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AN ANALYSIS OF CROP BIOTECHNOLOGY PATENT DATA



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ADAPTATION AND INNOVATION: AN ANALYSIS OF CROP BIOTECHNOLOGY PATENT DATA

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ABSTRACT

Innovation in technologies that promote mitigation and adaptation will be critical for tackling climate change. It can decrease the costs of policy measures and provide new opportunities for the private sector. However, most discussions of innovation have focused on mitigation, while little attention has been paid to innovation for adaptation. This paper uses agricultural crop biotechnology as a case study of innovative activity. The agricultural sector is considered to be particularly vulnerable to climate change, in addition to facing the pressures of meeting the demands of a rising world population. Innovation in plant breeding to develop crop varieties that are more resilient to climate change impacts is one of several possible adaptation options for agriculture. This paper neither advocates nor discourages the use of biotechnology, but focuses on providing estimates of the level and trends of innovation in this field.

This paper provides the first empirical quantification of innovation in adaptation-related crop biotechnology. It analyses patent applications relevant to three forms of abiotic stress associated with climate change: drought, soil salinity and temperature extremes. Patent data provides an indication of the evolution of inventive activity, the countries where innovation takes place, where patent applications are submitted, how technology is transferred between countries, and the institutions and organisations involved in patenting.

Patenting of adaptation-related biotechnology has accelerated over the last quarter century – annual patent applications in adaptation-related biotechnology have increased from fewer than 10 in 1995 to almost 200 by 2007. Patent data indicates that OECD member countries and emerging economies dominate innovation in adaptation-related biotechnology – more than 80% of patent applications were invented in OECD member countries. The United States, Europe and Japan are the most active inventors for adaptation-related biotechnology patents, which is consistent with general findings on biotechnology patenting activity. However, patent counts could underestimate innovative activity in countries where patents are less frequently used to protect innovations, such as China.

The analysis of cross-border patenting finds that patents are primarily submitted for registration in industrial countries. The United States is the most active in registering adaptation-related biotechnology patents in foreign countries, while Australia receives the most registrations from abroad. OECD member countries account for 85% of patents registered in foreign countries, and also receive 70% of all registrations which originate from foreign countries. The analysis finds only limited patent flows to developing countries, South America and Asia.

An examination of applicants in patent submissions indicates that the private sector plays an important role in adaptation-related biotechnology innovation – four of the five most active patenting organisations are from the private sector and together account for 23% of all patent applications. The analysis also indicates that in some countries, such as Japan, China and Korea, the public sector plays a larger role in patenting.

JEL Classification: Q54, Q16, O39

Keywords: Climate change, Adaptation, Innovation, Biotechnology, Agriculture, Patents

RÉSUMÉ

L'innovation dans les technologies liées à l'atténuation et à l'adaptation sera capitale dans la lutte contre le changement climatique. Elle peut permettre de réduire le coût de l'action des pouvoirs publics et offrir de nouvelles opportunités au secteur privé. Cependant, la plupart des débats sur l'innovation portent sur l'atténuation, au détriment de l'adaptation. Le présent document se fonde, pour une étude de cas sur l'activité d'innovation, sur les biotechnologies agronomiques. Le secteur agricole, déjà sollicité pour répondre à la demande d'une population mondiale en augmentation, est en effet considéré comme particulièrement vulnérable face au changement climatique. Innover pour améliorer les espèces végétales et développer des variétés plus résistantes aux incidences du changement climatique est l'une des nombreuses possibilités d'adaptation qui s'offrent à l'agriculture. Le présent document n'a pas vocation à prôner ou décourager le recours aux biotechnologies, mais fournit des estimations sur le degré d'innovation dans ce domaine et sur les tendances qui se dégagent.

Le présent rapport propose la première quantification empirique de l'innovation dans les biotechnologies agronomiques adaptatives. Il analyse les demandes de brevet concernant trois formes de stress abiotique liées au changement climatique : sécheresse, salinité du sol et extrêmes de température. Les données sur les brevets sont un indicateur de l'évolution de l'activité créative. Elles renseignent sur les pays où sont déposées les demandes de brevet et d'où provient l'innovation, sur les modalités des transferts de technologie entre pays et sur les institutions et les organisations impliquées dans les dépôts de brevet.

Le brevetage de biotechnologies adaptives s'est accéléré ces 25 dernières années – les demandes de brevet annuelles portant sur des biotechnologies adaptives sont passées de moins de 10 en 1995 à près de 200 en 2007. Les informations sur les brevets mettent en avant la domination des pays de l'OCDE et des économies émergentes dans le domaine des biotechnologies adaptives – plus de 80 % des demandes de brevet concernent des inventions de pays membres de l'OCDE. Pour les biotechnologies adaptives, les États-Unis, l'Europe et le Japon sont les inventeurs les plus créatifs, ce qui corrobore les résultats globaux sur l'activité de brevetage dans le domaine des biotechnologies. Le comptage des brevets pourrait néanmoins ne pas refléter l'activité créative de pays, comme la Chine, dans lesquels le recours au brevet pour protéger une innovation est moins fréquent.

L'analyse transfrontière du brevetage révèle que les demandes de brevets sont essentiellement déposées dans les pays industriels. Le pays enregistrant le plus de brevets dans les biotechnologies adaptives à l'étranger est les États-Unis, et c'est l'Australie qui reçoit le plus de demandes de brevet étrangères. Les pays membres de l'OCDE représentent 85 % des brevets enregistrés dans des pays étrangers et ils accueillent 70 % des enregistrements de brevets étrangers. L'étude fait apparaître une activité de brevetage limitée à destination des pays en développement, de l'Amérique du Sud et de l'Asie.

L'analyse des candidats à un brevet d'invention montre que le secteur privé joue un rôle important dans l'innovation concernant les biotechnologies adaptives – quatre des cinq organisations qui déposent le plus de brevets appartiennent au secteur privé et regroupent 23 % de l'ensemble des demandes de brevets. Cependant dans certains pays, notamment le Japon, la Chine et la Corée, le secteur public joue un plus grand rôle dans ce domaine, ainsi que le montre l'analyse.

Classification JEL: Q54, Q16, O39

Mots-clés: changement climatique, adaptation, innovation, biotechnologie, agriculture, brevets

FOREWORD

This report on "Adaptation and Innovation: An Analysis of Crop Biotechnology Patent Data" has been overseen by the Working Party on Climate, Investment and Development (WPCID).

This report has been authored by Shardul Agrawala, Cécile Bordier, Victoria Schreitter and Valerie Karplus. In addition to WPCID delegates, the authors would like to thank Anthony Arundel, Nils-Axel Braathen, Bertrand Dagallier, Ivan Haščič, Nick Johnstone, Peter Kearns, Nicholas Kingsmill, Nicolina Lamhauge, Elisa Lanzi, Helen Mountford, Michael Mullan, Carl Pray, Marie-Christine Tremblay and Fleur Watson for their valuable input and feedback.

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Further enquiries on ongoing work on Adaptation to Climate Change should be directed to Michael Mullan, OECD Environment Directorate (Email: Michael.Mullan@oecd.org; Tel: +33 1 45 24 13 17)

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LIST OF ACRONYMS

EPO	European Patent Office
EU	European Union
EUR	Euro
IPC	International Patent Classification
IPR	Intellectual Property Rights
OECD	Organisation for Economic Co-operation and Development
PatStat	EPO/OECD Patent Statistical Database
PVC	Plant Variety Certificates
UPOV	International Union for the Protection of New Varieties of Plants
WIPO	World Intellectual Property Organization

1. INTRODUCTION

Effective climate policy requires both mitigation and adaptation. Increasing innovation in technologies that promote mitigation and adaptation is critical to face climate change. Such innovation can decrease the costs of policy measures and help to more effectively respond to the complexities of climate change. A wide range of literature has examined the role of innovation in climate policy (for a review see *e.g.* Popp, 2010; Carraro *et al.*, 2010). However, most analytical discussions have focused on mitigation, while little attention has been paid to innovation for adaptation technologies. There are significant challenges associated with the assessment of innovation for adaptation. For example, it remains difficult to define what falls within the purview of adaptation. At the same time, unlike mitigation, adaptation decisions are typically not only implemented by central governments, but also at individual levels or by the private sector. This makes it more challenging to quantify innovation for adaptation.

Against this background, the purpose of this paper is to present a case study on innovation[1] in the area of adaptation technologies. More specifically, this case study uses the count of patent applications as an indicator for innovation in adaptation-related biotechnology; an indicator that is also frequently drawn upon by literature on innovation in mitigation technologies (*e.g.* Dechezleprêtre *et al.*, 2011). In this context, this report neither advocates nor discourages the use of biotechnology, but focuses on providing estimates of the level and trends of innovation in this field. This report provides the first empirical quantification of innovation in biotechnology to develop crops that are more resilient to three forms of abiotic stress associated with climate change: drought, soil salinity and temperature extremes.

Innovation in plant breeding (including biotechnology) that aims to develop crop varieties that are more resilient to climate change impacts is part of a larger basket of possible adaptation options in agriculture. Agriculture is considered one of the most vulnerable sectors to climate change and faces high pressure to meet the demands of a rising world population, using a finite resource base (see Rosegrant *et al.*, 2008). In any specific context, there could be several successful strategies for adapting agriculture to climate change. Possible strategies include the use of weather and climate information systems, diversification, adoption of new farming techniques and the use of financial risk management instruments (such as crop insurance) (Wreford, Moran and Adger, 2010). An exclusive focus on biotechnology is clearly not enough to face all changes in agriculture. Nonetheless, ongoing and increasing innovation to develop crops with higher resilience to climate stress indicates that biotechnology is being considered as one option in a multi-faceted adaptation approach to agriculture.

Patents are a useful indicator of innovation in agricultural biotechnology as they illustrate the evolution of inventive activity in adaptation-related biotechnology over time, the countries where innovation takes place, where patent applications are submitted and the institutions involved. Trends in cross-border patenting can be used to analyse international technology transfer of adaptation-related biotechnology. Cross-border patenting from developed to developing countries indicates how technology

[1] In this paper, innovation refers to all innovation activities, *i.e.* "all scientific, technological, organisational, financial and commercial steps which actually lead, or are intended to lead, to the implementation of innovations. Some of these activities may be innovative in their own right, while others are not novel but are necessary to implementation" (OECD, 2005).

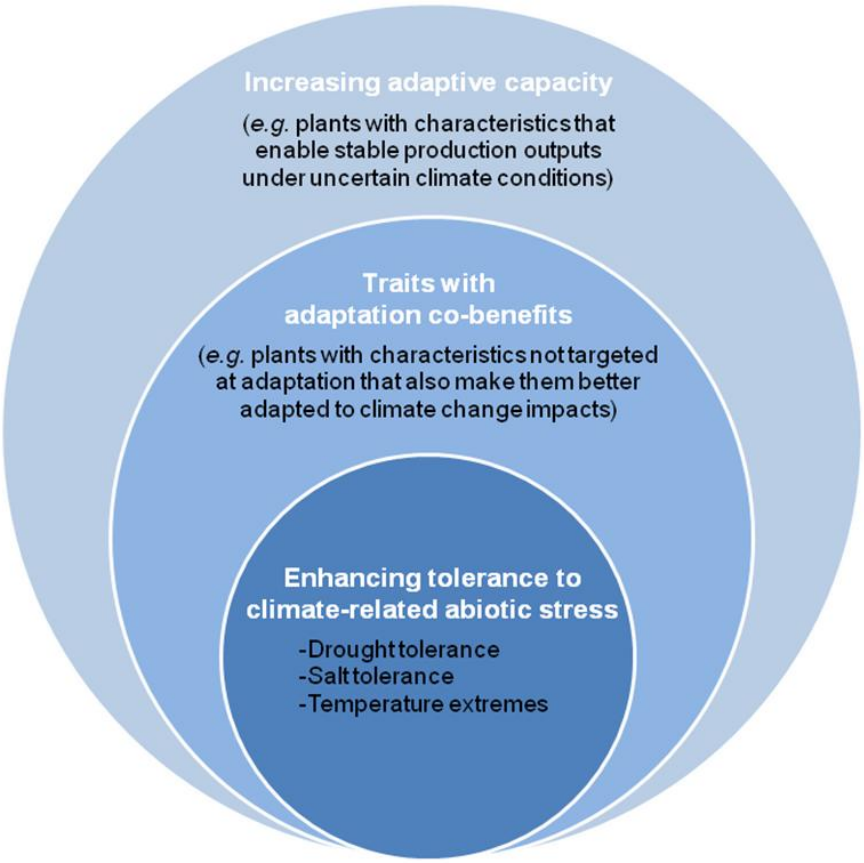
diffuses to countries that are particularly vulnerable to climate change. Finally, patents can also indicate potential market areas for crops that show higher resilience to the impacts of climate change.

