
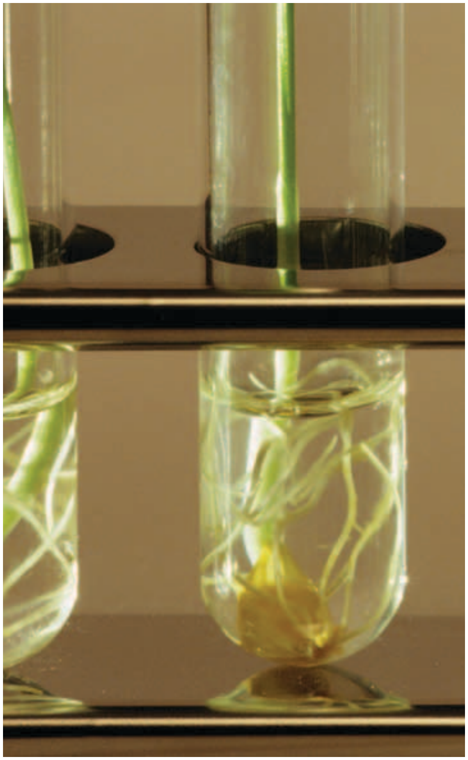


Bioscience at a Crossroads

Access and Benefit Sharing in a Time of Scientific, Technological and Industry Change:

The Agricultural Sector

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Bioscience at a Crossroads:
Access and Benefit Sharing in a Time of Scientific, Technological and Industry Change: The Agricultural Sector

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The focus of this brief is on plant genetic resources for food and agriculture, although its conclusions and recommendations have broad applicability to other sub-sectors. Note that separate policy briefs review ABS issues pertaining to the pharmaceuticals, cosmetics, botanicals, industrial biotechnology and food and beverage sectors. The reader is also referred to the overview brief in this series: Laird, S. and Wynberg, R. 2012. *Bioscience at a crossroads: Implementing the Nagoya Protocol on access and benefit sharing in a time of scientific, technological and industry change*. Secretariat of the Convention on Biological Diversity, Montreal. The overview brief is available at http://www.cbd.int/abs/doc/policy-brief-01-en.pdf

INTRODUCTION

Genetic resources for food and agriculture underpin human well-being and are vital for food security. The critical need to ensure the continued use and exchange of these resources therefore raises distinctive access and benefit-sharing (ABS) issues. The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization, together with the International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), create opportunities to develop ABS solutions that are supportive of the special needs of this sector.

Long histories of interdependence characterize exchanges of genetic resources in the agricultural sector, which comprises traditional and customary systems of breeding, selection, saving and exchange existing alongside western, scientific processes of breeding and crop improvement. Most of the genetic resources used in the agricultural sector are human-modified forms of biodiversity, with their existence closely linked to human activity together with lengthy and complex processes of direct intervention or domestication.[1]

In the agricultural sector, countries may act both as providers and users of genetic resources for food and agriculture, with most countries being net recipients of genetic material from other countries or regions. Moreover, the innovation process is usually of an incremental nature, arising from the contributions of a variety of different actors and several different genetic resources, in different locations and at different points in the research and development process.[2] The origin of genetic resources is also highly convoluted due to millennia of cross-border transfers, multiple parental sources, and the variety of location-specific traits that are acquired.

Because many agricultural products developed from genetic resources can be used for further research and development (R&D), it is also sometimes difficult to determine who are the providers and users of these resources, and to track the movement of genetic resources through different value chains and geographical locations. Many agricultural products may also reach the marketplace in a form in which they can be used both as biological resources, for direct production or consumption; and as genetic resources, which can be developed into different products. Benefit sharing can thus be complex because of the cumulative nature of breeding, because the R&D leading to the final product may require extensive exchanges that do not take place within one company, and because intermediate products themselves are sometimes marketed.

Scientific and technological developments in molecular biology combined with the phenomenal consolidation of the commercial seed and agrochemical industry over the past two decades, and the rapid advancement of available communication and information technologies, have had profound effects on the way in which genetic resources are used and developed by this sector, opening up access to the astonishing variability that exists within the genome.

This brief provides an exploration of these issues, beginning by providing a description of the policy context; an overview of the industry and market; an analysis of key research, development and technological changes over the past two decades; and concluding with suggestions as to how the implementation of the Nagoya Protocol can respond to the concerns of the sector.

