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Cultivating innovation:

Celebrating 30 years of gene technology in Australian crops

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Contents

1 Evolution of genetic technology in Australian crops over the past 30 years

The year 2026 marks 30 years of Australia's commercial agricultural genetic technology era, a milestone that highlights the country's long-standing, evidence-based engagement with genetically modified (GM) crops.

Australia's experience with GM crops demonstrates that the question is no longer whether these technologies can deliver value, but whether the systems that support adoption are equipped for the next wave of innovation.

Over the past three decades, the adoption of agricultural GM crops in Australia has progressed steadily. This reflects the country's strong national regulatory framework, differing state-based market settings, and the need to demonstrate clear value to growers. Supported by responsible industry stewardship and ongoing R&D, GM crops have established a strong safety record with no confirmed reports of adverse health or environmental impacts.

Early GM adoption demonstrated that clear market demand and consumer acceptance, coupled with tangible benefits for growers, the environment and consumers, were key drivers of uptake, despite the challenge of adapting to evolving regulatory settings domestically and internationally. This was most evident in cotton where GM traits addressed severe industry threatening insect pressures, delivering substantial economic gains and major environmental benefits, including sharp reductions in pesticide use. In sectors where GM technologies have provided clear, practical value and aligned with existing farming systems and markets, they have become deeply integrated. Where such conditions are absent, adoption has remained limited.

Agricultural genetic technologies include modern scientific tools like genetic modification (GM),[1] gene editing,[2] marker assisted selection (MAS),[3] mutagenesis,[4] and TILLING,[5] to rapidly improve crop traits for sustainability, environmental resilience and health outcomes.

GM introduces desirable genes from different organisms, while gene editing makes targeted changes in a plant's own genes to enhance or reduce specific traits. Together, these technologies accelerate crop improvement, overcome genetic constraints, and expand the range of traits that can be targeted.

This report largely focuses on Australia's experience with GM.

1 Genetically modified (GM) crops are created by inserting new or modified genes to confer novel functionalities, such as pest resistance, herbicide tolerance, enhanced nutritional profiles, or improved stress resilience.

2 Gene editing makes precise changes to existing genes which are indistinguishable from changes that can occur naturally.

3 MAS incorporates molecular markers which are genetic variations at specific locations to enable easy detection and analysis using advanced molecular techniques to expedite the selection of desirable traits.

4 Mutagenesis introduces genetic variations through induced mutations (such as UV, X-ray or chemical agents, etc.) to enhance crop traits.

5 TILLING or targeting induced local lesions in genomes is not a mutagenesis method itself but a screening strategy used after mutagenesis to screen mutagenized populations for specific gene mutations.

1.1 Waves of adoption

Wave 1: Pest and weed management – Beginning in 1996, the first wave of GM adoption in Australia has focused on improving agricultural productivity through pest and weed management, led by the commercial introduction of insect-resistant GM cotton. This marked Australia's entry into commercial GM and remains the most significant adoption success. In cotton, GM traits delivered clear and immediate on-farm value, particularly through substantial reductions in insecticide use, improved worker safety, and more reliable pest control. The technology delivered the same high quality cotton output and substantially reduced production risk and operational complexity, supporting rapid and sustained uptake across the industry.

Following cotton, a small number of additional GM crops, including herbicide-tolerant canola,[6] Indian mustard,[7] and disease-resistant banana,[8] have been approved for commercial cultivation in Australia. These applications extended GM technologies into oilseeds and biosecurity-driven use cases, yet adoption has remained more limited and variable.[9] Barriers to adoption are generally high, with early traits needing to overcome significant market acceptance challenges, including clear demonstration of value, and regulatory hurdles before development of second-generation products can be considered. This first wave of adoption continues, and demonstrates that where GM traits deliver clear, practical benefits and align with existing farming systems and markets, adoption can become widespread and enduring.[10]

Wave 2: Value adding – While the first wave of GM adoption focused on improving how crops are grown, primarily through pest and weed management, the second emerging wave expands GM's role to shaping what crops produce and how value is created across the supply chain. This includes traits that alter crop composition, enable new industrial and food applications, and support the use of crops as biofactories to produce high-value molecules through molecular farming via GM or gene edited pathways. The 2018 commercial release of super-high oleic acid GM safflower marked this transition by targeting specialty oil applications and broader industrial value chains, signalling the potential for GM to support value-added and non-traditional agricultural markets. Omega-3 canola was also approved for commercial release in 2018.

Today, six GM crops have regulatory approval for commercial cultivation in Australia – reflecting 30 years of progressive, evidence-based integration of GM into Australian agriculture (Figure 1). The waves of GM crop adoption in Australia and select pivotal moments are shown in Figure 2.

