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Research Article

Study on Technology Development Status of Genetically Modified Soybean Based on Patent Analysis

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Abstract: Genetically modified soybean is a product of the emerging bio-technology in the 1980s and is widely concerned all over the world. This study analyzed GM soybean related patent documents in China, the United States and Europe, aiming to find out the R and D status and trends as well as technical distribution pattern of GM soybean in the world. It analyzed the patent general tendency, regional distribution and key technologies, clarified major countries who master such technologies, relevant companies, technologies, etc. Finally, the author put forward solutions for the strategic development of GM soybean patents.

Keywords: Genetically modified soybean, patent analysis, patented technology

INTRODUCTION

Genetically modified soybean refers to a soybean variety, featured by specific traits and is cultivated by introducing exogenous genes with genetic engineering methods. After the 1980s, modern biotechnology centered by genetic engineering developed rapidly. By genetic modification methods, people can greatly improve soybean traits, enhance the nutritional value and added value of soybean and its processed products. Since its birth, GM soybean has developed rapidly and been widely applied. According to traits of modified genes, GM soybean that has been already commercially planted and/or is still in development process can be classified into three categories (Zhong *et al*., 2005): herbicide-resistant GM soybean, fatty acids changed GM soybean and insect-resistant GM soybean. With the deepening of technology study and increasing of its acreage, GM soybean has become the main driving force of the world's soybean development in the main producing countries.

About 84.5 million ha of MG soybean was planted in 11 countries in 2013. The coverage accounted for almost 48% of that of global MG crops and 79% of that of global MG soybean (James, 2013). With the development of farming, some new technologies and methods for MG soybean breeding and gene function research have been put into practice. For example, genome editing (Esvelt and Wang, 2013), TALE nucleases (TALEs) (Shan *et al*., 2013a), Zinc Finger Nucleases (ZFNs) (Li *et al*., 2013) and CRISPR/Cas system (Shan *et al*., 2013b; Feng *et al*., 2013; Cong *et al*., 2013), have represented new exploration field when they are combined with MG technology. And genetic modification research on soybean has become one of the hot spots in plant molecular biology research at home and abroad.

Patent intelligence is an important source of technical and scientific information and it can reflect the current technological progress in the field of science and technology research and development. From literature retrieval, statistics and analysis of patent intelligence, people can see the future development trends of technology, the main technical areas, the technical and economic strength of a country (regions) or an enterprise and so on. This study targets to provide information support and decision making reference for the strategic choices of our country on GM soybean by analyzing patent intelligence in GM soybean field.

DATA SOURCES AND METHODS

Data sources: The Patent Analysis Online 2.0 of Chinese Academy of Sciences, which has the feature of analyzing patents of seven countries and two organizations are retrieved in order to obtain patents granted from January 1, 1980 to December 31, 2013. Because a lag period of 18 months exists from patent application to patent discloses, many a patent applications are still undisclosed, so 2013 patent information is for reference only.

Search strategy: Retrieval can be done by keywords together with International Patent Classification codes (IPC classification codes), while keywords are obtained from GM soybean technology structure based on intelligence research and experts interviews. Retrieved IPC numbers include C12N, C12Q, A01H, G01N,

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Table 1: Main technical composition of GM soybean

Technology categories	Technology name	
Exogenous genes introduced	Herbicide-resistant genes	Glyphosate-resistant EPSPS gene; original porphyrin oxidase gene; anti-glutamine synthetase inhibitor gene; ADP Ribosylation Factor (ARF) gene
	Genes improving quality traits	Change the content of protein; change the content of amino acid; change the content of oil content; increase trace element content; change the content of sugar
	Antifungal genes	Chitinase gene; cytochrome p450 gene; lipoxygenase pathway genes; brown rot-resistant gene; β-1, 3 glucanase gene
	Anti-bacterial genes	Antimicrobial peptide gene; soybean isoform calmodulin gene
	Anti-viral genes	Viral coat protein of soybean chlorosis and mosaic virus resistant gene
	Male sterility genes	Soybean msMOS male sterility gene; male sterility factor gene
	Insect-resistant genes	Bt gene; protease inhibitor gene; soybean cyst nematode-resistant gene
	Salt-tolerant gene	Salt-tolerant ammonia valley thalidomide gene; salt-tolerant soybean
	Pharmaceutical protein genes	Animal vaccines; enzyme preparation for special use
	Other genes	DNA binding protein gene; physiological growth-related genes; promoter gene; transcriptional activator gene
Genetic modification methods	Agro-bacterium mediation	
	Gene gun mediation	
	Pollen tube pathway method	
	Electric shock transformation method	
	Particle mediation	
	Other methods	
Other technologies associated with GM soybean	Tissue culture technology	
	Cultivation and breeding	
	Soybean trait gene mapping	
	Molecular markers	