INTERNATIONAL POLICY SETTING: THE NAGOYA PROTOCOL AND THE INTERNATIONAL TREATY FOR PLANT GENETIC RESOURCES FOR FOOD AND AGRICULTURE

The policy environment for agriculture has changed significantly over the past twenty years, particularly with the adoption of the ITPGRFA and the Nagoya Protocol. The ITPGRFA, which entered into force in 2004, is a legally-binding international agreement that promotes the conservation and sustainable use of plant genetic resources for food and agriculture (PGRFA) and the fair and equitable sharing of the benefits arising out of their use, in harmony with the Convention on Biological Diversity (CBD). The ITPGRFA establishes a Multilateral ABS System for 64 of the most important food security and forage crops (included in Annex I of the Treaty). Although the ITPGRFA applies to all PGRFA, the Multilateral System applies only to those genetic resources included in Annex I. Crops listed comprise a pool of genetic resources that are accessible to everyone. Through this system, PGRFA that are in the public domain and under the management and control of Contracting Parties to the Treaty share a set of rules of facilitated access to genetic resources. Those who access genetic materials agree that they will freely share any new developments with others for further research and, if not, will pay a percentage of any commercial benefits from their research into a common benefit-sharing fund for developing countries. A Standard Material Transfer Agreement (SMTA) sets agreed terms and conditions for the transfer and use of these crops for the purpose of research, breeding and agricultural training.

In addition, a significant number of non-Annex I genetic resources fall under the ITPGRFA, governed by Article 15 of the Treaty. These include *ex-situ* collections of PGRFA held by the Centres of the Consultative Group on International Agricultural Research (CGIAR), which are governed and exchanged under similar terms and conditions as material included in the Multilateral System.

Genetic resources not covered by the ABS regime of the ITPGRFA comprise many food and agricultural crops and all ornamental crops. Legal access to these genetic resources as well as to Annex I crops used outside the scope of the ITPGRFA, for example for pharmaceutical purposes, is thus governed by the CBD – as well as the Nagoya Protocol once it enters into force. This includes animal, aquatic, forestry, invertebrate and microbial genetic resources used in the agricultural sector.

The Nagoya Protocol explicitly recognizes in its preamble the importance of genetic resources to food security; the distinctive features and problems of agricultural biodiversity and thus the need to find distinctive solutions; and the interdependence of all countries with regard to genetic resources for food and agriculture. The Nagoya Protocol also acknowledges the ITPGRFA and the FAO Commission on Genetic Resources for Food and Agriculture (CGRFA).

In its operational provisions, the Nagoya Protocol provides that Parties shall consider the importance of genetic resources for food and agriculture and their special role for food security in the development and implementation of their ABS measures.[3] The Protocol also contains provisions on its relationship with other international agreements and instruments. While it does not explicitly mention the ITPGRFA, Article 4 recognizes the possibility of other specialized international ABS instruments and specifies that the Nagoya Protocol would not apply for Parties to the specialized instrument "…in respect of the

A selection of the astonishing diversity of maize. Photograph: Shutterstock

Farmer working in rice paddy. Photograph: Shutterstock

specific genetic resource covered by and for the purpose of the specialized instrument".[4] It also leaves room for the development of specialized ABS instruments in the future.[5]

In addition, the relationship between the Nagoya Protocol and the ITPGRFA is envisaged in Article 4(3), which provides that the Protocol shall be implemented in a mutually supportive manner with other international instruments relevant to the Protocol. Finally, Parties are required to encourage the development, update and use of sectoral and cross-sectoral model contractual clauses for mutually agreed terms and of voluntary codes of conduct, guidelines and best practices in relation to ABS.[6]

Against this background, the CGRFA, which has a long history of work on ABS, has recently established an Ad Hoc Technical Working Group on Access and Benefit Sharing for Genetic Resources for Food and Agriculture which is examining approaches and options to assist countries with the implementation of ABS measures while taking into account the distinctive features of genetic resources for food and agriculture.[7]

The ITPGRFA has been in force for almost ten years and has led to new ways of exchanging genetic resources and ensuring equitable benefit sharing. Harnessing these experiences and tailoring them to suit new technological, scientific and environmental challenges is a vital task in forthcoming years. The Nagoya Protocol represents an important next step to ensure that ABS goals are comprehensively implemented to meet food security, conservation and development goals in a world where agrobiodiversity is increasingly under threat.

INDUSTRY OVERVIEW AND MARKET TRENDS

AN OVERVIEW OF THE AGRICULTURAL SECTOR AND ITS USE OF PLANT GENETIC RESOURCES

A diverse group of players is involved in the collection and maintenance of agricultural genetic resources, their evaluation and testing, regulation, improvement, multiplication, distribution and sale. These include multinational seed, biotechnology, horticultural and chemical corporations, smaller companies operating at national or regional levels, universities and other research institutions, public and private genebanks, farmers and a multitude of supporting and servicing organizations. The variety of company sizes, the multiplicity of markets they service, the range of technologies that are used, the diversity and range of genetic resources that are sought, and the different international agreements and intellectual property rights that regulate use of these resources, reflect a sector where ABS questions often manifest themselves in divergent ways.