Cotton	Canola	Banana	Safflower	Indian Mustard	Purple tomatoes
					
99.5% of national crop	46% of national crop (2024)	No commercial planting to date	Limited commercial plantings	No commercial plantings to date	Received commercial scale growth approval
Pest resistance, herbicide tolerance	*Herbicide tolerance*	*Disease resistance*	*Super-high oleic acid*	*Herbicide tolerance*	*Rich in antioxidant*

Figure 1: GM crops approved in Australia

6 Office of the Gene Technology Regulator. (2014). DIR 127: Commercial release of canola genetically modified for herbicide tolerance [Licence]. Australian Government. https://www.ogtr.gov.au/gmo-dealings/dealings-involving-intentional-release/dir-127

7 Office of the Gene Technology Regulator. (2022). DIR 190: Commercial release of Indian mustard genetically modified for herbicide tolerance (RF3) [Licence]. Australian Government. https://www.ogtr.gov.au/gmo-dealings/dealings-involving-intentional-release/dir-190

8 Office of the Gene Technology Regulator. (2024). DIR 199: Commercial release of banana genetically modified for resistance to Fusarium wilt tropical race 4 (TR4) [Licence]. Australian Government. https://www.ogtr.gov.au/gmo-dealings/dealings-involving-intentional-release/dir-199

9 Office of the Gene Technology Regulator (2025) Genetically modified cotton in Australia (Version 2.1). Australian Government. Office of the Gene Technology Regulator. (2025). Snapshot of genetically modified (GM) crops in Australia [Fact sheet]. Australian Government.

10 Brookes, G. (2016). Adoption and impact of genetically modified (GM) crops in Australia: 20 years' experience. CropLife Australia Ltd.

Wave 1: Pest and weed management

Aims to improve agricultural productivity (insect resistance (IR), herbicide tolerance (HT), etc.)

Examples

1996: First commercial planting of ***insect resistant GM cotton*** (Bt-cotton).

2000*: GM herbicide tolerant cotton* commercialised.

Wave 2: Value adding

Aims to build value through the composition of crop outputs and traits, such as quality, nutrition, functionality (e.g. omega-3 canola, dairy protein alternatives).

Examples

2018: First commercial release of ***GM safflower*** (super-high oleic acid oil for industrial use).

2018: OGTR approval of ***omega-3 canola***.
2025: OGTR approved field trials of ***GM safflower*** for dairy protein production.

Figure 2: Waves of GM crop adoption and key pivotal moments in Australia

1.2 State moratoria and GM adoption

Australia's GM crop system operates within a national, science-based regulatory framework under the Gene Technology Act 2000, administered by the Office of the Gene Technology Regulator (OGTR),[11] with complementary assessments by Food Standards Australia New Zealand (FSANZ) and the Australian Pesticides and Veterinary Medicines Authority (APVMA). While safety approvals are made at the national level, state and territory governments determine whether approved GM crops can be grown within their jurisdictions for market and trade reasons.

11 Department of Agriculture, Fisheries and Forestry. (2026). Regulatory framework in Australia: Biotechnology. <https://www.agriculture.gov.au/agriculture-land/farm-food-drought/biotechnology/framework>

From the early 2000s, several states introduced moratoria on the commercial cultivation of GM crops, reflecting market, trade and community considerations rather than health or environmental safety. These decisions responded to uncertainties around export market access, supply-chain segregation and consumer acceptance at the time and resulted in asynchronous adoption of GM crops across Australia (Figure 3).

Over time, this layered governance approach shaped how and where GM technologies were adopted, contributing to fragmented adoption patterns and added complexity for investors, researchers, supply chains and growers operating across jurisdictions. Although most moratoria have since been lifted, their legacy highlights the importance of policy coherence and predictability in supporting innovation and commercialisation at scale.

This experience suggests that future genetic technology adoption will be strengthened by policy settings that balance safety assurance with market clarity, reduce unnecessary complexity across jurisdictions, and provide confidence for long-term investment and supply chain planning.

