

CANADIAN CANOLA BIOTECHNOLOGY



BIOTECHNOLOGY AND CANOLA IN CANADA — APPLICATIONS AND BENEFITS

Over the past 20 years, the canola industry in Canada has undergone a technological revolution. As a result, canola production today is more sustainable than ever. While canola production has steadily increased, farmers have used fewer pesticides in lower quantities, burnt less fuel, sequestered more CO₂ and earned higher incomes from canola than ever before.

A key to this development has been modern agricultural biotechnology, that is: genetic engineering (sometimes referred to as genetic modification). First introduced in 1996, genetically engineered (GE) canola has become a very important technology for canola farmers. However, misconceptions about genetic engineering in general, and GE canola in particular, cast a shadow over this innovation. Many consumers continue to question the safety of genetically modified organisms (GMOs) and their impact on human health and the environment.

In reality, genetically engineered crops are no less safe for humans or the environment than crops developed by other means. Comprehensive new analysis by the National Academies of Sciences, Engineering and Medicine proves it.^[1]

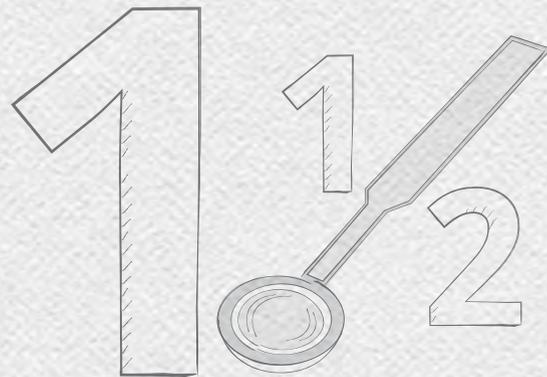
This paper will discuss not only the benefits of canola in general, but the benefits provided by genetic engineering technology. In the process, it will show that GE canola is equivalent to — and just as “natural” as — canola created by traditional breeding methods. Genetic engineering has been important to increase the sustainability of canola in Canada, and many of the benefits of GE canola could likely not have been achieved as quickly through traditional breeding.

CANOLA – AN OVERVIEW

Every summer, about 20 million acres of prime Canadian farmland turn brilliant yellow as canola crops go into bloom. These vast fields yield millions of tonnes of tiny seeds that are filled with one of the world's healthiest culinary oils. After the oil is extracted, the seed solids are processed into a protein-packed meal co-product that is an excellent addition to livestock feed.

Canola oil is one of the healthiest cooking oils available, containing the least saturated fat (only 7%) of any common culinary oil (half that of soybean or olive oil). A growing body of studies have suggested that a diet with canola oil can have a positive effect on several widespread and chronic health problems, including heart disease and diabetes.^{[2] [3]}

At the same time, canola oil is the most versatile. It is suitable for cooking at high temperatures and has a neutral taste and light texture that makes it easy to produce a wide range of healthy foods. It is, therefore, not surprising that canola is the world's second largest oilseed crop after soybeans (while palm oil leads plant-based oil production overall).



*WHEN CANOLA OIL IS USED TO REPLACE A SIMILAR AMOUNT OF SATURATED FAT

**TABLESPOONS
(OR 19 GRAMS)**

**OF CANOLA
OIL DAILY***

**MAY REDUCE
THE RISK OF CORONARY
HEART DISEASE**^[49]

Canola oil is absolutely safe and nutritious. Families in over 40 nations around the world choose canola oil because it contains the least amount of saturated fat (only 7%) of any common cooking oil and may help protect the heart.

Western Canada is one of the leading canola-growing regions worldwide and canola is the top source of farm crop receipts in Canada, totaling \$8 billion in 2015.^[4] Canola exports in 2015 were valued at \$8.9 billion, including seed, oil and meal.^[5] A study released in 2013 shows Canadian-grown canola contributes \$19.3 billion to the Canadian economy each year, including more than 249,000 Canadian jobs and \$12.5 billion in wages.^[6] In short, canola has been a major boon to Canadian farmers and the Canadian economy.



Canada exports 90% of its biotech canola around the world. Producing, moving and processing this much grain into top-quality oil and meal takes a lot of people. The canola industry is responsible for 249,000 jobs in Canada and an annual economic impact of \$19.3 billion.

THE FIGHT AGAINST WEEDS

One of the greatest challenges for farmers is weeds. Weeds can overgrow crops, depriving them of nutrients and even sunlight. To destroy weeds, farmers have ploughed, harrowed and hoed their fields for thousands of years. Other methods included burning fields after the harvest, planting different crops in one field and converting wilderness to farmland in order to grow more crops to compensate for losses to pests.

The development of modern herbicides over the past century has made it easier for farmers to manage weeds. Many of these substances take advantage of the differing biology of plants and allow farmers to spray herbicides that destroy grasses, but not broadleaf plants like canola. Instead of mechanical weeding, farmers can apply highly selective herbicides that destroy certain weeds, but not crops. As herbicides have become more specialized, farmers can fight an ever-increasing number of specific weeds without damaging their crops. This helps farmers grow more on existing farmland and limits the need for expanding agricultural area to increase production.

However, all of these methods come at a cost. Farmers need to spend time, money and labour fighting weeds. Pesticides alone represent anywhere between 7.5% (soybeans) to 35% (navy beans) of total farm-operating costs.^[7] Of these, expenditures on herbicide are the most significant, representing anywhere from 50–60% of global pesticide sales.^[8]

Furthermore, traditional weed-management methods, especially ploughing and harrowing, are significant contributors to the environmental cost of farming: regular inversion of the soil kills weeds but also destroys the structure of the soil, reduces soil biodiversity and increases water evaporation. All these factors combined can lead to the long-term degradation of soil, causing soil erosion to the point of large-scale desertification. Soil erosion has always been a risk to agriculture, whether on the small fields of medieval Europe,^[9] or the large fields of modern mechanized agriculture.^[10]

Finally, and of increasing significance in the face of global climate change concerns, farming is a major contributor to global CO₂ emissions,^[11] while tillage significantly reduces the soil's ability to absorb CO₂ from the air.^[12] Climate change, in turn, is likely to increase the risk of soil erosion — especially in the Canadian Prairies.^[13] Soil erosion is therefore a significant concern for canola farmers.