Genetic resources which are used range from plants, animals or microbes collected in the wild, including wild relatives of domesticated species, as well as landraces and commercial or elite varieties. Combined, these are used in three main ways:

- For **conventional breeding** purposes, through the selection and development of germplasm, including through the use of molecular markers;
- For **"molecular-assisted" breeding using biotechnology**, incorporating transgenic traits into germplasm to develop selected characteristics or traits; and
- For **crop protection**, through R&D of active ingredients, biocontrol agents as well as the use of genes that confer pest, disease and herbicide resistance.

The goals of these different activities include yield improvement, yield stability under stress (e.g. cold, heat, drought), quality improvement (e.g. taste, colour, odour, shelf-life, nutrition) and pest protection (e.g. disease, insects, weeds, herbicide resistance). Each of these activities requires access to genetic resources, but does so in distinct – but often overlapping – ways.

INDUSTRY CONSOLIDATION

There has been massive transformation of the agricultural sector over the past 40 years, beginning with the purchase by pharmaceutical and petrochemical companies of small, family-owned seed firms in the 1970s, the emergence of a "life sciences industry" in the 1980s, incorporating seeds, agrochemicals and pharmaceuticals, and a proliferation of mergers and acquisitions in the 1990s and 2000s.[8] While these trends have been due in part to the desire to control markets and eliminate competition, they have also been underpinned by strategies to take ownership of new genetic technologies through the purchase of biotechnology companies, the acquisition of patents for key technologies and traits, and, importantly, the need to increase access to germplasm.[9] The high costs associated with R&D, and with compliance to government biosafety regulations have contributed towards this consolidation trend.

Technological change and patents have been major drivers of the consolidation of the global seed and crop protection industries, enabling greater ownership and control by fewer companies of key technologies and processes. Through achieving vertical and horizontal integration, companies have been able to consolidate research efforts, earn higher returns than they could from conventional plant breeding,[10] and increase control of distribution channels and agricultural inputs.[11]

These trends are very striking in the crop protection industry where ten companies control 82% of the global pesticide market, with more than half (54%) controlled by the top four corporations (Table 1). Increasingly, seed and agrochemical interests are converging, allowing companies to position themselves as major suppliers of both seed and agrochemicals. For example, the leading multinational seed company, Monsanto, genetically engineers its seed to be resistant to its own herbicides, a strategy which has helped position the company as the third largest agrochemical supplier globally.[12]

TABLE 1. Turnover and Market Share of Top 10 Companies in the Global Pesticides Market[13]

COMPANY	COUNTRY	AGROCHEMICAL SALES 2009 ($ MILLION)	MARKET SHARE
Syngenta	Switzerland	8,491	18%
Bayer	Germany	7,544	17%
Monsanto	USA	5,007	10%
BASF	Germany	4,427	9%
Dow AgroSciences	USA	3,902	9%
Du Pont	USA	2,403	5%
Makhteshim Agan	Israel	2,374	4%
Nufarm	Australia	2,082	4%
Sumitomo Chemical	Japan	2,042	4%
Arysta Lifescience	Japan	1,196	2%
TOTAL Top 10		**39,468**	**82%**
Others			18%

In contrast to these trends, ornamental horticulture is still largely carried out by small- and medium-sized companies, which continue to rely largely on conventional breeding methods and mid-level technologies. Similarly, research and breeding of fruit species is often a focus of public institutions and universities due to the high costs involved.[14] Across all continents, however, there is a general trend towards fewer and larger horticultural growers, and a concentration of other retail pathways.[15]

MARKET TRENDS

The combined turnover and market share of the top ten companies in the global commercial seed market represented over $20 billion in 2009, equating to some 59% of

TOP: Tea plantations near Mount Fuji, Japan Photograph: May Fong Robinson
BOTTOM: Developments in genomics and molecular biology have fundamentally changed plant breeding. Photograph: Thinkstock

the sector's value in that year (Table 2).[16] The value of this sector has grown from some $30 billion in 2005 to approximately $45 billion in 2011, with the United States and China having the highest valued domestic seed markets (Table 3).[17] The percentage made up by the global proprietary[18] seed market has risen dramatically – from 46% in 2000, to 57% in 2005, reaching 94% in 2010.[19] Genetically modified (GM) seed, as a sub-sector of this market, has also shown an increase – from 15% in 2000, to 30% in 2005, and 35% in 2010.[20]