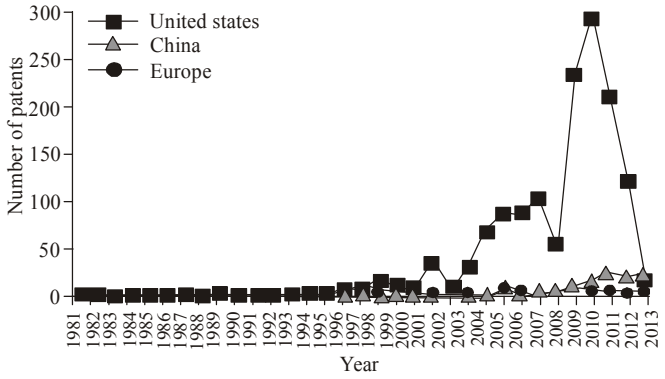


Fig. 1: Trends of application for GM soybean patents

C07K, C07H, A01C, C12M, A01G, G01S, etc., among which C12N, A01H, C12Q, A01G are mostly applied, while C12N involving genetic breeding methods of GM soybean; A01H involving tissue culture breeding methods and purity testing methods for GM soybean; C12Q involving molecular marker-assisted breeding methods and seed purity testing methods for GM soybean; and A01G involving seed production methods for GM soybeans. Main technical composition of GM soybean is shown in Table 1.

Analysis methods: Keywords together with IPC number are retrieved and patents unrelated to GM soybean are excluded. Using the analysis module of the Patent Analysis Online of Chinese Academy of Sciences, this study has compared and analyzed GM soybeans technology trends as well as situations in key technologies fields in China, United States, Europe and other places from the perspectives of year of application, IPC classification and so on. It has also discussed the development of GM soybean in our country from the perspective of patent technology.

RESULT ANALYSIS

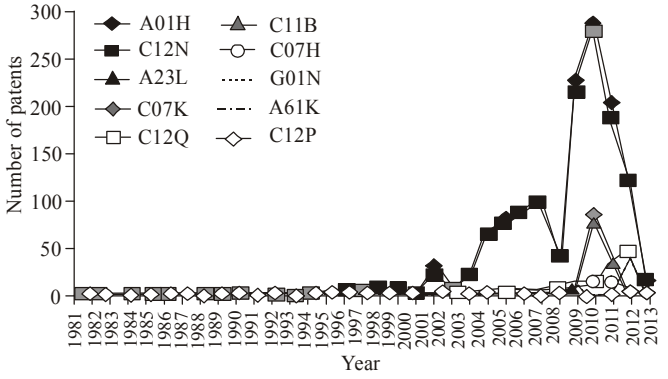
Analysis of development trends: From the annual change in the number of patents and patent IPC classification, people can see the basic development of GM soybean technology in China, United States and Europe.

Patent development trends: From the annual distribution of patent applications (Fig. 1), research in the field of GM soybean developed is relatively slow and the volume of patent changed gently before 1994 and then the overall situation began to change, especially after 2000, the number of GM soybean patent applications grew faster as a whole. Since 2009, the number of GM soybean patents in United States has declined, the reason for which may relate to the increasing emphasis on GM food safety issues all over the world.