Farmers are caught in a quandary: they need to reduce the risk of crop losses from pests, like weeds, while minimizing risks posed by management practices like mechanical weed management. Until the early 1990s, this balancing act was limited to using mechanical weed management as much as possible, supplemented by a range of herbicides.



A NEW WAY TO MANAGE WEEDS

In the 1990s, biochemists began developing a new approach to weed management — herbicide tolerance, starting with tolerance to glyphosate. Glyphosate is an effective, non-selective herbicide that kills all plants and is also relatively benign in terms of human and environmental health.^{[14][15][16]} However, since glyphosate kills all plants, it could only be used before crops started to grow; farmers still needed other herbicides throughout the growing season.

Starting in 1995, seed companies introduced plants that were resistant to glyphosate and similar non-selective herbicides. With this one small change in the plant genome, farmers could introduce innovative weed-management processes on a global scale; instead of ploughing, harrowing and spraying several herbicides, weeds could be controlled almost exclusively with glyphosate. The magnitude of this change is hard to exaggerate. Herbicide tolerance was nothing short of revolutionary, and probably the most significant change in agricultural technology since the beginning of agriculture.

The key to this development has been modern agricultural biotechnology.

BIOTECHNOLOGY AND CANOLA

Canola was originally developed by Canadian plant breeders in the 1970s using traditional breeding methods, such as selective breeding and crossbreeding. However, while crossbreeding and selective breeding may be traditional, they are — strictly speaking — examples of biotechnology. According to the Food and Agriculture Organization of the United Nations, “biotechnology is any technique that uses living organisms or substances from these organisms to make or modify a product for a practical purpose.”^[17] In this sense, biotechnology includes brewing, baking, cheesemaking and the breeding of animals and plants.

Genetic engineering is a subset of biotechnology and generally describes processes that intentionally change the DNA of living organisms. Still, genetic change or genetic modification is an essential part of the natural evolutionary process that has been going on since the beginning of life, and much of what scientists do in the lab is either very similar or identical to natural processes. Farmers have intentionally changed the genetic makeup of all the crops they have grown and the livestock they have raised since domestic agriculture began 10,000 years ago. Every fruit, vegetable and grain that is commercially available today has been altered by human hands, including organic and heirloom seeds.^[18] While traditional breeding can involve controlled mating or taking advantage of “happy accidents” from random mutation in the field, modern breeding methods are more selective, precise and predictable.



VARIOUS TYPES OF BIOTECHNOLOGY

“**Biotechnology**” means the application of science and engineering in the direct or indirect use of living organisms, or parts or products of living organisms, in their natural or modified forms. This term is very broad and includes the use of traditional or conventional breeding, as well as more modern techniques such as genetic engineering.

“**Modern biotechnology**” is used to distinguish newer applications of biotechnology, such as genetic engineering and cell fusion from more conventional methods such as breeding or fermentation. Most often the term “biotechnology” is used interchangeably with “modern biotechnology.”

“**Conventional breeding**” or “**selective breeding**” means propagating plants or animals sexually, selecting for certain traits. Using selective cross breeding, people can produce different varieties of plants and breeds of animals.

GM stands for “**genetically modified.**” An organism such as a plant, animal or bacterium, is considered genetically modified if its genetic material has been altered through any method, including conventional breeding. A “**GMO**” is a genetically modified organism.

GE stands for “**genetically engineered.**” An organism is considered genetically engineered if it was modified using techniques that permit the direct transfer or removal of genes in that organism. Such techniques are also called recombinant DNA or rDNA techniques.

“**Transgenic**” organisms have a gene from another organism moved into them. For example, the plant product known as “Bt corn” is a transgenic plant because it has a gene from the bacterium *Bacillus thuringiensis* (Bt). That gene produces a protein with pesticidal properties that, when incorporated into a plant, allows the plant to produce this protein, thus transferring the bacteria’s natural defence to the plant.

“**Mutagenesis**” is the use of methods to physically change or “mutate” the genetic sequence without adding DNA from another organism. Various chemicals and ionizing radiation can be used to invoke these changes. “Site-directed mutagenesis” can also be used to invoke changes in specific genes. In plants, such agents are used to change a plant’s genetic sequence, and the plant can pass on these new characteristics to its offspring.

These definitions are from the Canadian Food Inspection Agency. For more information, check out “Modern Biotechnology: A Brief Overview” at <http://www.inspection.gc.ca/plants/plants-with-novel-traits/general-public/overview/eng/1337827503752/1337827590597>



