential benefits both in terms of increased crop yields and reduced production costs (Mayer and Furtan 1999).

Flax was the first genetically modified crop to receive regulatory approval in Canada (McHughen, 2000). It is important to remember GM flax was never grown in Canada because producers were afraid of consumer reaction. Canola was the second crop for which GM varieties were developed in Canada. The rapid adoption rate of HT canola in western Canada indicates that farmers have seen benefits in its use. Indeed, HT canola is one of the most rapidly adopted technologies in the history of western Canadian agriculture. The market share of HT canola in Canada has reached 70% of total canola production in 1999 (Fulton and Keyowski 1999). Producers have more than one alternative when considering the use of a HT canola system. The two most common HT canola systems that have become available through genetic engineering are the Roundup Ready™ variety and Liberty Link™. Smart™ canola is HT but is not a GMO; rather, it was developed through a process known as *mutagensis* (see McHughen 2000).

WHY DO FARMERS ADOPT GMO VARIETIES?

Farmers adopt new technology because they believe it is in their best interests economically. The results usually show up as an increase in output or a decrease in production input, either of which can have considerable impact on the profitability of the

farming operation. If the new technology causes a permanent increase in the level of profit, land values will increase to reflect this higher profitability.

Most new technologies result in higher output levels and lower consumer prices. The latter benefit consumers, not farmers, and the consumers of farm products are most often processing firms. These firms are thus able to source their raw product at a lower cost, and some of these savings are passed on to the final consumer. The amount passed on to the final consumer depends on the degree of competition in the processing and retail sector (Moss and Schmitz, 2000).

Why does the cost of production decline when farmers adopt a technological change? First, output may increase without a corresponding input increase, lowering the per-unit cost of production. Second, certain characteristics of the product may change — for example, the rate of ripeness in fruit or resistance to diseases and pests. Finally, management may be simplified, allowing farmers to increase the size of their operations without a corresponding increase in machinery or labour. The use of HT crops, for example, requires a less complex use of herbicides, increasing the farmer's ability to expand acreage. All these factors may cause the cost of production to decline, potentially making the farmer better off.

Canadian farmers have generally adopted new technology when it has become available. The evidence of this is everywhere on the modern Canadian farm — new crop varieties, new breeds of animals, computer-guided equipment — yet many producers feel they have not benefited from the process of adopting new technology. They feel that most of the benefits have been passed on to processors and consumers and, now with biotechnology, input suppliers.

The statement has often been made that, if farmers do not adopt new innovations and technology, they will be worse off economically, but there is no general agreement as to the truth of this statement. If farmers had not adopted Marquis wheat, they would certainly be worse off today. On the other hand, their refusal to adopt rBST in the Canadian dairy industry does not appear to have hurt either dairy farmers or consumers.

Two important assumptions must be made before we can assert that technology improves the economic welfare of farmers. First, we have to assume the new technology does not lower the profit farmers receive for their product after the innovation has been fully adopted. For a small country like Canada, it is usually assumed that an increase in output has no impact on world price. This presumes that other countries do not adopt the same technology. If we take wheat, for example, a new variety made available to prairie producers may also be used in Australia, Russia, or parts of the United States. Taken together, the new variety may lower the world price, reducing benefits to farmers (Edwards and Freebairn, 1984). As shown by Edwards and Freebairn (1985), if the price effect is large, the benefits from adopting the new technology may be negative for farmers. Second, the presence of government subsidies can make the aggregate benefit of adopting new technology negative, especially if the increase in output is exported (Schmitz *et al*, 1997).

For example, a recent paper by Flack-Zepeda *et al* (2000), estimating the benefits of Bt corn, completely disregarded the subsidies corn farmers receive for the production of corn.

ADOPTION OF GMO CROPS

The adoption of GM crops is occurring at a rapid pace. The world area planted to GM crops in 1996 was approximately 6.4 million acres. GM crop production has increased each year since 1996, with an estimated 102.1 million acres of GM crops planted in 1999. The United States is the leading producer of GM crops accounting for 75.4 million acres of the total GM crop acres. Argentina is second, producing 14.3 million acres of GM crops. Canada produced an estimated 9.8 million acres of GM crops in 1999, which accounted for approximately 10% of the total world production of GM crops (Directorate-General for Agriculture 2000).

As of January 2001 there is no publicly available survey or data on how individual farmers have benefited from the adoption of GM crops in Canada. Therefore, it is not possible to say how much economic benefit farmers have experienced from adopting this technology. There are estimates of expected economic benefits, for example Mayer and Furtan 1999, but these remain forecasts until a survey of actual farm experience has been completed.

There have been a few studies completed in the U.S. that estimate the economic benefit to farmers from adopting GM crop varieties, for example Carlson *et al* 1997. These results can not be extended to Canada because in most cases the crops are completely different. As well, some of the methodological assumptions made in the U.S. studies do not apply to Canada, for example the importance of the export market. None the less we do draw on these U.S. studies because they are the best that is currently available.

The majority of Canada's GM crop production has been in the form of HT canola. In 1996, the first commercial production of HT canola took place in western Canada. At this time HT canola accounted for only 4% of total canola acres (see table 1.). After only four years of commercial production the number of HT canola acres had risen to approximately 70% of total canola acres.[3]

Table 1. Adoption of HT Canola in Canada (000s acres)

	1996	1997	1998	1999
Total Canada	8,843	12,040	13,535	13,700
Herbicide Tolerant (HT)	350	4000	6000	9500
Percentage of Total	4	33	44	70

Sources: Fulton and Keyowski 1999, CCGA 1999.

[3] Only 55% of total canola acres are seeded to genetically modified HT varieties (CCGA 1999). This includes both the Roundup Ready™ and Liberty Link™ canola systems.

The rapid adoption of GM crops would indicate that producers have experienced benefits from the use of GM varieties. Producer adoption of GM crops will depend on whether GM varieties provide an advantage in terms of profitability and/or make farm operations more convenient. The profitability criteria will be dependent on a comparison of both the yield and cost of production for GM and non-GM crop varieties (assuming no price differential for either crop). The convenience factor will be measured by estimating the labour and management requirements for GM and non-GM crops.

Yield Comparison of GM and non-GM Crops

The first factor that will determine the profitability of any new crop variety is its yield potential compared to existing varieties. Several studies have been reported that make yield comparisons between HT and conventional crop varieties. The most important factor in comparing HT and conventional crop yields is the level of weed infestation and the subsequent control provided by the herbicide. The major benefit of HT crops is they permit the in crop application of non-selective herbicides such as glyphosate. Non-selective herbicides control weeds such as cleavers, wild mustard, buckwheat, and stinkweed that are traditionally difficult to control with selective herbicides. Controlling these weeds not only provides a potential yield advantage, but also reduces the amount of dockage in the grain.

In the United States, the majority of studies have focused on comparing the yields of HT and conventional soybeans. Fernandez-Cornejo and McBride (2000) found a statistically significant relationship between the adoption of HT soybeans and an increase in soybean yields. Although the yield gains were statistically significant, they were relatively small and varied across regions.

In terms of insect resistant crops, a number of studies have compared the yields of conventional and Bt corn. Trials conducted in the United States found that Bt corn provided yield gains of up to 8% over conventional varieties (Koziel *et al*, 1993). The studies pointed out that yield gains attributed to Bt corn are very sensitive to weather conditions and the level of insect infestation.

There is very little empirical evidence available to show the yield impact of HT canola. The evidence that is available suggests that the adoption of HT canola varieties has resulted in increased canola yields due to improved weed control. Research has also shown that seeding canola in the fall or early spring increases canola yields and reduces the risk of frost. Weed control problems often prevented producers from seeding in the fall or early spring. Introducing HT canola varieties tolerant to post emergent herbicides that control a broad-spectrum of weeds has allowed producers to take advantage of fall or early spring seeding (CCGA, 1999).

Cost of Production Comparison

The second factor that will determine the profitability of GM crops versus conventional crops is the cost of production for each crop, including seed, pesticides, and fuel. In terms of seed, GM varieties are generally more expensive than conventional seed varieties. On the other hand, GM crop varieties are expected to provide cost savings by reducing the application of chemical pesticides. Reducing the number of chemical applications should also result fuel cost savings.

The cost of Bt corn seed, for example, exceeds that of conventional corn seed by U.S. $12 to U.S. $13 per acre (Directorate-General for Agriculture, 2000). On the positive side, the introduction of Bt corn varieties has also reduced the use of insecticides, resulting in estimated cost savings of U.S. $2.80 to U.S. $14.50 per acre (Carlson *et al*, 1997). Potential fuel cost reductions would likely increase the estimated savings of Bt corn.

The cost of HT soybeans exceeds conventional varieties by U.S. $11 to U.S. $13 per acre (Fernandez-Cornejo and McBride, 2000). This cost includes the technology use fee. The benefit of planting HT soybeans is the reduction in the number of chemical applications required to control weeds. Fernandez-Cornejo and McBride (2000) estimated herbicide cost savings from the adoption of HT soybeans to be in the range of U.S. $9 to U.S. $11 per acre. This estimate does not include potential fuel cost savings resulting from a reduction in chemical applications.

Fulton and Keyowski (1999) compared the Canadian production costs of HT and conventional canola varieties. The results presented in Table 2 indicate seed cost premiums for HT varieties in the range of Cdn. $5 to Cdn. $11 per acre. As was the case with HT soybeans, the introduction of HT canola appears to provide herbicide cost savings. The study estimated herbicide cost savings attributed to HT canola in the range of Cdn. $4 to Cdn. $10 per acre.

Table 2. Canola System Cost Comparison (Canada)

	Roundup Ready	Liberty Link (Hybrid)	Smart	Conventional
Seed Cost ($/acre)	$18.70	$24.75	$18.70	$13.47
Herbicide Cost ($/acre)	$5.00	$22.75	$26.20	$30.00
TUA ($/acre)	$15.00	$0.00	$0.00	$0.00
Total Cost ($/acre)	$38.70	$47.50	$44.90	$43.47

Source: Fulton and Keyowski (1999)

Overall Profitability of GM Crops

The complexity of the variables involved in the comparison of yields and production costs make it difficult to determine the overall profitability of GM and conventional crops. The results appear to be mixed on whether HT crops have increased producer profits as compared to conventional crops. Carlson *et al* (1997) estimated that HT soybeans

increased producer profits by an average of U.S. $5.65 per acre. In contrast, the USDA-ERS (1999) study showed increase in profits from adopting HT soybeans to be insignificant. Marra *et al* (1998) found that yield gains attributed to Bt corn outweighed seed premiums and technology fees, resulting in net gains of U.S. $3 to U.S. $16 per acre.

A limited number of studies that have examined the effect of HT canola on producer profits. Mayer and Furtan (1999) estimated the economic impact of introducing HT canola in the range of Cdn. $5 to Cdn. $8 per acre for farmers in western Canada. These benefits accounted for all cost increases such as technology fees, and cost reductions such as reduced herbicide usage.

Convenience Factor

A third benefit from GM technology is that it may allow for greater economies of size as it simplifies the production system. The use of HT canola, for example, has given producers greater flexibility in terms of the timing of weed control (Fulton and Keyowski, 1999), but calculating the economic benefit of this flexibility is difficult. The benefit of only having to use one herbicide — for example, Roundup™ — is greater than simply the reduced cost of herbicide. The introduction of GM crops has also reduced the number of pesticide applications required, with a concomitant reduction in the amount of labour and management time required to control pests. The labour-cost savings attributed to the introduction of GM crops is not always factored into profitability assessments.

Whether the adoption of GM crops will provide a labour and management advantage in the long run is still uncertain. As the number of GM crop acres continues to rise, there may be additional management costs involved in controlling the spread of GM plants. For example, producers will have to take additional management precautions to prevent the development of volunteer HT plants and herbicide resistant plants.

ENVIRONMENTAL IMPACTS OF GM CROPS

An important consideration in the debate over GM crops is the effect this new technology will have on the environment. The environmental impact of GM crops is a topic in itself, and chapter three of this report deals with it in detail. Nevertheless, there may be important agronomic costs and benefits arising out of the potential environmental impacts of GM crops that deserve discussion here. The potential environmental concerns associated with the introduction of transgenic crops include the potential for gene transfer, crop and herbicide rotational restrictions, and the development of pest-resistant species. These problems could increase the production costs for adopters and non- adopters of GM crops alike.