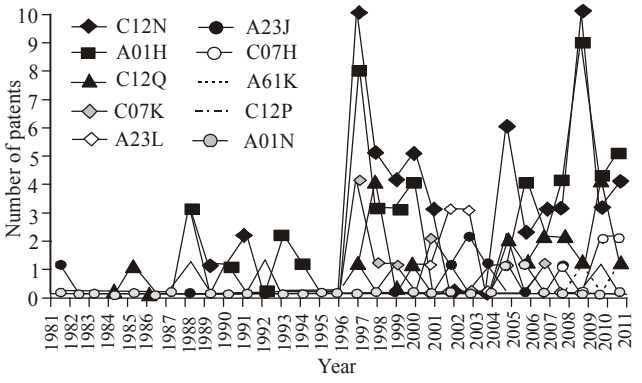
In 1994, Monsanto's glyphosate herbicide-resistant GM soybean was permitted for commercial cultivation;

in 1997, DuPont obtain FDA's approval to promote the cultivation of genetically modified high oleic soybeans (Yu *et al*., 2010). The major breakthrough of these genetically modified products in large-scale agricultural cultivation has greatly accelerated the process of technological innovation of genetically modified soybeans. Meanwhile, plant genetic engineering research on soybean based on recombinant DNA technology and plant *in vitro* regeneration technology is acclaimed, providing effective receptor system for introducing exogenous gene into soybean and contributing significantly to the research on genetic transformation of soybean and other genetic engineering research work (Wang *et al*., 1999).

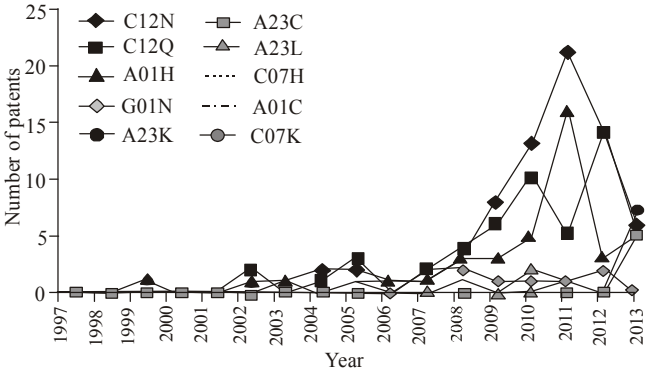
The cultivation and large-scale plantation of GM soybean varieties represents a milestone in the history of world soybean technology and has become the main trend of the world's soybean production development with the emerging of GM soybean technology and the increasing of soybean acreage.