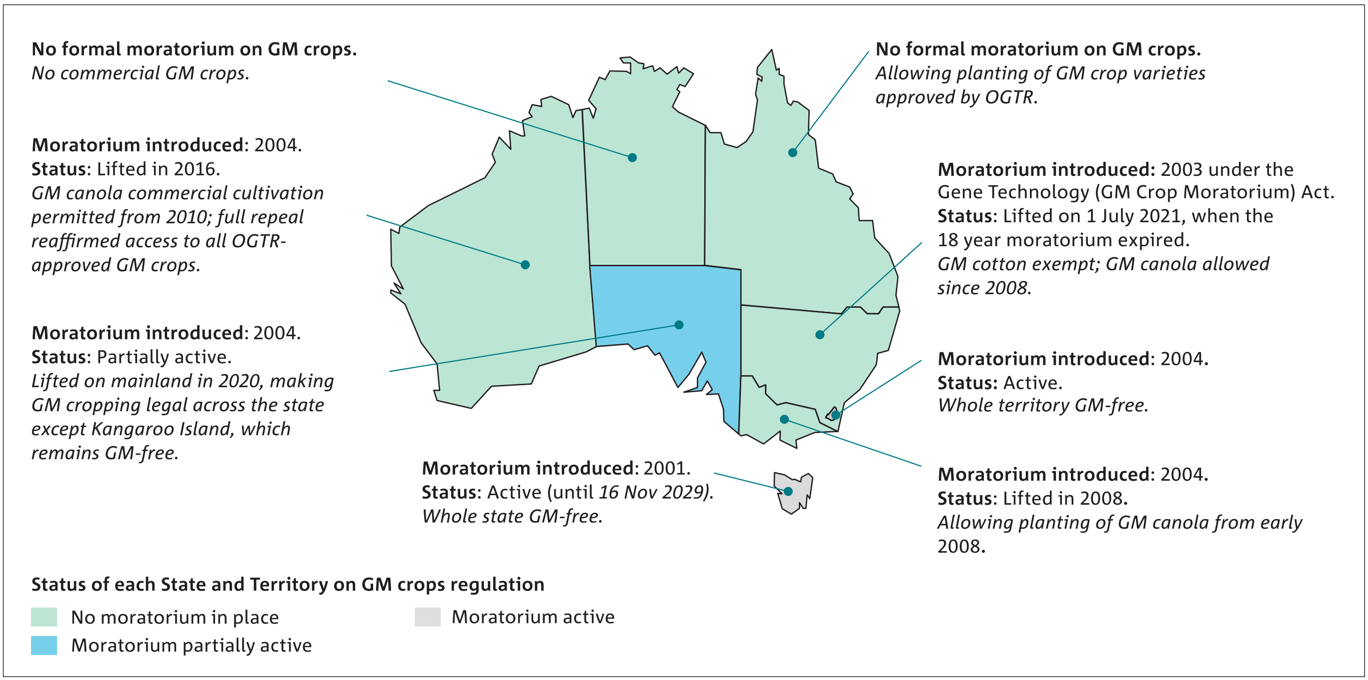

Figure 3: GM crop moratoria status across Australia (2026)

2 Legacy of GM in Australian crops

The impacts of GM crop adoption in Australia have been gradual, reflecting the limited number of approved GM traits and the narrow range of cropping systems in which they have been deployed. Where GM traits have been adopted, they have delivered clear benefits, particularly in pest and weed management, operational efficiency and environmental performance, but these outcomes have remained concentrated in specific regions and crops.

Within this context, the economic, environmental, and social impacts of GM crop adoption provide important insights into both the value created to date and the constraints that have shaped its overall scale.

Economic impacts

Operational efficiency

Reduced costs by avoiding intensive insecticide and herbicide programs.

Enabled sustainable intensification with reduced chemical reliance.

Simplified weed control by replacing multi-stage programs with a cost-effective herbicide tolerance trait introduction.

Targeted pest interventions reducing routine programs.

Improved farm-level risk management

Improved yield reliability through effective weed and pest protection.

Stabilised farm outputs across variable seasons.

Reduced seasonal risks and improved climate resilience for certain GM traits that buffer short-term climate shocks.

Value-added & future market opportunities

Unlocked premium crop markets by enhancing intrinsic quality of the crop (e.g. oil composition or protein content).

Enabling molecular farming using crops act as biofactories for high-value proteins, enzymes, and specialty compounds.

For example: Australia's GM Super-High Oleic (SHO) safflower potential to produce dairy proteins.

Across Australian cropping systems, the primary economic contribution of GM adoption has been improved risk management rather than consistent yield gains.[12] By reducing reliance on intensive pesticide regimes and simplifying pest and weed control, GM traits have lowered operational complexity,[13] reduced injury related downtime and safety management costs, and delivered more reliable production outcomes[14] across variable seasons.[15]

These benefits have been most pronounced where GM traits are well aligned with existing production systems and market structures, particularly in cotton and canola. Although GM technologies have also enabled early value-added applications, such as altered oil profiles and novel industrial uses, these opportunities remain limited in scale and have yet to translate into widespread commercial uptake.

12 Australian cotton growers reduced insecticides by 96 per cent per hectare between 1998 and 2024. Cotton Research and Development Corporation. (2024). Pesticides: Efficient, responsible pest control [Fact sheet].

13 Finger, R., El Benni, N., Kaphengst, T., Evans, C., Herbert, S., Lehmann, B., Morse, S., & Stupak, N. (2011). A Meta Analysis on Farm-Level Costs and Benefits of GM Crops. Sustainability, 3(5), 743-762. <https://doi.org/10.3390/su3050743>

14 Brookes, G. (2016). Adoption and impact of genetically modified (GM) crops in Australia: 20 years' experience. CropLife Australia Ltd.