The environmental impacts of GM crops, however, are not all negative. Environmental benefits may well accrue from reducing the amount of pesticides used in crop production.

Contamination from GM Crops

The first environmental concern over the introduction of GM crops is the potential transfer of genes from GM crop plants into non-GM plants. The most common form of gene transfer is through hybridization, in which pollen from one plant is carried by wind or insects to fertilize the stigma of another (Powell, 1999).

There are two areas of concern regarding gene transfer from GM plants. The first is that genes from GM crops will transfer to non-GM crops. The likelihood of this is dependent on a number of factors, including the crop species and its location. The potential for gene transfer is clearly increased if GM and non-GM crops are grown adjacent to one another. Gene transfer is not only possible between members of the same species, but also between crops of different species. There is concern that herbicide-tolerant genes will be transferred to non-herbicide-tolerant crops, or to other GM crops, resulting, in future crops, in HT volunteer plants that cannot be controlled by conventional methods (Royal Society, 1998). The second area of concern is the potential transfer of genes from GM plants to wild species. The likelihood of this is, again, dependent on the species and the location of the crop. The potential for gene transfer is minimal when no sexually compatible wild relatives are found in the region (Royal Society, 1998). It is also unlikely for inbreeding crop species such as rice and soybeans. With out-breeding crops that have many wild relatives, there is a greater danger of gene transfer.

The main concern regarding gene transfer is in the area of HT crops, in that genes may transfer to wild relatives of the crop species and produce weed species that are resistant to herbicides (Royal Society 1998).

Mayer and Furtan estimated the potential economic loss caused by increased weed infestation through gene transfer (see Table 3).

Table 3. Economic Losses in Canola Resulting From Wild Mustard Infestation

Infestation (plants/m2)	Yield Loss (%)	Economic Loss Given Yield ($Cdn/ac)			
		18 bu/ac	22.78 bu/ac	27 bu/ac	32 bu/ac
2	5	5.53	6.99	8.29	9.82
4	10	11.05	13.98	16.58	19.65
5	15	16.58	20.98	24.87	29.47
10	22	24.31	30.77	36.47	43.22
15	27	29.84	37.76	44.76	53.05
20	32	35.36	44.76	53.05	62.87

Note: Canola price is assumed to be $6.14/bu.
Source: Mayer and Furtan, 1999.

The potential economic losses presented in Table 3 show that any increase in weed infestation quickly removes the economic benefits of growing GM varieties. The potential also exists for HT genes to transfer into crop and weed species in neighbouring fields. If

gene transfer is a problem, the production costs for neighbouring producers will also be significantly increased.

The other concern regarding potential contamination from GM crop varieties is the spread of seeds via spillage from farm machinery. The fear is that GM seeds will spill from farm equipment such as combines, swathers, and grain trucks into the field being harvested. The potential also exists, particularly for small-seeded crops, for seeds to be transferred into neighbouring fields and ditches, resulting in volunteer GM plants sprining up in the following year's crop. A volunteer GM crop will create a farm management problem for the producer. Controlling it may require the use of alternative chemicals, and will likely increase the producer's cost of production. Volunteer crops also reduce the yield potential of the commercial crops grown the following year. If spillage into adjacent fields results in volunteer GM crops, this will also be an additional cost for neighbouring producers.

It is difficult to measure such costs. Weed infestation on the land of a neighbouring farmer who does not use HT varieties is an externality that has never been measured. Nonetheless, it remains a potential cost.

Pest-Resistant Species

The second environmental concern regarding the introduction of GM crops is the potential for pests to develop resistance to traditional pesticides. This has been a problem in the past with conventional crops, and there is now concern over the potential development of resistant insect species owing to the regular use of Bt crops. The problem with Bt crops is that they are present in the environment longer than Bt sprays, therefore potentially shortening the time for insects to develop resistance to Bt sprays. Insect resistance to Bt could have devastating effects on both conventional and organic producers who rely on Bt sprays.

There is also concern over the increasing numbers of herbicide-resistant weed species. In 1998, an estimated 216 species had become resistant to one or more herbicide (Heap, 1999). It is difficult to predict how the introduction of genetically modified HT crops will affect the number of herbicide-resistant weed species, but the concern is that HT crop varieties encourage the use of a single herbicide or herbicide group for weed control. The continued use of a single herbicide could increase the chances of developing herbicide-tolerant weed populations. If weed species do develop resistance to common herbicides, producers will have to consider alternative, and potentially more expensive, herbicides. Herbicide-resistant weeds are not only a problem for HT crop producers, as it is likely that would spread to neighbouring fields. Controlling herbicide-resistant weed species would affect the production costs for both adopters and non-adopters of HT crop varieties.

Rotational Restrictions

The third concern regarding the introduction of GM crops is the potential restrictions that may be imposed on traditional crop and pesticide rotations. Crop rotations will play a major role in reducing the risk of developing pesticide-resistant species. If a number of genetically modified HT crops are available on the market, for example, it will be important to ensure that a single HT technology is not overused in a crop rotation.

The choice of HT crops in a rotation will also have an effect on traditional herbicide rotations. The use of glyphosate herbicides on GM crops may impose a restriction on current herbicide rotations. Glyphosate is currently used for weed control in chem-fallow, as a spring burn-off chemical, and a pre-harvest desiccant. Producing Roundup Ready crops may limit the use of glyphosate in these areas, forcing producers to use other herbicides for weed control. In many cases, producers have been forced to tank-mix 2,4-D to control volunteer Roundup Ready canola. If GM crop contamination is a problem, neighbouring producers may also be forced to change crop and herbicide rotations. Forcing producers to use alternative crop and herbicide rotations could increase production costs for both adopters and non-adopters of GM crops.

Environmental Benefits

The majority of pesticides used by producers today are more environmentally sensitive than those used in the past. But they can still have negative environmental effects when they enter the air, soil, and groundwater. One of the benefits of GM crop varieties is the potential to reduce the amount of pesticides used in intensive agriculture. A study performed by the USDA-ERS (2000) found that the introduction of Bt cotton resulted in a significant decrease in the use of insecticides such as aldicarb. This clearly benefits the environment by reducing the amount of chemical residue and potentially decreasing the deaths of non-target organisms.

The development of genetically modified HT crop varieties has allowed producers to use non-selective herbicides during the crop season. The use of non-selective herbicides has reduced the number of chemical applications required, thereby reducing the amount of herbicide that can enter the soil and groundwater. The ERS report examined the affect of HT soybeans on the amount of herbicide use. The study found that introducing HT soybeans increased the amount of glyphosate herbicide used, but also resulted in a large decrease in the amount of synthetic herbicide used. The net result was an overall reduction in pounds of herbicide applied.

The chemical activity of glyphosate herbicides such as Roundup may also benefit the environment. Roundup only affects the plants which it contacts directly and is deactivated by micro-organisms once it reaches the soil (Powell, 1999). This reduces both the amount of chemical residue left in the soil and the potential contamination of water through runoff

or leaching. Improving the quality of the soil and groundwater through reduced pesticide use will benefit both GM crop producers and their neighbours.

A final environmental benefit relates to the impact HT crops have had on direct-seeding operations. Direct seeding, in which there is no tillage prior to seeding, maintains surface cover and is a proven method for reducing erosion (CCGA, 1999). Previously, canola producers used pre-emergent herbicides for weed control, which required additional tillage in the spring or fall. The introduction of HT crops has reduced the need for pre-emergent herbicides, allowing producers to convert to direct-seeding practices and still maintain effective weed control. The expanded use of direct seeding benefits both producers and society through decreased soil erosion.

CONCLUSIONS

The review of the available literature indicates that the introduction of GM crops has improved the producer's ability to control pests, which has, in turn, resulted in an increase in the yield potential of GM crops compared to conventional varieties. What is uncertain is whether the introduction of this new technology has, in fact, increased the profitability of farmers. The rapid adoption of HT canola varieties in western Canada would indicate that producers have benefited from adopting the new technology.

A question that needs to be addressed is the impact that more than one GM crop in the rotation will have on profitability. As yet, there is no data on this important question.

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5.0 Consumer Responses to Food Quality, Food Safety, and Health Concerns

Jill E. Hobbs

THE ISSUE

Consumers have expressed growing unease with genetically modified (GM) food. However, these concerns are not universal. There appear to be significant differences in consumers' awareness and acceptance of GM food and in their trust of national regulatory systems. Whether the presence of genetically modified organisms (GMOs) should be labelled, and how this might be implemented and enforced, are contentious policy questions. Consumer preferences are important. Regardless of whether they have a scientific basis, we need to understand and respect these preferences, whether as regulators developing policy responses or in the private sector developing industry strategy.

IMPLICATIONS AND CONCLUSIONS

There is a growing, yet disparate, body of survey evidence documenting consumer preferences toward products of biotechnology in different countries. While providing useful background information, such evidence often lacks the deeper analysis and interpretation necessary for the formulation of policy and industry strategies. Other research has explored the conceptual issues underlying the consumer information problem and different policy scenarios. This work has been important in framing the nature of the problem and exploring potential outcomes. It needs to be taken to the next step to quantify some of these effects. A cohesive research strategy is called for which combines both these elements and focuses on four key areas: deepening our understanding of consumer segments, mapping expected reactions to future biotechnological developments, measuring willingness-to-pay, and examining the efficacy of regulatory systems.

BACKGROUND

Consumer Survey Evidence

Surveys of public opinion in various countries toward GM food, and toward biotechnology in general, broadly agree that the level of awareness with respect to "biotechnology,"

"genetic engineering," or "genetic modification"[4] is higher in northern European countries relative to the United States and Canada. Also, the extent of consumer concern is greater (for example, Angus Reid Group and *The Economist*, 2000; Perdikis *et al*, 2000; Hoban, 1998; Hoban, 1999; Bredahl, 1999). The levels of awareness and concern have increased in most countries, although to differing degrees, since the mid-1990s.

Eurobarometer surveys of public opinion toward biotechnology in the European Union were conducted in 1991, 1993, 1996, and 1999. Although some of the questions changed between the surveys, several broad trends were evident (European Commission, 2000). The proportion of respondents who believed biotechnology would improve their way of life in the next twenty years declined from 50% to 45% between 1996 and 1999, while the percentage believing that genetic engineering would lead to improvements fell to 37% from 43%. The Eurobarometer surveys found that the public's knowledge of biotechnology and genetics improved only slightly between 1993, 1996, and 1999. Two notable exceptions emerged. First, there was a marked improvement in the understanding of what is meant by "cloning." There was more uncertainty, however, about the potential outcomes of biotechnology. For example, more people were unsure whether a person's genes could be modified by eating a genetically modified fruit in 1999 (34%) than had been the case in 1996 (29%).[5]

In the 1996 and 1999 Eurobarometer surveys, attitudes toward four applications of biotechnology were compared: the production of food, the development of insect resistance in plants, the development of medicines or vaccines, and the use of genetic testing to detect hereditary diseases (European Commission, 2000). Over the three-year period, public opinion became less optimistic about the potential usefulness of these applications, although there was little change in attitudes toward the perceived riskiness of the applications. Fewer respondents felt the applications to be morally acceptable, and fewer (12%-16%) thought these applications should be encouraged, relative to the 1996 survey results.

Apparent contradictory results between some of the surveys reported in the literature may stem from differences in methodology. For example, Hoban (1998) found that over 70% of U.S. consumers surveyed through the 1990s supported agricultural biotechnology, whereas the Angus Reid Group (1999) put the acceptance of GM foods in the United States at around 47%. They further suggest that 60% of U.S. consumers would be less likely to buy food if labelled as containing GM ingredients (Angus Reid Group and *The Economist*, 2000).

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[4] A variety of different terms are used in the consumer surveys, and the terms may or may not be defined. This makes comparisons between the studies problematic, and partly explains why the results of different studies sometimes appear contradictory.

[5] The question was not asked in the earlier Eurobarometer surveys.

Although still positive, it appears that acceptance in Canada may be on the decline (Angus Reid Group, 1999). It is argued that Canadian public perception of the issue has shifted from a science and technology issue to one of food safety and public health — a shift that has not occurred to date in the United States. This finding is confirmed by Einsiedel (2000), who compared the attitudes of Canadian consumers in 1997 and 2000. Although Canadians remained "cautiously supportive" of biotechnology, Einsiedel found their optimism had declined since 1997. She also found that consumers were relatively more positive when the term "biotechnology" was used than when the term "genetic engineering" was used. This illustrates how the use of different terminology in a survey can elicit a different response, and underlines the need for caution when comparing surveys that were conducted using different methodologies.