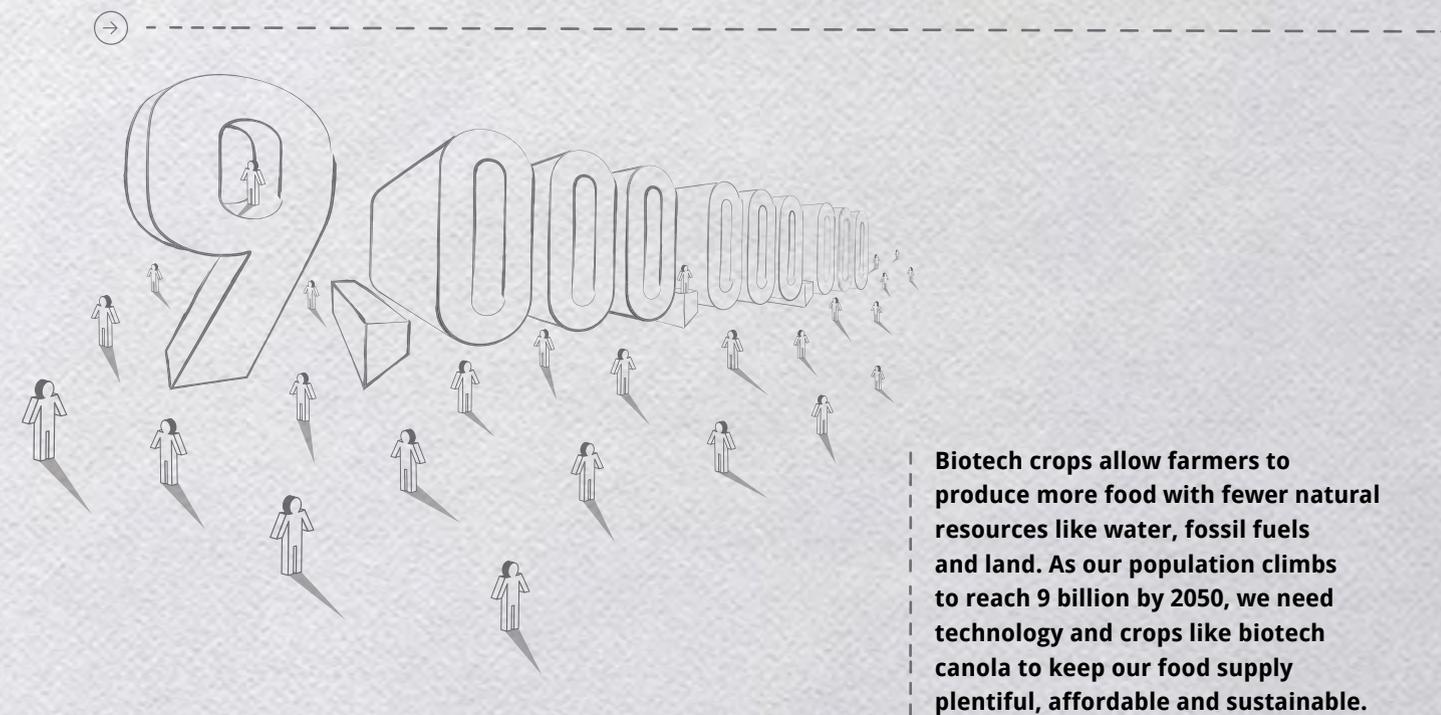
A good example of a process that directly mimics natural processes is induced or accelerated mutagenesis. Mutagenesis is the primary mechanism of genetic modification in nature. Mutagenesis, as a science, was developed in the first half of the 20th century. When done by humans via plant exposure to radiation or chemicals in the hopes of producing a desirable trait, mutation breeding is generally described as “accelerated” or “induced” mutagenesis and has been applied to almost every major agricultural crop since the 1920s. As of January 2016, there are 3,222 unique plant varieties worldwide produced by this method — including wheat, rice, potato, beans, sweet cherry, ruby red grapefruits, apples and canola.^[19] While mutagenesis is a very effective process, it can be unpredictable and plays a much smaller role in agricultural biotechnology today.

Instead, the most important technology today is recombinant DNA technology, or rDNA — generally referred to as “genetic engineering.” In fact, rDNA technology has become so dominant that it is often confused as a synonym for biotechnology in general. Rather than changing the DNA randomly in thousands of locations through mutagenesis, rDNA technology introduces very small and targeted changes. rDNA technology can be used to introduce new traits into bacteria, plants and even animals. (A related technology is silencing, in which similar methods are used to turn off an undesirable trait, without necessarily introducing any new genes.^[20])



While often viewed as unnatural, rDNA technology is very similar to a natural process known as “horizontal gene transfer,” in which viruses insert either their own genetic material, or that of a completely different species, into another organism.^{[21] [22] [23] [24]} There is evidence that this process has been an important factor in evolution.^{[25] [26]} This discovery has led some biologists to reject the entire concept of the “tree” of life, with distinct branches that never mingle once separated. Instead, at the smallest scale, life is promiscuous and knows few boundaries. In other words, rather than being unnatural, genes moving between species, even across classes, kingdoms and domains, is an integral part of nature.

While it is possible for traditional breeding methods to develop traits like herbicide tolerance, for example, it would require much more time and resources than doing so with genetic engineering approaches. Whether selective breeding, induced mutagenesis, or rDNA technology is used, the purpose of all agricultural biotechnologies is the same: to make farming more productive and more sustainable and food more nutritious. In the case of canola, these advances are already helping farmers to earn more money, protect the environment and provide consumers with healthier food.



Biotech crops allow farmers to produce more food with fewer natural resources like water, fossil fuels and land. As our population climbs to reach 9 billion by 2050, we need technology and crops like biotech canola to keep our food supply plentiful, affordable and sustainable.

THE TRIUMPH OF GENETICALLY ENGINEERED CANOLA

Since their introduction in 1996, herbicide-tolerant crops like soybeans, canola, cotton, corn and alfalfa were adopted at breakneck speed in the United States, Canada, Brazil, Argentina and India.^[27] By 2013, 85% of all U.S. corn was herbicide-tolerant.^[28] In Canada, the numbers are just as high: 95% of all canola, for example, is herbicide-tolerant, an adoption rate that was reached within a decade.^[27]