15 Boyce Chartered Accountants. (2024). Australian Cotton Comparative Analysis: 2024 interim results.

Economic trade-offs and market risk considerations

While GM canola has delivered operational efficiencies in some production systems, these benefits have often been moderated by broader commercial trade-offs. Up-front technology access fees need to be weighed against expected savings in inputs and labour, while beyond the farm gate, segregation, storage, and supply-chain logistics costs can diminish net returns. In addition, market dynamics in which non-GM canola attracts price premiums have, at times, reduced the commercial incentive to adopt GM varieties. Collectively, these factors highlight that adoption decisions are shaped as much by market design and supply-chain arrangements as by on-farm performance.

Environmental impacts

Reduced chemical burden, improved environmental outcomes

Reduced reliance on traditional insecticides lowering overall chemical load in farming systems.

Enhanced environmental impact quotient (EIQ) outcomes, with application of less intensive or toxic pest control chemicals.

Lower emissions & climate-positive farm operations

Fewer spray passes reduces on-farm carbon emissions through reduced fuel consumption.

Lowered weed-control impacts by replacing conventional, persistent herbicides with more targeted systems that support soil biodiversity.

Improved water quality & ecosystem health

Improved water catchment quality, due to reduced insecticide applications.

Lowered chemical run-off supporting aquatic ecosystems and soil biodiversity.

Enabled reduced and/or no-till systems, improving soil structure, increasing soil carbon and reducing erosion risk.

The adoption of GM crops in Australia has delivered measurable environmental benefits, most notably through reduced reliance on insecticides and herbicides. In cotton, the widespread uptake of insect-resistant traits has driven sustained reductions in insecticide use,[16] contributing to improved environmental performance, including lower Environmental Impact Quotient (EIQ) outcomes.

These changes have produced flow-on benefits beyond reduction in chemical use. Fewer spray applications have reduced machinery use and fuel consumption, lowering on-farm emissions.[17] Reduced chemical runoff has improved water quality in key agricultural catchments and lessened impacts on non-target organisms.[18] Herbicide-tolerant crops have also supported the uptake of reduced-tillage systems, helping to maintain soil structure and reduce erosion in some production systems.[19]

At the same time, the environmental performance of GM crops is dependent on effective stewardship and resistance management. Over-reliance on specific traits can accelerate the emergence of resistant weeds and pests, undermining long-term sustainability. Australia's experience indicates that strong regulation supports the industry, not only by assessing potential adverse effects but also by enforcing sound management practices. This regulatory oversight helps ensure that GM traits are used responsibly and remain effective over time. In practice, environmental benefits are maximised when GM technologies are deployed as part of integrated, well-managed farming systems rather than as standalone solutions.

16 The adoption of GM technology has reduced pesticide spraying by 8.1% and the environmental impact associated with herbicide and insecticide use on these crops by 18.6%. Brookes, G., & Barfoot, P. (2017). Environmental impacts of genetically modified (GM) crop use 1996–2015: Impacts on pesticide use and carbon emissions. GM Crops & Food, 8(2), 117–147. <https://doi.org/10.1080/21645698.2017.1309490>

17 The fuel savings associated with making fewer spray runs relative to conventional crops have resulted in permanent savings in CO_2 emissions. Brookes, G. (2016). Adoption and impact of genetically modified (GM) crops in Australia: 20 years' experience. CropLife Australia Ltd.

18 Rashad, S., El-Chaghaby, G.A., Abdul Moneem, M. (2025). Pesticide Runoff and Its Impact on Water Quality. In: Babaniyi, B.R., Babaniyi, E.E. (eds) The Interplay of Pesticides and Climate Change. Springer, Cham. <https://doi.org/10.1007/978-3-031-81669-7_4>

19 Lee, S., Clay, D.E., Clay, S.A. (2014). Impact of Herbicide Tolerant Crops on Soil Health and Sustainable Agriculture Crop Production. In: Songstad, D., Hatfield, J., Tomes, D. (eds) Convergence of Food Security, Energy Security and Sustainable Agriculture. Biotechnology in Agriculture and Forestry, vol 67. Springer, Berlin, Heidelberg. <https://doi.org/10.1007/978-3-642-55262-5_10>

Environmental considerations and long-term system resilience

While GM crops have delivered measurable reductions in chemical load and associated emissions, their environmental performance remains dependent on effective stewardship and resistance management. Over-reliance on specific herbicide or insect resistance traits can accelerate the emergence of resistant weeds and pests, posing risks to long-term sustainability. Australia's experience highlights that these benefits are best sustained when GM technologies are deployed as part of integrated management and rotational practices that support productivity, soil health and broader system resilience.