TABLE 2. Turnover and Market Share of Top 10 Companies in the Global Seed Market[21]

COMPANY	COUNTRY	SEED SALES IN 2009 ($ million)	MARKET SHARE
Monsanto	USA	7,297	27%
Du Pont	USA	4,641	17%
Syngenta	Switzerland	2,564	9%
Groupe Limagrain	France	1,252	5%
Land O' Lakes	USA	1,100	4%
KWS AG	Germany	997	4%
Bayer Cropscience	Germany	700	3%
Dow AgroSciences	USA	635	2%
Sakata	Japan	419	2%
DLF-Trifolium A/S	Denmark	387	1%
TOTAL Top 10		**20,062**	**64%**
Others			36%

The rapid uptake of GM crops has been one of the most profound industry trends over the past 15 years, its escalation surpassing that of any new technology ever embraced by the agricultural industry. In a span of 15 years, the global area of GM crops increased more than 94 fold, from 1.7 million hectares in 1996 (the first year of commercial GM crop plantings) to 160 million hectares in 2011.[22] Leading growers of GM crops are dominated by the United States (64 million ha), Brazil (21.4) and Argentina (21.3).[23] While the spread of GM crops is predicted to continue, particularly in the developing world,[24] in other areas, notably western and eastern Europe, their adoption is either static or declining, largely due to consumer resistance and stringent regulatory requirements.[25]

TABLE 3. Top Ten Domestic Seed Markets Globally[26]

COUNTRY	VALUE in 2011 ($ billion)
USA	12
China	9
France	3,6
Brazil	2,6
India	2
Japan	1,6
Germany	1,2
Argentina	0.8
Italy	0.6
Canada	0.6

Crop protection sales have climbed steadily from $25 billion in 1990 to a global market value of almost $40 billion in 2010. Herbicides accounted for almost 50% of the total crop protection market in 2009, with fungicides comprising 25.6%, insecticides 24.8% and others 3.6%.[27]

The global horticulture industry has been expanding steadily since the 1980s but the shift of production to developing countries has caused market prices to drop.[28] The world import trade value in horticulture in 2011 was $19 billion (Table 4), an increase of more than 40% since 2004. Historically, the Netherlands has been the centre of world flower production, but increasingly, growing takes place in developing and newly industrialized countries, where horticulture may represent the fastest growing sector of the economy.[29]

TABLE 4. World Import Trade Value in Horticulture (2011)[30]

CATEGORY	VALUE	PERCENTAGE
Live plants	$7,5 billion	40%
Fresh cut flowers	$7,6 billion	40%
Bulbs, tubers and corms	$1,7 billion	9%
Fresh cut foliage	$0,9 billion	5%
Other (e.g. trees, dried flowers, etc.)	$1,1 billion	6%
TOTAL	**$19 billion**	**100%**

RESEARCH, DEVELOPMENT AND TECHNOLOGICAL CHANGE

OVERVIEW OF TECHNOLOGICAL CHANGES

Plant breeding and crop improvement have changed dramatically as a result of developments in genomics[31] and molecular biology.[32] These advances reflect a distinct paradigm shift from twenty years ago – away from screening genetic resources for a clearly defined character, recognizable in the phenotype (physical appearance), towards evaluating material directly for the presence of useful genes.[33]

Increasingly, new molecular tools and approaches are leading to better understanding of metabolic processes, allowing for greater precision in the identification of genes for use in crop improvement.[34] Molecular marker tools, for example, are now commonly used to trace genetic inheritance in plant breeding programmes or to look for useful gene patterns. Whole genome sequencing is revolutionizing analysis of crop germplasm, and is fast becoming a quick and cheap way to find traits for a breeding programme. This has been accelerated by the rapid advancement of information and communication technologies, which have greatly enhanced the analytical capacities of researchers.

Improved molecular techniques are also proving invaluable for conservation, leading to increased efficiency of genebanks, deeper insights about genetic diversity and greater understanding about the history and structure of genetic diversity in key crops.[35]

New geographic methods such as Global Positioning Systems (GPS) are also enabling precise information to

Growing interest in wild species such as these from Morocco raises the importance of benefit sharing with traditional knowledge holders Photograph: Thinkstock

be obtained about exact collection locations, and have been extremely effective in mining germplasm for specific adaptive traits for crop improvement.[36] At a broader level, satellite mapping and hyperspectral imaging using airplanes bring together opportunities to identify crops or livestock with unique genetic traits and to triangulate information on soils, microbes and plants for industrial use.[37] Combined, these approaches have significant implications with regard to existing and future prospecting activities.