(a) United States



(b) Europe



(c) China

Fig. 2: GM soybean technology trends

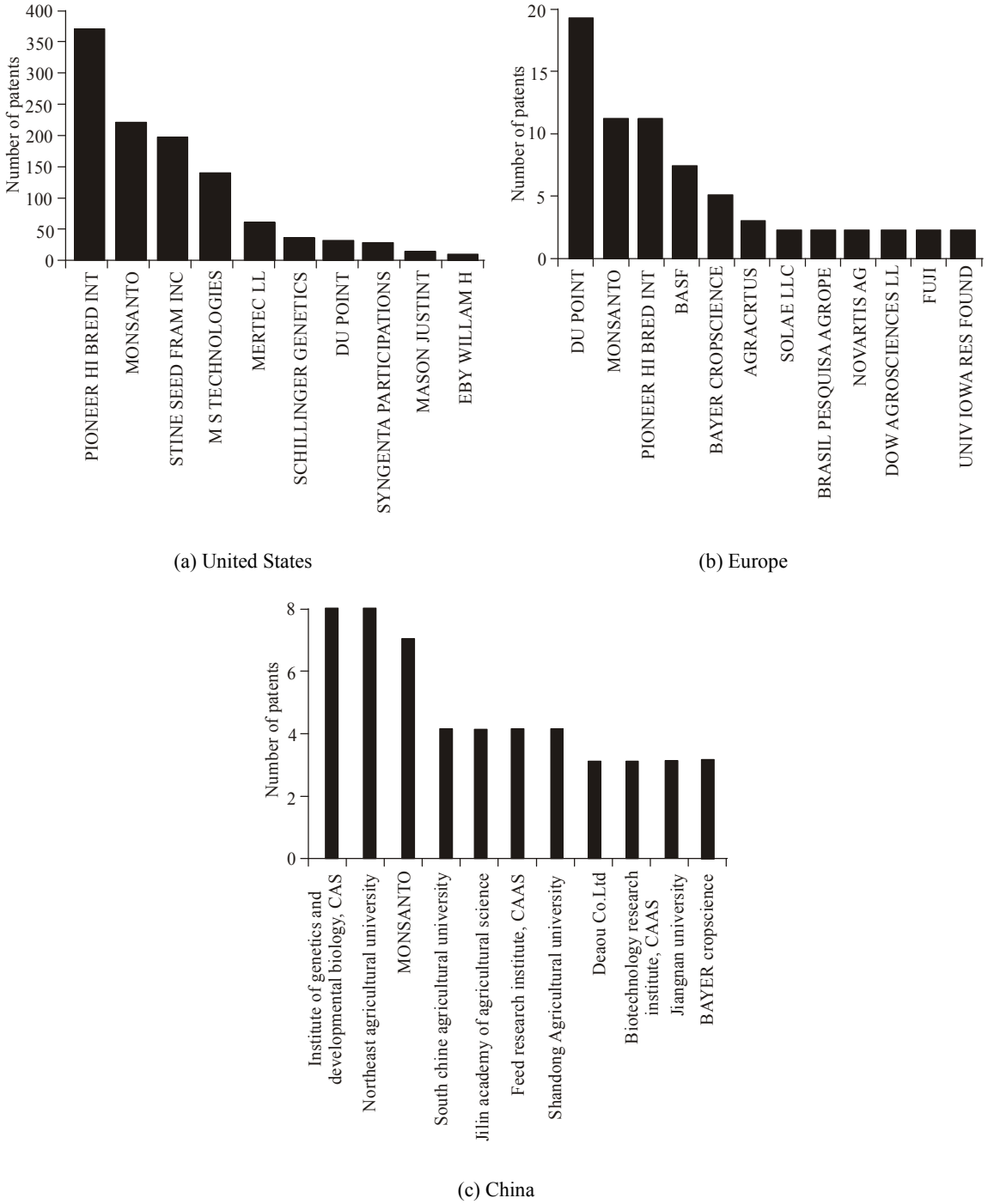


Fig. 3: Top ten GM soybean patent applicants

Technology trends: This study has counted respectively the number of patent applications in IPC subclasses in the field of GM soybean in China, the United States and Europe year by year and the results are shown in Fig. 2. As can be seen in the figure, C12N and A01H are the fastest growing varieties. In some years, their numbers of applications are much higher than that of others, indicating that research on GM soybean genetics and breeding as well as soybean tissue culture is always the priority of every country. In the two IPC subclasses, United States experienced peaks of patent application in 2001, 2007 and 2010, which has dropped slightly in the past three years; while European's peaks of patent applications appeared in 1997 and 2010. In 2010, the United States saw peaks of A23L, C07K and C11B application, indicating that in

recent years, the United States has increased investment in R and D for soybean quality improvement in recent years.

For GM soybeans in China, the number of patents related to C12N, A01H and C12Q increases the fastest, indicating that in addition to breeding, the GM soybean R and D also pays attention to molecular marker-assisted breeding methods and seed purity testing methods.

Analysis of competition dynamics: GM soybean competition dynamics may be discussed by analyzing the patent development and technology distribution of GM soybean applicants and key applicants in China, United States and Europe.

Analysis of R and D strength: Details of the top ten applicants with the most GM soybean patents in China, United States and Europe are shown in Fig. 3. As can be seen in the figure, in United States, Pioneer Corporation, Monsanto Company, Stern Company and MS Technology Company patents own the largest number of patents; in China, Institute of Genetics and Developmental Biology of Chinese Academy of Sciences, Northeast Agricultural University and Monsanto Technology Company own the largest number of patents; while among all of companies applying for GM soybean patents in Europe, DuPont Company, Monsanto Company and Pioneer Company own the maximum number of patents. It is reported that, 80% of the world's genetically modified crops come from Monsanto, DuPont and other five multinational companies of the United States (Jiang and Wang, 2010) currently, indicating that these multinational companies have obvious advantages in fields of technology development and application promotion of genetically modified crops. Monsanto, Pioneer Corporation and other world leading companies in the development and application of genetic modification technology have applied for a large number of patents, indicating that these multinational companies have paid more attention to intellectual property rights on genetically modified soybeans and this strategy in turn also helps these companies form a technical monopoly in some way.