Social impacts

Improved farm safety & occupational health

Reduced grower and farm-worker exposure to insecticides and herbicides, due to fewer chemical applications.

Improved on-farm safety from fewer spray passes, lowering risks from chemical handling, spray drift, and machinery use.

Community & environmental health benefits

Local communities and downstream environments supported by healthier agro-ecosystems and improved catchment water quality.

Resilient & stable farming communities

Workforce certainty supported by stable production outcomes.

Strengthened farm businesses and long-term system resilience due to lower risk and greater predictability.

The adoption of GM traits in Australia has delivered clear social benefits, particularly through improved farm safety and occupational health. Reduced reliance on routine insecticide and herbicide applications has lowered grower and farm-worker exposure to hazardous chemicals, contributing to safer working conditions across affected industries.

These changes have also generated broader community benefits. In sectors such as cotton, reduced insecticide use has been linked to improved water quality in production catchments, delivering flow-on benefits for rural communities and downstream users. Cleaner local environments can enhance amenity and quality of life in regional areas.

More reliable pest and weed control has supported greater production stability, helping to reduce seasonal volatility and support employment certainty within farming enterprises. Together, these outcomes suggest that GM adoption can contribute to more resilient farming communities when technologies align with local systems, markets and stewardship practices.

Commercial dependency and grower autonomy

Most GM crop systems operate under commercial seed-licensing arrangements that require growers to purchase new seed annually. These agreements play an important role in supporting regulatory compliance, stewardship, and the recovery of substantial private investment in R&D. However, the scale and structure of some licensing models have raised concerns around grower autonomy and dependence on proprietary technologies. Australia's experience highlights the importance of balancing incentivises for innovation with transparency, choice and public confidence to support the long-term social sustainability of GM crop adoption.

2.1 Success factors and future lessons

Australia's 30 years of GM crop experience shows that successful adoption depends on more than agronomic performance alone. Enduring uptake has occurred where strong regulatory oversight, market acceptance, clear farm-level benefits, coordinated industry stewardship and supportive policy settings have aligned with sustainability and climate objectives. Together, these factors explain the legitimacy and lasting value of GM cotton and canola and provide practical lessons for the design and rollout of future genetic technology applications.

Strengthening regulation, scientific oversight, and policy coherence

Australia's regulatory framework, particularly the roles of the OGTR and FSANZ, have been instrumental in building public confidence in GM crops. Independent, evidence-based assessments of human and environmental safety, combined with transparent processes and public communication, have established a credible foundation for the commercial deployment and long-term trust among growers, supply chains, and the broader community.

Over time, changes in state-level policy settings, including the lifting of moratoria in most jurisdictions, further supported this confidence by normalising regulated adoption and providing greater clarity for industry and communities. As market conditions and public understanding evolved, these shifts helped reduce uncertainty and strengthened the social licence for GM crop use.

LESSON: Clear, coherent policy settings are critical to enabling adoption at scale.
Australia's experience highlights that emerging technologies rely on robust safety regulation, as well as policy frameworks that support predictable market access and minimise unnecessary complexity across jurisdictions. As future genetic technology pathways increasingly blur the boundaries between GM and non-GM methods, policy clarity will be essential to reduce avoidable logistical constraints, give growers and supply chains confidence, and support informed adoption decisions.

Favourable cost benefit and incentivised market adoption

For growers, GM adoption has depended on the ability to realise clear and reliable economic value. In crops such as cotton and canola, insect-resistant and herbicide-tolerant traits have delivered benefits primarily through improved risk management: reducing input costs, protecting yields, and supporting more stable production outcomes across variable seasons. Demonstrating these benefits at the farm level has been critical in building confidence and driving uptake.

At the same time, a new generation of GM products with consumer-focused traits such as enhanced colour, flavour, nutrition, or shelf life, is emerging. These developments signal that the value proposition for genetic technologies is expanding beyond farm-level performance to include attributes that resonate directly with consumers, potentially broadening market acceptance and future adoption pathways.

LESSON: Adoption is strongest where growers can clearly see and capture economic value.
Australia's experience suggests that growers are more likely to adopt new genetic technologies when performance is visible, locally relevant and supported by credible evidence across different environments. A key lesson from earlier safflower innovation efforts is that grower adoption is enhanced when novel traits are incorporated into well adapted germplasm; early lines containing the traits were not introgressed into locally adapted germplasm and underperformed compared to growers expectations. Future uptake will be strengthened where value propositions are transparent and when market and supply chain settings allow the benefits of adoption to be shared fairly, rather than concentrating costs at the farm gate.