RESEARCH AND DEVELOPMENT TRENDS IN BREEDING

Changes to public and private sector research

Traits that improve performance and farming efficiency are a major focus for large seed companies, with a particular focus on the development of high value commercial lines through advanced marker-assisted selection and breeding techniques.[38] For smaller seed companies, levels of technological investment have been much lower, with the development of DNA markers, for example, seldom being pursued for varieties where margins are low (e.g. grasses).[39]

Breeding efforts are increasingly divided between the public and private sector, with the former largely devoted to open-pollinated crops and the latter working predominantly on hybrid crops.[40] However, this is not the case all over the world. A striking and continuing trend has been the escalation of private sector interest in agricultural research and an associated decline in public sector research.[41] Nearly all R&D done by the private sector has been based on crops and traits important to developed-country farmers, with little attention paid to crops important to poor farmers.[42] In developed countries, public funding has tended to move further upstream into research and germplasm development, with a shift towards increased seed production by the private sector.[43] Although public seed production in developing countries was supported in the 1980s and 1990s, donors have been reducing this support, leading to rising private sector involvement in seed supply in developing countries.[44]

Growing interest in crop wild relatives

An important trend is the growing interest and investment in crop wild relatives, due in part to the fact that they contain important genes for stress resistance and for improved productivity.[45] The increased use of crop wild relatives has significant implications for crop variety and breed improvement, more especially in the context of climate change, population growth, shrinking areas of arable land, and the rapid erosion of agrobiodiversity. Changes in consumer demand are also transforming the interest in crop wild relatives. An increasing desire for healthy food qualities, for example, is leading to stronger interest in compounds that could contribute towards a nutritious diet.

Despite this growing interest in crop wild relatives, significant scientific, technological and informational changes have not, to date, been matched by changes in the nature of the raw genetic materials that are used.[46] About 7,4 million accessions are held worldwide, in over 1,750 genebanks, yet breeders have tapped less than 1% of these collections for crop improvements.[47] About 90-95% of all genetic resources used in the plant breeding industry today are elite, modern varieties, the remaining 5-10% representing landraces or wild relatives. The effort required to use landraces or wild relatives for the development of commercially viable resources is considerable, when compared to using an established elite variety that already incorporates desired characteristics. Wild species have thus typically been considered to have little commercial value, requiring considerable investment, with risky returns.[48] As one industry commentator noted, "you only use land races and wild varieties when you search for something in particular that you cannot find in modern varieties".

The paucity of information about wild genetic resources and landraces and an associated lack of characterization and evaluation data remains a central reason for historical low levels of interest in crop wild relatives.[49] This is set to change, however, with the unlocking of information about wild diversity using molecular genetic techniques. Several studies on the molecular diversity of crop plants and their wild relatives are shedding new light on the domestication process, and ways in which the diversity in *ex-situ* collections can be accessed in a much more targeted manner. At the same time, the wild-to-domesticated transi-

Local seed varieties from farmers in Ingwavuma, KwaZulu-Natal, South Africa. Photograph: Rachel Wynberg

Identifying crops with adaptive traits for climate change is becoming increasingly important. Photograph: Thinkstock

tion is becoming better understood due to technological advances, and the sharply declining cost of technologies. There is a dramatic increase in our capacity to understand genetic structure, catalyzing a move towards precision breeding and the ability to incorporate desirable traits from crop wild relatives into cultivated crop material in a more efficient, faster and effective manner.[50]

Public and private ex-situ collections

While access to *in-situ* crop wild resources is becoming increasingly important in crop improvement, by far the most commercially significant source of material is located in *ex-situ* collections throughout the world. Among the largest collections are those of the CGIAR, which include both Annex I and non-Annex I genetic resources that are governed under terms and conditions similar to those of the Treaty's Multilateral System of ABS. In addition to the CGIAR centres, genetic resources are maintained in genebanks at local, national and regional levels by, among others, governments, botanical gardens, non-governmental organizations, universities, farmers and the private sector.

A significant source of genetic material resides with companies themselves, and larger companies in particular. Historically, these were considered as "working collections" within individual companies, with most material sourced from national and international genebanks and elsewhere. As access became increasingly restricted in the early 1990s, companies turned their attention towards maintaining and renewing their collections from available public and *ex-situ* collections.[51] Although the SMTA has facilitated access to Annex I crops, in recent years the maintenance and expansion of private collections has intensified by many of the larger companies, largely to reduce reliance on public sector collections and to avoid any risks of reduced access.[52] Acquisitions and mergers have bolstered such collections, but other strategies such as the dramatic increase in cross-licensing of germplasm to other companies and strategic alliances with technology companies, along with continued access to the International Agricultural Research Centres, ensure that companies have unrestricted access to a broader germplasm pool. All these factors have led to a trend of decreased use of national genebanks over time by larger companies.