The result also shows that the United States and American companies in GM soybean technology development area have far more technological innovation capabilities than other countries and regions. Enterprises form the main part of U.S. genetically modified soybeans R and D system. For the full protection of intellectual property rights of transgenic plants in the U.S. has formed technological monopoly to some extent, brought huge profits, motivated and mobilized the enthusiasm of breeders, enabling breeders to invest more energy and resources in breeding innovation so as to breed more new varieties that can be commercialized. But in China, GM soybean technology innovation is mostly promoted by research institutes, indicating that business-oriented innovation system has not yet been formed in this area and the connection among technology innovation, market and applications is not so close, which to a certain extent have impeded the promotion and application of related technologies.

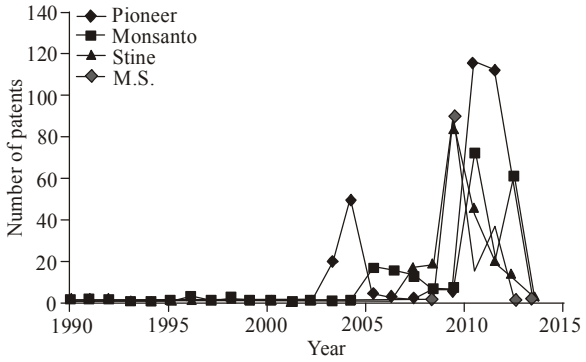


Fig. 4: Patent applications of four U.S. companies

Analysis of competitiveness of key patent applicants: From a global perspective, American Pioneer, Monsanto, Stern and MS Technologies with large volume and wide coverage of patent applications have a clear technological advantage, so this study takes them as the main targets to analyze the competitiveness of applicants, patent applications of Four U.S. Companies are shown in Fig. 4.

According to the retrieval results of GM soybean in the United States, Pioneer owns the largest number of patents, up to 368, accounting for 29.73% of the total GM soybeans patents in the United States, indicating that Pioneer's overall competitive strength in this area is stronger. The numbers of patents of Monsanto, Stern and MS Technologies are 218, 196 and 142, respectively. From the view of potential commercial value of patents, Monsanto has a large number of patents in the United States, Europe and China and is more prominent on patent strategy implementation, patented technology layout and intellectual property protection, indicating that these patents can bring Monsanto greater commercial interests. From the view of annual patent application, Pioneer and Monsanto have a long-term accumulation in GM soybean field, for they have patent records early in the 1990s. From the view of the number of patent applications during 2010-2012, Pioneer's application amounted to 281, far more than Monsanto's 153, Stine's 71 and MS Technologies' 53, indicating an obvious competitive advantage.

Details of the technical field distribution of each company are shown in Fig. 5. As can be seen in the figure, the similarities of GM soybean technologies among these four companies varies with the type, but they have basically the same focus on C12N15/82 and A01H5/10 in the technology research and development. Pioneer has the largest number of patents in these two areas, 283 and 218, respectively. Monsanto has paid attention to all these technical fields. In addition to