Industry-led stewardship and preparedness across the supply chain

Australia's experience with GM crops demonstrates the importance of strong industry-led stewardship in supporting safe and durable adoption. In the cotton sector, the introduction of GM traits occurred within an established integrated pest-management framework, supported by coordinated efforts from CSIRO, the Cotton Research and Development Corporation (CRDC), and Cotton Australia. This enabled consistent resistance-management practices, reinforced responsible use, and helped build long-term confidence in GM technologies.

However, strong stewardship alone has not always been sufficient to accelerate adoption. In some cases, limited preparedness across seed distribution, licensing and retail networks constrained timely access to GM varieties, slowing uptake despite demonstrated on-farm benefits.

LESSON: Adoption is enabled when stewardship is matched by commercial and supply-chain readiness.
Australia's experience highlights the importance of ensuring that distribution channels, licensing arrangements and retail networks are fully prepared ahead of commercial release. Successful commercialisation depends on well-integrated supply chains, both for the supply of traits and post farm-gate to process initial small and variable batches that are typical of early-stage adoption; without this readiness, even technically promising traits can fail to reach market. Aligning stewardship with end-to-end supply chain preparedness can remove avoidable barriers and support equitable access for growers across regions.

Future innovation

Australian producers continue to express interest in future GM traits that address persistent production challenges, including crop disease, water constraints and climate variability. Positioning genetic technology as an ongoing pathway for solving these challenges (rather than a series of discrete product releases) has helped reinforce its relevance and legitimacy within broader efforts to improve crop performance and regional adaptation.

LESSON: Innovation is most compelling when it is locally relevant and delivered as a sustained pipeline.

Australia's innovation performance is strengthened when it is well connected to the global innovation system, enabling offshore technologies to be adapted to local production needs. Aligning global inputs with region-specific challenges is essential, as grower demand is strongest when new traits address local constraints and fit within a longer-term innovation trajectory. A coordinated pipeline approach, linking international technology with locally relevant trait development will support the relevance of GM technologies and innovation over time.

CASE STUDY: Bt cotton in Australia

Bt cotton was introduced in Australia in 1996 as the nation's first GM field crop to address severe pest pressures from *Helicoverpa* caterpillars.[20] This was developed through a long-standing CSIRO-industry joint venture that combined public-sector innovation with strong commercial delivery. This partnership played a central role in enabling safe, effective adoption, supporting research, stewardship, grower training, and coordinated resistance management strategies from the outset. Bt Cotton deployment occurred within a stringent regulatory framework and an established industry stewardship system.

Following the initial commercial release, Australia progressively introduced GM cotton traits conferring insect resistance, herbicide tolerance, or both. Adoption was phased and closely managed, with strong coordination between researchers, growers, technology providers and regulators. Over time, stacked traits became standard, supporting durable pest control and robust resistance-management practices.[21]

The impacts of GM cotton have been substantial. Australian cotton growers now use 85% less insecticide,[22] delivering environmental benefits such as reduced chemical runoff and improved on-farm biodiversity, alongside economic gains from lower input costs and more reliable production outcomes. Today, over 99.5% of Australia's cotton crop is genetically modified,[23] underpinning an export-oriented industry worth more than $1.5 billion annually,[24] with most production destined for international markets.

Australia's experience with Bt cotton demonstrates that successful GM adoption depends on more than scientific innovation alone. Its durability and scale reflect sustained public research leadership, clear and demonstrable grower value, phased deployment, strong industry stewardship, and a credible, science-based regulatory framework operating in concert.

20 Office of the Gene Technology Regulator (2025) Genetically modified cotton in Australia (Version 2.1). Australian Government.
21 Cotton Australia. (2026). Biotechnology and cotton. <https://cottonaustralia.com.au/biotechnology-and-cotton>
22 Ward, C. (2014). Genetically modified cotton varieties. CSIROpedia. <https://csiropedia.csiro.au/genetically-modified-cotton-varieties/>
23 Office of the Gene Technology Regulator (2025) Genetically modified cotton in Australia (Version 2.1). Australian Government.
24 Ward, C. (2014). Genetically modified cotton varieties. CSIROpedia. <https://csiropedia.csiro.au/genetically-modified-cotton-varieties/>

3 The future of genetic modification in Australian crops

Australian agriculture is entering a new phase of genetic technology development, shaped by advances in genetic modification, gene editing, molecular farming, and next-generation breeding technologies. Building on three decades of experience, the opportunity is no longer defined solely by what these technologies can deliver, but by how effectively they can be integrated into existing production systems, markets and governance arrangements.

This chapter explores the emerging directions likely to shape the next generation of Australian crops, and outlines the strategic questions that growers, industry, policy makers and the research community will need to consider supporting confident, responsible adoption in the years ahead.