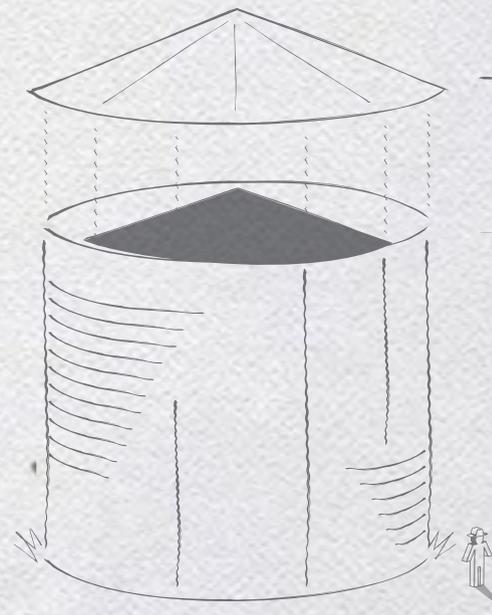
In other parts of the world, the share of genetically engineered crops continues to grow in both industrialized and developing countries. "The global hectarage of biotech crops has increased 100-fold from 1.7 million hectares in 1996 to 179.7 million hectares in 2015."^[29] This makes "biotech crops the fastest adopted crop technology in recent times."^[29]

HIGHER FARMER INCOMES

The success of genetically engineered crops, like canola, is primarily driven by the significant financial advantages it offers to farmers.

In 2000, just four years after its introduction, "direct producer benefits of transgenic canola were estimated at \$66 million (or \$10.62 per acre)," though other estimates put the net benefit at \$70 million."^[30] From 2005 – 2007, this had increased to between \$1.06 billion and \$1.19 billion (an average of \$26 per acre) in annual net and indirect benefits for producers. This was partly attributed to lower input costs and partly attributed to better weed control.^[31] Another study reported a similar farmer benefit of over \$1 billion in 2012.^[32]

While herbicide-tolerant seeds can be significantly more expensive than conventional seeds, farmers save time and money by using less herbicide, fuel, labour and inputs. Globally, over the last 20 years, "on average, GM technology adoption has reduced chemical pesticide use by 37%, increased crop yields by 22% and increased farmers' profits by 68%."^[27] Over the period of 1996 – 2013, herbicide-tolerant canola in Canada increased yields per hectare by up to 12% — about 8 million tonnes additional production — while farm incomes increased by an average of \$53 per hectare (\$21.45 per acre), despite the higher cost of the seed.^[33]



BIOTECH =
EXTRA 8
MILLION TONNES OF CANOLA

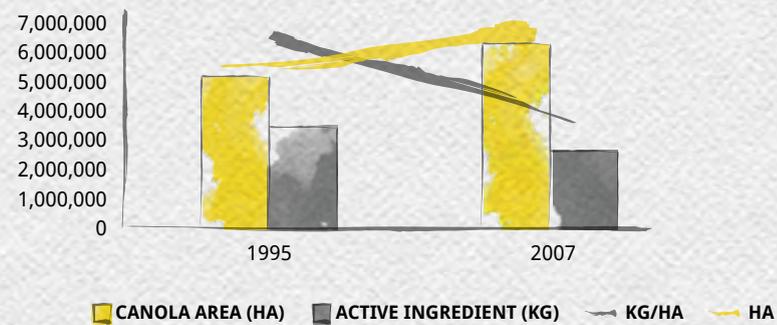
Farmers can get more yield from every acre of farmland by growing biotech canola compared to conventional varieties. Between 1996 and 2013, it increased farmers' yields up to 12% per hectare, adding up to an extra 8 million tonnes of production.



REDUCED HERBICIDE USAGE

Herbicide-tolerant canola enables farmers to use smaller amounts of herbicides to control fast-growing weeds that rapidly absorb herbicide without damaging the canola seedlings growing alongside. The adoption of herbicide-tolerant canola made it possible to dramatically reduce the total amount of herbicide used. While total canola acreage in Canada grew by 236% between 1996 and 2013,^[34] the quantity of herbicide used declined by 17.9%, reducing overall herbicide usage by 15.8 million kilograms.^[35]

CANOLA AREA, HERBICIDE USE 1996 - 2007



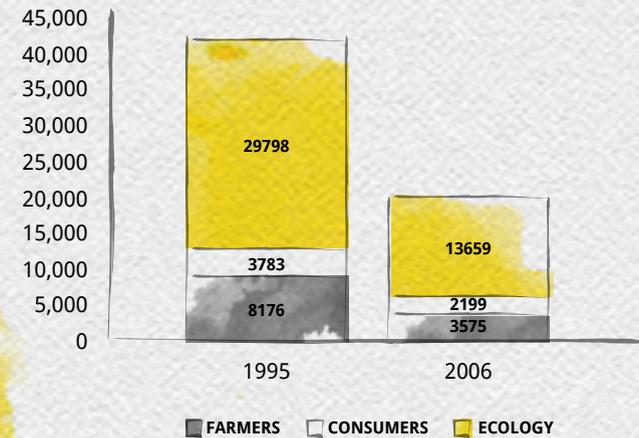
Farmers immediately benefitted from reduced costs. In 1999, while farmers using conventional seeds faced an average cultivation cost of \$18.72 per acre, farmers employing herbicide-tolerant seed faced an average cost of only \$14.03.^[36] By 2006, this had dropped as low as \$3.78 per acre.^[36] With 13 million acres under canola cultivation, using herbicide-tolerant canola reduced cultivation expenses by \$149 million in 2006 alone, compared to what they would have been without herbicide-tolerant canola.