1.1 Definition of and complexities involved in adaptation-related biotechnology

There are several linkages between biotechnology and adaptation (see Figure 1). A broad definition of adaptation-related biotechnology could, hypothetically, include traits with the potential to increase farmers' incomes. The argument being that increased incomes would (indirectly) lead to adaptation through improvements in farmers' adaptive capacity.

A narrower definition could include the introduction of traits in plants that have co-benefits, which make them better adapted to climate change. For example, trees that are modified to resist root worms could have stronger roots. These stronger roots could potentially have the co-benefit of also being more resistant to strong winds that would destroy a similar tree with weaker roots. A second example of biotechnology advances which could potentially express an adaptation co-benefit is the development of transgenic trees. Although such trees are still at research level in most countries,[2] they might offer features supporting adaptation to climate change in the future, such as stabilising coastal zones or reducing vulnerability to extreme weather events. In addition, disease resistance could play a role when climate change affects the spread of plant pests and diseases, and increased ability to use nutrients could also help adapt crops to climate change.

Figure 1. Linkages between biotechnology and adaptation to climate change



[2] One exception is the plantation of transgenic poplar trees in China since the late 1980s.

The focus of this report is, however, on a more tightly-focussed definition of adaptation-related biotechnology, namely on the development of traits which directly aim at improving resilience to the impacts of climate change. These traits can be summarised by the term "abiotic stress", which can be categorised into physical stress (salt), water stress (drought and water logging), temperature stress (heat and cold), metal toxicities (aluminium, iron, cadmium, lead, nickel, chromium, copper, zinc, *etc.*), non-metal toxicities (boron, arsenic), oxidative stress (production of free radicals) and atmospheric stress (air pollution, radiation, climate change) (Roy and Basu, 2009). This report focuses on innovation for three types of stress that plants are expected to encounter under climate change: drought, saline soils and temperature extremes.

This narrow definition has limitations. Several other techniques of plant breeding could also help to develop plants with higher resilience to climate change. In addition, exclusive focus on advances in biotechnology with regard to three types of abiotic stress will not be enough to adapt agriculture to climate change. At the same time, not all three forms of abiotic stress that are considered in this analysis might necessarily be related to climate change in all contexts.[3] One further limitation could stem from the fact that the decision to use a certain type of breeding methods may not depend on the traits to be improved. By contrast, application of transgenic biotechnology (or genetic engineering) is trait-specific. Thus, analysing specific traits might bias the results of this study towards transgenic approaches. However, even if the total level of innovation could be underestimated in this study, analysing innovation for three common forms of abiotic stress allows for an indication of trends related to innovation in adaptation-related biotechnology. Even if not all innovation on adaptation-related biotechnology is driven by adaptation concerns, it can be considered adaptation-related if it helps crops to better adapt to climate change.

Plant breeding programmes test for the occurrence of the three traits that lead to higher resilience to drought, saline soils and temperature extremes. Traits may be simple and involve only few genes (as is the case for resistance to some phytopathogenic fungi and viruses). Attempts to improve the salt and drought tolerance of crops, however, need to deal with the genetic and physiological complexity of salt and drought tolerance traits (see Box 1). The success of breeding programmes can be measured by yield improvements during periods of drought, increased soil salinity or temperature extremes. In this effort, breeding techniques and methods act as complements and the combination of several techniques is critical for successful plant breeding.

[3] For example, in Australia salinity in agricultural systems might not be a climate-induced phenomenon. Salinity problems in Australian agriculture primarily stem from the clearing of deep rooted perennial plants, as well as the cultivation of shallow-rooted annual crops. This causes water tables to rise and leads to dissolution of salt deposits that were previously above the water table, which can bring saline water to the surface. Dryland salinity from shallow watertables could threaten agricultural production in 4.6 million hectares of Australian land, with an expected doubling by 2050 (Natural Heritage Trust, 2001). Another source of salinity in Australia is related to the over exploitation of ground water reserves for irrigation, where salinity increases with water extraction at increasing depth. However, it is forecast that climate change may exacerbate salinity problems in some Australian regions and for certain crops (Stokes and Howden, 2008).

Box 1. Complex mechanisms involved in salt and drought tolerance

Salt tolerance

There is evidence that salt tolerance is determined by a number of sub-traits, any of which might be determined by multiple genes. For example, soil salinity can increase sterility in rice and lead to fewer produced grains; the sub-trait sterility is determined by at least three genes.

Moreover, it remains difficult to test salt tolerance in crops. Under saline conditions, yields are difficult to measure due to the variability of salinity within fields and interactions with other environmental factors (e.g. gaseous pollutants, soil fertility, drainage to temperature, transpirational water loss). The assessment of tolerance is also difficult, because rice is more sensitive to salt during the grain yield period, as compared to the vegetative growth period.

Drought tolerance

Similar to salt tolerance, there does not exist one single drought-tolerance gene. Plants have developed two main strategies to increase drought tolerance: drought avoidance and dehydration tolerance. The first refers to a plant's ability to remain hydrated in situations of scarce water, *e.g.* by growing long roots or restricting leaf openings. Dehydration tolerance refers to plants which can withstand water scarcity, but 'resurrect' when moist soil conditions return. However, multiple factors describe how resilient a crop is to drought:

- How efficiently a plant draws water from the soil;
- How well cells retain water;
- How much water is released through leaf openings, called stomata;
- The timing of flowering relative to the seasonal onset of drought.

This complexity makes it very difficult for researchers and breeders to enhance the drought-resilience of plants. As stated by Jian-Kang Zhu, a molecular geneticist at the University of California, Riverside, "drought stress is as complicated and difficult to plant biology as cancer is to mammalian biology".

Source : Flowers (2004); Pennisi (2008); Cominelli and Tonelli (2010)

In the product pipeline, the stage of breeding programmes and laboratory research is followed by the protection of some inventions, *e.g.* by use of patents. In crop biotechnology, the discovery of new inventions is typically followed by several phases of testing in a greenhouse setting and in the field. After all regulatory approval processes have successfully been completed, a crop can be commercialised.

Although to date no crop that confers abiotic stress tolerance in case of drought, temperature extremes or saline soils has been commercialised, one variety of drought-tolerant maize is expected to be commercialised after 2012. Following various stages of testing, Monsanto has submitted an application for transgenic maize aimed at reducing yield loss under water-limited conditions in several countries.[4] The MON87460 variety is a result of the collaboration between the companies BASF and Monsanto which was announced in March 2007. MON87460 is said to express reduced grain yield loss under water-limited conditions compared to conventional maize. The first commercialisation of drought-tolerant maize can be expected after 2012, based on the length of the approval procedure. No other applications related to abiotic stress have been submitted for commercialisation.

1.2 Patents as an indicator of innovation

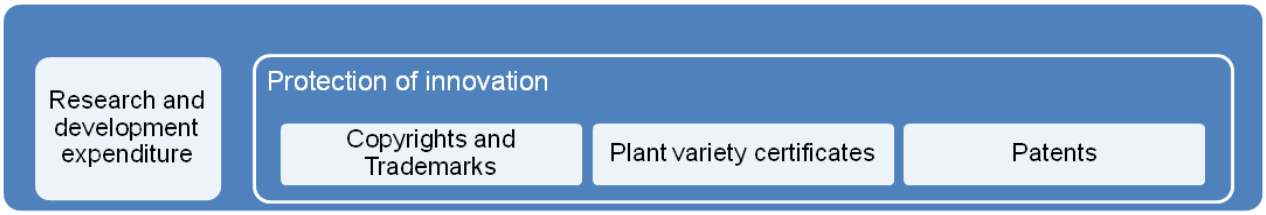
In this analysis, a variety of variables could serve as indicators of innovation in biotechnology (see OECD, 2010). Different means of protecting an invention, such as Intellectual Property Rights (IPR), can as such be interpreted as indicators of innovation. IPR relevant for biotechnology are patents, plant variety

[4] United States (USDA, 2010), Canada (CFIA, 2009), the EU, Australia and New Zealand.

certificates and, to a smaller degree, copyright and trademarks. However, not all inventions are protected, and variables such as research and development expenditure may also be useful to quantify the state of inventive activity. The propensity to protect an invention differs by sector and product. If a technology can be reproduced easily, companies may face a greater incentive to protect it. Protection can also be a strategic decision, which could prevent other institutions from research in a certain area.

At the same time, industrial secrecy may be a strategic decision for institutions to avoid divulging information on internal research agendas and processes (Griliches, 1990). Arundel (2001) concludes that the majority of firms in the United States, Europe and Australia value secrecy higher than patents. However, the probability that a firm values secrecy higher decreases with an increase in firm size for product innovations, thus making large firms more likely to use patents (Arundel, 2001). Data on innovation which is protected through secrecy would only become available once the invention has been commercialised and comparable quantifiable data is not available. Figure 2 summarises key variables that could act as indicators of innovation in this report.

Figure 2. Key indicators of innovation



The analysis of research and development expenditure of institutions aimed at making crops more resilient to climate change could provide valuable information on the state of innovation. However, access to such microdata is difficult and the information is often aggregated, which would not allow for a selection of adaptation-related biotechnology only. In addition, research and development expenditure could not be used to describe where the technology is intended to be applied.

Copyrights could, for example, protect research notes and reports, or even computer programmes and databases and exclude others from using it without authorisation. However, in practice copyrights play a small role in protecting biotechnology inventions. Similarly, although trademarks could theoretically be used to protect innovations, they are rarely used in biotechnology (Groombridge, 1992).