TOP: Large seed companies typically focus on high value commercial lines and traits that improve performance and farming efficiency Photograph: Thinkstock
BOTTOM: Ntombenhle Sithole from KwaZulu-Natal, South Africa, with her Jugo bean crop. Photo: Rachel Wynberg

Different access and technology needs

Companies and governments often have different research interests and different needs to access genetic resources and technology. For larger companies, the emphasis is on high value seed such as maize, soybean, cotton and canola, and vegetables such as tomatoes, peppers and melons.[53] These companies also tend to have vast collections, rely less on others for genetic resources, and often focus on technologically advanced approaches. Multinational companies and life science "giants" are not only becoming self-sufficient in seed, but also have access to, and often ownership of, the necessary technology to comprehensively exploit what is in their possession.

Seed self-sufficiency is not, however, the case for small- and medium-sized companies (which tend to focus on vegetables, grasses and more marginal crops) and developing country governments which are likely to continue to be dependent on public sector collections. This implies that ABS measures may create more hurdles for these companies and developing country institutions in the long term.[54] Moreover, despite scientific advances, small- and medium-sized companies and developing countries are less able to apply new techniques in crop improvement, not only due to the expense and technical challenges, but also because many are proprietary and thus present significant access barriers.[55] Smaller companies are thus expected to become increasingly dependent on access to technologies developed by third parties through plant breeder's rights systems.

RESEARCH AND DEVELOPMENT TRENDS IN CROP PROTECTION

Continued focus on herbicide and insect resistance

One of the greatest demands in the crop protection industry is to develop new insect control traits, particularly to manage resistance.[56] Here, chemical discovery has been aided significantly through the use of genomics to identify suitable candidates, and combinatorial chemistry which has dramatically increased the number of products subject to biological screening. As an example, a large agrochemical company may work with a smaller company to collect samples of soil microorganisms, test the microbes, and screen the DNA from these microbes to find look-alikes based on existing known insecticides. Sophisticated databases may assist to screen interesting germplasm, although researchers still rely on having the germplasm in hand.[57]

A key trend has been a shift in expenditure from conventional agrochemical research to an expansion of in-house R&D efforts on transgenic crops. First generation "input traits" of herbicide tolerance, along with insect resistance, continue to dominate R&D efforts.

Progress towards second generation "output trait" products with nutritional, environmental or other benefits has been slow, believed in part to be due to the complexities of manipulating multiple genes.[58] Some so-called stacked traits[59] have been developed and introduced, intended to improve the performance of transgenic crops but these demonstrate a continued focus on herbicide tolerance and insect resistance. This has led some to suggest that under current industry structure, the scope of genetic engineering as a crop improvement strategy may be limited.[60]

Ongoing search for interesting compounds

Despite the consolidation of the agricultural sector, research strategies remain tailored towards different products. For example, in contrast to the seed and plant biotechnology sectors, the crop protection and agrochemical sector uses genetic resources in a manner akin to pharmaceuticals – searching for interesting compounds, screening these for active ingredients, moving to a process of pre-development for the few that hold promise, and commercializing those that are viable. This sector therefore demands access to a much wider range of genetic resources – from *ex-situ* collections through to *in-situ* biodiversity such as microbes and insects. ABS questions are therefore highly significant for crop protection activities.

An ever-increasing interest in natural-product derived insecticides adds to this relevance. Indeed, two out of the five most commonly used insecticide classes (neonicotinoids and pyrethroids) are in fact natural product or natural product-derived, accounting respectively for 19.5% and 15.7% worldwide sales.[61] In contrast, the use of natural product-derived herbicides in conventional agriculture is limited, restricted to Bialaphos, obtained from the actinomycete *Streptomyces hygroscopis*, which is also produced synthetically for commercialization as glufonisate (sold under such commercial names as Basta and Liberty).