REDUCED ENVIRONMENTAL IMPACT

The reduction in herbicide use tells only part of the story. To assess and compare the environmental impact of pesticides, including herbicides, researchers use a measure called the Environmental Impact Quotient or EIQ.^[37] The EIQ averages the impact of a substance on farmers, consumers and the environment. The EIQ takes into account the amount of pesticides used with the toxicity of these pesticides for animals, fish, birds, non-target insects, bees, farm workers and consumers.ⁱⁱ Between 1995 and 2006, the environmental impact per hectare of canola sank by 53% for farmers, 56% for consumers and 54% for the ecology.^[36]

ENVIRONMENTAL IMPACT PER HA FOR HERBICIDES APPLIED TO CANOLA, 1995 – 2006



ENVIRONMENTAL IMPACT

REDUCED BY

30%

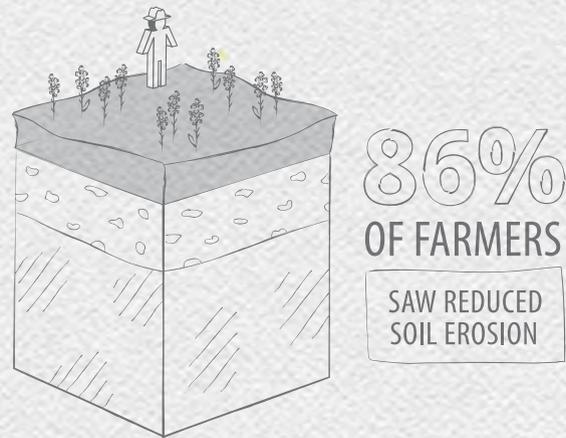
In 2013, the use of herbicide-tolerant canola reduced the environmental impact of farming, as measured by the EIQ indicator of 31.5%.^[35]



CONSERVATION TILLAGE

The key to this development was the adoption of conservation tillage, also known as minimum-tillage and zero-tillage farming; that is, farming with little or no ploughing or harrowing, and managing weeds primarily through the application of non-selective herbicides. As discussed previously, tillage increases the overall cost of farm operations and puts significant stress on soils and the environment.

Prior to the introduction of herbicide-tolerant crops, there was little scope for farmers to reduce tillage without a parallel increase in herbicide application. With herbicide tolerance, it became possible to forgo both ploughing and harrowing prior to seeding and to fight weeds primarily with herbicide.



Farmers used to rely on tilling the soil to remove weeds from their fields. It dried out the soil, leading to erosion and reduced fertility. Biotech crops like Canadian canola are tolerant to herbicides. By spraying herbicides on their fields, farmers can control weeds while protecting their crops and soil. They no longer need to till their fields every year, keeping our soil moist and fertile.

In 1999, conventional farmers on average applied 2.63 tillage operations per year, while farmers using herbicide-tolerant crops used only 1.79.^[36] By 2006, 10 years after the introduction of herbicide-tolerant canola, 66% of farmers had adopted some kind of reduced-tillage system, while the average number of tillage operations per year had fallen to 0.48 — more than half of all canola fields weren't tilled at all that year.^[36] In 2011, this practice had extended to over 80% of the land prepared for seeding,^[38] and 86% of farmers planting herbicide tolerant-canola reported reduced soil erosion.^[31]

REDUCTION IN GREENHOUSE GAS EMISSIONS

According to Statistics Canada, “total fuel expenditures and repair costs on farms using no-till systems were approximately one-third that of those in typical conventional tillage in 2006.”^[39] The same Statistics Canada study also found that no-till farming was most common in canola-growing regions.^[40] It is therefore not surprising that in 2006, average net greenhouse gas emissions per acre were 40% lower than they had been in 1986, and 65% lower per unit of dried canola seed.^[41] And while total canola production more than doubled over 20 years, total greenhouse gas emissions increased by only 10.5%.^[41] By 2013, the use of herbicide-tolerant canola reduced total greenhouse gas emissions by about one billion kilograms of CO₂ — equivalent to removing half a million cars from Canadian roads.^[35]



Farmers also save a lot of fuel when they don't need to till their fields to control weeds. That means they spend less time operating the tractor and produce fewer greenhouse gas emissions. In just one year of growing Canadian canola, farmers saved one billion kilograms of carbon dioxide — that's equivalent to removing nearly 500,000 cars from the roads!

CANADA AS A BIOTECHNOLOGY POWERHOUSE

The rapid adoption of GE canola by Canadian farmers has also directly contributed to the growth of Canada's biotechnology industry. Through continual research and innovation, farmers have access to the necessary tools to farm sustainably. "Prior to 1985, all of the varieties introduced were developed by public institutions."^[30] But starting in 1990, private biotechnology companies began to take the lead in developing new varieties, and by 1999, out of 162 varieties registered, 140 (86%) were developed by private institutions.^[30] "By 2001, private firms were capturing \$250 million in revenue and had nearly crowded out public-sector sales."^[30]

In 2012, private sector investment in plant breeding, research and development amounted to at least \$110 million — 70% more than in 2007.^[42] The total economic impact of the seed industry in Canada was estimated at \$5.61 billion in 2013, creating 57,420 jobs and generating \$1.67 billion in wages and salaries.^[42] Seed exports alone were valued at approximately \$450 million.^[42]

Since Canadian researchers created canola, canola has proven to be a major boon not just for farmers, but for the Canadian economy and the environment. By offering Canadian consumers a healthy cooking oil, helping producers farm more sustainably and lowering greenhouse gas emissions, canola is one of the signal achievements of modern agricultural biotechnology in Canada and the world.

It has made Canada into one of the world's agricultural biotechnology leaders, both in terms of its private and public research and development, as well as the rate of adoption by Canadian growers. Modern Canadian agriculture was shaped, and continues to be shaped, by agricultural biotechnology.

CHALLENGES REMAINING

Still, the perception of modern agricultural biotechnology as unnatural continues to persist. While government researchers, scientific agencies and multilateral institutions from around the world have found that foods from biotechnology pose no particular risk to either human health or the environment,^{[1][43]} public attitudes towards the technology continue to be negative. For example, a study published in 2015 found that 57% of U.S. adults believe that "genetically modified (GM) foods are generally unsafe."^[44] A similar study from 2010 found that 57% of EU-27 citizens did not support genetically modified foods.^[45]

In response to vocal opposition in the European Union during the late 1990s, the European Union introduced mandatory labelling for foods containing protein from plants developed using some types of biotechnology (e.g. genetic engineering or modification) but not others, despite opposition from the EU's own food research agency.^[46] Furthermore, some EU countries have implemented bans on the growing of crops developed with rDNA technology.^[47] Consequently, the Canadian canola sector no longer considers the EU a top-priority market and has instead focused their export efforts on countries where science-based food and environmental safety policies have created favourable market conditions.