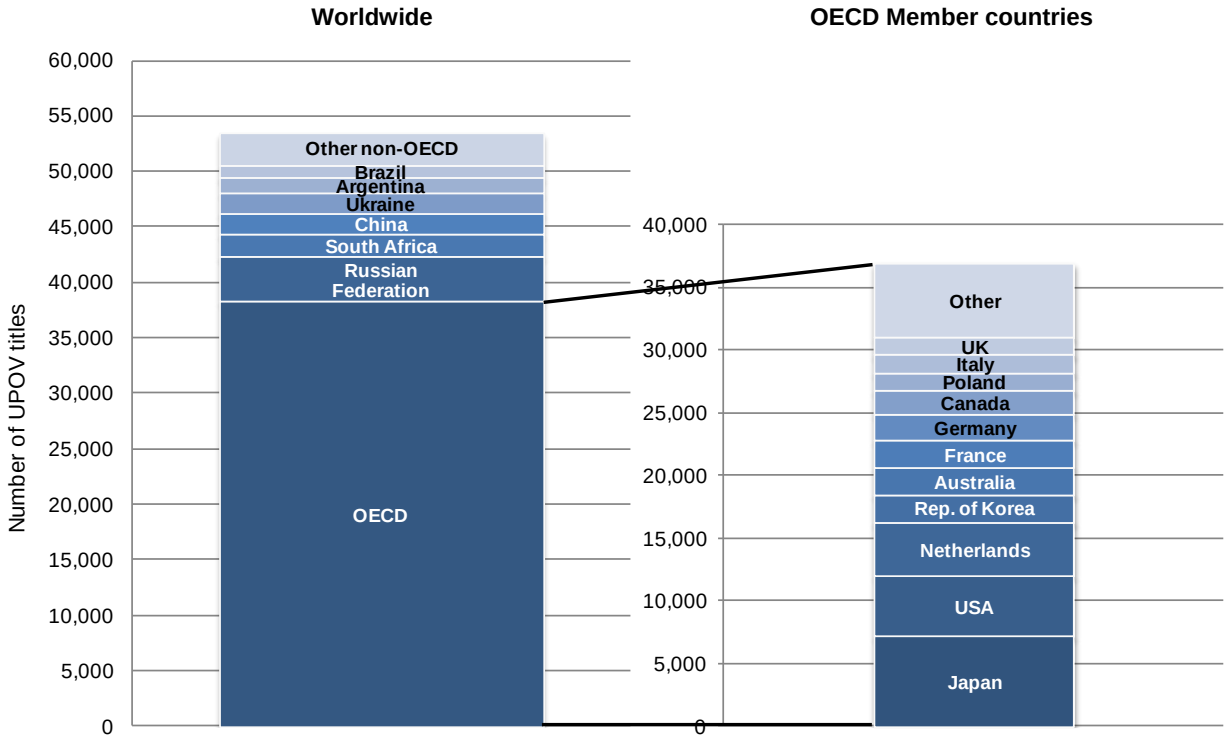
Plant Variety Certificates (PVC) are a form of IPR protection that is specifically adapted for the process of plant breeding, and implemented by the International Union of New Varieties of Plants (UPOV, French acronym). Adopted in 1961 as a result of the international conferences held in Paris in 1957, the objective of the intergovernmental organisation UPOV is the protection of new plant varieties. A number of countries have become member parties to UPOV and operate within its framework.[5]

[5] As of August 2011, the following 70 countries and organisations were UPOV members: Albania, Argentina, Australia, Austria, Azerbaijan, Belarus, Belgium, Bolivia, Brazil, Bulgaria, Canada, Chile, the People's Republic of China, Colombia, Costa Rica, Croatia, Czech Republic, Denmark, Dominican Republic, Ecuador, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Georgia, Germany, Hungary, Iceland, Ireland, Israel, Italy, Japan, Jordan, Kenya, Kyrgyzstan, Latvia, Lithuania, Mexico, Moldova, Morocco, Netherlands, New Zealand, Nicaragua, Norway, Oman, Panama, Paraguay, Peru, Poland, Portugal, Republic of Korea, Romania, Russian Federation, Singapore, Slovakia, Slovenia, South Africa, Spain, Sweden, Switzerland, Trinidad and Tobago, Tunisia, Turkey, Ukraine, United Kingdom, United States, Uruguay, Uzbekistan, Viet Nam and the European Union.

PVC provide exclusive and time-limited rights of exploitation for a plant variety that is distinct, uniform, stable and satisfies a novelty requirement (Groombridge, 1992; Blakeney *et al.*, 1999). Certificates also allow others to use protected varieties for research, which is referred to as "breeder's exemption". This exemption allows free access to a protected variety for the purpose of breeding other varieties. This way, the UPOV system aims to increase the efficiency of the programmes designed to modify plants. The formalities required for the registration of PVC are relatively simple and the cost is reasonable for most research budgets. For example, the Community Plant Varieties Office charges an annual fee which will not exceed EUR 1 000 for a variety that is to be disseminated in several member countries of the European Union (WIPO-UPOV, 2002).

To scope the importance of PVC worldwide, Figure 3 shows the total number of UPOV titles in force at the end of 2008. OECD member countries[6] account for about two-thirds of worldwide UPOV titles. Among OECD countries, Japan, the United States and the Netherlands make most use of the UPOV system in absolute terms. Since UPOV information does not distinguish the protection of plant varieties which express abiotic stress tolerance from other plant varieties, it remains difficult to identify the relative importance of PVC for registering crops that confer abiotic stress tolerance.

Figure 3. Importance of plant variety certificates: UPOV titles in force at the end of 2008



Notes: "Other" aggregates countries with less than 1 000 UPOV titles each.

Source: UPOV (2009)

In biotechnology research and development, the free utilisation of protected varieties by other breeders might prevent inventors from solely using this type of protection. Also, the UPOV system only concerns novel varieties of plants and not the techniques leading towards their development, which is often the desired subject of protection in biotechnology. Plant breeding techniques under the UPOV systems range from basic selection to more technically advanced procedures. Thus, while it is important to take into

[6] OECD refers to the 34 OECD member countries as of August 2011.

account PVC as a form of protection, patents are likely to be a better indicator of investments and processes in biotechnology.

Patents have evolved as the main indicator for measuring general inventive activity. In the specific case of plant breeding patenting is a good indicator of innovation in biotechnology, but may not account for all inventive activity in this area due to the availability of PVC as an alternative mechanism for protecting innovation. Before inventive activity becomes an innovation, *i.e.* the invention is used in economic processes, downstream, entrepreneurial efforts are necessary to develop, manufacture and market it (OECD, 2009b). As patents are used to assess adaptation-related biotechnology in this report, their application as an indicator of innovation is described in more detail in the next section. Table 1 presents a comparison of PVC and patents.

Table 1. Comparison of plant variety certificates and patents

Provisions	Plant Variety Certificates (UPOV 1991)	Patent Law
Protection coverage	Plant varieties of all genera and species	Inventions
Requirements	Novelty, distinctness, uniformity, stability	Novelty, non-obviousness and industrial applicability
Protection term	Minimum 20 years	20 years (for 3 main patent offices EPO, JPO and USPTO)
Protection scope	Producing or reproducing (multiplication), conditioning for the purpose of propagation, offering for sale, selling or other marketing, exporting, importing and stocking for any of the purposes mentioned above	Making, using, offering for sale or selling an invention
Breeder's exemption (research only)	Yes	Variable
Breeder's exemption (commercial use)	Up to national laws	No
Farmer's privilege	Permitted (through national legislation). Additional exception to breeder's rights for acts done privately and for non-commercial purposes, such as subsistence farming.	Limited provision within patent acts (*e.g.* via compulsory licensing, but increasingly restricted by international agreement).

Note: EPO – European Patent Office, JPO – Japan Patent Office, UPSTO – United States Patent and Trademark Office

Source: Adapted from van Wijk et al. (1993); Blakeney et al. (1999); UPOV (2010); Phillips (2007)

Alongside other science and technology indicators, patents provide a detailed source of information on inventive activity. Patents allow their owners to exclude competitors from making, using, offering for sale or selling an invention for a limited time period. Each patent application has to prove its novelty, non-obviousness and industrial applicability (also referred to as "utility") through a detailed description of the invention with supporting references (OECD, 2009b). Novelty means that the invention was not available to the public before the patent filing, and was not described in a publication either. Non-obviousness implies substantial improvements as compared to existing technology. Industrial applicability requires a functional purpose of the invention, *e.g.* useful characteristics of genes outside their natural environments. A patent can either protect techniques, such as transgenic processes, or new products (a transgenic plant variety), but not existing genetic material itself.

Filing a patent is costly for the applicant, and includes administrative fees (*e.g.* filing fees, search, examination, country designation, grant/publication fees and sometimes validation fees), process costs

associated with drafting of the application and monitoring of the patent procedure, translation costs in case of applications abroad, and maintenance costs to keep the patent valid. Costs, and also the duration of a patenting process, vary across patent offices. For example, a survey of patent applicants in 2004 found that the cost of direct filing to the EPO in 2003 was estimated at EUR 30 530; and average pendency time between filing and a grant at the EPO was 40.6 months in 2005 (OECD, 2009b).

Patents are imperfect indicators of inventive activity. Not all successful research and innovative efforts are protected through patents. Arundel and Kabla (1998) found that patent propensity rates among European firms increase with firm size. Patents are time-limited and after the expiration of the patent protection, usually 20 years, the patented technology is no longer restricted and becomes available to the general public. Once a plant comes off patent, the costs of renewing authorisations may be too high to be maintained. Thus institutions may not seek patent protection at all. At the same time, applying for the patenting of an invention does not necessarily imply its adoption and commercialisation. This could bias an analysis of counts of patent applications, assuming that inventors patent widely without intention to commercialise their inventions. However, since the patent application process is costly, both in terms of administrative and financial effort, firms will only patent inventions they expect to be profitable or for strategic reasons.

One advantage in using patents as an indicator of innovation, as compared to other introduced indicators, is that they can be disaggregated to specific technological areas and provide detailed information on the nature of the invention and the applicant. They show not only where an invention is made, but can also indicate where new technologies are protected. The detail in publicised patent descriptions is useful to analyse patent counts for inventions in a specific industry or sector. Unlike research and development expenditures, patents identify owners and inventors of patents and can thus illustrate research processes and mobility (OECD, 2009b). When a patent is granted, it generally refers to earlier patents which relate to the invention. This should narrow the reach of a patent and provides an indicator of previous knowledge that was used to develop an invention (Popp, 2005).

Research has demonstrated a positive relationship between patent counts and other indicators of inventive activity. For example, Griliches (1990) and de Rassenfosse and van Pottelsberghe (2008) found a strong positive correlation between patent counts and research and development performance at the country level. Therefore, patents not only serve as a measure of innovative output, but also indicate the level of innovative activity itself (Popp, 2005).

Moreover, patents provide wide geographical coverage. Patent data are available from nearly all countries in the world. Since patents generally grant protection only in the country which has granted the patent, economists have used sets of patents related to the same invention that were filed in different countries to track diffusion of knowledge (Popp, 2005). Furthermore, patent data are usually available at a low cost. This is a result of the fact that the collection of patent statistics does not impose supplementary cost on the reporting institutions, as data has to be collected by patent offices to process applications. In addition, no confidentiality rules restrict access to patent information (OECD, 2009b).

The remainder of this paper is organised as follows. Section 2 outlines the methodology for this patent analysis. In Section 3, the number of patent applications in adaptation-related biotechnology is analysed to track innovation activity. Countries that are sources of innovation in adaptation-related biotechnology are identified. Inventor countries are then compared with countries of registration, where these developments are protected. Furthermore, the section describes the ownership of patent applications and crops that are being protected. Section 4 concludes.

2. METHODOLOGY

This section describes the methodology used to support the empirical analysis of ongoing research and development in adaptation-related biotechnology to adapt crops to three forms of abiotic stress: drought, saline soils and temperature extremes. As Section 1 concluded, patents are a useful indicator of innovation in agricultural biotechnology as they can help to understand where novelties are invented, where inventions are protected and how the technology diffuses to other countries. Patents can also indicate potential market areas for crops that show higher resilience to the effects of climate change.

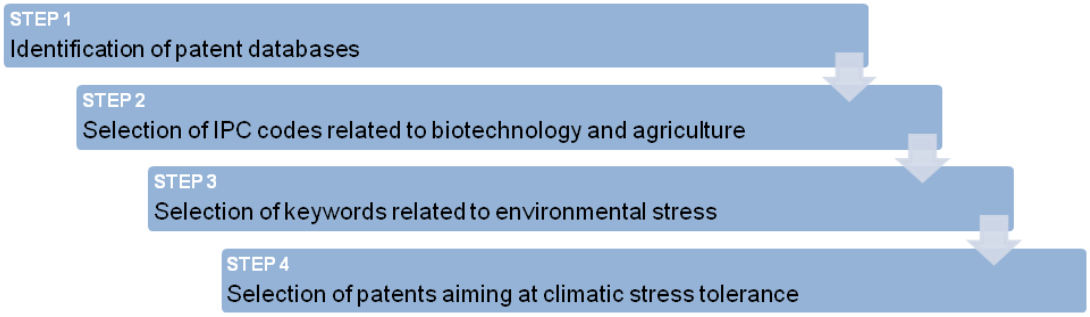
However, patent data are complex. This is due to, for example, the diversity of patent offices and procedures (national or regional), different routes to file for patent protection (national or international) and different status and dates in a patent document (grants, international phase, *etc.*). Differences in procedures can also affect the time and cost associated with filing an application. The data complexity requires the choice of an adequate methodology and data filters to obtain useful indicators.

