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A STUDY ON THE DIFFERENT STAGES OF THE PLANT BIOTECHNOLOGY INDUSTRY AND THE CONCENTRATION OF THE GLOBAL SEED MARKET

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ABSTRACT

This study aims to analyze the structural changes experienced by the seed industry in the face of the development, patenting, and commercialization of genetically modified organisms (GMOs). We use the classification codes defined by the Cooperative Patent Classification (CPC) to categorize a bank of 7,221 biotechnological patents into three technological fields: i) enabling technologies, ii) genetic sequences, and iii) germplasm. The article also outlines a timeline of plant biotechnologies to visualize the evolution over the 1982–2013 period of patent filings in each of the three technological fields. The results revealed that, as of 2006, much of the research efforts dedicated to GMOs were redirected from molecular biology techniques to traditional plant breeding programs in an attempt to strengthen corn, soybean, and cotton germplasm banks. Monsanto and Dupont's increasing control over these germplasm banks has contributed to ensuring competitive advantages in the commercialization of GMOs and restricting the spread of transgenic seeds developed by rival firms. It is concluded that such competitive advantages expanded the market share of the two companies, increasing the concentration level of the seed industry in the first half of the 2010s.

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INTRODUCTION

The sowing of soybean seeds tolerant to the herbicide glyphosate started in the U.S. in 1996. Since then, a global process of sturdy growth of the area dedicated to the cultivation of genetically modified organisms (GMOs) and, consequently, of the world market for transgenic seeds has been observed. In just 23 years, the world area dedicated to GMO cultivation went from 1.7 million hectares in 1996 to 191.7 million hectares in 2018, with strong advances each year. In 2018, approximately 55% of the world's agricultural areas were cultivated with GMOs (ISAAA, 2018). James (2014) estimates that transgenic seeds moved US$117.9 billion globally in the 1996–2013period. In 2013 alone, this figure reached US$15.6 billion, which corresponds to 35% of the global seed market (estimated at US$45 billion for the same period). Graff, Rausser, and Small (2003) identify three groups of assets needed for the development of new GMOs: i) enabling intermediate technologies, ii) genetic sequences and genetically coded attributes, iii) germplasm. Enabling technologies consist of the research tools necessary for the creation of GMOs. Such technologies are the genetic engineering techniques used to transfer DNA from other species to plant cells and regulate the expression of exogenous DNA fragments inside host cells (Graffet al., 2003). Nucleic sequences provide the genetic basis for new agronomic and non-agronomic functionalities. The first relates to attributes that alter the allocation of inputs during the agricultural production process and are therefore called input traits. In contrast, the non-agronomic attributes (output traits) consist of nucleic sequences designed to promote qualitative changes in agricultural products grown from transgenic seeds. For example, we can note the improvement of the nutritional content of plants and the development of new varieties for medicinal purposes. In addition, according to Graff, Rausser, and Small (2003), the elite germplasm group constitutes the hardware of the GMO. These are the host agronomic varieties that will have fragments of exogenous genetic material inserted into their genotype. Investments in plant biotechnology research and development (R&D) began in the U.S. during the first half of the 1980s. During this period, various transgenic techniques appeared, derived directly from the technology of recombinant DNA, which created the conditions for obtaining new agronomic functionalities through the manipulation of the genetic code of plants (Kalaitzandonakes and Bjornson, 1997). These technologies, classified as "general purpose technologies" (Feldmanand Yoon, 2012), paved the way for the establishment of the technological paradigm of molecular biology in agriculture, which has attracted large investments in the last three decades. In this context, the present study presents two central objectives: i) to draw a timeline capable of revealing the temporal evolution of the main agricultural biotechnologies necessary to obtain GMOs, and ii) to discuss the structural changes experienced by the seed industry in view of the strategies for the development and patenting of new technologies within organizations trading GMOs. To attain these objectives, the present study used the classification codes defined by the Cooperative Patent Classification (CPC) to categorize the documents that are part of the biotechnological patent bank built by Ferrari, Silveira, and Dal-Poz (2021) into three groups: i) enabling technologies, ii) genetic sequences, and iii) germplasm. This procedure allows for the analysis of the temporal evolution of the three technological fields, essentially through the account of patents belonging to each group in different periods. In parallel to the technological categorization, the study also gathers information about the main holders of patent documents. In addition to this introduction, the article presents three sections. Section II describes the patent bank of Ferrari, Silveira, and Dal-Poz (2021), as well as the process of producing patent data. The results are presented in Section III, which analyzes three distinct steps associated with the development of plant biotechnologies. Section IV concludes the study, highlighting the main results obtained by empirical research and the reflections that emerged throughout the elaboration of this article.