RESEARCH AND DEVELOPMENT TRENDS IN ORNAMENTAL HORTICULTURE

Improved understanding of existing products

Ornamental horticulture tends to be far downstream of new scientific and technological developments in the agricultural sector. Such developments typically happen first in field crops, then vegetables, finally trickling down to ornamental horticulture.[62] DNA technology is considered too expensive and the industry has stayed away from genetically modified organisms because of the expense, regulations and intellectual property issues.[63]

Although other technological developments have impacted this industry, the fundamentals of horticultural science remain paramount. "Much of what we do today hasn't changed since Mendel", remarked one Chief Executive of a major ornamental horticulture company. While the industry continues to rely on conventional breeding, improved understanding of plants and their genetics has enabled old cultivars and varieties to be looked at with new eyes. Commented one industry representative "... we understand plants much better now and can discern specific traits more easily. Faster breeding is now possible and is more focused – even without using genetic modification".

R&D trends across the ornamental horticultural sector vary considerably depending upon the size, form and location of companies. In North America, for example, significant consolidation in the retail market has had a direct influence on some companies, which have responded to very specific retail demands such as uniform timing and habit, and particular sizes for greenhouses and benches.[64] The development of traits suited to these characteristics, based on improvements or extensions to existing products, comprises a major focus for these companies rather than novel R&D to develop new products.[65] Companies are also focused on garden performance for existing products, to ensure longevity once planted. Some companies have reported a decline in new germplasm development over the last five years. This is not necessarily related to any difficulties in securing access to wild material, but rather to lengthy product development cycles, a tendency towards increased selectivity, limited markets and the complexities and cost of combining new germplasm with existing classes. Remarked one company representative, "It takes time ... [to combine new germplasm] and we haven't found a lot of traits to make the investment worth it".

Interest in wild species

The ornamental horticulture sector relies predominantly on genetic resources already available in their own or other commercially available stocks, acquired prior to the enactment of ABS laws.[66] Almost all plants used in ornamental horticulture, and the diversity of cultivars derived through selection and breeding, came from wild plants. However, the modern-day horticulture industry has relatively low reliance on wild genetic resources, and many of the genetic resources it uses have been developed over decades and exist within industry collections.[67]

This sector does, however, require access to new genetic material for two main reasons: (1) for the development of species completely new to horticulture, adapted from wild species, and (2) to develop new traits, colours, and characteristics that may add to established classes. In large part, however, focus is given to the development of new traits and characteristics, rather than to the development of entirely new horticultural species. Despite the potential of wild species for new ornamental products, there are challenges to get new products into the marketplace. Although a small segment of the market is looking for something "different", companies have remarked on the difficulties of connecting consumers and growers to unfamiliar new products, largely due to a lack of awareness.

IMPLICATIONS FOR ABS AND THE NAGOYA PROTOCOL

The implications of both the market and business trends as well as the trends and changes in research, development and technology for ABS are profound, yet are only beginning to be understood, since historical ways of accessing genetic material are changing dramatically.

Consolidation in the seed, agrochemical and pharmaceutical industries means that larger companies have become increasingly self-sufficient in PGRFA and, unlike twenty years ago, have little demand for access to genetic resources. Technology ownership and intellectual property rights have enabled greater market capture and have both fueled and been products of the mergers and acquisitions that created the large life sciences companies.

This is not, however, the case for all companies. Access to genetic resources for food and agriculture is highly variable and both fluctuates and differs within the agricultural sector depending on the materials sought, the size of the company and the purpose of its use.

Moreover, there is growing interest in wild species for breeding, crop protection and, to a lesser extent, for horticulture. Perhaps the short-term focus will continue to be on *ex-situ* collections, but in the longer term, a shift towards new collecting missions of *in-situ* genetic resources is likely.[68] The growing interest in wild species is likely to raise the importance of benefit sharing with those providing traditional knowledge and ensuring that farmers' rights are recognized.

Technological changes and research developments in microbiology have increased access to the variability of the genome in ways previously unimaginable, dramatically accelerating the speed and throughput of activities such as screening and DNA extraction. This has also influenced the scale at which research can be undertaken. Research now begins much earlier, with a wider base of information, and there is thus a much bigger sample size that is collected before screening begins. Greater efficiency has led to reductions in costs and time, equipment has become cheaper and thus more accessible, and an increasing amount of data on genetic diversity is also now publicly available.[69] These developments along with substantial increases in computing power and the development of bioinformatics to manage and organise large, complex datasets, mean that a broader base of germplasm can now be mined and tested for efficacy. These technological changes will require those implementing ABS to have greater engagement and familiarity with bioinformatics and understanding of how these informational resources are shared and used.