Not all adaptation-related biotechnology inventions will be captured by the following analysis of patent counts. Inventions in the public sector may not be patented at all, given different incentives for innovation. In addition, some inventions might have more market impact than others, which cannot be considered in an analysis of an unweighted count of patents (Johnstone *et al.*, 2010). Also, in some regions of the world, including Europe, South America, Australia and Africa, plant varieties are not protected using patents, but only processes leading to that variety. For example, in Europe, a specific process technology for developing a plant variety can be patented, while in the United States actual plant variety patents exist. In addition, analysing patent applications does not consider the possibility of patents being withdrawn in the application process. For example, when examining patent applications filed with the EPO from 1985 to 2004, Lazaridis and van Pottelsberghe de la Potterie (2007) find that 35% of filed patent applications do not reach the final stage due to being withdrawn by the applicants. Schettino and Sterlacchini (2009) identify a variety of different motives for patent withdrawals based on a sample of Italian patents. As long as the rate of withdrawal does not vary significantly across country, time and sector, the data in this analysis can nonetheless indicate trends in adaptation-related biotechnology.

Patents are widely used to secure companies' investments in agricultural biotechnology (Groombridge, 1992). Their application is also confirmed by the United States Department of Agriculture, which states that the use of patents and other intellectual property rights has accelerated with the pace of scientific discovery in agricultural biotechnology over the past decades (USDA, 2004). Patents can thus be considered the best available indicator to examine inventive activity in adaptation-related biotechnology.

The methodological steps in scoping adaptation-related biotechnology patents are outlined in Figure 4. After an identification of patent databases, the selection of relevant International Patent Classification (IPC) codes is followed by a selection of keywords, which can be linked to these IPC codes. The selected adaptation-related biotechnology patents are then analysed to gain an insight into inventive activity. The methodology is most closely related to a previous study by OECD (2011).

Figure 4. Methodology to select adaptation-related patents



Two errors could occur with this methodology:

- Patents that are not related to inventions in adaptation-related biotechnology could be represented in the analysed dataset (false positive);
- Patents relevant for this research might not appear in the analysed dataset (false negative).

Whereas the first error is unlikely to occur due to the specific keyword search for each IPC class, this same argument could lead to the rejection of some accurate patents with very technical titles. The latter error possibility is accepted as the dataset aims to provide an indicative picture of the innovative activity in biotechnology to adapt crops to climate change. Due to the second error, the level of innovation might be underestimated, but changes or trends are not expected to be significantly biased (OECD, 2011).

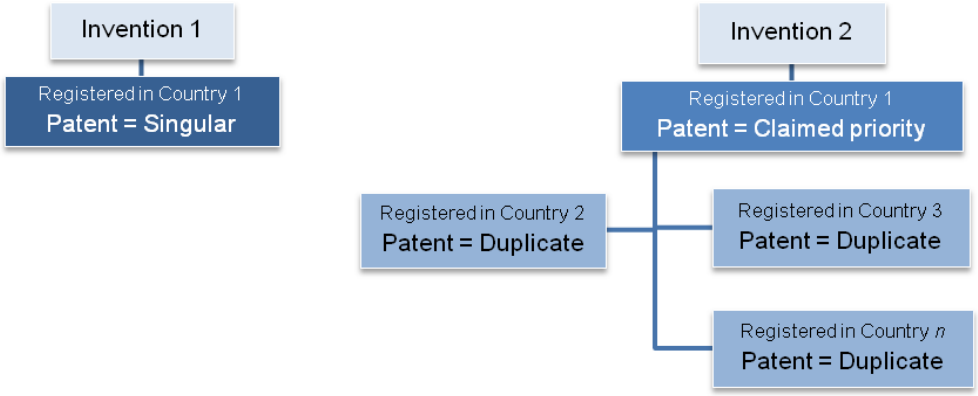
2.1 Step 1: Identification of patent databases

This patent analysis is based on the EPO/OECD Patent Statistical Database (PatStat), a world-wide patent database which was developed by the European Patent Office (EPO) and the OECD's Directorate for Science, Technology and Industry. It is specifically designed for use in the statistical analysis of patent data. The database gathers patents registered in more than 80 national and international patent authorities in a standardised form, which allows for a global cross-country analysis of innovative activity and trends. Updated bi-annually, PatStat contains over 70 million patent documents.[7] In this analysis, all examined patents are extracted from PatStat.

Three types of patent documents can be distinguished based on their status within a patent family (see Figure 5). *Singulars* refer to patent applications filed in only one country. *Claimed priorities* refer to patent applications that have been filed in at least two different countries. *Duplicates* are the copies of patent applications that were already submitted in another country (for further details see OECD, 2011).

[7] The following countries are covered in PatStat: United Arab Emirates, Argentina, Austria, Australia, Bosnia and Herzegovina, Belgium, Bulgaria, Brazil, Switzerland, Chile, China, Colombia, Czechoslovakia*, Cuba, Czech Republic, German Democratic Republic*, Germany, Denmark, Egypt, Spain, Finland, France, United Kingdom, Guadeloupe, Greece, The Hong Kong Special Administrative Region of the People's Republic of China, Croatia, Hungary, Indonesia, Ireland, Israel, India, Iran (Islamic Republic of), Iceland, Italy, Jordan, Japan, Republic of Korea, Kazakhstan, Lebanon, Liechtenstein, Sri Lanka, Luxembourg, Latvia, Monaco, Republic of Moldova, Mali, Mexico, Malaysia, New Caledonia, Nicaragua, Netherlands, Norway, New Zealand, Philippines, Poland, Portugal, Romania, Russian Federation, Saudi Arabia, Seychelles, Sweden, Singapore, Slovenia, Slovakia, Suriname, Soviet Union*, El Salvador, Tokelau, Turkey, Taiwan (Province of China), Ukraine, United States of America, Uruguay, Venezuela (Bolivarian Republic of), Virgin Islands (British), Yugoslavia/Serbia and Montenegro*, South Africa. States marked with a star no longer exist.

Figure 5. Three types of patent documents



A patent protects a technology only in the countries that grant it. Inventors seeking protection in several countries must file separate applications there. One exception is the European Patent Office which can give protection in several of the 38 member countries of the European Patent Organisation.[8] Nonetheless, the applicant must specify in which countries a patent is requested and may need to 'validate' it. Once granted, a European patent represents a bundle of national patents.

Espacenet (*www.espacenet.com*) was developed by the EPO and member countries of the European Patent Organisation. It provides descriptions of submitted patents, but is not organised as a database. The included patents are classified according to the International Patent Classification (IPC) and the more detailed European classification, categorising the patented technology. Due to its detailed descriptions, Espacenet was used to identify relevant classification codes and keywords, through a screening of patent titles and descriptions. This combination of IPC codes and keywords was then used to select relevant patents from PatStat.

2.2 Step 2: Selection of IPC codes related to biotechnology and agriculture

Patent categorisations assign a standardised code to patents associated with their technical content. This analysis consults two types of patent categorisations: the International Patent Classification (IPC) and the European Patent Classification.

The IPC was developed at the World Intellectual Property Organisation (WIPO). This standardisation in the description of patents helps intellectual property offices identify closely-related patents, to decide on the novelty of patent applications. The IPC consists of over 70 000 classification codes, which enables precise characterisation of each patent. Usually patents are associated with several codes. Box 2 provides further details on the WIPO classification system.

[8] 27 member countries of the European Union, Albania, Croatia, Iceland, Liechtenstein, Monaco, Norway, Former Yugoslav Republic of Macedonia, San Marino, Serbia, Switzerland and Turkey (as of 04 October 2010). In addition, Bosnia and Herzegovina and Montenegro may recognise European patents upon request.

Box 2. Description of International Patent Classification (IPC)

The IPC is based on an international multi-lateral treaty administered by the World Intellectual Property Organization (WIPO). This treaty, called the Strasbourg Agreement Concerning the International Patent Classification, was concluded in 1971 and entered into force in 1975. The IPC divides technology into eight sections with approximately 70,000 subdivisions. The IPC symbols are allotted by the national or regional industrial property office that publishes a patent document.

Sections are the highest level of hierarchy of the Classification. Each section is designated by one of the capital letters A through H. They are named as follows:

A HUMAN NECESSITIES
B PERFORMING OPERATIONS; TRANSPORTING
C CHEMISTRY; METALLURGY
D TEXTILES; PAPER
E FIXED CONSTRUCTIONS
F MECHANICAL ENGINEERING; LIGHTING; HEATING; WEAPONS; BLASTING
G PHYSICS
H ELECTRICITY

Each section is subdivided into classes and subclasses to give a more precise indication of the content of a patent.

Example of a class: A01 AGRICULTURE; FORESTRY; ANIMAL HUSBANDRY; HUNTING; TRAPPING; FISHING
Example of a subclass: A01H NEW PLANTS OR PROCESSES FOR OBTAINING THEM; PLANT REPRODUCTION BY TISSUE CULTURE TECHNIQUES

Finally, groups and subgroups form the last subdivision of a classification.

A Section	01	H	1/00 or 1/02
Class			
Subclass			
Group or Subgroup			

Example of a group: A01H 1/00 Processes for modifying genotypes
Example of a subgroup: A01H 1/02 Methods or apparatus for hybridisation; Artificial pollination

Source: WIPO (2009)

In comparison to the IPC, the European Classification is more detailed. Box 3 gives an example of the type of information available at Espacenet, which provides both IPC and European codes.

After a screening and review of WIPO classification guidance describing IPC codes and consultation of patent abstracts in Espacenet, the following IPC codes are identified as relevant for adaptation:

- **A01H**, related to new plants and processes for obtaining them;
- **C12N 15/82**, related to mutation or genetic engineering for plants cells;
- **C12N 15/29**, related to genes encoding plant proteins;
- **C12N 15/05**, related to the preparation of hybrid cells by fusion of two or more plant cells.

Box 3. Example of a patent as presented on Espacenet

Below is the description of a patent entitled *"Transgenic Plant with increased stress tolerance and yield".* This example shows which information is available on Espacenet. Very similar information can be found in the PatStat database, with the exception that PatStat only lists IPC, but not the European classification.

- The **publication date** is the date of publication of the data in Espacenet. It is not to be confused with the **priority date** which indicates the earliest application date of the invention worldwide.
- **Inventors** are the individuals who invented the product, with country of residence in brackets.
- The **applicant** denotes the institute that registers and owns a patent.
- **Classification** describes the technological fields according to IPC and/or European classification.
- An **abstract** with more details about the protected innovation is also provided.