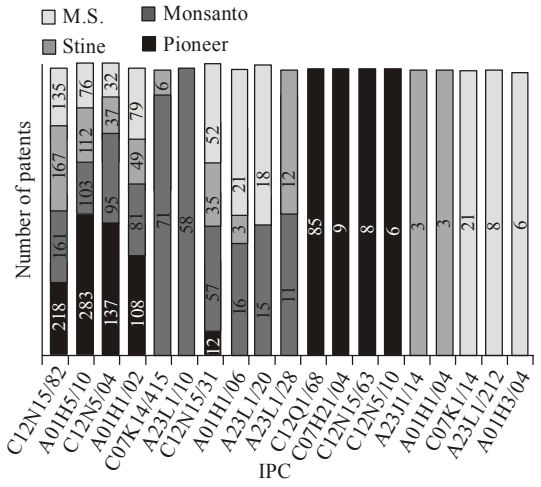


Fig. 5: Analysis of competitiveness of key patent applicants

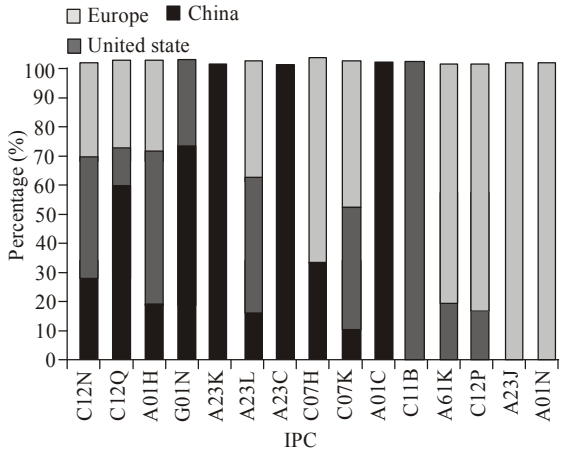


Fig. 6: Distribution of key technology areas of GM soybean

these two areas, it also enjoys obvious advantage in C07K14/415 (plant-derived peptides) and A23L1/10 (products obtained by containing cereal), while Pioneer has certain advantages in C12Q1/68 (including enzymes or microbial assay or test methods) and MS obtains certain advantages in C07K1/14 (extraction, separation and purification of peptides).

Analysis of current technology situations: Technology hot spots and trends of GM soybean can be described by analyzing the technology distribution, R and D hot spot and technology life cycle of GM soybean patent in China, the United States and Europe.

Analysis of key technology areas: This study has counted the IPC classification of GM soybean patents in China, the United States and Europe and analyzed the distribution of their patented technologies based on the number of patents of top ten IPC classification numbers and their proportion in the total, as is shown in Fig. 6. It can be seen from the figure that the distribution of GM soybean patented technology is substantially the same, although there may be some differences in IPC subclasses, these patents are mostly concentrated in C12N, A01H and C12Q subclasses, in other words, the main focus is technologies related to the breeding and identification of GM soybean. From the perspective of the composition of each sample, the United States boasts higher technology intensity in GM soybean breeding and identification. (92.37%) of its patents are related to A01H and 87.68% are related to C12N, while in China and Europe, percentages of patents related to these two subclasses are 57.36, 41.09, 68.63 and 53.92%, respectively. There are also some differences in the technical development of GM soybeans in China, the United States and Europe. For instance, some of GM soybean patents in China are related to A01C, A23K and A23C, indicating that we have done some research in GM soybean planting and application; 7.77% of GM soybean patents in the United States are related to C11B, indicating that U.S. has paid more attention to GM soybean oil; while some of European patents are related to A01N, indicating that Europe has done some research in GM soybean growth regulation.

Analysis of R and D hot spots: R and D hot spots of GM soybean technologies in China, the United States and Europe are shown in the following table (Table 2). As can be seen, the main focus of GM soybean patents in the United States and Europe are basically the same, namely IPC classification C12N15/82, in other words, using plant cells as the host and genetic engineering and breeding. Both Europe and the United States focus on genetics and breeding of GM soybeans in this field. At the same time, the United States has more patents related to IPC classification A01H5/10 (Seeds), indicating that it has obvious advantages in GM soybean tissue culture breeding method. In patents in China, the number of C12Q1/68 patents represents the largest, indicating that the R and D focus of GM soybean technology in our country lies on the seed purity testing.

Analysis of technology life cycle: The life circle of patented technology can be researched by analyzing the number of patents and patent applicants chronologically. According to the life circle of patented GM soybean technologies in the United States, the number of patent applicants and patents reached the peak after the rapid growth in 2000 and then the quantity of patent applications declined and the number of applicants was reduced, demonstrating the characteristics of technical recession. According to the life circle of patented GM soybean technologies in Europe, patented GM soybean technologies in this region have gone through several stages of development. In recent years, the number of patent applications and patents applicants has rebounded, indicating that research and development activities of patented GM soybeans technology tend to be active,

Table 2: GM soybean technology hot spots

United States		Europe		China	
IPC No.	Number of patents	IPC No.	Number of patents	IPC No.	Number of patents
C12N15/82	977	C12N15/82	55	C12Q1/68	52
A01H5/10	722	C12Q1/68	19	C12N15/11	25
C12N5/04	460	A01H5/10	16	C12N15/82	23
A01H1/02	380	C12N5/10	13	C12N15/63	16
C12N15/31	175	C12N15/29	11	C12N15/66	11
C12Q1/68	127	C12N9/02	10	C12N15/113	10
C07K14/415	105	C07K14/415	10	C12N15/10	9
C07H21/04	78	C12N9/10	9	A23K1/16	7
A23L1/10	60	C12N15/54	7	C12N15/84	6
A23L1/20	57	C12N15/09	6	C12N15/29	6