In assessing the attitudes of consumers in the United States and Canada toward different food safety issues, a number of researchers have found that pesticide and chemical residues and bacterial contamination of food are regarded as bigger food safety threats than GM food (Hoban, 1999; Einsiedel, 2000). Consumers appear to be less accepting of the use of biotechnology in animals relative to plants, and appear more accepting of its use in medicine than in agriculture generally (Hoban, 1998; Hoban, 1999; Einsiedel, 2000; Moses, 1999).

What Are the Consumer Concerns?

The negative consumer response toward GM foods is multi-faceted. Another branch of research has focused on understanding and interpreting these concerns. Four broad groups of concerns are apparent: specific food safety and quality concerns, fear of the unknown, ethical objections, and environmental concerns (Hobbs and Plunkett, 1999; Einsiedel, 2000; Moses, 1999).

Specific food safety and quality concerns include the fear that transgenic manipulation of genes could introduce allergens to products — for example, if a peanut gene were to be used in soya. The use of anti-biotic-resistant marker genes has raised the spectre of increased anti-biotic resistance in humans and animals (Hobbs and Plunkett, 1999). Other potential side-effects identified in the literature include known toxicants, whereby toxicants naturally occurring in a plant at safe levels are unintentionally magnified to unsafe levels. Unintended changes in nutrient content or nutrient absorption properties is another concern (Nelson *et al*, 1999). These potential risks are dealt with specifically — and, many would argue, adequately — in current national regulatory systems for product approval and varietal development. Nevertheless, there remains unease among some consumers who do not trust regulatory systems or the science used to assess these risks.

In addition to these specific food safety concerns, some consumers simply fear the unknown.[6] This is not a typical food safety fear, e.g., "If I eat this GM canola product for lunch, will I be sick by tonight?" Rather, it is the fear that there may be unforeseen negative side-effects from consuming a GM food over a long period of time. This creates problems for public policy and industry strategy because it undermines the effectiveness of risk assessment, risk management, and risk communication. There is a difference between "risk," where one can provide scientifically-determined statistical probabilities of an event occurring, and "uncertainty," where one cannot. It is not possible to calculate the probability of something completely unknown and totally unforeseen becoming a problem in the future. Yet we need to know the probability of an event for risk assessment.

An entirely different set of consumer concerns are ethical and relate to the notion that genetic engineering equates to "playing God." This is not a safety concern, *per se*, but a philosophical objection to the technology or its application. Finally, concerns over potentially negative environmental concerns are also important to some consumers, and are dealt with elsewhere in this report. It is important to recognize that all these concerns are manifest, to a greater or lesser degree, in the reported results of consumer opinion polls, yet it is sometimes difficult to disentangle the impact of one concern from another. It is important to separate them, however, because they may invite different responses from regulators, different industry strategies, different roles for science, and different roles for public information and communication.

Regulatory Implications

The divergence in consumer attitudes is reflected in different regulatory approaches between countries. The United States and Canada have adopted a product-based regulatory system for GM foods in which the focus is on establishing the safety of the product, regardless of whether it is GM. If it is shown that a GM food is substantially equivalent to a non-GM counterpart, the same set of regulations apply. The EU has taken a process-based approach with its 1997 Novel Foods regulation, which applies if the food is transgenic. Implicit in the EU approach is the notion that the risks of GM food are inherently different than the risks of non-GM food.

Food labelling regulations also differ. Phillips and Foster (2000) report that eighteen countries have indicated their intentions to adopt some form of labelling for GM foods. This ranges from mandatory labelling in the EU, Japan, Australia, and New Zealand, among others, to voluntary labelling in the United States, Canada, Argentina, and Russia. Most countries, including Canada, are still formulating their labelling policies, and in only

[6] In a recent study, fear of unknown impacts was the second most important risk or disadvantage from GM foods mentioned by consumers in six of eight countries surveyed (Canada, the United States, France, Germany, Japan, and Brazil) and was the most important risk mentioned by consumers in the UK and Australia (Angus Reid Group and *The Economist*, 2000).

a few cases, such as the UK, have policy decisions actually been enshrined in regulatory action. Disparate labelling policy approaches, not least the variety of "thresholds" setting the level of acceptable GM content (e.g., 1% in the EU; 5% in Japan), create significant challenges for the food industry, particularly for those exporting to a number of different markets with potentially different regulatory requirements.

Whether or not to label the presence (or absence) of GMOs is highly contentious. On one side of the debate is the argument that consumers have a right to know what is in their food or how their food is produced. This is also becoming an issue with other "process" attributes, such as farm animal welfare or environmentally friendly production practices. These process attributes are "credence" attributes, meaning that the consumer cannot detect their presence even after consumption. In this way, they differ from "search" attributes — those which a consumer can detect or evaluate prior to purchase, such as the size of an orange — and they differ from "experience" attributes — those which a consumer can evaluate after consumption, such as the juiciness of an orange. This is significant because it creates an information problem for consumers. Process attributes may be important to a consumer's purchase decision for various food safety, quality, or ethical reasons; however, without more information, consumers cannot detect the presence of these attributes. Left to its own devices, the market may fail to provide this information. This may well be true for GM foods. Unlike organic foods or environmentally friendly foods, producers of GM foods might expect a negative backlash against their product if it were labelled as GM. This is particularly so for "input-trait" products (e.g., herbicide or pesticide resistant) with little direct consumer benefit (Angus Reid Group and *The Economist*, 2000; Gath and Alvensleben, 1998). This weakens the incentive for the firms to label their products correctly, creating credibility problems for a voluntary labelling system (Hobbs and Plunkett, 1999).

On the other hand, there may be an incentive for voluntary labelling of "GM-free" or "Non-GM" food, as is the case with Non-BST labelled milk in the United States,[7] if some consumer segments are sufficiently averse to GM products. Whether or not voluntary labelling is a viable solution to consumers' information asymmetry in the long-run remains to be seen. Certainly, there is anecdotal evidence of the existence of "GM-free" labels in some markets, notably in the EU. However, the potential remains for producers of GM-food to cheat and misrepresent their food as GM-free if there is a market premium for GM-free food, and in the absence of a credible system of monitoring and enforcing voluntary labelling systems.

An alternative is to make labelling mandatory, but this policy option also has drawbacks. The value to consumers of a "GM" label that provides no additional useful information about the known safety or nutritional value of a product can be questioned. Under the principle of "substantial equivalence," GM and non-GM foods should have the

[7] The author is grateful to an anonymous reviewer for suggesting the Non-BST milk example.

same level of known safety. Critics of mandatory labelling argue that it misleads consumers, implying that there is a difference in quality and safety between GM and non-GM foods which has no scientific basis. It has been suggested that there is confusion among consumers over the meaning of the term "genetically modified" (Kenny, 1999). Furthermore, it is argued that providing nutritional information may be more important to the long-term health of consumers. As such, adding "GM" labels could create a problem of "information overload," diluting the impact of the scientifically proven nutritional information (Kenny, 1999). Presumably, for those consumers with an ethical rather than a safety objection to biotechnology, mandatory labelling would still confer information benefits. This debate highlights the importance of understanding consumer preferences and distinguishing between ethical, safety, and environmental concerns.

A further drawback to mandatory labelling lies in the costly and time-consuming process of testing for the presence of GMOs — where this is technologically feasible — and in segregating GM and non-GM products. Without technological advances in testing, this can only be expected to worsen as the number of potential GM traits in complex processed food products multiplies. Instead, segregation and identity preservation of GM from non-GM agricultural products will be required. Paradoxically, it will be the non-GM products that will likely bear the brunt of this cost, since it will be more costly to substantiate the absence rather than acknowledge the possible presence of GMOs (Kerr, 1999). If the transaction costs incurred in implementing, monitoring, and enforcing a mandatory labelling policy are sufficiently high, a ban on the approval, production, and importation of GM food could be the policy solution which produces the highest net benefits for society (Hobbs and Plunkett, 1999). Further empirical work is needed to determine the answer to this question.

A preliminary assessment of the economic impact of mandatory labelling of GM food products in Canada has suggested that compulsory labelling would result in cost increases equivalent to 9%-10% of the retail prices of these products (KPMG Consulting, 2000). The total cost to Canadian consumers of labelling was estimated to be in the range of $700-$950 million per year. The major component of these costs is segregation costs. Further discussion of segregation and labelling issues for GM products can be found in chapter six.

DISCUSSION

An examination of existing research suggests that it falls into two main camps. The first is a series of consumer surveys and polls that capture the current flavour of consumer attitudes. The more useful of these provide us with a guide as to trends in consumer opinion over time and the motivations behind these attitudes (for example, Einsiedel, 2000). In most cases, however, while they provide a surface-level picture of the state of consumer attitudes, the studies often lack in-depth analysis of consumer preferences and motivations. The second set of research initiatives delves deeper into the nature of the

consumer information problem and the impact of different regulatory systems. These studies helped define the problem, setting it in its policy context and laying out various scenarios or potential outcomes. As yet, there appears to little empirical work to quantify the potential impact of these different scenarios. Thus, a number of gaps in our knowledge are apparent and would benefit from further research. These fall loosely into four broad groups:

1. consumer segments,
2. future biotechnological developments,
3. willingness-to-pay, and
4. regulatory systems.

Consumers are not a homogeneous mass. There is not "*a* Canadian consumer" or "*a* British consumer"; instead, there are consumer segments with different attitudes. We need a better understanding of the preferences and motivations of different consumer segments in the markets of interest to the Canadian agri-food sector. We need a better understanding of what motivates consumer attitudes (positive or negative) toward biotechnology, of who or what influences consumer opinion, of consumer responses to "information" messages from different sources, of consumer responses to different perceived states of risk, and of which consumers have different attitudes, and why. This requires a deeper level of analysis and interpretation than is apparent in much of the opinion poll research to-date. Caswell and Noelke (2000) propose a unified framework that combines the insights of economic models of consumer information asymmetry with those of applied psychology, consumer behaviour, and marketing that focuses on perceived quality. Future analyses of consumer preferences should distinguish between quality characteristics that are vertically differentiated (i.e., all consumers share the same quality ranking) and horizontal differentiation in which consumers have different quality rankings.

How will consumers react to future biotechnological developments? This includes output-trait GM foods with positive benefits for health or food quality, and applications of medical biotechnology. Although related on one level, these two issues need to be treated separately. Will the positive attribute of an output-trait GM food be sufficiently valued by consumers to outweigh the perceived negative attribute of the GM process? This emphasizes the importance of identifying and understanding different consumer segments and of being able to separate out food safety, health, and quality issues from ethical issues. It has policy implications because the incentives for a credible voluntary private sector labelling system are much stronger in the case of output-trait products.

There is a need for research to measure consumers' willingness-to-pay for "GM-free" food, GMO labelling, or GM foods with positive output traits. Gath and Alvensleben (1998) estimate the willingness-to-pay of German consumers for GM-labelling and tentatively suggest that, if labelled, the prices of GM food would need to be 30-40% lower.

Theirs is an aggregate analysis, however, and further work would benefit from identifying willingness-to-pay by consumer segments. Economists have at their disposal a number of proven "stated-preference" valuation techniques that could facilitate this analysis.

A final set of research objectives centres on further analysis of different regulatory issues with consumer impacts, including (but not limited to), labelling, market access, accreditation/certification of GM/GM free products, product approval, transparency of the regulatory system, and so on. Necessary background information for this analysis includes an in-depth understanding of consumers' trust in current regulatory systems. Again, this underlines the importance of a comprehensive understanding of consumers' attitudes. How to deal with consumers' fear of the unknown is particularly challenging for the regulatory system (and for private industry). How do we incorporate uncertainty as to future outcomes into a policy framework? How does this affect risk assessment?[8] Finally, should there be mechanisms for involving the public more directly in decision-making? Is this desirable? How would it be facilitated? Would it assuage consumer concerns, and would it improve the efficacy and responsiveness of the regulatory system? Initial research has touched on this issue (for example, Citizens' Panel, 1999); however, further exploration of this model would be useful. Future work should be from an interdisciplinary standpoint, including input from economics, political science, sociology, public administration, and public communications.