TRANSGENIC PLANT WITH INCREASED STRESS TOLERANCE AND YIELD

Bibliographic data | Description | Claims | Mosaics | Original document | INPADOC legal status

Publication number: EP2129783 (A1)
Publication date: 2009-12-09
Inventor(s): SHIRLEY AMBER [US]; ALLEN DAMIAN [US]; MCKERSIE BRYAN [US]
Applicant(s): BASF PLANT SCIENCE GMBH [DE]
Classification:
- international: *C12N15/82; A01H5/00;* C12N15/82; A01H5/00
- European: C12N15/82C8; C12N15/82C8B2
Application number: EP20080718097 20080320
Priority number(s): WO2008EP53382 20080320; US20070896505P 20070323

Also published as:
WO2008116829 (A1)
CA2681515 (A1)
AU2008231785 (A1)
AR066193 (A1)

View INPADOC patent family
View list of citing documents
View document in the European Register

Report a data error here

Abstract not available for EP 2129783 (A1)
Abstract of corresponding document: **WO 2008116829 (A1)**

Polynucleotides are disclosed which are capable of enhancing growth, yield under water-limited conditions, and/or increased tolerance to an environmental stress of a plant transformed to contain such polynucleotides. Also provided are methods of using such polynucleotides and transgenic plants and agricultural products, including seeds, containing such polynucleotides as transgenes.

Data supplied from the ***esp@cenet*** database — Worldwide

Source : www.espacenet.com

Although some IPC codes explicitly mention the involvement of genetic engineering (*e.g.* C12N15/82), others (*e.g.* A01H) are less restrictive about whether transgenic biotechnology must be part of the patented procedure. This implies that both transgenic and non-transgenic patented biotechnology is included in this analysis of patent data.

The selection of relevant IPC codes in Step 2 allows for identification of patent applications that are related to biotechnology and agriculture. However, IPC categories are not precise enough to select patents corresponding exclusively to adaptation-related biotechnology. For example, IPC code C12N 15/05 may include other techniques which are not necessarily related to adaptation. In addition, the latter three classes, namely C12N 15/82, C12N 15/29 and C12N15/05, might comprise of applications that could still be far from being used in breeding practice. To mitigate these concerns, it is thus crucial to link the IPC codes with specific keywords to retain only biotechnology patents relevant for this study.

2.3 Step 3: Selection of keywords related to environmental stress

Keywords to be associated with IPC codes need to cover a maximum number of title possibilities. These keywords are identified using the European Classification system on Espacenet. After a review of patent titles and their abstracts on Espacenet, relevant keywords are selected. In addition, one particular European code, C12N15/82C8B2, explicitly referring to mutation or genetic engineering for plant cells for drought, cold and salt resistance, is used to complete the list of keywords. Table 2 provides the full list of keywords identified.

Table 2. List of keywords related to abiotic stress

Keywords		
abiotic stress(es)	osmotic stress	salt + resistance
Drought	plants overexpressing	salt + resistant
Dryness	salinalized soil	salt + stress
enhanced agronomic traits	stress + regulated	temperature + tolerant + plant(s)
environmental + stress	stress + resistance	water deficit
glycine betaine	stress + resistant	water stress
heat + plant	stress + response	stress-related polypeptides
heat + stress	stress + tolerance	stress-related proteins
heat + tolerance	stress + tolerance + plant(s)	stress-responsive gene(s)
nucleotide + saline + conditions	salt + tolerant	

Note: Whereas some keywords clearly indicate a direct relation to abiotic stress resistance of crops, others may not indicate such a connection at first sight. After careful review of abstracts and descriptions in Espacenet, this list of keywords was found most appropriate to cover patents relevant for adaptation. One limitation of using keywords is that it biases the search towards patent applications for which abstracts are available, and within those towards applications that are in English language.

2.4 Step 4: Selection of patents aiming at climatic stress tolerance

Following this step of identification, only patents corresponding to both selected IPC codes (A01H, C12N15/82, C12N15/29 and C12N15/05) and identified keywords (see Table 2) are used to extract patent data from PatStat. One limitation of this approach is that adaptation to climate change might not be an explicit breeding goal. In fact, adaptation is often part of another breeding goal such as yield stability. Thus, a keyword-based search could narrow the analysis to cases that use eye-catching keywords in their titles. In addition, some of the patent applications might be withdrawn by the applicants at a later stage. Although this combination of codes with keywords shows limitations, the extensive review of detailed descriptions in Espacenet make it the most comprehensive available method to extract adaptation-related biotechnology patents.

Patents are sorted by their priority year, *i.e.* the earliest application date of the invention worldwide, which closely corresponds to the registration date of the patent application.[9] The patent data for this analysis were extracted from the September 2009 version of PatStat. Taking into account that the publication of a patent typically takes 18 months, the analysed dataset gathers patents registered until the end of 2007.

[9] Initially, information on patents was published only when the patent was granted. This entailed a long delay in publication and in some cases lead to the duplication of innovations. Starting in the 1960s, most patent offices adopted the "deferred examination process" (OECD, 2008a). This requires an application to be published while it is still pending. Nonetheless, the publication of a patent application typically occurs after 18 months from the earliest filing date (Adams, 2006).

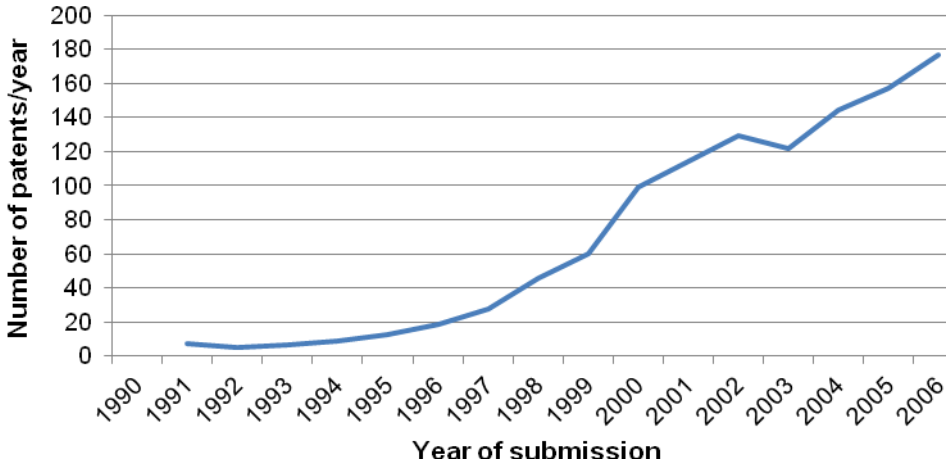
3. ANALYSIS OF PATENT DATA

This section provides results from the analysis of patent data in adaptation-related biotechnology to develop crops that are more resilient to three types of abiotic stress: drought, saline soils and temperature extremes. It looks at the evolution of inventive activity over time, the countries where the invention takes place, where patent applications were submitted and the institutions involved. Finally, it also examines cross-border patenting to analyse international technology transfer.[10]

3.1 Evolution of patents in adaptation-related biotechnology

The number of biotechnology patents related to climate change adaptation in agriculture has surged since the end of the 1990's (see Figure 6). The number of annual submissions increased from fewer than 10 in 1995 to almost 200 patents in 2007. Since 2000, the number of newly submitted patents has surpassed 100 each year.

Figure 6. Adaptation-related biotechnology patent applications submitted each year



Note: Patent counts are based on the priority year, 3-year moving average.

Source: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database (PatStat)

The evolution of the number of patent applications reveals an increase in patents in adaptation-related biotechnology. The boost at the beginning of the 21st century could be explained by general advances in biotechnology: research made significant progress when the first complete plant genome was sequenced in 2000. This allowed determining more genes within a plant species, which enhanced research in functional genomics projects (Jenks *et al.*, 2009). Also, the increasing awareness of impending impacts of climate change and reduced water availability for agriculture have driven research in plant response to drought and

[10] For detailed discussion and justification of using patent data as an indicator of international technology transfer see OECD (2011).

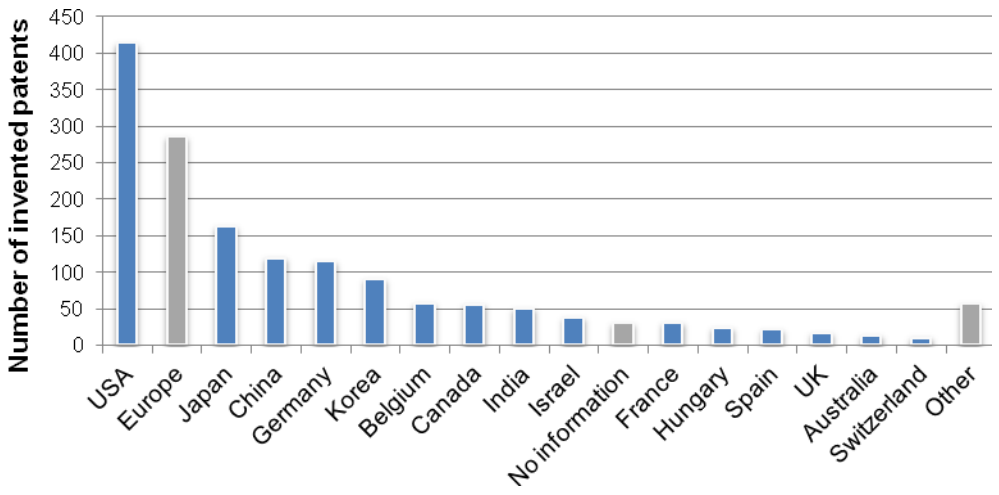
heat (Trethowan *et al.*, 2009). Over time, legal guidelines had to evolve along with the biotechnology sector to accommodate licensing procedure for the innovations (OECD, 2009a).

3.2 Inventor countries

Patent data allow identifying countries that develop biotechnology research. Figure 7 provides details on the regional distribution of inventors from 1990 to 2007. Of all patents identified, more than 80% were invented in OECD member countries. The United States leads the sector with more than 400 patents registered during the timeframe of the dataset, representing slightly more than one third of all patents. The United States is followed by Japan and China, where the public research sector is leading innovation. European countries as an entity also play an important role in adaptation-related biotechnology. European patenting activity is lead by Germany and Belgium. This result in one specific area of biotechnology is consistent with general results on patenting activity. An OECD compendium of patent statistics finds the highest patenting activity in the United States, Japan and the European Union (OECD, 2008b).

It is important to bear in mind that patents are registered by the country of residence of the inventors, which can differ from the headquarters of the inventing institution. For example, although a company might have headquarters in one country, its research units might be based in other countries.

Figure 7. Adaptation-related biotechnology patent applications by inventor country (1990-2007)



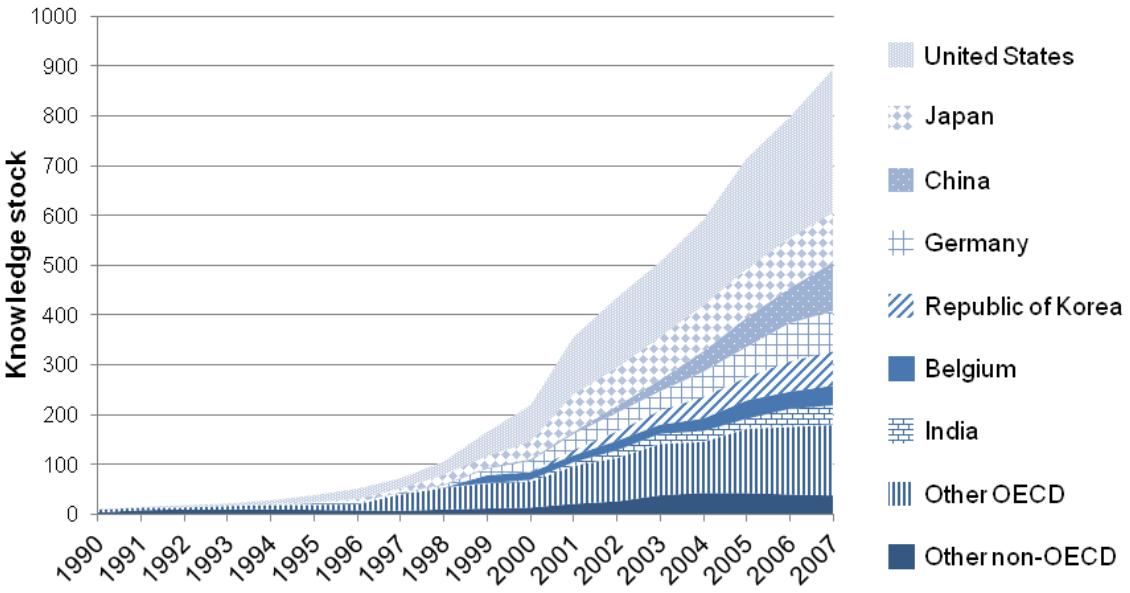
Note: Patent counts are based on the priority year and the inventor's country of residency. If several inventors claim one patent, the patent is fractioned equally to the number of countries of residency of inventors. "Europe" represents the aggregate number of patents invented within Members of the European Patent Office. "Other" summarises patents from inventor countries with less than 10 patents each.