Watering crops in south-east Asia Photograph: Thinkstock

Experiences with implementing the ITPGRFA also suggest that there are important opportunities for benefit sharing in the agricultural sector, from facilitated access to PGRFA in the Multilateral System to corporate social responsibility projects and donor contributions, partnerships, job creation, and the easing of licensing mechanisms to make patented material more freely available. For example, nearly all R&D done by the private sector has been based on crops and traits important to developed-country farmers, with little attention paid to crops important to poor farmers. ABS instruments could encourage technology transfer and cooperation, along with research that has greater benefits for small-scale famers in developing countries. The Nagoya Protocol also provides in its Annex I an indicative list of monetary and non-monetary benefits that can help to guide the development of equitable arrangements and a common understanding of benefit sharing.

THE NAGOYA PROTOCOL: RESPONDING TO SCIENTIFIC, TECHNOLOGICAL, POLICY AND MARKET CHANGE

The challenges and opportunities of implementing ABS are well recognized by many involved in the agricultural sector. Through the Multilateral System, significant strides have been made to facilitate the exchange of genetic resources for food and agriculture in the interests of food security and the public good. Harnessing these experiences and tailoring them to suit new technological, scientific and environmental challenges is the task for the next decade. It is important that the implementation of the Nagoya Protocol builds on past achievements to ensure that in a climate-changed and biodiversity-depleted world, exchanges are equitable, workable and contribute towards conservation and the adaptive capacity of agricultural systems and farming communities. Through careful and committed implementation, the Nagoya Protocol can respond in particular to the following concerns:

Providing legal certainty – Uncertainty about ABS obligations and compliance under the Nagoya Protocol remain major anxieties for those using and exchanging PGRFA. Common concerns have focused on the multiple policies governing genetic resources at a national level, the variety of government departments involved, the perception that procedures may be cumbersome or unclear, and the lack of clarity about which authority has the responsibility to negotiate ABS agreements.[70] There has therefore been little legal certainty. The Nagoya Protocol recognizes this concern and seeks to create an environment of legal certainty and mutual trust by requiring Parties to designate a national focal point on ABS and one or more competent national authorities to grant access. ABS national focal points will make information available on procedures for obtaining prior informed consent and reaching mutually agreed terms (Article 13). Establishment of an ABS Clearing-House (Article 14) for sharing information will help to achieve this goal.

Providing clarity on scope – Many PGRFA fall outside the Multilateral System. Access to these resources, to animal, invertebrate and microbial genetic resources used in the agriculture sector, and to PGRFA used outside the scope of the ITPGRFA (e.g. Annex I crops used for pharmaceutical purposes) is governed by the CBD, as well as the Nagoya Protocol once it enters into force. The Nagoya Protocol thus fills a regulatory gap by clarifying the relationship between multilateral and bilateral approaches to ABS, and underlining the importance of ensuring that governments, farmers, companies, researchers and other interest groups are aware of the implications and ABS requirements.

Streamlining procedures and reducing administrative bottlenecks – Different ministries often administer the ITPGRFA and the CBD and may introduce different access requirements for the same genetic resources, depending on their use. Implementation of the Nagoya Protocol can help to bring coherence and consistency to administrative procedures for PGRFA by making sure that both instruments are implemented in a mutually supportive manner, and lead to a strengthening of partnerships between users and providers. Given that the ITPGRFA was negotiated in harmony with the CBD, the Protocol provides an important opportunity to further enhance coordination and policy coherence between the agricultural and environmental sectors as regards ABS issues.

Improving tracking and monitoring – Improved tracking and monitoring of PGRFA is critical for effective implementa-

Potato varieties from the Andes, the centre of potato diversity.

Horticulture tends to be downstream of new scientific and technological developments. Photograph: Shutterstock

tion of the Nagoya Protocol as genetic resources that are accessed for one purpose (e.g. agriculture) may enter different value chains and pass through multiple countries for incorporation into many different types of non-agricultural products. Through the checkpoints described in Article 17, the Nagoya Protocol can help to monitor the use of genetic resources and ensure equitable benefit sharing. Developing understanding between different stakeholders on what constitutes best practice may be a practical step towards ensuring compliance.

Building the capacity of governments, researchers and companies to engage with ABS and changing scientific and technological developments – Many governments remain ill-informed about bioscience developments in agriculture, and may have misunderstandings about how ABS can work in practice. Research institutions, genebanks, companies and other user and provider groups would also benefit from awareness-raising about their obligations under the Nagoya Protocol and the ITPGRFA. Bringing such groups into national and international policy processes to contribute views and experiences would be an important way to ensure that ABS measures are relevant and effective in the agricultural sector. Capacity development thus remains an important need among all provider and user groups, an issue well recognized by the Nagoya Protocol (Article 22) which calls for a strengthening of human resources and institutional capacities to effectively implement the Protocol.

ENDNOTES

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