Clearly, these four broad groupings of research needs are inter-related. One forms the information base and policy framework for another. This suggests that they should be undertaken in concert in a co-ordinated, strategic approach, with ongoing communication between the researchers in each of the areas. The Canadian Biotechnology Advisory Committee seems well placed to perform that co-ordinating role.

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[8] See Caswell (1999) for a discussion of risk analysis as applied to agricultural biotechnology.

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6.0 Labelling Food Containing GMOs: The Segregation Requirement

Dustin Gosnell

THE ISSUE

By September 2000, eighteen countries and the European Union, twenty-one food retailers, twenty-nine food manufacturers, and six restaurant chains around the world had introduced either mandatory or voluntary labeling requirements for genetically modified (GM) foods (Phillips and Foster, 2000). To allow genetically engineered crop varieties to be grown in Canada while maintaining access to export markets that request labeling, crop segregation or identity preservation (IP) systems must be introduced. These systems have costs that will be borne by consumers, producers, or marketers. The extent and distribution of these costs will influence the overall gains or losses from the introduction of GM varieties.

IMPLICATIONS AND CONCLUSIONS

A growing number of crop segregation and identity preservation systems are emerging in the agriculture industry. In the past, these systems have been reserved for special crops and other markets where premiums exist. More recently, with the need to separate non-GM and GM varieties, these systems are becoming more prevalent.

A number of studies have also been conducted examining the added costs involved with implementing these systems, and attempts have also been made to determine the most efficient system available, given varying circumstances. Finally, a number of studies have looked at the feasibility of several proposed systems to determine whether current supply chains can be altered to accommodate them.

Estimating the costs of such systems can be problematic. With variables such as tolerance levels and opportunism playing a large role in each scenario, accurate estimation becomes difficult. As a result, different studies have resulted in estimates of system costs ranging between Cdn. $10 and Cdn. $50 per tonne (Roederer *et al*, 2000). The upper end of these estimates represent potentially large costs for the industry from the introduction of GMOs, while at the lower end, segregation costs may be small relative to the potential gains.

BACKGROUND

Labeling food allows the transformation of product characteristics that consumers are unable to evaluate even after purchase — referred to as credence attributes — into search attributes that consumers can learn about by inspecting a product prior to purchase (Caswell, 1998). With the labelling of attributes that are important to the decision to purchase, consumers can make informed decisions about what foods they will purchase. Credible labelling of GM foods requires that the product be segregated throughout the supply chain. As a result, agriculture industries in a number of countries, including Canada, have recognized the need to implement crop segregation and IP systems.

Crop segregation and IP systems require the close management of all links in the supply chain where contamination could potentially occur. A report prepared by the Canadian Grain Commission (CGC) (1998) outlines the critical points where monitoring and enforcement are required to ensure that contamination is prevented. They propose, first, that variety breeders and owners, seed growers, and the registration system all be responsible for ensuring that the initial seed grown is of a guaranteed quality. The system would include a contract facilitator, responsible for having a variety-specific delivery and/or a production contract for the commodity in question. The system then advances through producers, primary elevators, transportation companies, and port/transfer terminals, outlining which member of the supply chain would bear the responsibility of preventing contamination and who would be liable should contamination occur.

Although the system proposed by the CGC includes the primary elevator infrastructure and other components of the Canadian bulk grains system, the control points should not change greatly if a containerized system is implemented. Reichert and Vachal (2000) allude to this in their report comparing containerization and the traditional bulk system. Containerization modifies the chain by allowing the product to bypass certain critical points where contamination could occur. The number of points being bypassed in a system of this nature depends on where the grain is loaded into containers and the mode of transportation used.

Roederer *et al* (2000) identify three potential IP situations in the context of GMOs: voluntary IP of GM products, voluntary IP of GMO-free products, and compulsory IP of GM products. Each alternative outlined in the report has been analyzed in various studies by other authors to determine its feasibility and costs. While some of these studies utilize historical data, others rely on estimation and comparison to existing IP channels in the grain industry for their cost analysis. As a result, there are discrepancies among the studies as to the actual costs of implementing an IP system.

VOLUNTARY IP OF SPECIFIC GM TRAITS

In this scenario, all members of the supply chain for GM varieties voluntarily implement an IP system, and are therefore also responsible for the costs. In order for this to work, a

specific incentive would be required for GM producers, grain-handlers, processors, and retailers to adopt the strategy. This incentive could arise in the case of genetic modification involving output traits aimed at providing a product for which consumers are willing to pay a premium relative to a conventional product. Specific examples would include specialty oil products, GM pharmaceutical traits, and nutraceutical traits.

In this type of system, because the costs are borne wholly within the GM marketing chain, the market can be used to determine whether the production and segregation of these varieties is economically viable. Owing to low volumes of these varieties in the market, this scenario has yet to play a significant role. There have been a few positively labelled GM products — Flavr-Savr tomatoes, for example — that have been voluntarily segregated to extract market premiums. However, there have been no studies conducted to determine the costs and effectiveness of these systems.

VOLUNTARY IP OF GMO-FREE PRODUCTS

In this scenario, the non-GM supply chain voluntarily segregates non-GM products and bears the cost of segregation. This is currently the most common system being utilized in the market owing to the fact that the majority of varieties currently registered are those that contain input traits. Input traits are aimed at providing cost-of-production benefits to producers, most commonly through built-in insect and herbicide resistance. Consumers generally do not benefit directly from this technology, and therefore are not willing to pay a premium for the product (Buckwell *et al*, 1999). Instead, consumers in regions requesting labelled products may be willing to pay a premium for a GMO-free product.

The majority of the literature to date focuses on this scenario. Bender *et al* (1999) at the University of Illinois examined segregation costs incurred by the grain-handling link in a supply chain for specialty corn and soybeans. The specialty corns were high-oil varieties that were bred using traditional methods, and segregated to attract a premium in livestock feed markets as a high-energy feed alternative. The specialty soybeans, STS soybeans, were traditionally bred varieties that are resistant to a specific herbicide. They were segregated to attract a premium as a non-genetically modified, herbicide-resistant variety.

Although only part of the University of Illinois study focused on non-GM crops, the system being examined could be used to preserve the identity of all non-GM crops. Their estimates were obtained by surveying a sample of elevators in the United States that were identified as possible handlers of specialty oilseeds. The estimates of added costs were U.S. $0.17 per bushel for corn and U.S. $0.48 per bushel for soybeans.

Lin *et al* (2000) modified the Illinois study to provide estimates for non-GM segregation. Their results indicated that costs for segregating non-biotech crops could be higher than the estimates for specialty crops. They made adjustments to account for increased testing costs and two-tier segregation. They also mentioned potential cost increases owing to risk management.

The adjustment for increased testing costs reflects the higher cost of testing for GM content compared to physical characteristics such as oil content. The adjustment for two-tier segregation reflects the costs required to segregate GM from non-GM varieties, and then to further separate the GM varieties approved for shipment to the EU from the EU-non-approved varieties. Risk management costs reflect the implications of contamination when attempting to guarantee non-GM requirements. In specialty crop markets, contamination may result in a lower premium in the market. The contamination of a product targeted at non-GM markets could result in a load being rejected and thereby have much more serious consequences for grain exporters.

Maltsbarger and Kalaitzandonakes (2000) expanded on the two previous studies in their report on the hidden costs in IP supply chains. Specifically, they factored in lost-opportunity costs at the primary elevator level, including margins from value-added activities (i.e., grinding), storage, or from carrying grain over an extended time period in expectation that there will be a positive spread, the spread being the net difference between current price and expected future price less storage and lost-interest costs. The results of their study show that including these opportunity costs can result in increased costs to the system in the range of U.S. $0.07 to U.S. $0.22 per bushel.

Fulton and Giannakas (1999) examined the issue of contamination and the resulting product mislabelling in their study of the consumption effects of genetic modification. When they introduce this concept to their analysis, they conclude that the higher the probability of mislabelling, the greater the loss in consumer welfare. Without faith in the labelling system, consumers will be less likely to buy GM or non-GM products. Therefore, the implementation of a segregation system must also instill consumer faith in order to be effective.

Vandeburg *et al* (1999) used IP cost estimates from industry experts when comparing two alternative segregation strategies; namely, designating specific IP elevators versus segregating within the elevators. They use a cost minimization model to determine that, as the cost of maintaining IP increases, using designated IP locations becomes the cost-effective strategy.

COMPULSORY IP SYSTEM FOR GM PRODUCTS

A compulsory IP system for GM products could take a number of forms. The strictest would fall under the Canadian Food Inspection Agency (CFIA) contract registration provision. This category of registration is used for those varieties whose delivery into traditional commodity channels would cause harm to those channels. Under these circumstances, the applicant must make available a quality control system that describes fully how potentially adverse effects of a variety will be managed (CGC, 2000). To date, there have been no genetically engineered varieties in Canada that fit into this category.

Alternatively, there have been cases in which compulsory systems have emerged from voluntary initiatives on the part of certain members of a supply chain. To deem these systems compulsory requires the assumption that, as soon as rules are imposed on upstream levels of a supply chain, the system becomes compulsory in nature.

In 1996, the canola industry in Western Canada saw the commercial production of GM varieties for the first time. Japan and the EU had yet to approve the varieties being grown. Because the Government of Canada does not have the legal mandate to govern the exporting of GM canola, the industry was forced to implement an IP structure of its own (Phillips and Smythe, 1999).

The research/seed companies, Monsanto and Agrevo, were approached by industry representatives and urged to introduce an IP system until Japan approved the technologies in question. Both companies co-operated and vertically aligned themselves with grain companies to manage the systems that segregated GM canola to ensure that it remained within the domestic market.

The IP system included contracts with growers, and kept the export market free from the specific varieties. The entire production (approximately 100,000 tonnes) was crushed at Canadian facilities and remained in the domestic market. Costs of the systems per tonne were estimated between Cdn. $34 and Cdn. $37 by Manitoba Pool Elevators and between Cdn. $33 and Cdn. $41 by the Saskatchewan Wheat Pool. Only one dollar per tonne of these added costs was incurred by producers as increased on-farm costs. As a result, many producers were still able to realize a net benefit from adopting the new technology.

The remainder of the costs were incurred during transportation, by the processor, in administration, and through opportunity costs. Opportunity costs were included in the estimates owing to the strict requirement that segregated grain remain in the domestic market. This prevented grain companies from marketing products to countries that were willing to pay a higher price than that of the domestic market (Phillips and Smythe, 1999).

Table 1 summarizes a number of the studies mentioned, outlining the crop being studied, their GM/non-GM status, the identity preservation or segregation strategy implemented, and the estimated costs.

Table 1: Examples of IP and segregation systems for GM and non-GM crops

Country	Crop	Gm/ Non-Gm	Identity Preservation and Segregation System Attributes	IP Costs
USA	Soybeans	Non-GM	Farm loaded containers moved to export position.	US $20/ton[1]
USA	Soybeans	GM Quality Traits	Farm level through elevator and processor to refinery level	US $17-$25.2/tonne[2]
Canada	Canola	GM Input Traits	Direct trucking from farm to domestic processor.	Cdn $34-$37/tonne[3]
Canada	Canola	GM Input Traits	Direct trucking from farm to domestic processor.	Cdn $33-$41/tonne[3]
USA	High Oil Corn	Non-GM	Farm level through to processor/export position.	US $0.17/ Bushel[4]
			– including higher testing costs, two-tier segregation costs, and risk-management costs.	US $0.22/ Bushel[5]
			– including lost-opportunity costs from value-added activity, storage, and marketing at the primary elevator level.	US $0.29-$0.44/ Bushel[6]
USA	STS Soybeans	Non-GM	Farm level through to processor/export position.	US $0.48/ Bushel[4]
			– including higher testing costs, two-tier segregation costs, and risk-management costs.	US $0.54/ Bushel[5]

Sources: [1]Reichert and Vachal 2000; [2]Buckwell et al. 1999; [3]Phillips and Smythe 1999; [4]Bender et al. 1999; [5]Lin et al. 2000; [6]Maltsbarger and Kalaitzandonakes, 2000.

OTHER FACTORS

An examination of the existing research indicates a wide variety of segregation alternatives that are directly related to or could be altered for use in segregating GMOs. The majority of these studies agree that the costs and feasibility of the proposed systems depend on a few key issues. Requested tolerance levels, testing costs and procedures, market volumes, agronomic traits, and differences in approval status of GMOs in importing countries have immense impacts on system costs.