Source: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database (PatStat)

Information on patent applications by inventor countries also allows analysing the patenting "knowledge stock" of a country in the field of adaptation-related biotechnology. A "knowledge stock" shows the cumulative amount of knowledge, defined by patent counts, that was created through research and innovation. According to the perpetual inventory method, as used by Popp (2002), the knowledge stock at a certain moment in time is equal to the total number of patents in that period plus the discounted existing knowledge stock from the previous period. The knowledge stock is discounted to account for the decay of knowledge over time. The decay rate used in Figure 8 is 0.1, set in line with the literature on innovation (Keller, 2002). The knowledge stock is constructed under the assumption of zero cross-country

spillovers (autarky). Figure 8 illustrates the patent stocks for the OECD, China, India and other non-OECD countries covered by PatStat.

Figure 8. Knowledge stock of adaptation-related biotechnology patent applications (1990-2007)



Note: Patent counts are based on the priority year and the inventor's country of residency. In cases where several inventors file a claim for one patent, the patent is fractioned equally to the number of countries of residency of inventors. Patent stock is created with the perpetual inventory method following Popp (2002), with a decay rate of 0.1. The United States, Japan, Germany, the Republic of Korea and Belgium are OECD countries. China and India are non-OECD countries.

Source: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database (PatStat)

Across nations covered in the PatStat database, OECD member countries dominate the sector of patented adaptation-related biotechnology. This may be due to high costs, which can accrue during the development of crops or in the patenting process. The scale of finance required may not be accessible to developing countries. Furthermore, industrialised countries also benefit from higher technological levels, better developed research structures and institutional frameworks. At the same time, the knowledge stock could be underestimated in countries such as China and India, where patent systems have only recently been used to protect inventions. China has experienced substantial growth in the total patenting activity over the past years (WIPO, 2010). In terms of general patenting activity, China is among the three top ranked countries (with Korea and Japan) when considering resident patents-to-GDP ratio (WIPO, 2010). This increase in general patenting activity is also reflected in the analysed patent data of adaptation-related biotechnology and is visible in Figure 8.

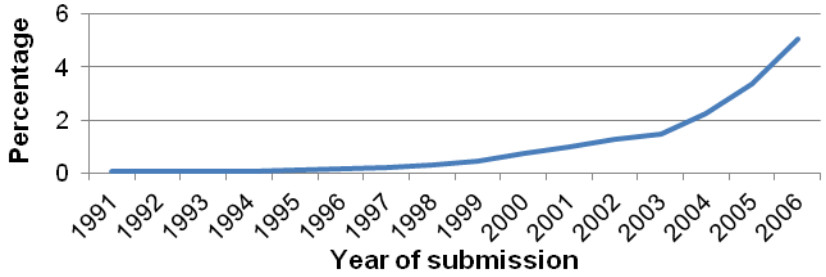
In order to examine whether the results on the evolution of innovation as well as inventor countries are specific to adaptation-related biotechnology or apply more generally to biotechnology, the analysis compares the number of adaptation-related biotechnology patent applications to aggregate patent data on biotechnology. This comparison, illustrated in Box 4, indicates an increasing interest in adaptation over time relative to other biotechnology inventions. Box 4 also provides information on the countries of inventors who registered most patents. The analysis finds that the countries that are most active in overall biotechnology partly correspond to the ones most active in adaptation-related biotechnology.

Box 4. Comparison of survey results with aggregate patent data on biotechnology

In order to analyse whether the results of this study are specific to adaptation-related biotechnology or apply more generally to biotechnology, patent data on biotechnology is extracted from PatStat. A comparison of the subgroup of adaptation-related biotechnology with the reference group of overall biotechnology over the same time period can indicate whether the results of this study are specific to adaptation-related biotechnology.

The first figure below shows the percentage of annual adaptation-related biotechnology patent applications relative to annual total biotechnology patents. The increasing percentage from 1991 to 2006 indicates that adaptation gained in relative importance compared to overall biotechnology.

Percentage of adaptation-related biotechnology patent applications relative to total biotechnology patents (1990-2007)

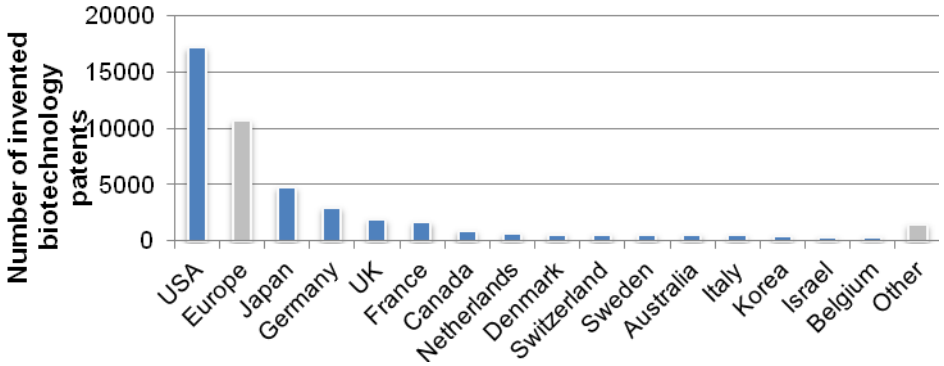


Note: Patent counts are based on the priority year, 3-year moving average.

Source: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database (PatStat)

The second figure below shows the aggregate number of patent applications by country and thus allows identifying the key inventors in overall biotechnology. Inventors from the United States, Europe (as an aggregate), Japan and Germany have registered more than 2000 biotechnology patents each from 1990-2007. This result is partly reflected in the subgroup of adaptation-related biotechnology, which identified the United States, Europe and Japan as the three main inventors in adaptation-related biotechnology (see Figure 15). However, some countries appear higher in the ranking for adaptation-related biotechnology compared to overall biotechnology. For example, China, Korea, Belgium, India and Israel are among the top 10 inventor countries in adaptation-related biotechnology, but appear in a rank lower than 10 when considering overall biotechnology patenting activity. This may indicate a higher relative interest in adaptation-related biotechnology patenting in these countries.

Inventors and number of total biotechnology patents (1990-2007)



Note: Patent counts are based on the priority year and the inventor's country of residency. If several inventors claim one patent, the patent is fractioned equally to the number of countries of residency of inventors. "Europe" represents the aggregate number of patents invented within Members of the European Patent Office.

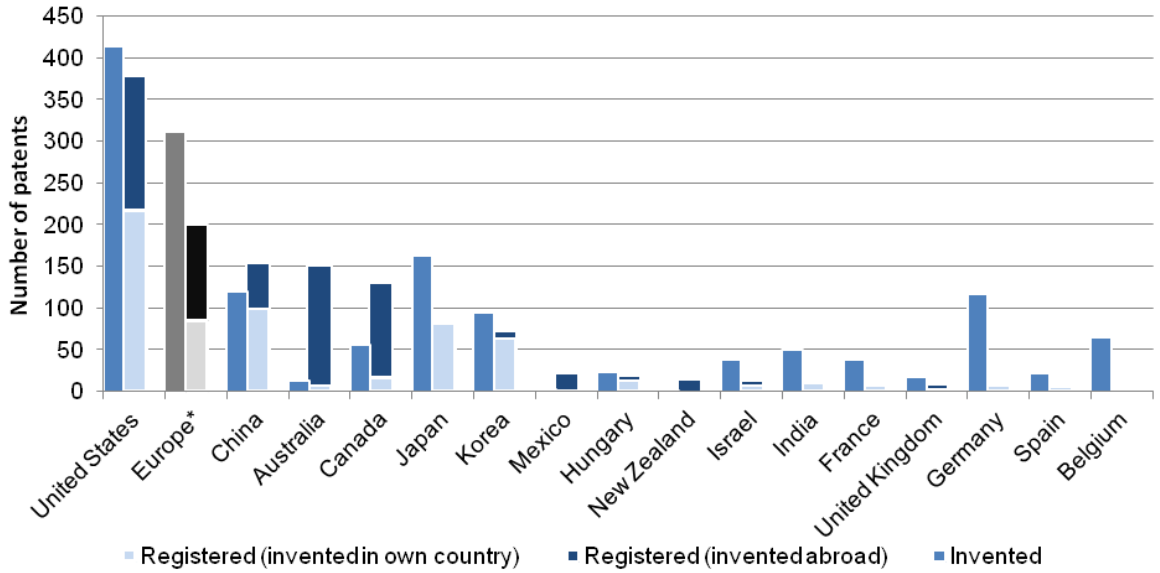
Source: Based on data extracted from EPO/OECE Worldwide Patent Statistical Database (PatStat)

The comparison of adaptation-related biotechnology with total biotechnology patents therefore indicates an increasing interest in adaptation over time relative to other biotechnology inventions. The countries that are most active in overall biotechnology partly correspond to the ones most active in adaptation-related biotechnology.

3.3 Cross-border patenting

Inventors do not necessarily apply for protection of an invention in their own country. They would rather (or in addition) submit patent applications where there is high market potential. To visualise this international patent transfer, Figure 9 compares the number of patents invented to the number of patents that have been registered in a country. Among registered patents it distinguishes patented innovations that were invented in the country from ones that were invented abroad.

Figure 9. Invented vs. registered adaptation-related biotechnology patent applications (1990-2007)



Note: The first columns represent invented patents in a given country. The second columns denote registered patents, and again distinguish patents which were invented abroad from ones invented nationally. Patent counts are based on the priority year, the patent office and the country of residency of inventors. In case of several inventors claiming for one patent, the patent is fractioned equally to the number of countries of residency of inventors. Europe* represents the aggregate number of patents registered and invented within members of the European Patent Office. Since no same identified patent was registered in more than one European country, the European aggregate is the sum of patents registered in various European countries.