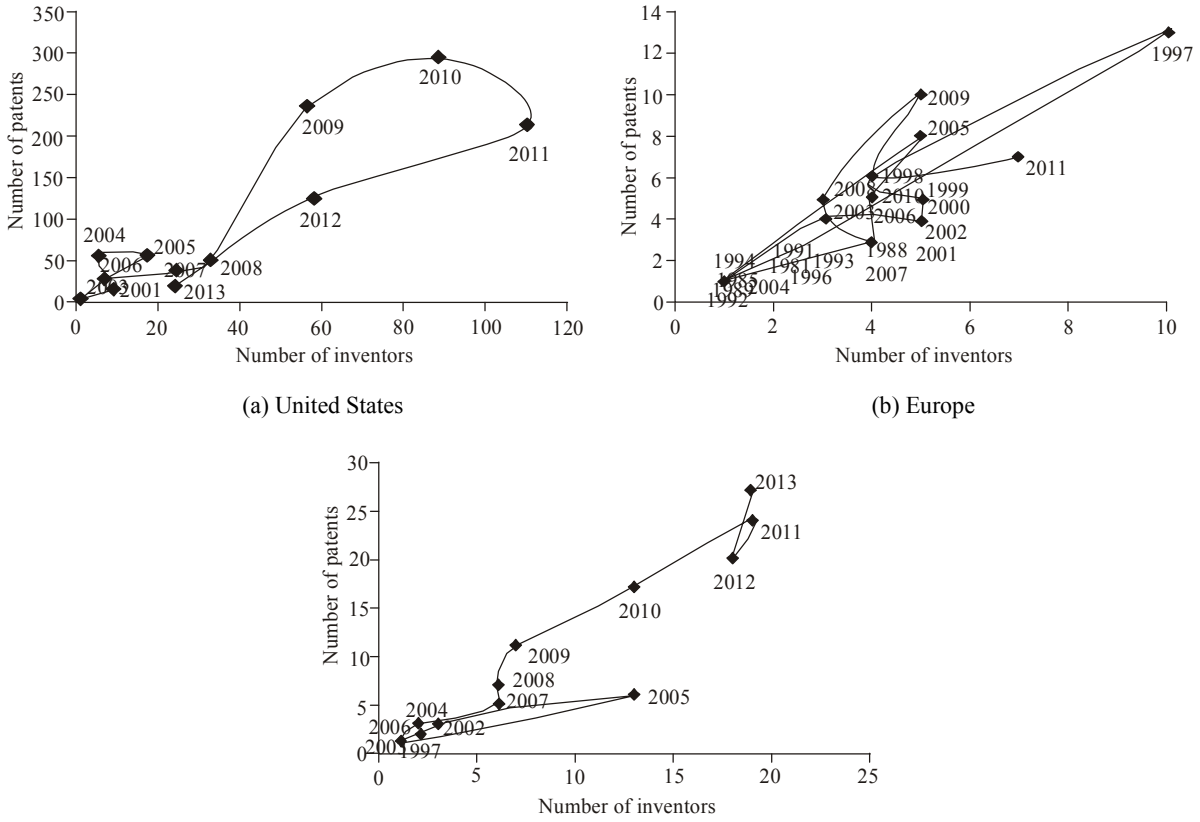


Fig. 7: GM soybean technology life circle

entering the technical recovery period. The number of GM soybean patent applicants and patents is in overall upward trend, indicating that GM soybean technologies in our country are in development period (Fig. 7).