The range of tolerance levels for GM content being requested by various countries appears to be between 1% and 5%. Industry experts and economic studies suggest that to guarantee contamination levels at or below 1% would entail much higher costs and require a much more closely managed system than would the 5% level. The tolerance levels of importing nations may be the decisive factor in determining system costs.

Roederer *et al* specify all points in a given supply chain where increased costs could appear. Costs begin to accumulate at the seed research and production stage, and continue upward until the product reaches the consumer.

Seed production costs increase as the tolerance level falls owing to testing requirements and increased isolation distances between GM and non-GM crops. These costs depend on the crop in question, as cross-pollination problems vary with the seed being produced. Industry representatives indicate that they could provide seeds at any tolerance level requested; however, the costs of doing so rise considerably as the tolerance level approaches zero (Roederer *et al*, 2000).

Prevention of contamination at the farm level involves minimizing volunteer plants, avoiding cross-pollination, and preventing mechanical commingling. Once again, the costs incurred by farmers will be relative to the tolerance level requested and the crop being grown. Canola cross-pollinates relatively easily, for example, and its pollen can travel further distances than would be the case for wheat. As a result, controlling this problem will be more costly when growing crops such as canola.

Current testing procedures for GMOs are both time-consuming and costly. The fewer the tests required, the less costly the IP system. However, taking the costs of a load of grain being rejected into consideration, the system must ensure that enough testing is conducted to guarantee that all shipments satisfy the tolerance level requested. The testing procedure required is dependent on the number of modified genes within a given variety and the number of varieties within the grain class that have been altered.

Enzyme Linked Immunosorbant Assay (ELISA) and strip-testing can be used if the modification being tested for is known. ELISA is a lab test allowing quantification of the GMO content of a sample for a given transformation event. Strip-tests are qualitative tests, giving a yes or no answer to the detection of a targeted GMO in a sample (Bullock *et al*, 2000). Both procedures are relatively cheap, and results are known quickly. In the case of canola, however, ELISA and strip tests would only indicate whether a specific protein for a given trait is present. Separate tests would be required for all potential modified traits.

Polymerase chain reaction (PCR) tests examine the genetic makeup of a seed to determine if any modifications have been conducted. PCR is also required if testing is being conducted on processed food. It is important to note that testing will become much more costly once plant breeders begin to stack traits in a single crop, thereby requiring multiple testing for given samples. Even if the crop contains only one GM trait, testing would be required for all other potential GM traits for that crop. If this becomes prohibitively expensive, it may not be economically efficient to test them all. Instead, closer vertical co-ordination may be required to guarantee a labelling claim through closer supply chain monitoring and control of downstream activities.

Transportation and storage cost increases will depend on the number of varieties requiring segregation, the amount of product being segregated, and the tolerance level for contamination. Increased trading involving IP crops will reduce the value of a commodity-

based system, and with lower volume, highly specific trading taking place, economies of scale may not be reached. Bullock *et al* stress the importance of this issue in their study of the economics of non-GMO segregation and identity preservation. They conclude that the major costs of the systems will not come from cleaning machinery or testing, but rather from the restructuring of the grain handling system.

The processing industry costs are dependent on variables similar to the transportation and storage links in the chain. Costs will increase if processing facilities have to be shut down and cleaned numerous times throughout the year to avoid mixing GM and non-GM product. These added costs could be lowered or prevented if volumes are present to designate processing facilities to handle only one product.

After examining the impacts of segregation on a supply chain, one can see the problems facing the manufacturers of processed foods. Supply chains of processed products often involve up to thirty separate ingredients. If all ingredients being sourced must be GM-free, identity preservation may become prohibitively costly.

Golder *et al* examined this issue in their report on the potential costs of mandatory labelling for food products, and report that 70%–85% of all processed food products could be subject to labelling if derived additives, processing aids, and flavourings are subject to labelling. Subsequently, labelling costs could be equivalent to at least 9%–10% of the retail price of processed food and 35%–41% of producer prices. Knowing this, some EU processors have reformulated their recipes to use ingredients from non-GM sources in order to obtain GM-free status. In such cases, the problem no longer involves the costs of segregation, but the costs of substitution and lost markets.

DISCUSSION

With segregation becoming essential, the next question is, Who is responsible for implementing and paying for the system? The three alternatives outlined show that there is considerable uncertainty about this. Should non-GM producers be required to segregate their production when GM producers gain the cost of production benefits? They may not be responsible, but they may have an incentive to do so for two reasons. First, importing regions such as the EU and Japan may be willing to pay a premium for imports that are free from GMOs. Second, producers will see a reduction in demand for their products unless they incur a cost to segregate their non-GM product.

Depending on the volumes being produced, it may be more efficient for GM producers to segregate their production. The problem with this, however, is that they generally do not have incentives to do so. Until GM varieties emerge that attract a premium above the cost of production for the entire supply of a given variety, this will remain a problem. The question then becomes whether or not regulatory policies need to be put in place to force these producers into a compulsory IP system.

A variety of potential systems have been analyzed to differing degrees and with different results. The most popular alternatives appear to be segregating within elevators, designating specific handling, storage, and processing facilities to handle the product being segregated, and containerized shipping.

The studies to date provide a good understanding of the steps and procedures necessary to implement each strategy, but they do not provide a satisfactory answer to which system would be most suited to the Canadian grains industry. As a result, the industry needs to determine which system will operate most efficiently for given situations and for each crop being grown.

The problem is that there are many uncertainties over what situation is being faced. There are uncertainties over the tolerance level being requested by importing nations. There are uncertainties over what volumes of GM and non-GM crops will need to be segregated. There are uncertainties over how effectively a system will work, given problems such as opportunism and human error. And there are uncertainties regarding the markets that will require labelling. Opportunism may occur in the event that individual producers realize a potential economic gain from cheating the system. In the case where non-GM crops are being segregated for premium markets, for example, GM producers may attempt to market their grain as non-GM to gain the premium. These problems create difficulty in attempting to pinpoint effective systems and, as a result, need to be solved before an answer can be found. They also underline the importance of understanding the regulatory and consumer requirements of target export markets before a segregation system is designed and implemented.

It is evident that many potential systems exist for segregating GM and non-GM products, each with a unique level of reliability, absolute costs, and distribution of costs. The costs of these systems are part of the overall cost-benefit impact of GM introduction, and therefore must be considered. Given the range of cost estimates, determining the best system is an important decision that will influence the extent to which GM technology is beneficial to society as a whole. Further research is needed to determine the appropriate segregation systems to be used for specific crops in specific situations and to assess the wider economic impact of these systems.

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7.0 Commercial Trade Issues in Biotechnology

William A. Kerr

THE ISSUES

Access to International Markets and International Protection of Intellectual Property

Firms making investments in developing biotechnology need transparent rules for determining access to international markets and for the international protection of the intellectual property they create. Given that the life cycles of individual biotechnology products may be short, access to international markets for exports or to undertake foreign production will be an important determinant in investment decisions. Currently, the international rules for the trade and protection of international property are opaque, leading to a high degree of risk.

Protecting Consumers and the Environment from the Possible Risks Associated with a New Technology

Biotechnology is a major technological change. As with all new technologies, there are risks and unknowns. Countries must weigh the need to protect the health and safety of their consumers and their environment against their international obligations to provide access to their markets for foreign products. Domestic regulatory agencies, consumers, and those who are concerned with the environment in different countries have appraised biotechnology in different ways. The existing World Trade Organisation (WTO) rules do not appear to be sufficiently robust to resolve the issue to the satisfaction of all parties. This suggests that renegotiation may be necessary. Until a new agreement is reached, the rules of trade in biotechnology will remain opaque and the potential for trade conflicts high.

Developing Countries' Trade at Risk

Some developed countries may either ban imports of Genetically Modified (GM) food products or require imports to be labelled. This will require product segregation and certification that may be beyond the technical capability of developing countries' governments. This may result in the closure of some existing markets to the products of export-dependent developing countries with a low degree of technical capability, or those

countries' having to rely on transnational agribusiness firms to organize their international trade. Neither result is likely to be consistent with those countries' development goals.

IMPLICATIONS AND CONCLUSIONS

Lack of Transparency in the International Trade Régime

Given the high levels of investment involved and the differing degrees of resistance to the acceptance of biotechnology in different countries, trade negotiations in this area are likely to be long and acrimonious. As a result, in the near term, countries will put in place regulatory régimes that do not take account of international disciplines. This means that the rules for market access and the protection of intellectual property will remain opaque for those wishing to engage in international transactions in the products of biotechnology.

Costly Investments in Segregation Systems and Infrastructure

As countries will, at least in the intermediate run, individually determine the rules for access, a plethora of different importing régimes will evolve. This will require exporting countries licensing biotechnology for production either to invest in segregation and certifications systems or to write off some foreign markets.

Risk of Trade Conflicts High

As the existing WTO rules are not able to resolve the issues pertaining to biotechnology to all countries' satisfaction, trade conflicts will arise. These will likely lead to some disruptions to existing trade in unrelated industries and increased international animosity until a new mutually agreed international trade régime can be negotiated.

Background

Little or no empirical work on the international trade aspects of biotechnology has, as yet, been undertaken. This is because GM foods and other products of biotechnology have only recently become available for international trade. Governments around the world are scrambling to put domestic regulatory régimes in place for the licensing of production using biotechnology and the conditions under which GM products can be sold. Countries' international trade régimes follow the implementation of domestic régimes and reflect their intent. As a result, the international trade picture for GM products is in considerable flux. As no government provides separate statistics on trade in GM and non-GM products as yet, the literature on trade issues surrounding biotechnology remains largely theoretical.

Biotechnology and the WTO

The most recent round of international trade negotiations (Uruguay) was completed in 1994, just before trade in GM products became a major issue. The Uruguay Round led to a major revamping of the multilateral international trade régime. The new WTO was constituted to incorporate the existing General Agreement on Tariffs and Trade (GATT), which regulates trade in goods, and to encompass two new agreements, the General Agreement on Trade in Services (GATS) and the Agreement on Trade Related Aspects of Intellectual Property (TRIPS). The inclusion of the TRIPS agreement under the WTO was at the insistence of developed countries. They wanted a means of coërcing developing countries into protecting the intellectual property of their firms. That mechanism is cross-agreement retaliation, whereby trade sanctions can be applied to the exports of developing countries for violation of TRIPS commitments (Kerr and Perdikis, 1995). As the value of biotechnology is largely intellectual property, the operation of the TRIPS and WTO will be of central importance for those investing in biotechnology.

The Uruguay Round also incorporated a new sub-agreement of the GATT — the Agreement on the Application of Sanitary and Phyto-sanitary Measures (SPS) that established rules for putting trade barriers in place to protect human, animal, and plant health. Any trade restrictions are to be science-based, and require that a formal risk assessment be done. Trade restrictions can be put in place in cases of insufficient scientific information, but the restrictions are expected to be temporary and the country must be actively seeking to fill in the gaps in its information. It should be remembered that the SPS is new and untried, and, thus, its interpretation at the WTO is not yet clear. The Uruguay Round also strengthened disciplines on technical barriers to trade (TBT), the major improvement being that, if barriers are put in place to protect consumers, the benefits to consumers must be commensurate with the costs imposed on producers in meeting the regulations.

The WTO, however, has not been able to come to grips with issues dealing with trade and the environment; it has only agreed to study the issue (Nelson *et al*, 1999). The WTO is also not an international legal system; rather, it is a political compromise in which limited sovereignty is temporarily surrendered to the organization. Countries can choose to ignore the WTO, but not without cost. The current cost is retaliation of other members for violations of WTO commitments. When countries choose to accept retaliation, it indicates that the political compromise has broken down and renegotiation is required.