Source: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database (PatStat)

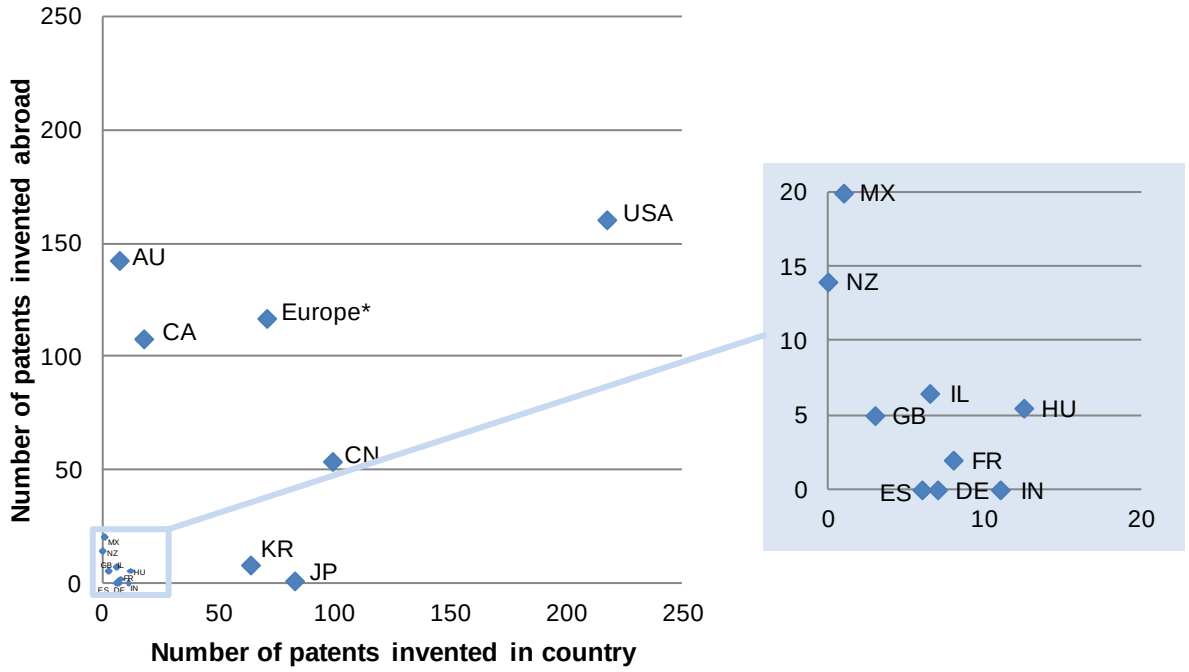
The United States receive the most patent applications in absolute terms, followed by the European Patent Office. This could be an indication that individual European countries tend to submit their patent applications directly to the European office rather than to their own country. Other countries that have approved transgenic crop plantings are also well represented, such as China, Canada, Japan and Korea. This analysis also shows that Australia, which is expected to be highly affected by drought, is the third country receiving most applications. However, based on this analysis, innovation in adaptation-related biotechnology seems less prominent in Australia.

Figure 9 also describes whether patents registered in a country stem from inventions in the same country or from inventors abroad. More than half of all patents submitted in the United States result from the country's own inventive activity. Similarly, developers in China, Japan and Korea mostly register patents for inventions in their own country. On the contrary, patents on adaptation-related biotechnology that were registered in Australia, Canada, Mexico and New Zealand mainly stem from foreign applications. These patterns of domestic versus foreign inventions broadly track the wider trends for all patent applications over the same period. The main exception to this overall picture is that the majority of patent

applications in Australia and New Zealand relate to domestic inventions, which is not the case for adaptation-related biotechnology patenting.

A further question is whether countries that are important recipients of foreign patents invent less domestically. Comparing patent receipts with domestic inventions is critical in helping to understand whether there is a "crowding out" effect of national patenting by foreign applications. Figure 10 depicts the relationship between patents protecting domestic inventions versus foreign inventions. While this Figure shows that there are some countries that receive foreign patents but do not invent comparably (*e.g.* Australia and Canada), there tends to be a positive correlation between domestic patenting and the receipt of foreign patents. This data therefore shows no indication of a replacement of national patenting through foreign patent applications. The analysis of all patent applications over the same period similarly suggests that there is no general pattern of foreign patenting replacing domestic applications.

Figure 10. Adaptation-related biotechnology patenting of domestic versus foreign inventors (1990-2007)

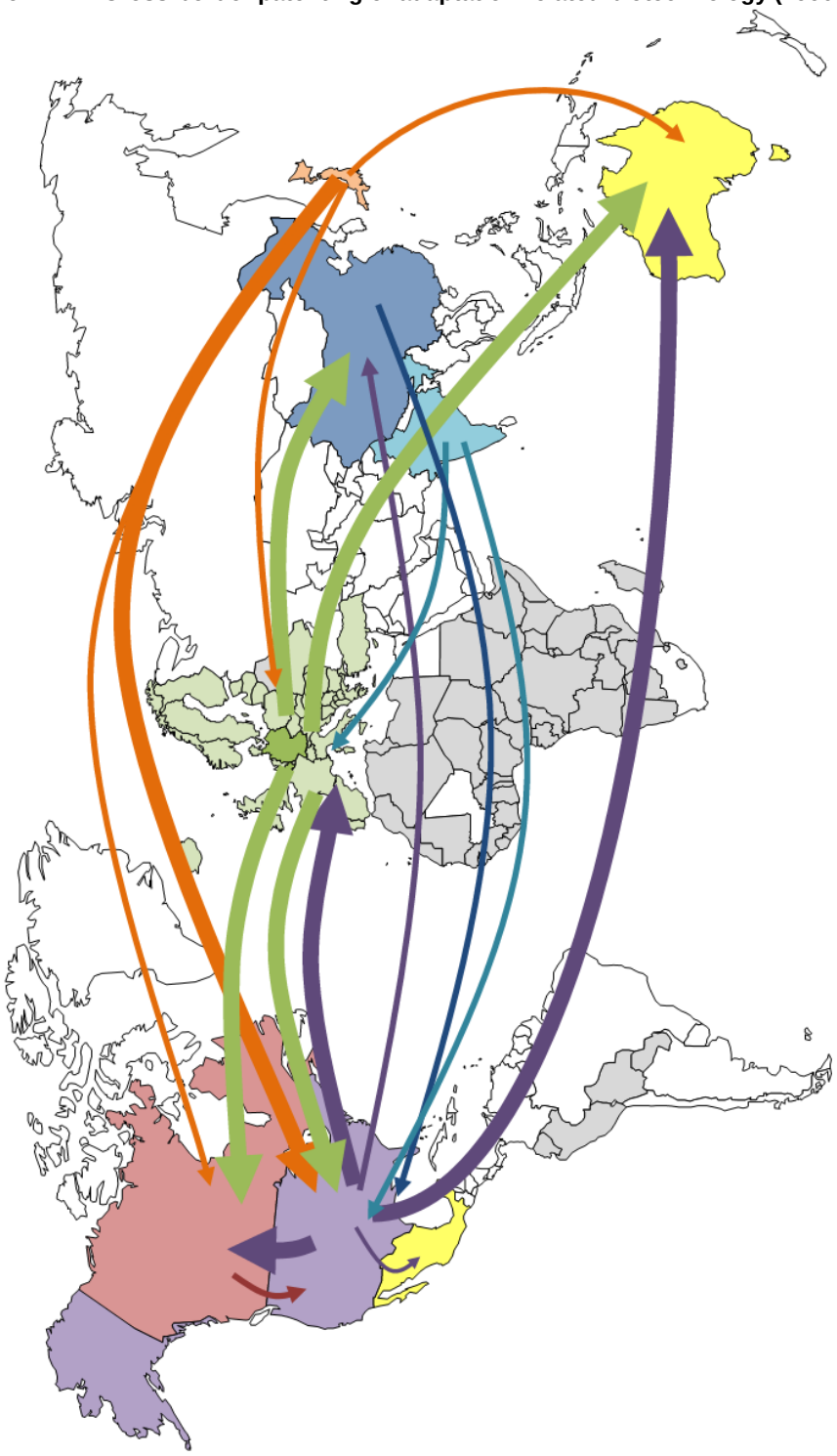


Note: Patent counts are based on the priority year, the patent office and the country of residency of inventors. In case of several inventors claiming one patent, the patent is fractioned equally to the number of countries of residency of inventors. Europe* represents the aggregate number of patents registered and invented within members of the European Patent Office. AU – Australia, CA – Canada, CN – China, DE – Germany, ES – Spain, FR – France, GB – United Kingdom, HU – Hungary, IL – Israel, IN – India, JP – Japan, KR – Republic of Korea, MX – Mexico, NZ – New Zealand, USA – United States.

Source: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database (PatStat)

Examining cross-border patenting can help to understand innovation patterns across developed and developing countries. To depict the cross-border pattern of patenting activity, Figure 11 illustrates the origin (inventor country) and receiving country (duplicate office) of patents deposited internationally. Only cases of more than 10 duplicate patents in adaptation-related biotechnology are shown in the Figure, with the relative size of the arrows indicating the magnitude of flows (thicker arrows: above 20 patent applications; thinner arrows: 10-20 patent applications). Patents submitted to the European Patent Office by a member country of the European Patent Organisation are considered domestic.

Figure 11. Cross-border patenting of adaptation-related biotechnology (1990-2007)



Note: Patent counts are based on the priority year, the transfer from inventor country to duplicate office. In case of several inventors claiming for one patent, the patent is fractioned equally to the number of countries of residency of inventors. Countries not covered by PatStat are filled in light grey. Arrow colours represent the origin country of patent flows. The size of arrows represents the magnitude of patent flows.

Source: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database (PatStat)

Figure 11 shows that the United States is the most active country in registering adaptation-related biotechnology patents in foreign countries. Most inventions from the United States that are patented outside the country are received by the European Patent Office, followed by Canada and Australia. A minor flow of patents from the United States is directed towards Mexico and China. Japan patents half of the inventions by its nationals abroad, mainly in the United States, but also in Europe, Australia and Canada. European inventions are patented in the United States, Canada, China and Australia. This analysis finds that Australia is the country receiving most patent applications from other countries, mainly from Europe and the United States.

Patents for adaptation-related biotechnology are mainly invented and submitted for application in industrialised countries. OECD member countries account for 85% of patents registered in foreign countries, and also receive 70% of all registrations which originate from foreign countries. In particular, this analysis could find little evidence for cross-border patenting in Asia and South America. Since PatStat does not cover the majority of African countries, it is clear that a technology flow towards this region cannot be observed based on the data. The case of South America and Asia is more difficult to explain, as crop biotechnology is known to be economically important in Argentina, Brazil, Paraguay, China and India.

There are several possible reasons for the limited evidence of patent transfer to South American and Asian countries in our dataset. As explained above, one limitation is the use of English keywords to search for relevant patent applications. This could lead to a language bias that might be of particular importance for Asian offices. In addition, some developing countries do not have a system which allows patenting of gene applications. Instead, techniques or final products may be protected in the context of the national law (PBS and ABSP II, 2004). The lack of uniformity in the coverage of regulatory systems is thus one of the major limitations of the analysis presented here, confirming that uncorrected patent counts are only an imperfect indicator of biotechnology innovation.[11]

In other countries the patent system for agricultural biotechnology is relatively young. For example, Brazil and China only allowed for genes to be patented in 1997 and 1994 respectively (Chan, 2010). Some countries had made use of Plant Variety Certificates, which are excluded from this analysis, before establishing a patent system. In comparison, the United States already began awarding patent rights for genes and plant varieties in the 1980s.

Approval rates of patent applications vary across patent offices. Analysing inventions applied for and granted by patent authority, Chan (2010) finds that approval rates vary substantially across countries. Whereas in the United States 81.4% and in Australia 29.8% of all patent applications are granted, in Brazil only 3.3% are approved. Rates are comparably low in China (4.1% of applications granted) and Japan (8.4% of applications granted). Although Chan (2010) does not use PatStat for his analysis, the approval rates could help understand the observed lack of applications in Brazil, China and Japan.

Patent flow to South America and parts of Asia may also be limited due to differences in their legal frameworks. The United States, Japan and Australia have the most comprehensive systems allowing for the patenting of plant varieties (Commission on Intellectual Property Rights, 2002). These three countries also display high cross-border patenting in this analysis, whereby Japan is characterised by an outward flow of patents and Australia is a net recipient.

[11] To create uniformity in a minimum level of protection among WTO members, the Agreement on Trade Related Aspects of Intellectual Property Rights (TRIPs) came into force in 1995. Article 27.3(b) of TRIPs provides that WTO members may exclude plants, animals and "essentially" biological processes from patentability. However, plant varieties have to be eligible for protection either through patent protection or a system created specifically for that purpose (such as the UPOV system), or a combination.