The mandatory labelling requirement can lead to surprising challenges for Canadian farmers. For example, honey from canola exported to the European Union may need to be labelled as a genetically modified food. Since about 80% of all Canadian honey is produced in the canola fields of Western Canada, this poses a significant barrier to trade for Canadian canola honey and is one of the reasons very little Canadian honey is exported to the European Union.

More broadly, asynchronous approvals — when biotechnology seed traits are approved at different times in different countries — are of increasing concern for the sector: they delay the introduction of new technology and create risk that shipments will be rejected. As Canada's export markets maintain zero-tolerance policies for trace amounts of GM traits they have not yet approved, the presence of an unapproved GM trait could result in rejected shipments. This is a concern for all crops because it is impossible to completely segregate grain on the farm or throughout the bulk handling and transportation system.^[48] With over 90% of canola produced in Canada exported, the detection of an unapproved biotechnology trait could be devastating and result in significant financial damage. The patchwork of approvals adds uncertainty and risk; delaying farmers' access to new, innovative varieties leaves them without the full range of available solutions.

Despite these challenges, production of herbicide-tolerant canola in Canada continues to grow, while demand for Canadian canola continues to increase globally. With ongoing research into new, advanced traits, the future for canola in Canada and around the world is promising.

SOURCES

- [1] National Academies of Sciences, Engineering, and Medicine. "Genetically Engineered Crops: Experiences and Prospects." Washington, DC: The National Academies Press, 2016. Available: <http://nas-sites.org/ge-crops/>
- [2] L. Lin, H. Allemekinders, A. Dansby, L. Campbell, S. Durance-Tod, A. Berger, and P. J. Jones, "Evidence of health benefits of canola oil," *Nutr. Rev.*, vol. 71, no. 6, pp. 370–385, Jun. 2013. Available: <http://www.ncbi.nlm.nih.gov/pubmed/23731447>
- [3] D. J. A. Jenkins, C. W. C. Kendall, V. Vuksan, D. Faulkner, L. S. A. Augustin, S. Mitchell, C. Ireland, K. Srichaikul, A. Mirrahimi, L. Chiavaroli, S. Blanco Mejia, S. Nishi, S. Sahye-Pudarth, D. Patel, B. Bashyam, E. Vidgen, R. J. de Souza, J. L. Sievenpiper, J. Coveney, R. G. Josse, and L. A. Leiter, "Effect of lowering the glycemic load with canola oil on glycemic control and cardiovascular risk factors: a randomized controlled trial," *Diabetes Care*, vol. 37, no. 7, pp. 1806–1814, Jul. 2014. Available: <http://care.diabetesjournals.org/content/37/7/1806.long>
- [4] Statistics Canada, CANSIM, table 002-0001. Available: <http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/agri03a-eng.htm>
- [5] Statistics Canada, Canadian International Merchandise Trade Database
- [6] "The Economic Impact of Canola on the Canadian Economy," LMC International, 2013. Available: http://www.canolacouncil.org/media/545722/lmc_economic_impact_of_canola_on_the_canadian_economy_october_2013.pdf
- [7] "Guidelines for Estimating Crop Production Costs 2016 in Manitoba." Manitoba Agriculture, Food and Rural Development, Jan-2016. Available: https://www.gov.mb.ca/agriculture/business-and-economics/financial-management/pubs/cop_crop_production.pdf
- [8] N. P. Singh and I. S. Yadav, "Herbicide Tolerant Food Legume Crops: Possibilities and Prospects," in *Herbicides – Properties, Synthesis and Control of Weeds*, INTECH Open Access Publisher, 2012. Available: <http://www.intechopen.com/books/herbicides-properties-synthesis-and-control-of-weeds/herbicide-tolerant-food-legume-crops-possibilities-and-prospects>
- [9] M. Dotterweich, M. Stankoviansky, J. Minár, Š. Koco, and P. Papčo, "Human induced soil erosion and gully system development in the Late Holocene and future perspectives on landscape evolution: The Myjava Hill Land, Slovakia," *Geomorphology*, vol. 201, pp. 227–245, Nov. 2013. Available: <http://www.sciencedirect.com/science/article/pii/S0169555X13003450>
- [10] M. Dotterweich, "The history of human-induced soil erosion: Geomorphic legacies, early descriptions and research, and the development of soil conservation—A global synopsis," *Geomorphology*, vol. 201, pp. 1–34, Nov. 2013. Available: <http://www.sciencedirect.com/science/article/pii/S0169555X1300370X>
- [11] "Climate change and agriculture - OECD Observer." [Online]. Available: http://www.oecdobserver.org/news/fullstory.php/aid/3213/Climate_change_and_agriculture.html. [Accessed: 11-Jan-2016].
- [12] J. M. Holland, "The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence," *Agric. Ecosyst. Environ.*, vol. 103, no. 1, pp. 1–25, Jun. 2004. Available: <http://www.sciencedirect.com/science/article/pii/S0167880904000593>