Access to Foreign Markets

The returns to investment in biotechnology will be determined, in part, by the size of the market and the life cycle of the product. Given the rate of technological change currently taking place in biotechnology, the life-cycle of any product is likely to be short, with new products with superior traits being developed quickly. This means that firms will require

access to the largest possible market. Given that the major value of biotechnology lies in its intellectual property, access to foreign markets has two elements: firms can capture the value of intellectual property by embodying it in goods that are exported to foreign markets, or they can capture the value by licensing the product for foreign production or producing it in a foreign subsidiary (Kerr *et al*, 1999). In the latter two cases, protection of intellectual property in the foreign country is required. If reverse engineering is relatively simple, then intellectual property protection will be required in the case of directly exported products. Thus, market access will depend critically on the efficacy of the WTO's ability to enforce TRIPS commitments. Developing countries hold serious reservations regarding protecting foreign intellectual property in the case of pharmaceuticals and seeds — major areas of biotechnology (Yampoin and Kerr, 1998). Given that some developing countries are not likely voluntarily to protect intellectual property, the question arises as to whether the as-yet-untried, cross-retaliation application of trade sanctions for TRIPS violations will be sufficient to induce compliance. Theoretical examinations of this issue to date indicate that the levels of retaliation currently allowed in the WTO will not be sufficient to induce countries to live up to their TRIPS commitments (Kerr *et al*, 1999; Tarvydas *et al*, 1999). This suggests that market access will be limited unless stronger disciplines can be negotiated. Developing countries can be expected fiercely to resist any strengthening of the TRIPS.

Intellectual property protection is relatively strong in developed countries, and trade issues have focussed instead on the licensing of products for local production, access to markets for GM products, and conditions of access of GM and non-GM products. If products are not licensed for local production, then foreign production under license or through a subsidiary is a moot point. Thus, intellectual property protection is not an issue, but market access remains an issue. If a product is not licensed domestically, should foreign products be allowed access, and under what conditions? This becomes the central issue. It is complicated by the fact that biotechnology gives a technological advantage to producers who are allowed to use the product relative to those who cannot (Weatherspoon *et al*, 1999a). Producers in countries where the product is not licensed will lobby for protection from foreign producers who are allowed to use the more efficient technology, even if this is not the primary reason for the trade restriction.

Countries have been licensing GM products at different rates. This is largely in response to consumer acceptance of GM products and the influence of those who fear the effects of biotechnology on the environment. In particular, the EU has been slow to develop mechanisms to licence biotechnology, reflecting a high level of consumer and environmentalist concerns (Perdikis, 2000). In the United States, on the other hand, consumer resistance and the influence of environmental lobbies has been minimal. As a result, licensing has been taking place at a much faster rate. The United States and the European Union represent extremes, but all other countries are in the process of putting

regulatory régimes in place that probably lie somewhere along a continuum between the two. This means a plethora of régimes and significant problems for international trade.

While the unofficial (but real) reason for the differences in the European and U.S. approach to licensing GM products is different levels of consumer/environmentalist pressure, the official reason is alternative regulatory approaches. The United States treats GM products as simple extensions of (substantially equivalent to) existing foods. The EU treats GM products as new (novel) products requiring a much stricter (and evolving) licensing régime (Perdikis, 2000). The reality is that the development of an EU licensing régime has ground to a halt as European politicians attempt to find a way to licence products in a way that will satisfy consumer and environmentalist concerns.

Firms in the United States that have invested in biotechnology and have had their products licensed for production in the U.S. seek access to the European Union and other international markets. The United States considers the products safe and tends to see foreign foot-dragging in protectionist terms. Countries, such as the EU, which do not wish to license biotechnology domestically have three policy options: ban the import of non-licensed products, require that products be labelled as GM and allow their import, or simply allow unlabelled imports. Unlabelled imports may reduce welfare if some consumers perceive biotechnology products as undesirable (because their quality cannot be detected it becomes a market for lemons — i.e., all products are suspect of being inferior). An import ban has been shown to be inferior to labelling (Gaisford and Lau, 2000) on strict welfare grounds, but countries continue to contemplate both policies.

Restricting Trade on Health Grounds

If a country wishes to ban imports for health reasons, it must do so under the rules of the SPS agreement. The SPS requires a scientific justification for the implementation of a ban. In the case of GM products, however, there is no scientific evidence as yet to justify their exclusion. The problem is that biotechnology is a relatively new technology and it can be argued that there is insufficient scientific information (Kerr, 1999a). In that case, the country imposing the ban must be actively seeking to fill the gaps in scientific knowledge. The problem in the case of biotechnology is that the questions being asked relate to long-term health concerns rather than short-term food safety. The SPS is set up to deal with questions such as "If I eat this tomato for lunch will I be sick at dinner?" rather than "If I eat these GM tomatoes for twenty years will I be at increased risk of cancer (or liver disease, or heart disease)?" This raises the question, How much science is enough? Science is both statistical and open ended; you can always find new questions to answer. One cannot have a *science-based* system if recourse to more science is always allowed (Kerr, 2000). The SPS attempted to handle that question by allowing for a scientific consensus through the establishment of international standards — for food safety at the Codex Alimentarius. Given the newness of biotechnology, there is no scientific consensus. Further, it seems clear that a major problem in the EU is that consumers (or at least a

sufficient number of them that they cannot be ignored by governments) no longer trust the scientific establishment (Kerr, 2000).

The recent case regarding the EU import ban on beef that had been produced using hormones suggests that, regardless of an international scientific consensus and large quantities of scientific information, EU officials do not feel they can remove the ban, and have accepted retaliation (Roberts, 1998). They would do the same if faced with an SPS challenge on biotechnology. As expected, given that the political compromise has broken down, the EU has asked that the SPS be renegotiated to allow for *consumer concerns*. The SPS, however, is probably working as intended, and negotiations regarding consumer requests for protection may need an entirely separate agreement (Perdikis and Kerr, 1999). Such negotiations are likely to be long and involved. In the interim, exporting countries will be faced with being shut out of some markets (Weatherspoon *et al*, 1999b). Further, they must put segregation and certification systems in place if they wish to retain access for non-GM exports. Developing countries may not have the technical capacity to prove that their crops are GM free, and thus face exclusion from banned markets. To retain market access, some developing countries may have to turn over control of their international trade to technically capable multinationals. Neither prospect is likely to appeal to the governments of developing countries. Of course, developing countries with higher levels of technical capability will be able to put in place systems that protect their market access, and some, like Thailand, have already done so — by, for example, changing the source of soy oil they use in canning tuna from GM sources to non-GM India.

Labelling

Some countries may opt for the labelling of products, whether or not they licence them domestically, to provide information for consumers. Exporters must then be able to certify and segregate their products. Firms producing or handling GM products in exporting countries have resisted this approach because they feel that their products are not different, and signalling them as different to consumers through labelling may create false concerns and negative impacts on demand. The TBT agreement, which deals with non-health consumer protection issues, may provide some recourse, given its provision that the cost of implementing the standard must be proportional to the purpose of the standard: consumer benefit versus exporter cost. The TBT is untested at the WTO; how a panel would rule on a challenge on biotechnology is unknown. Firms wishing to export GM products might, however, actually benefit from labelling. The direct cost of labelling products that contain GMs is low; one simply puts a label on the product. No one will care if the GM product is contaminated with non-GM products. Producers of non-GM products, however, must establish expensive segregation and certification systems because some consumers will care if non-GM products are contaminated with GM products. The cost of ensuring that products are non-GM may put those producers at a considerable commercial disadvantage (Kerr, 1999b). If the commercial disadvantage is sufficient, the intent of the labelling

policy — to give consumers a non-GM choice — may be thwarted. As a result, the level of tolerance for contamination becomes of crucial importance, because lower tolerances may become prohibitively expensive. Negotiations in this area will be complex.

Trade and the Environment

Countries may wish to control the import of the products of biotechnology for environmental reasons. The WTO has consistently put forth the position that it does not have competency in environmental questions, and that these issues should be handled in Multilateral Environmental Agreements (MEAs). The WTO's Committee on Trade and the Environment has not, however, yet been able to clarify the relationship between the WTO and MEAs and, in particular, which organization's rules should take precedence when trade provisions of MEAs conflict with the WTO (Kerr, 2000).

The BioSafety Protocol — or Cartegena Protocol — is an MEA that was reached in Montreal in January 2000. It was initiated under the auspices of the Convention on Biodiversity, but appears to go well beyond biodiversity issues that might be affected by trade in GM products. In particular, it goes beyond regulating trade in seeds or other organisms that are destined to be released directly into the environment to cover trade in GM products generally. The preamble fails to clarify the relationship between the Biosafety Protocol (BSP) and the WTO, and it has many provisions that directly conflict with those of the WTO (Phillips and Kerr, 2000). The BSP's trade provisions directly conflict with the WTO principles and practices in four areas: (1) trade barriers justified on the basis of production practices (e.g., biotechnology is a process); (2) inclusion of the precautionary principle as a reason for import bans (in direct conflict with the SPS scientific approach); (3) allowing socio-economic factors to be considered in the decision to import (e.g., if jobs might be lost), and; (4) mandatory labelling of GM products (the TBT requires benefits to be weighed against costs). The arguments need not be detailed here (see Phillips and Kerr, 2000 for details). Given that it has not been established which rules apply, trade will be in confusion and disputes likely. Further, because the BSP and the WTO do not have totally overlapping memberships, two sets of rules may apply, depending on the trading partner. Most important, the United States is not party to the BSP. Further, the BSP will not come into force until it is ratified by fifty countries.

Given that regulatory régimes are in a state of flux, major exporting countries have not had their export markets significantly disrupted as yet. One of the reasons for this is that the EU, where resistance to GM products has been strongest, was already relatively closed to exports. The major exception is in feed grains where the market has remained open to GM products such as corn and soy products (Ballenger *et al*, 2000).

DISCUSSION

The area of trade in biotechnological products is clearly in flux. This is because the current international trade régime is not equipped to regulate the trade in genetically modified products; no political consensus exists among the major trading countries. The central problem is the domestic treatment of GM products. These vary considerably, and the import régimes (or, more often, the proposed import régimes) largely reflect differing domestic approaches to GM products. Part of the problem relates to the newness of the technology. It seems clear that some renegotiation at the WTO will be necessary. Further, even within Canada, there is a direct conflict between our WTO commitments and what was agreed to in the Biosafety Protocol. Fundamentally, the rules of trade are there to provide transparency for firms wishing to engage in international trade. Currently, there is no transparency regarding the trading régime that will apply to GM products.

No strong, well-researched proposals for finding an acceptable solution to the differing positions of the various trading parties exist. Canada is one of the countries that has been early to licence GM products. Its agricultural sector is heavily dependent on exports. It is important to have the trade issue resolved. But so far there has been little innovative thinking regarding trade in GM products. Developing a well-reasoned set of proposals for resolving the multitude of issues surrounding international trade in biotechnology could be a major contribution in moving the process of devising new rules along. Until these issues are resolved, the true potential for the role of biotechnology in Canadian agriculture cannot be assessed — particularly for those who are considering investing in the technology.

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8.0 Biotechnology and Lesser Developed Countries: An Overview of the Issues

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THE ISSUE

The impact of agricultural biotechnology on Lesser Developed Countries (LDCs) has become an area of considerable public debate. While these countries share many of the issues that are a concern in developed countries, many LDCs have characteristics that differ from developed countries, specifically: (1) food production and consumption make up a larger portion of the economy; (2) nutrition and food security continue to be important challenges; (3) there is a lack of the research resources to develop and apply these technologies in either the public or private sector; and (4) there is a lack of the institutional infrastructure effectively to manage any of the biosafety risks associated with the technologies. These characteristics will influence the impact that biotechnology will have on LDCs.

As occurs with most "drastic" technological change, two schools of thought have evolved. One school (the proponents) believes that agricultural biotechnology will be beneficial to LDCs, and the other (the opponents) believes that agricultural biotechnology will be detrimental to LDCs.

IMPLICATIONS AND CONCLUSIONS

The use of biotechnology to create genetically modified transgenic crops has potential benefits for both the developed and the developing worlds. Like any technological change, however, there are adjustment costs and potential adverse outcomes. Given the disparate income levels, production methods, and institutional structures, the effect on LDCs will differ from developed countries.

There are a number of products of genetic modification (GM) that offer a great deal of promise in lowering the cost of production, improving crop yields, and improving food

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quality. These potential benefits are of greater relative importance to LDCs because of their heavy reliance on agricultural production and the prevalence and/or threat of malnutrition in many of them. GM crops are seen as a potential means of addressing critical food and resource issues, and consumers are much more willing to take additional food safety risks to obtain greater food security.

The ability of a particular LDC to benefit from biotechnology will be dependant on whether the country will have low-cost access to new genetics adapted to their growing conditions and economic situation, whether they have institutions in place effectively to mitigate any risks associated with the technology, and whether they continue to have access to their agricultural export markets. Given that these conditions are unlikely to be met in many LDCs, the net benefits from agricultural biotechnology will likely vary a great deal by country.