INDICATIONS FOR GM SOYBEAN TECHNOLOGY DEVELOPMENT IN OUR COUNTRY

Comparison of patented technologies in china and foreign countries: From the analysis of current situation of patented GM soybean technology, developed countries started early and own mature technology in this field, especially the United States who owns absolute leading edge technologies in the field. The GM soybean technologies in China still have a long way to go. China is the country of origin and birthplace of soybean which has 5,000 years of cultivation history. Before 1996, China had been a net exporter of soybeans, but with the opening up of vegetable oil market, the rapidly increasing demand for protein-rich soybean and its products and the commercialization genetic modification technology, now China has already become the world's largest importer and consumer of GM soybean, which seriously impacts our country's soybean market (Zhang and Li, 2012):

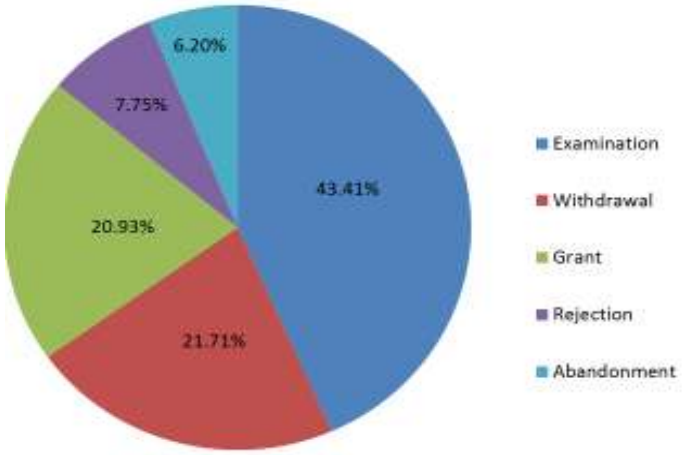


Fig. 8: Legal status of GM soybean patents in our country

- From the view of legal status of the patents (Fig. 8), only 20.93% of all retrieved patent applications in our country have been authorized and 43.41% are in review process, indicating a disadvantage in intellectual property rights related to GM soybean.
- From the view of technology areas, foreign breeders have advantages in breeding, but China is still relatively weak in GM soybean breeding. Among all relevant patents, 35% are concentrated on GM soybean testing, 18% are concentrated on GM soybean utilizations, patents of key technologies directly related to GM soybean breeding account for a lower proportion and are more dispersed.
- From the view of R and D strength, enterprises take up the main part in foreign companies, but mainly research institutes and universities carry out GM soybeans research in our country, accounting for 66% of retrieved patents. Patents applied by enterprises focusing GM soybean are mainly concentrated in GM soybean utilization and testing, with lower level of technological innovation. This R and D pattern is not conducive to the utilization and promotion of technological achievements related to GM soybeans in our country.
- From the view of patent strategy, Monsanto, Bayer, BASF and other multinational companies in the world have stepped up efforts to protect the intellectual property rights of genetically modified seeds and have laid out their plans in our country. From the view of patents applied by multinationals in our country, these patents involve mainly in GM soybean breeding and relevant technologies with key and source type features, which have obviously hindered the development of GM soybean in our country. Coupled with the fact that domestic research and development of GM soybeans lags behind, study on GM soybean is still in research stage and there is no GM soybean varieties independently developed by ourselves having been put into production. With large-scale cultivation of GM soybeans all over the world, China's international competitiveness in soybean industry declines sharply.

Indications for GM soybean technology development in our country: The retrieval, counting and analysis of GM soybean patent intelligence in the United States, Europe, China and other countries and regions show that, the United States and Europe conduct key areas of GM soybeans Research and development, especially the United States represented by 5 multinational companies including Monsanto and DuPont which have taken up the current 80% of the world's genetically modified crops. They basically monopolized the core GM soybeans technologies, while China as a large soybean importer is still weak in technology strength and lacks of core patent achievements. All of the facts are extremely unfavorable to the guarantee of the sustainable development of our agriculture and food security. China should strengthen the research and development of GM soybean from the following aspects.

China should firstly strengthen the strategic deployment of GM soybean technology development closely based on the security strategy and the actual needs of food and carry out the research and development of key technologies in genetic engineering and plant regeneration and tissue culture areas, in order to develop anti-stress, high-fat, high-protein soybean suitable for China's development needs; secondly, introduce measures encouraging the close integration of research institutes and enterprises so as to promote the establishment of the GM soybean technology innovation system with enterprises as the main body; thirdly, enhance the layout of intellectual property rights of GM soybean, highlighting the importance and future prospects fundamental research, focusing on

quality improvement of soybean genes to get original patent, in order to gain the upper hand in the future competition in GM soybean field.

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