RESEARCH ELABORATIONS METHODS

Ferrari, Silveira, and Dal-Poz (2021) performed several patent searches in the database of the United States Patent and Trademark Office (USPTO). The searches gave priority to patent documents that claim a type of biotechnological tool called a "promoter." This term refers to DNA sequences that instruct plants to initiate the gene expression process (Périer, Junier,and Bucher, 1998). In addition to this procedure, the authors conducted searches for additional patents based on the names of companies active in the seed industry to identify other key technologies for the development of transgenic seeds. These searches gave rise to a bank of 7,221 patents that were granted by the USPTO between 1976 and 2013. The present study imported the patent database obtained by Ferrari, Silveira, and Dal-Poz (2021) using VantagePoint™ software. The tools provided by the software facilitated the classification of intellectual property documents according to the technological subclasses provided by the taxonomies of the CPC and the International Patent Classification (IPC/WIPO). In the mid-2000s, the USPTO and the European Patent Office (EPO) reached an agreement to develop a joint system for classifying the technological content of patents. The result of these efforts was the CPC publication which began to exhibit a much higher level of technological detail in relation to the IPC[1]. In brief, the present study used the classification codes defined by the CPC to categorize patents into six major technological groups: i) enabling technologies;ii) attributes encoded by genetic sequences; iii) germplasm; iv) peptides; (v) other technologies; and vi) methods of identification of nucleic sequences in plants. In addition to the technological classification, the patents were also grouped according to the date of the USPTO grant, which allowed the comparison of the research efforts conducted in different periods. In addition to this timeline related to plant biotechnologies, the VantagePoint™software was also used to organize information regarding the ownership of patent documents.

[1]For a more detailed discussion about the advantages of using the CPC over the IPC in studies based on patent data, we suggest reading Ventura et al. (2013).

RESULTS

Table 1 highlights the importance of molecular biology for modern agriculture. For over more than three decades, companies working on the development of plant biotechnologies have directed much of their efforts to research the amino acid chains that make up the molecular structure of plants' DNA. Consequently, during all the periods covered by the analysis, the peptides technological subclass (represented by CPC C07K14325) occupied a prominent position in the R&D investments made by the seed industry. Moreover, the timeline of plant biotechnologies presented in Table 1 allowed the identification of the three different stages that characterized the development and commercialization of GMOs: i) pre-commercial phase; (ii) commercial phase; and iii) post-commercial phase.

Pre-commercial phase (1982–1995): The pre-commercial phase is directly associated with the development of enabling technologies. The analysis of Columns 4 and 5 in Table 1 revealed that patent deposits made in the 1982–1995 period aimed to protect the transgenic techniques used to transfer DNA from other species to plant cells. During this time, the main methods employed to insert transgenes in plants by biological means (e.g., agrobacterial intermediation) or by genetic engineering techniques based on cell bombardmentwere registered. The development of biotechnological tools that act on the processes of gene expression, such as markers, promoters, and molecular mechanisms designed to improve the efficiency of biochemical processes of DNA transcription and RNA translation, is also observed in this period.

The composition of the world seed market during the pre-commercial phase reflects some characteristics inherited from previous decades. The period from the 1960s to the 1980s is characterized by the existence of a clear separation between the agrochemical sector and the seed industry. Table 2A shows that until the first half of the 1990s, the world seed market was occupied mainly by companies specialized in the production of agricultural cultivars. Except for the Swiss group Novartis[2] and Shell Nickerson, the corporations listed in Table 2A have never held prominent positions in the agrochemical market. Furthermore, the concentration of the sector was relatively small;in 1996, the nine largest seed-producing companies dominated 16.70% of the world market. For the most part, large agrochemical corporations showed a certain disinterest in the seed industry during the 1960s and 1970s. This scenario began to change in the early 1980s. The environmental problems caused by the use of chemicals in agriculture spread a feeling of rejection against agricultural pesticides throughout society. The motivation to move towards plant biotechnology in the 1980s was precisely to face the threats caused by environmental problems (Possas, Salles-Filho, and Silveira, 1996). As a result, the first discoveries involving plant biotechnologies conducted by Monsanto and Novartis dates back to this period. For this reason, the analysis of the technological composition of patents filed in the 1982–1995period reveals the concern of firms in the development of first-generation GMOs[3]. According to Table 1, even in the pre-commercial phase, R&D projects prioritized acquiring technologies aimed at obtaining agronomic attributes, especially proteins capable of making plants resistant against pests or tolerant in relation to the application of the herbicide glyphosate. As Rausser (1999) points out, the first generation of transgenic products was developed to merge the seed industry with the agrochemical sector. The protection of the herbicide Roundup™, the basis of which is the chemical compound glyphosate, represented a strong stimulus for Monsanto to enter the market of transgenic seeds. The expansion of the market share obtained by glyphosate-tolerant seeds tended to concomitantly stimulate Roundup™ sales and vice versa.