Given the potential of GM crops to address food and resource issues in LDCs, there should be an onus on the international community to provide the support necessary for these countries to take full advantage of the technologies. In the short run, this will require significant international public investment in biotechnology that is targeted toward the creation of crops and genetic traits suitable for LDCs. It will also mean facilitating the transfer of knowledge to the LDCs and the creation of human capital in the LDCs in order to develop and effectively manage these technologies. Given the difficulty in segregating GM products in LDCs, there is a need to recognize the adverse impact that labelling standards and import restrictions will have on the development of these countries. Finally, given the very real differences between developed and lesser developed countries, it is important that LDCs are allowed the opportunity to make informed and independent decisions about the adoption of genetically modified crops.

BACKGROUND

Transgenic Research and Adoption in LDCs

The are a number of LDCs currently involved in transgenic research, but few countries with commercial plantings of GM crops. In the year 2000, 24% of the world-wide plantings of GM crops was in LDCs, with the vast majority of these acres in China and Argentina. (Pinstrop-Anderson and Cohen, 2001). While planting in the developed countries fell between 1999 and 2000, area increased by more the 50% in LDCs, suggesting that LDCs may be in the process of more widespread adoption.

As outlined by Skeritt (2000), several governments in Asian countries including China, India, Indonesia, Malaysia, Pakistan, Philippines, Thailand, and Vietnam have committed significant human and financial resources for R&D in modern biotechnology. Biotechnology research in other LDCs has been limited, and what there is is dominated by expenditures by domestic governments and international research organizations. Despite

massive private investments in some developed countries, there is little private funding of biotechnology research in LDCs.

The differences in the pursuit of GM technologies among the LDCs can be explained by three main factors. The first has to do with the effect of income and expenditure shares on the choice or the willingness to take perceived risks related to GM consumption. The second has to do with the potential production-related benefits. The third relates to the institutional barriers that may prevent the creation and adoption of the technologies.

Potential Benefits of GM Crops in LDCs

Individuals in developing countries can potentially benefit from transgenic crops in three main ways: improved incomes for small farmers, greater long-run stability in local food supplies, and better health through nutritionally enhanced foods. These benefits will only be realized if suitable GM crops are developed for LDCs and widely adopted by their producers.

Small farmers in developing countries are currently faced with pre- and post-harvest crop losses from insects, diseases, weeds, and drought. In addition, acidic soils, low soil fertility, lack of access to reasonably priced plant nutrients, and other biotic and abiotic factors contribute to low yields, production risks, and the degradation of natural resources (Pinstrup-Andersen, 1999; Pinstrup-Andersen and Cohen, 1999). Farmers must often clear forests or farm marginal land in order to maintain production. Increased urbanization exacerbates the situation through the loss of quality farmland (John Innes Centre, 2000). New developments in agricultural biotechnology can counteract these production problems. GM techniques can produce plants that use less water and can survive drought, flooding, or extreme temperature (Robinson, 2000). The development of cereal plants capable of capturing nitrogen from the air could contribute greatly to plant nutrition and help small farmers who cannot afford fertilizer (Pinstrup-Andersen and Cohen, 1999). In addition, the introduction of genes that delay ripening or spoilage could help reduce post-harvest losses of perishable fruits and vegetables, especially for areas where poor farm-to-market roads, inadequate transportation, and inadequate storage facilities is the norm (Spillane, 2000). Weed control is a major time-, labour-, and resource-consuming task for most farmers, especially resource-poor farmers who cannot afford herbicides. It is estimated that in developing countries approximately 60% of farmers' time is spent weeding (Spillane, 2000). Much of it is done by women and children, and is unpaid work. Herbicide-resistant crops could bring advantages to poor farmers, especially those with limited labour availability. Labour previously spent weeding could be released for more productive activities, such as increasing literacy and schooling for children. While herbicide tolerance may be of limited value for these small holdings, the development of crops with a greater ability to compete with weeds may be important for them.

Agricultural biotechnology could also result in significant health benefits to individuals. For example, scientists have now developed a new strain of rice that is

enhanced with Vitamin A (Spillane, 2000). Vitamin A and iron deficiency cause severe health problems in LDCs. Approximately 100 million children suffer from vitamin A deficiency, and each year half a million go blind, and some two million die (Conway, 2000). Iron deficiency is also common. Approximately 500 million women of childbearing age (15-49 years old) are afflicted by anemia caused by iron deficiency. Other health problems stem from the limited supply of vaccines owing to the prohibitive expenses of production and the lack of effective cold storage facilities (Spillane, 2000). There is potential for agricultural biotechnology to alleviate some of this problem by using plants such as bananas and potatoes as vaccine delivery mechanisms (Smith, 2000). Opponents note, however, that these products may have to be distributed freely, and must be culturally accepted if they are to be effective.

Consumer Concerns for Food Safety

The issue of food safety that has led to consumer opposition in the EU and other developed countries is generally far less of an issue in LDCs. Seventy nine percent of consumers in China and 76% of consumers in India favour biotechnology for the development of pest-resistant crops, as compared to 54% and 36% of consumers in Germany and the UK, respectively (Pinstrop-Anderson and Cohen, 2001). As Pinstrop-Anderson and Cohen effectively argue, this differing perspective is likely owing to the importance of food quantity over food safety. In LDCs, consumers spend a large portion of their household resources to acquire food, and are therefore willing to accept some risks for lower-cost food. Consumers in developed countries, in contrast, spend a much smaller portion of their income on primary agricultural products, and are willing to forego a potential reduction in food prices to avoid any perceived risks associated with GM foods.

Given the potential for GM crops to lower the cost of nutritious food production and the concern for food quantity over food safety, many citizens of lesser-developed countries agree that the benefits of biotechnology are greater than the risks. But the view is not unanimously held. Wealthier consumers in these countries may share concerns about food safety with consumers in other countries. In addition, many LDCs lack the institutions that will allow them to take advantage of new technologies, and, as a result, they will be left behind the countries that do. Opponents expect that these new technologies will contribute to income disparity, and not address the farm income, poverty, or food insecurity problems. Without complementary social policies, good governance, and sufficient public financial resources, it is argued that the potential benefits of biotechnology for LDCs will not be realized (Leisinger, 1999).

Agricultural Biotechnology and Institutions in LDCs

The potential benefits of transgenics for LDCs can be realized only if these technologies are applied to create GM crops that are grown by these countries in such a way that

existing markets and biosafety are not jeopardized. These conditions are not currently met within LDCs for a number of reasons.

Perhaps the greatest challenge will be to obtain the resources required to do the research and development. Funding for biotechnology research in developed countries is characterized by private sector investments in research. Private, commercial-sector expenditures in the United States fund approximately 70% of the agricultural biotechnology research (Falconi, 1999). In lower-income countries, on average, the private sector accounts for a mere 8% of biotechnology research. This is a real problem, given that public institutions are significantly under-investing in agricultural research. The World Bank recommends that each country invest at least 2% of its agricultural GDP in agricultural research and development (Spillane, 2000). Currently, developing countries spend less than 0.5% of the value of their agricultural production in agricultural research (Pinstrup-Andersen and Cohen, 1999). In Sub-Saharan Africa, for instance, real spending per scientist has fallen by 2.6% a year since 1961, with the rate of decline accelerating from 1.6% a year during the 1960s to 3.5% a year during the 1980s (Spillane, 2000).

A large amount of private biotech research in developing countries is unlikely to be forthcoming for a number of reasons. Given the small holdings and largely self-sufficient nature of production, it is difficult for private firms to capture the value of their innovation from the marketplace in these countries. The long-held traditions of retaining seed, the lack of property rights, and the large number of small producers makes it difficult for firms to capture the value for their GM crops. To compound the problem, many of the crops grown in LDCs are small, regional crops grown on acreage that is extremely limited. These "orphan crops" are likely to be ignored in transgenic research programs, and the nature of the growing conditions makes it difficult to cover the fixed costs of cultivar development. Finally, many LDCs lack the human and physical capital required to take advantage of transgenic technologies. This makes it very expensive for private firms to conduct research.

If large-scale private research is unlikely to occur in many LDCs, the public sector must play a large role in research and development. This presents problems of its own. First, tax revenue is difficult to raise. Second, it is increasingly difficult to obtain public access to genetics and processes protected by Intellectual Property Rights (IPR). Finally, there is often a lack of human and physical capital. The inability of LDCs to attract and keep scientists with advanced training is particularly problematic. Further, training in developed countries, using technologically advanced and expensive equipment, is often not appropriate to the conditions under which scientists in LDCs must conduct research (Woodward, Brink, and Berger, 1999). If any type of research in LDCs is to be performed successfully, however, broad infrastructure needs must be met. It is not possible to master biotechnological methods or products without the proper buildings, laboratories, and equipment (Brenner, 1997). In addition, modern communication systems are not readily available (Brink, Woodward, DaSilva, 1998). Without the basic components of human and

physical capital, biotechnology research is unlikely to take place in many LDCs. Getting enough biotechnology research to create transgenic crops adapted to LDCs is a significant challenge.

Segregation and Market Access

Many agricultural products and processed goods are exported from LDCs to developed countries. Often these exports make up a large portion of foreign exchange earnings. The EU has placed a ban on the import of some GM food products, and requires labelling of others. Other countries, including Japan, Korea, and Australi,a have introduced mandatory labelling requirements. A recent poll suggested that 75% of Canadians would not buy GM food if they had a choice (McIlroy, 2000). North Americans are thought to be much less concerned about GMOs than their European counterparts. Retaining access to these markets may require that exporters guarantee the GM-free status of their exports. This will require an effective segregation system, which may be very difficult for LDCs to achieve.

If physical segregation of GM and non-GM commodities were to be required, LDCs could find the costs of compliance prohibitive. The physical and institutional infrastructure necessary for LDCs to segregate GM from non-GM food currently does not exist. Basic physical infrastructure, such as roads, telecommunications, and refrigeration, is still lacking to a considerable degree in many LDCs. Transportation and storage facilities are inadequate for current commodity markets to function efficiently, let alone for sophisticated markets that require credible monitoring and enforcement mechanisms. Even if the physical resources and infrastructure were available, the lack of effective monitoring and enforcement would be a severe problem. Thus, if agricultural biotechnology were available for production of a particular commodity in an LDC, international markets would likely treat all of that country's product as GM.

Biosafety

Managing the risks associated with the genetic modification of crops requires resources to identify health and environmental risks, an efficient means of developing the regulations to address the problems, and the ability effectively to enforce the regulations. LDCs often lack all three.

LDCs generally lack the resources required for the adequate testing of new products. In developed countries, GM crops and their products are subject to testing and assessment to determine whether they pose a threat to human health or pose environmental risks. While some would argue that these tests are inadequate to quantify all the risks, there is nevertheless a system in place in most developed countries to protect citizens against large quantifiable risks. For instance, GM foods are tested for known allergens. While the owners of the innovation incur substantial costs to test products, the public regulators also require a substantial human and physical infrastructure to review the evidence provided to

them. Without the resources to assess these technologies, many LDCs will by default have to rely on testing and assessment done in other countries. This situation exists currently in many non-agricultural products.

The creation of regulations designed to protect human health and the environment is often a difficult process in LDCs. In many countries, other, more important issues take priority in governance. Often there is a scarcity of the human resources to draft the statutes required to regulate new products. In some countries, the process is further complicated by frequent radical changes in leadership or government structure.

LDCs often also lack the legal infrastructure and the resources required effectively to enforce regulations that could restrict the production of a hazardous GM crop. Most LDCs have a large portion of their population engaged in agriculture, with much of the consumption taking place in the same households that produce the products. The shear number of producers makes the enforcement production difficult and expensive. If a GM crop was found to be a threat to human health after it was introduced, a regulation that banned the production of this variety would be difficult to enforce once the seed was in the countryside. Regulating production would be prohibitively expensive, for the same reasons that the enforcement of IPR and segregation would be difficult to achieve. To a large extent, this makes the decision to introduce a GM crop essentially irreversible in many LDCs.

DISCUSSION

Despite the potential benefits of agricultural biotechnology for LDCs, concerns remain regarding the accessibility of new technologies. Owing to economies of scale in agricultural biotechnology research, a small number of multinational companies produce the vast majority of these new products. Even if the institutional structure was sufficient for multinational companies to choose to make their intellectual property available in LDCs, could small-hold farmers afford the new production technologies? Many observers believe that the current GM products, which are typically labour saving, would not be in high demand because labour on small farms is plentiful and hard currency is scarce.