3.1 Emerging technologies complementing genetic modification in Australian agriculture

Advanced genetics and nextgeneration breeding tools

Several key lessons from GM adoption have directly influenced how gene editing is now assessed, regulated, and deployed. Amendments to the Gene Technology Regulations clarified that some gene edited organisms (including SDN-1 edits where no foreign DNA is introduced[25]) are not regulated as GMOs.[26] This has reduced regulatory friction for specific applications, potentially enabling faster development and deployment of new crop varieties targeted to productivity, resilience and sustainability outcomes. Importantly, Australia must navigate regulatory differences in export markets before releasing gene edited traits commercially, international divergence will influence market access, compliance, and supply-chain requirements.

Advances in gene editing tools, such as CRISPR[27]-based approaches, are accelerating crop improvement by shortening development timelines and enabling more precise modification and stacking of desirable traits.[28] While emerging gene editing applications are broadening opportunities to enhance traits such as heat, frost, and salinity tolerance, certain innovations will necessarily remain within the scope of GM. For instance, traits requiring the addition of bacterial genes for nitrogen fixation will continue to be regulated as GM, regardless of future technological advances. Together, these capabilities expand the range of traits that can be targeted and increase the likelihood that future biotechnology solutions can be tailored to diverse Australian production environments.

Molecular farming and novel crop applications

Molecular farming is emerging as a new application of agricultural genetic technology, using crops as biofactories to produce high-value compounds. Although these technologies are not yet widely commercialised in Australia, introducing molecular-farming traits into crops that are already genetically modified, such as GM canola, may offer a more streamlined and practical development pathway, building on existing regulatory and stewardship frameworks. Recent approvals for trials of GM oilseed crops for applications such as dairy protein production and altered oil composition illustrate how molecular farming could extend the role of crops beyond traditional food, feed and fibre markets (e.g., animal proteins, nutraceuticals and bioenergy). These applications highlight both the opportunity for value creation and the need for regulatory, supply-chain and market arrangements capable of supporting non-traditional crop outputs.

25 CRISPR/Cas9 is a genome-editing technique that uses a guide RNA and the Cas9 enzyme to make precise, targeted DNA changes in crops; edits without foreign DNA (SDN-1) may be regulated differently from transgenic GM crops, while edits involving inserted DNA are regulated as GMOs.

26 Office of the Gene Technology Regulator. (2025, February). Overview – status of gene editing and other new technologies.

27 CRISPR employs the Cas9 protein and single guide RNA (sgRNA) to enable the precise targeting and modification of desired DNA sequences within the focal genome.

28 Gao, W., Long, L., Tian, X., Xu, F., Liu, J., Singh, P. K., & Botella, J. R. (2017). Genome editing in cotton with the CRISPR/Cas9 system. Frontiers in Plant Science, 8, 1364. <https://doi.org/10.3389/fpls.2017.01364>

Digital agriculture and artificial intelligence (AI)

Digital technologies are increasingly supporting the development and deployment of GM and gene edited crops by improving how traits are identified, tested and refined under real-world conditions. High resolution field data and advanced analytics are helping researchers and breeders better understand how crop varieties respond to environmental stresses, increasing the likelihood that new traits are relevant and robust across diverse production systems.[29]

AI and machine learning approaches further accelerate this process by improving prediction and decision-making throughout trait development. By enhancing precision, reducing development timelines and lowering research costs, these tools increase confidence in the performance and stability of new genetic technology applications.[30,31]

Together, digital agriculture and AI act as enabling technologies that complement advances in GM and gene editing. Their integration has the potential to support faster, more targeted innovation, and help narrow the cost gap between conventional germplasm improvement and genetic technology applications based on molecular and genomic insights.

Robotics and automation

Robotics and automation are also playing a role in the development of GM and gene edited crops by accelerating early-stage research, reducing development timelines,[32] and reducing the cost differential between traditional crop breeding and advanced genomic approaches. Automated platforms enable high-throughput, more consistent experimentation, allowing a greater number of traits and genetic combinations to be evaluated in parallel.

By increasing the speed, scale and reproducibility in trait development, these technologies complement advances in gene edited, GM, and digital agriculture. Their expanding use also reinforces the importance of research infrastructure, skills and investment capable of supporting more rapid and complex innovation pipelines. These tools will also provide deeper insight into potential off-target effects, metabolic changes and trait stability, supporting more robust risk assessments and enabling clearer pathways toward deregulation and commercial deployment.