- [13] D. Sauchyn and S. Kulshreshtha, "From Impacts to Adaptation: Canada in a Changing Climate; Chapter 7 - Prairies," Government of Canada, 2007. Available: <http://www.nrcan.gc.ca/environment/resources/publications/impacts-adaptation/reports/assessments/2008/10253>
- [14] S. M. Bradberry, A. T. Proudfoot, and J. A. Vale, "Glyphosate poisoning," *Toxicol. Rev.*, vol. 23, no. 3, pp. 159–167, 2004. Available: <http://www.ncbi.nlm.nih.gov/pubmed/15862083>
- [15] "Glyphosate." [Online]. Available: <http://pmp.cce.cornell.edu/profiles/extoxnet/dienochlor-glyphosate/glyphosate-ext.html>. [Accessed: 10-Jan-2016].
- [16] A. Székács and B. Darvas, "Forty Years with Glyphosate," in *Herbicides – Properties, Synthesis and Control of Weeds*, INTECH Open Access Publisher, 2012, pp. 247–284. Available: <http://cdn.intechweb.org/pdfs/25624.pdf>
- [17] "THE STATE OF FOOD AND AGRICULTURE 2003-2004." [Online]. Available: <http://www.fao.org/docrep/006/y5160e/y5160e07.htm>. [Accessed: 06-Jan-2016].
- [18] "What is a GMO? An introduction | GMO Answers." [Online]. Available: <https://gmoanswers.com/explore?carouselid=3&slideindex=0>. [Accessed: 18-Apr-2016].
- [19] "MVD - Home." [Online]. Available: <https://mvd.iaea.org/>. [Accessed: 06-Jan-2016].
- [20] R. Chawla, R. Shakya, and C. M. Rommens, "Tuber-specific silencing of asparagine synthetase-1 reduces the acrylamide-forming potential of potatoes grown in the field without affecting tuber shape and yield," *Plant Biotechnol. J.*, vol. 10, no. 8, pp. 913–924, Oct. 2012. Available: <http://www.ncbi.nlm.nih.gov/pubmed/22726556>
- [21] G. P. Barrera, M. N. Belaich, M. A. Patarroyo, L. F. Villamizar, and P. D. Ghiringhelli, "Evidence of recent interspecies horizontal gene transfer regarding nucleopolyhedrovirus infection of *Spodoptera frugiperda*," *BMC Genomics*, vol. 16, no. 1, Dec. 2015. Available: <http://www.ncbi.nlm.nih.gov/pubmed/26607569>
- [22] M. Sugieda, H. Nagaoka, Y. Kakishima, T. Ohshita, S. Nakamura, and S. Nakajima, "Detection of Norwalk-like virus genes in the caecum contents of pigs," *Arch. Virol.*, vol. 143, no. 6, pp. 1215–1221, 1998. Available: <http://www.ncbi.nlm.nih.gov/pubmed/9687878>
- [23] I. Eyres, C. Boschetti, A. Crisp, T. P. Smith, D. Fontaneto, A. Tunnacliffe, and T. G. Barraclough, "Horizontal gene transfer in bdelloid rotifers is ancient, ongoing and more frequent in species from desiccating habitats," *BMC Biol.*, vol. 13, no. 1, Dec. 2015. Available: <http://www.ncbi.nlm.nih.gov/pubmed/26537913>
- [24] C. Gilbert, S. Schaack, J. K. Pace II, P. J. Brindley, and C. Feschotte, "A role for host–parasite interactions in the horizontal transfer of transposons across phyla," *Nature*, vol. 464, no. 7293, pp. 1347–1350, Apr. 2010. Available: <http://www.ncbi.nlm.nih.gov/pubmed/20428170>
- [25] L. Boto, "Horizontal gene transfer in evolution: facts and challenges," *Proc. R. Soc. Lond. B Biol. Sci.*, vol. 277, no. 1683, pp. 819–827, Mar. 2010. Available: <http://www.ncbi.nlm.nih.gov/pubmed/19864285>
- [26] "Researchers Find Evidence for Horizontal Gene Transfer in Mammals, Reptiles," *GenomeWeb*. [Online]. Available: <https://www.genomeweb.com/researchers-find-evidence-horizontal-gene-transfer-mammals-reptiles>. [Accessed: 09-Jan-2016].
- [27] C. James, "Global Status of Commercialized Biotech/GM Crops: 2014," ISAAA Brief No. 49. ISAAA: Ithaca, NY. [Online]. Available: <http://www.isaaa.org/resources/publications/briefs/49/executivesummary/default.asp>. [Accessed: 31-Dec-2015].
- [28] J. Fernandez-Cornejo, S. Wechsler, M. Livingston, and L. Mitchell, "Genetically Engineered Crops in the United States," United States Department of Agriculture, Washington, D.C., 162, 2014. Available: <http://www.ers.usda.gov/publications/err-economic-research-report/err162.aspx>
- [29] C. James, "Global Status of Commercialized Biotech/GM Crops: 2015," ISAAA Brief No. 51. ISAAA: Ithaca, NY. [Online]. Available: <http://www.isaaa.org/resources/publications/briefs/51/executivesummary/default.asp>
- [30] S. Malla and D. Brewin, "The Value of a New Biotechnology Considering R&D Investment and Regulatory Issues," *AgBioForum*, vol. 18, no. 1, pp. 6–25, 2015. Available: <http://www.agbioforum.org/v18n1/v18n1a03-malla.htm>
- [31] S. J. Smyth, M. Gusta, K. Belcher, P. W. B. Phillips, and D. Castle, "Environmental impacts from herbicide tolerant canola production in Western Canada," *Agric. Syst.*, vol. 104, no. 5, pp. 403–410, Jun. 2011. Available: https://www.researchgate.net/publication/227411166_Environmental_impacts_from_herbicide_tolerant_canola_production_in_Western_Canada
- [32] D. G. Brewin and S. Malla, "The consequences of biotechnology: A broad view of the changes in the Canadian canola sector, 1969 to 2012," *AgBioForum*, vol. 15, no. 3, pp. 257–275, 2012. Available: <http://www.agbioforum.org/v15n3/v15n3a03-brewin.htm>
- [33] G. Brookes and P. Barfoot, "Global income and production impacts of using GM crop technology 1996–2013," *GM Crops & Food*, vol. 6, no. 1, pp. 13–46, Jan. 2015. Available: <http://www.tandfonline.com/doi/abs/10.1080/21645698.2015.1022310>