In some countries the patent record may generally not be a good proxy for examining innovation in adaptation-related biotechnology. For example, China's patent system has a short history and the country has only recently started to file international patents. Although patenting activity has grown substantially over recent years, biotechnology does not rank among the top patenting industries based on an analysis of industry patenting activity (WIPO, 2010; Hu and Jefferson, 2009). The plant variety certificates system has also faced problems with constrained resources and high costs for developers (Koo *et al.*, 2006). Also, alternatives to patents such as hybridisation have been available in China, which provided *de facto* protection for several years as an alternative to more formal IPRs (Wright *et al.*, 2007). Thus, research intensity, which is generally not reflected in patent data, may be a better measure for inventive activity in crop biotechnology in China (Wright *et al.*, 2007). This is especially true for earlier years.

There are many other possible reasons for the limited patent flow to South America and Asia. For example, some argue that countries which are less involved in trade also receive fewer patent applications (Chan, 2010).

3.4 Ownership of patents

Research and development in biotechnology related to abiotic stress is pursued by a number of institutions. Table 3 shows that 276 institutions have applied for less than 5 patents each since 1990. Of these 276 institutions, the majority (177) applied for one patent or fewer (i.e. they hold fractions of shared patent applications). 26 institutions have applied for 10 patents or more. In total, these 26 institutions represent approximately 50% of all patents submitted in adaptation-related biotechnology.

Table 3. Number of institutions applying for adaptation-related biotechnology patents

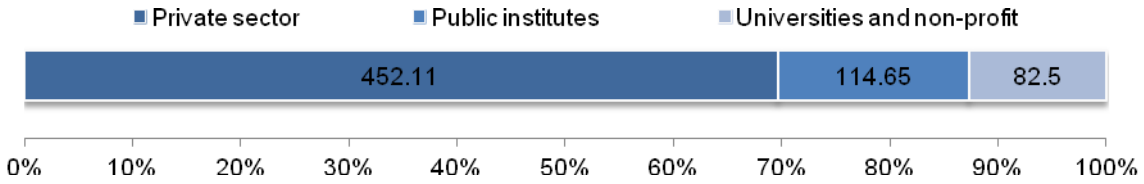
Number of patents	Number of institutions
0 - 5	276
5 - 10	28
10 +	26

Notes: The number of patents for each firm is calculated in fractions if several companies share a patent. In the given ranges, the initial number is inclusive, the last number exclusive.

Source: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database (PatStat)

Table 4 takes a closer look at the 26 institutions that have applied for 10 adaptation-related patents or more. It shows the share of patents registered by commercial firms, public institutions or universities and non-for-profit organisations since 1990. The majority of applicants come from the private sector (70%). BASF Plant Science GmbH is the most active institution, owning approximately 14% of all biotechnology patents related to adaptation. A quarter of all patent applications registered in PatStat are shared by five institutions: BASF Plant Science GmbH, Monsanto, Mendel Biotechnology, Bayer BioScience and the Japanese institute Riken.

Table 4. Ownership of adaptation-related biotechnology patent applications (1990-2007)



APPLICANT NAME	ORIGIN COUNTRY	NUMBER OF PATENTS	PERCENTAGE AMONG ALL	CUMULATIVE PERCENTAGE
BASF Plant Science GmbH	Germany	187.28	14.30%	14.30%
Monsanto Technology LLC	United States	42	3.21%	17.51%
Mendel Biotechnology, Inc.	United States	39	2.98%	20.49%
Bayer BioScience N.V.	Belgium	29	2.21%	22.70%
Riken - Institute of Physical and Chemical Research	Japan	27.5	2.10%	24.80%
Performance Plants Inc.	Canada	24	1.83%	26.64%
Syngenta Participations AG	Switzerland	21.83	1.67%	28.30%
BTG International Limited, London	United Kingdom	21	1.60%	29.91%
Cropdesign N.V.	Belgium	21	1.60%	31.51%
Ceres, Inc.	United States	20	1.53%	33.04%
National Institute of Agrobiological Sciences	Japan	18.66	1.43%	34.46%
The Regents of the University of California	United States	18.5	1.41%	35.88%
Chinese Academy of Sciences (CAS)	China	18	1.37%	37.25%
Korea Research Institute of Bioscience and Biotechnology	Korea	17	1.30%	38.55%
M.S. Swaminathan Research Foundation	India	15	1.15%	39.70%
Huazhong Agricultural University	China	14	1.07%	40.77%
Purdue Research Foundation	United States	14	1.07%	41.83%
Pioneer Hi-Bred International, Inc.	United States	13	0.99%	42.83%
National Agriculture and Food Research Organization and Bio-oriented Technology Research Advancement Institution	Japan	12.83	0.98%	43.81%
Evogene Ltd.	Israel	12	0.92%	44.72%
Cornell Research Foundation, Inc.	United States	11.5	0.88%	45.60%
University of Saskatchewan Technologies Inc.	Canada	11	0.84%	46.44%
Avesthagen Graine Technologies Pvt. Ltd.	India	10.5	0.80%	47.24%
Japan International Research Center for Agricultural Sciences	Japan	10.33	0.79%	48.03%
Japan Science and Technology Agency	Japan	10.33	0.79%	48.82%
Seoul National University Industry Foundation	Korea	10	0.76%	49.59%

Note: Patent counts are based on the priority year, the applicant authority and the fractional counts according to the number of applicants for one patent. This selection includes only applicants that applied at least 10 patents during the dataset. In the table, rows in dark blue indicate that the applicant is part of the private sector, light blue indicates that the applicant is a public institute and white indicates that the applicant is a university or non-profit organisation.

Source: Based on data extracted from EPO/OECD Worldwide Patent Statistical Database

As judged by this patent analysis, four out of the five most active institutions in adaptation-related biotechnology are part of the private sector: BASF, Monsanto, Mendel Biotechnology and Bayer Group. BASF Plant Science GmbH is the most active institution, accounting for 14% of applications. Alongside these commercial firms, a Japanese institute is also active in registering patents. Riken was founded as an independent administrative institution in 1917 and is almost entirely funded by the Japanese government.

However, while the majority of patenting appears to be undertaken by the private sector, the patent application data could underestimate the importance of the public sector in this field if public funding has been used to finance private sector research. Additionally, in some geographical regions a large share of adaptation-related biotechnology is pursued by the public sector. For example, this is the case in Japan, China and Korea. In Japan, all institutions with more than ten registered patents are public research institutes, such as Riken or the National Institute of Agrobiological Sciences. Likewise, the Korean Research Institute of Bioscience and Biotechnology and the Seoul National University Industry Foundation are leaders in patenting innovation towards crops resilient to environmental stress in Korea. The University of California and Cornell Research Foundation also coordinate research and have registered more than ten biotechnology patents in adaptation.

3.5 Protection of specific crops

Patent descriptions can indicate the crops that institutions target with their innovation activities. This can help to better understand the likely direction of innovation activities, as well as the flexibility that institutions might want to preserve when applying inventions.

In adaptation-related biotechnology, patent descriptions typically state that breeding techniques could be applied to several plant varieties. Some patents list more than ten plant varieties to which the patented invention could be applied. For example, a patent registered by Bayer BioScience NV (KR20060012581) states: "*The methods and means described herein are believed to be suitable for all plant cells and plants, both dicotyledonous and monocotyledonous plant cells and plants including but not limited to cotton, Brassica vegetables, oilseed rape, wheat, maize or corn, barley, alfalfa, peanuts, sunflowers, rice, oats, sugarcane, soybean, turf grasses, barley, rye, sorghum, sugar cane, vegetables (including chicory, lettuce, tomato, zucchini, bell pepper, eggplant, cucumber, melon, onion, leek), tobacco, potato, sugar beet, papaya, pineapple, mango, Arabidopsis thaliana, but also plants used in horticulture, floriculture or forestry (poplar, fir, eucalyptus etc.).*"

Although patents usually list a large number of crops the novelty can be applied to, this does not imply that institutions intend to expand the innovation to all listed crops in the near future. Thus, it remains analytically difficult to identify the likely direction of innovation activities. Further research would be necessary to identify which crops are targeted in the near term.

4. CONCLUSION

This report provided a case study on innovation in the area of adaptation technologies, an area where there has been less analysis relative to mitigation technologies. More specifically, it presented an analysis of patent data of three traits relevant to climate change: resilience to drought, to saline soils and to temperature extremes. It shows that innovation relating to these traits has accelerated over the last quarter century, with the number of relevant annual patent applications increasing from fewer than 10 in 1995 to almost 200 by 2007.

Based on patent data, OECD member countries and emerging economies dominate innovation in adaptation-related biotechnology. Of all patent applications identified, more than 80% were invented in OECD member countries. The United States leads the sector with more than 400 patent applications between 1999 and 2007, representing approximately one third of all adaptation-related biotechnology patents. The United States is followed by Europe and Japan. This result is consistent with findings on general biotechnology patenting activity, which finds the highest patenting activity in the United States, Japan and the European Union. However, the patent count may be underestimated in countries where patents are only a restricted indicator of inventive activity or where patents have only recently been used to protect inventions, such as China.

A comparison of adaptation-related biotechnology patent applications with total biotechnology patent applications indicates an increasing relative interest in adaptation in the biotechnology sector. The proportion of adaptation-related crop biotechnology patents to total biotechnology patents has increased from 0.5% in 1999 to over 5% in 2006. When comparing inventors, countries that are most active in overall biotechnology are also the ones that are most active in adaptation-related biotechnology.

Examining patent submissions, the United States receives most patent applications, followed by the European Patent Office and China. More than half of all patents submitted in the United States result from the country's own inventive activity. Similarly, developers in China, Japan and Korea mostly register patents for inventions in their own country.

However, patents are not necessarily registered in countries that invent. For example, patents registered in Australia, Canada, Mexico and New Zealand mainly stem from foreign applications. While an examination of domestic versus foreign inventions shows that there are some countries that receive foreign patents but do not invent comparably, it also indicates that countries which do invent tend to receive more foreign patent applications. Overall there is therefore no indication of a replacement of national inventions through foreign patents in adaptation-related biotechnology. These findings broadly match trends for all patenting activity over the same period.

The analysis of cross-border patenting trends finds that patents are primarily submitted for registration in industrial countries. The United States is the most active in registering adaptation-related biotechnology patents in foreign countries, while Australia receives the most registrations from abroad. OECD member countries account for 85% of patents registered in foreign countries, and also receive 70% of all registrations which originate from foreign countries. The analysis finds only limited patent flows to South America and Asia. This finding is unusual given the known economic importance of crop biotechnology in these regions. However, it may be partially explained by different patenting systems, varying approval rates between patent offices, and different legal frameworks compared to those countries which register

significant numbers of adaptation-related crop biotechnology patents. Future research could consider levels of non-patented innovation by drawing on supplementary measures of R&D, such as scientific publications on adaptation-related crop biotechnology. This data could help provide a more rounded picture of innovation, especially in countries or regions not widely involved in patenting.

An examination of applicants in patent submissions indicates that the private sector plays an important role in adaptation-related biotechnology innovation. BASF Plant Science GmbH is the most active institution, accounting for 14% of all patent applications. The analysis also indicates that in some countries the public sector plays a larger role. For example, in Japan, China and Korea a majority of adaptation-related biotechnology research is pursued by public research centres.

This study has looked at an early stage of the innovation pipeline: the development of traits that are resilient to abiotic stresses. Further analysis could examine the extent to which increasing activity at this stage of the process translates into the commercialisation of crops. As well as future research in this area, there is also the potential for work to investigate the factors driving this increase in activity. Lastly, research could identify countries' needs for adaptation-related biotechnology, and how these needs could be met. Developing countries, which are most vulnerable to climate change, ought to play a critical role in shaping such discussions.

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