29 Gill, T., Gill, S.K., Saini, D.K. et al. A Comprehensive Review of High Throughput Phenotyping and Machine Learning for Plant Stress Phenotyping. Phenomics 2, 156–183 (2022). <https://doi.org/10.1007/s43657-022-00048-z>

30 Crossa, J., Martini, J. W. R., Vitale, P., Pérez-Rodríguez, P., Costa-Neto, G., Fritsche-Neto, R., Runcie, D., Cuevas, J., Toledo, F., Li, H., De Vita, P., Gerard, G., Dreisigacker, S., Crespo-Herrera, L., Saint Pierre, C., Bentley, A., Lillemo, M., Ortiz, R., Montesinos-López, O. A., & Montesinos-López, A. (2025). Expanding genomic prediction in plant breeding: Harnessing big data, machine learning, and advanced software. Trends in Plant Science, 30(7), 756–774. <https://doi.org/10.1016/j.tplants.2024.12.009>

31 Chuai, G., Ma, H., Yan, J. et al. DeepCRISPR: optimized CRISPR guide RNA design by deep learning. Genome Biol 19, 80 (2018). <https://doi.org/10.1186/s13059-018-1459-4>

32 Annese, D., Romani, F., Grandellis, C., Ives, L., Frangedakis, E., Buson, F.X., Molloy, J.C. and Haseloff, J. (2025), Semi-automated workflow for high-throughput Agrobacterium-mediated plant transformation. Plant J, 122: e70118. <https://doi.org/10.1111/tpj.70118>

3.2 Beyond the first 30 years: enabling the next wave of GM crops in Australia

Australia's next wave of GM innovation will be shaped not only by what science can deliver, but by how effectively new advances, particularly in gene selection and modification, interact with the broader system. The pace and impact of future innovation will depend on how well these scientific advances can be integrated, scaled, and supported through coherent governance and stewardship, market readiness, and durable social licence.

The strategic challenge for the next 30 years is therefore not *"Can we build the traits?"*, but "***Can we build the necessary conditions for confident adoption?***"

Meeting this challenge will require continued attention to factors that have historically shaped uptake, including jurisdictional coherence, supply-chain and market readiness, farm-level economics, and public understanding and trust.

The strategic questions below are intended to help different stakeholder groups test these areas early, anticipate adoption bottlenecks, and strengthen the conditions needed for faster, more confident uptake.

Policy and regulatory stakeholders

Australia's experience with genetically modified crops highlights the important role that policy and regulatory settings have in shaping the pace and pattern of adoption. As the genetic technology opportunity expands, policy and regulatory stakeholders will be central to ensuring that decision-making frameworks remain clear, coherent and responsive to evolving market, trade and community contexts, while continuing to support public confidence.

Key questions

- How can policy and regulatory settings support more timely adoption of high-value genetically modified and gene edited crops in Australia, while maintaining alignment with international markets and trading partners?
- Which factors currently present the greatest constraints to adoption, and where could greater clarity, consistency or coordination make the most difference?
- Where do stakeholders across the agricultural biotechnology ecosystem see opportunities to contribute most effectively to the next phase, including across technology development, regulation, production, supply chains or market access?

Growers

Commercial uptake of genetically modified and gene edited crops will depend on whether productivity, profitability and sustainability benefits are clear, reliable and sufficient to offset regulatory, licensing, and stewardship costs at the farm level. Additionally, growers and investors also need confidence in domestic and export market acceptance. Australia's experience highlights the importance of value propositions that are transparent, locally relevant and demonstrated under real production conditions.

Key questions

- What will drive consumer acceptance and how can we support the use of appropriate technologies, which have been demonstrated to have safe use, to solve complex problems?
- How can the costs and benefits of genetically modified and gene edited crops be more clearly demonstrated to growers across different farming systems, regions and seasonal conditions?

Supply chain and grain industry

Market access and supply chain design play a critical role in shaping the commercial viability of GM and gene edited crops. In commodity-based systems, the costs and complexity associated with segregating GM and non-GM products can reduce or offset on-farm productivity gains, highlighting the importance of supply chain arrangements that are fit-for-purpose as new traits and applications emerge.

Key questions

- How can segregation and identity-preservation requirements be managed in commodity supply chains to support the commercialisation of high-value genetically modified or gene edited traits?
- How can technology licensing costs and commercial risks be shared more effectively across the value chain to reduce economic pressure on early adopters and support broader uptake?

3.3 Next steps

This discussion paper has outlined key impacts and lessons from Australia's three decades of commercial GM crop use and has framed the critical questions that will shape the next phase of adoption. Together, these insights point to the importance of moving beyond reflection toward more coordinated, forward-looking action.

To support coordinated progress and the uptake of new advanced breeding technologies, CSIRO sees a clear opportunity to develop a strategic, collaborative plan to guide future research priorities, industry capability building and commercialisation pathways. Such a plan would help translate emerging opportunities into practical outcomes by addressing system-level enablers, adoption barriers and market readiness in an integrated way.

CSIRO welcomes engagement from government, industry and research stakeholders interested in contributing to this next phase of work and shaping the direction of future planning.

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