- [34] Statistics Canada. Table 001-0017 – Estimated areas, yield, production, average farm price and total farm value of principal field crops, in imperial units, annual, CANSIM (database). Available: <http://www5.statcan.gc.ca/cansim/a26?lang=eng&id=10017>
- [35] G. Brookes and P. Barfoot, “Environmental impacts of genetically modified (GM) crop use 1996–2013: Impacts on pesticide use and carbon emissions,” *GM Crops & Food*, vol. 6, no. 2, pp. 103–133, Apr. 2015. Available: <http://www.tandfonline.com/doi/full/10.1080/21645698.2015.1025193>
- [36] S. J. Smyth, P. W. Phillips, and D. Castle, “Benefits of genetically modified herbicide tolerant canola in Western Canada,” *Int. J. Biotechnol.*, vol. 13, no. 4, pp. 181–197, 2014. Available: https://www.researchgate.net/publication/275720180_Benefits_of_genetically_modified_herbicide_tolerant_canola_in_Western_Canada
- [37] “The EIQ Equation.” [Online]. Available: <http://www.nysipm.cornell.edu/eiq>. [Accessed: 12-Jan-2016].
- [38] Statistics Canada, “Human Activity and the Environment: Table 5.8 – Tillage practices in Canada, by ecozone, 1991 and 2011.” [Online]. Available: <http://www.statcan.gc.ca/pub/16-201-x/2014000/t021-eng.htm>. [Accessed: 28-Mar-2016].
- [39] Statistics Canada, “EnviroStats: Conventional tillage: How conventional is it?” [Online]. Available: <http://www.statcan.gc.ca/pub/16-002-x/2008003/article/10688-eng.htm>. [Accessed: 30-Jan-2016].
- [40] Statistics Canada, “Map 1 Percentage of total area prepared for seeding using no-till, by sub-sub drainage area, 2006.” [Online]. Available: <http://www.statcan.gc.ca/pub/16-002-x/2008003/maps-cartes/5212578-eng.htm>. [Accessed: 30-Jan-2016].
- [41] B. M. Shrestha, R. L. Desjardins, B. G. McConkey, D. E. Worth, J. A. Dyer, and D. D. Cerkowniak, “Change in carbon footprint of canola production in the Canadian Prairies from 1986 to 2006,” *Renew. Energy*, vol. 63, pp. 634–641, Mar. 2014. Available: <http://www.sciencedirect.com/science/article/pii/S0960148113005533>
- [42] Agriculture and Agri-Food Canada, “Canadian Seed Sector Profile,” report, Jul. 2014. Available: <http://www.agr.gc.ca/eng/industry-markets-and-trade/value-chain-roundtables/seed/canadian-seed-sector-profile/?id=1405967530785>
- [43] OECD, “Safety Assessment of Foods and Feeds Derived from Transgenic Crops,” Volume 2. OECD Publishing, 2015. Available: http://www.oecd-ilibrary.org/environment/safety-assessment-of-foods-and-feeds-derived-from-transgenic-crops-volume-2_9789264180338-en
- [44] C. Funk and L. Rainie, “Public and Scientists’ Views on Science and Society,” Pew Research Center: Internet, Science & Tech, Jan. 2015. Available: <http://www.pewinternet.org/2015/01/29/public-and-scientists-views-on-science-and-society/>
- [45] G. Gaskell, European Commission, Directorate-General for Research, and Directorate E, “Europeans and biotechnology in 2010: winds of change?: a report to the European Commission’s Directorate-General for Research,” Brussels: European Commission, 2010. Available: http://ec.europa.eu/public_opinion/archives/ebs/ebs_341_winds_en.pdf
- [46] Council on Foreign Relations, “The Regulation of GMOs in Europe and the United States: A Case-Study of Contemporary European Regulatory Politics.” [Online]. Available: <http://www.cfr.org/agricultural-policy/regulation-gmos-europe-united-states-case-study-contemporary-european-regulatory-politics/p8688>. [Accessed: 13-Jan-2016].
- [47] “More than half of EU officially bans genetically modified crops,” *New Scientist*, 5 October 2015. Available: <https://www.newscientist.com/article/dn28283-more-than-half-of-european-union-votes-to-ban-growing-gm-crops/>
- [48] Agriculture and Agri-Food Canada, “Background – Low Level Presence of Genetically Modified Crops,” 06-Nov-2012. [Online]. Available: <http://www.agr.gc.ca/eng/about-us/public-opinion-and-consultations/update-on-domestic-low-level-presence-policy-development/background-low-level-presence-of-genetically-modified-crops/?id=1352157082711>. [Accessed: 28-Mar-2016].
- [49] U.S. Food and Drug Administration, “Qualified Health Claims: Letter of Enforcement Discretion – Unsaturated Fatty Acids from Canola Oil and Reduced Risk of Coronary Heart Disease.” [Online]. Available: <http://www.fda.gov/Food/IngredientsPackagingLabeling/LabelingNutrition/ucm072958.htm>. [Accessed: 09-Sept-2016].

¹According to data provided by Manitoba Agriculture, Food and Rural Development, in 2015, herbicide-tolerant canola seed was estimated to be about 20% more expensive than non-GE varieties.

²For a detailed discussion of how the EIQ is calculated, refer to <http://www.nysipm.cornell.edu/eiq>



CANOLA COUNCIL OF CANADA

400-167 Lombard Avenue, Winnipeg, Manitoba R3B 0T6

Phone: (204) 982-2100 **Toll-Free:** (866) 834-4378

admin@canolacouncil.org

CANOLACOUNCIL.ORG

Funding for this project has been provided by Agriculture and Agri-Food Canada through Growing Forward 2, a federal – provincial – territorial initiative.

Growing Forward 2 

Canada 