The challenge remains to facilitate the adoption of technologies that benefit the agricultural sector in LDCs, thereby acting as a catalyst for economic development. This challenge is magnified because of the poorly developed legal, financial, and market institutions typical of LDCs. In many ways, this is the classic problem facing developing countries, and is not peculiar to agricultural biotechnology. Policy makers in developed countries need to be aware of the challenges faced by LDCs in dealing with the multi-faceted aspects of agricultural biotechnology. They also need to be aware of the vital importance of agriculture in the economies of these countries, and their vulnerability when faced with the current climate of uncertainty internationally with respect to GM food.

Some of the lack of biotech research can be addressed through public and private collaboration. It has been suggested that public-sector institutions develop new partnerships with the private sector and advanced research institutions (Serageldin, 1999). This collaboration would give LDC public sectors a means of accessing research tools, attaining technical expertise, and expanding their financial resources. The private sector may also benefit from reduced investment risk, improved public relations, and a better understanding of local cultures, leading to improved assessments of market opportunities (Lewis, 1999).

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9.0 Overview and Conclusions

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GM crop production is a new technology with a wide range of effects that have the potential to influence the well-being of many groups and individuals in the world economy. The recent commercial introduction of these crops means that many of the impacts of these technologies are still hypothetical in nature and have yet to be realized. Many alleged costs and benefits are reported with a wide range of reliability; some are inconsistent with scientific or economic theory; some have the potential to exist in theory but have yet to be measured, while initial estimates of others have been made. Therefore, while there is much discussion of *potential* effects, in most cases it is simply too soon to provide concrete measures of the size and distribution of *actual* effects.

Many issues have yet to be resolved. While there is little concrete evidence of major adverse affects at this point, most would agree that many of the potential adverse effects would take a number of years to develop. Thus, it is simply too early to be sure. The unresolved uncertainty about the effects of GM crops creates a difficult situation for policy makers. On the one hand, if GM technology is eventually accepted as safe, then it would be important to continue to invest in and develop the industry. On the other hand, if the technology has some large, unforeseen costs, or even if consumers continue to mistrust it, then making in some cases irreversible decisions to adopt these technologies could come at an extremely high cost. This dilemma suggests that it would be prudent to spend resources continually to evaluate these technologies as more information becomes available. The uncertainty also suggests that irreversible decisions should be made with caution, and that it may be prudent in some cases to postpone some irreversible decisions until more information becomes available. Finally, as with any new technology, there will be both costs and benefits, winners and losers.

The analysis summarized in this report clearly illustrates that many of the costs and benefits are external to the GM marketing channel. Thus, the ability of a GM product to survive in the marketplace does not indicate the overall viability of the technology. The complex trade-offs involved suggest that the public needs to be as informed as possible so that they can participate in the debate and in the democratic processes required to make these important decisions.

Chapters 2 to 8 of this report reviewed some of the most important issues associated with the introduction of GM crop technologies. With a review of the literature, they

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attempted to summarize what is currently known about the costs and benefits of these technologies.

Table 9.1 below summarizes some of the key issues, research findings, or conceptual insights and research and policy needs.

Table 9.1: Summary

Issues	Research Findings/ Conceptual Insights	Research and/or Policy Needs
INDUSTRY STRUCTURE • Increasing concentration in seed and chemical industries • Increasing vertical linkages through "life-science" platforms • Is/will there be an abuse of market power? • Role of intellectual property rights in creating incentive for investment in R&D	• Industry structure in state of flux • Estimates of concentration ratios are preliminary and change rapidly • Appears to be limited opportunities for price discrimination in North American market but more evidence on international market	• Clear picture yet to emerge as to nature of concentration and whether this will create long-run losses in economic welfare • Lack of good data on production and R&D costs in biotech Sector • A need to determine whether business practices reflect anti-competitive behaviour or normal business practice.
ENVIRONMENT • Potential environmental benefits from virus-resistant, insect-resistant and herbicide-resistant crops, including reduced soil erosion, reduction in chemical inputs • Potential environmental costs include gene flow dispersal, outcrossing, increased pest and herbicide resistance, negative impacts on non-target organisms	• Little direct scientific evidence for many of the environmental concerns, given usual conditions of production environment • Too soon to observe actual long-run environmental costs and benefits. Research is largely theoretical or based on forecasts, not direct estimate of effects. • Although early evidence appears positive, very little known about potential impact (negative or positive) of virus resistant crops — too new.	• Potential irreversibility problem from releasing new varieties creates long-run uncertainties which are difficult to quantify • Possible need for stronger enforcement mechanisms — currently farmer insect resistance management programs are voluntary • Policy and research evaluations should also consider relative costs and benefits of conventional agriculture to provide a benchmark comparison • Case-by-case evaluation of environmental costs *and* benefits required
AGRONOMIC • Potential producer benefits from input trait crops	• Most research has focused on US crops and US production situations	• A need for Canadian, crop-specific studies • Need for research to

from input-trait crops include improved yields, reduced input costs and a convenience factor • Potential consumer benefits include lower prices (depending on competitiveness of downstream sectors)	• Good evidence of improved ability to control pest and increase yields, etc. • Impact on producer profitability is less certain. Estimates only available — suggest gain of Cdn. $5-$8/acre • Rapid adoption by western Canadian farmers suggests an improvement in profitability	establish impact of having more than one GM crop in rotation on profitability • Current lack of data to allow sufficient analysis
CONSUMER • A mixture of consumer concerns: ➢ Specific food safety concerns (allergens, toxicity, nutrient content) ➢ Long-run fear of the unknown food safety effect ➢ Ethical concerns ➢ Environmental concerns • Compulsory vs Voluntary labelling	• Numerous consumer opinion poll surveys but usually lack a basis of comparison • Conceptual research discussing the nature of the information problem and the different regulatory approaches to product approval, labelling, etc.	• A need for research to disentangle these concerns and understand causes & solutions • Research needed to identify consumer segments with different preferences and understand the motivations for those preferences • Research needed on likely consumer reaction (by segment) to future output-trait GM products • Research needed to measure consumers' willingness to pay (positive or negative) for labelling information, output traits. • Methods and desirability of involving public in decision-making need to be evaluated.

LABELLING & SEGREGATION • What are the costs of segregation? • Who bears these costs? • Should the system be voluntary or is there market failure indicating the need for a compulsory system?	• Almost all analyses is in absence of widespread segregation • Existing studies produce a wide range of estimates of the costs of segregation and labelling, ranging from Cdn. $10-$50/tonne. • Estimated costs depend on key assumptions regarding accepted tolerance levels; effectiveness of system (degree of cheating), testing costs and procedures; market volumes of GM vs non-GM crops	• Difficult to generalize U.S. studies to Canadian situation • Need for crop-specific, situation-specific analyses of which system(s) would be most suited to Canadian grains industry • Uncertainties over key variables, including tolerance levels and volumes make sensitivity analysis critical
TRADE • Access to international markets and the role of intellectual property rights • Protection of domestic consumers (health) and environment vs. obligations under international agreements • Threat to developing countries markets	• Little or no empirical work because it is too soon. Most countries still putting domestic regulations in place so international rules in a state of flux • Existing work theoretical and conceptual	• No government statistics yet exist on trade in GM and non-GM products • Need to improve transparency of international rules with respect to market access and protection of intellectual property rights • Expect complex negotiations over issues of labelling and market access. May require re-negotiation at WTO to establish mechanism for dealing with consumer concerns. • Need clearer picture of which international agreement takes precedence — e.g. WTO or Biosafety protocol. • Need for a well-reasoned, theoretically sound, yet politically realistic set of proposals for resolving looming trade issues.

LDCs • Potential benefits include improved incomes for small farmers, greater long-run stability of food supplies, and improved health through nutritionally enhanced foods. • Lack of research resources (public or private) is a severe constraint • Inadequate physical & institutional infrastructure may hamper adoption and regulation of biotech products, and will certainly create severe problems if segregation of GM/non-GM products required.	• Lack of consensus as to whether these potential benefits can be realized given the resource, infrastructure, and human capital constraints faced by many LDCs.	• Net benefits likely to differ country by country • Need for policymakers to be aware of vital role agriculture plays in LDCs • Need for international community to find ways of supporting public investment in biotech research designed for specific LDC needs. • Need for policymakers to recognize potential adverse impact of labelling & import restrictions
OVERALL	• In most cases it is too soon for definitive estimates of aggregate gains or losses in economic welfare • Important theoretical groundwork has been laid for later empirical work and to provide better understanding of the issues • Existing monetary estimates of costs and benefits are in most cases estimates or projections	• Need to establish data collection procedures to allow on-going monitoring of costs and benefits as they emerge • Need for multi-dimensional analyses which take into account trade-offs among producers, consumers, and non-market externality effects across society. • A need to establish a procedure for evaluating trade-offs between possible irreversibility of GM investment/release decisions vs potential costs of innovation foregone

POLICY IMPLICATIONS

As is clearly illustrated in this review, there are a large number of diverse impacts from GM crop production. Potential adverse environmental and food safety consequences are at the centre of the GM debate, and create a ripple effect throughout the GM and the non-GM marketplace. While concrete evidence of adverse impacts is difficult to find, there remains a doubt in the minds of many consumers and some producers. Even a small probability of

long-term adverse effects can be enough to reduce consumer demand for many of these products, and can induce consumers to demand that their governments ban these products, block trade, or require labelling. These market impacts have the potential to create large economic costs for GM and non-GM marketers and producers.

Three related policy implications emerge from this analysis:

1. Information & Data
   In the short run, there is a need to gather as much information as possible and swiftly address any concerns if there is evidence that an adverse impact exists. Equally important is the provision of credible information to the public when the concerns are unfounded. Over the longer run, there is a need to establish data-collection procedures to allow on-going monitoring and measurement of costs and benefits as they emerge. Information requirements include: measures of industry concentration, production and R&D costs in the biotech sector, environmental impact analyses, adoption rates of GM crops by region and crop type, producer agronomic and market benefits, measures of consumer preference and attitudinal changes over time and between regions, assessments of the costs of alternative segregation systems, statistics on trade in GM and non-GM products, and tracking of existing and proposed import regulations affecting GM products.

2. Multi-Dimensional Analyses
   The costs borne by non-GM producers, marketers, and consumers can be substantial. As far as is possible, given the data limitations mentioned above, steps should be taken formally to incorporate these costs into the decision to license a GM crop technology. Hence, there is a need for multi-dimensional analyses that take into account trade-offs among producers, consumers, and non-market externality effects across society. Frequently, this will present serious analytical challenges, since many of the costs may not become apparent until after commercialization, and will depend on the extent and rate of technology adoption. Rather than relying on a strict quantification of measurable costs and benefits in making a licensing decision, qualitative consideration of additional post-commercialization effects also will need to be made. Critical to the credibility of this assessment, then, will be an open and transparent licensing system in which the considered decisions of regulators are subject to public scrutiny.

3. The Irreversibility Conundrum
   When there is uncertainty about whether an adverse impact exists, the irreversibility of the introduction of a GM technology suggests that a cautious approach should be adopted, with careful consideration of the benefits of waiting until more information is available. In many cases, the approval of a GM crop for licensing and commercial

adoption may be a one-time only decision in terms of its potential environmental impact or the consequent need to segregate non-GM crops. There may be effects that cannot be undone by "de-licensing" the crop at a future date should it be discovered that its release had detrimental environmental or market impacts. Of course, there are two sides to this issue. A cautious "wait-and-see" approach may in itself create costs in the form of innovations foregone and economic growth and development opportunities passed by. Ultimately, we need a means of determining when "enough information is enough" to allow an irreversible investment decision to proceed. There is a need to establish procedures for evaluating the expected trade-offs between irreversibility of GM investment and release decisions versus the potential costs of innovations foregone. In an ideal world these would be internationally agreed-to procedures. International consensus is necessary to avoid the inevitable trade friction and market access issues that will result from the application of conflicting domestic policy approaches to what is essentially the same problem across a number of countries. Ongoing information collection and analysis, as identified in point 1 above, should help in this regard. Existing international institutions such as the Codex Alimentarius Commission and the World Trade Organization may provide the forums through which international consensus can be reached.