[2]The merger of Sandoz and Ciba Geigy in 1996 gave rise to Novartis. Later, Syngenta was created in 2000 through the merger of the agricultural divisions of Novartis and Astra Zeneca.

[3]Cultivars that carry genetic sequences capable of encoding herbicide tolerance or resistance against pests and insects are called first-generation GMOs (DE JANVRY et al., 1999).

Table 1: Classification of patents according to the most frequent technological fields (percentage of patents belonging to a given technological field in relation to total patent deposits in the same period)

Technological fields	CPC subclasses	Time Frame	1982–1990	1991–1995	1996–2000	2001–2005	2006–2012
		Total of Patents	112	661	1273	1637	3040
1 Enabling Technologies							
Constitutive Promoters	C12N158222; C12N158223; C12N158225; C12N158226; C12N158227; C12N158229;	529	16.0%	12.4%	8.5%	3.8%	0.6%
Methods of control and regulation of the gene expression process	C12N158216	480	11.6%	13.5%	11.9%	7.4%	3.5%
Markers	C12N158209; C12N15821; C12N158212	232	7.1%	3.3%	5.4%	4.3%	2.1%
Gene insertion via agrobacterium	C12N158205	185	17.0%	3.6%	4.3%	2.7%	1.4%
Gene insertion through particle bombardment	C12N158206; C12N158207	163	12.5%	6.5%	4.9%	1.6%	0.5%
2 Attributes Encoded by genetic sequences							
2.1 Non-agronomic attributes							
Changes in carbohydrate or sugar level	C12N158245; C12N158246	411	7.1%	9.6%	7.1%	4.1%	3.0%
Changes in lipid metabolism	C12N158247	373	1.8%	7.4%	7.5%	6.6%	3.9%
Plants with pharmaceutical applications	C12N158257; C12N158258	339	0.9%	2.7%	3.9%	5.3%	1.4%
2.2 Agronomic attributes							
Resistance against pests and insects	C12N158281; C12N158282; C12N158283; C12N158285; C12N158286	988	34.2%	24.7%	13.6%	6.8%	4.7%
Herbicide tolerance	C12N158274; C12N158275; C12N158277; C12N158278	457	16.1%	11.5%	10.1%	5.9%	4.6%
Drought tolerance	C12N158271; C12N158273	339	2.7%	1.2%	3.5%	7.1%	5.5%
Male-sterility	C12N158287; C12N158289; C12N15829	291	3.6%	10.0%	6.0%	5.0%	2.1%
3 Germplasm							
Cultivars	A01H510	2084	1.8%	3.2%	2.9%	16.6%	57.7%
4 Peptides							
Peptides with more than 20 amino acids for plants	C07K14415	1189	17.9%	28.7%	22.2%	21.1%	11.5%
Crystals from the protein *Bacillus thuringiensis*	C07K14325	278	5.4%	11.3%	6.0%	3.5%	2.1%
5 Other Technologies							
Industrial enzymes: lyase; transferase	C12N0988; C12N091029	418	6.3%	12.1%	8.9%	7.4%	3.2%
Technologies associated with the production of fatty oils	A23D09; C11B01	379	0.0%	2.0%	2.3%	2.0%	10.0%
6 Methods of identification of nucleic sequences in plants	C12Q016895	124	0.9%	1.2%	1.8%	2.1%	1.9%

Source: Author's elaboration from the use of VantagePoint™ software

Table 3 shows that in parallel to the agrochemical corporations Monsanto and Novartis, three biotech-based companies (Calgene, Mycogen, and Plant Genetic Systems) and two seed companies (Pioneer and Dekalb) played a prominent role in the research carried out during the pre-commercial phase of GMOs. According to De Janvry et al. (1999), the interest of U.S. universities in research about technologies applicable to agriculture began during the end of the 1970s and the beginning of the 1980s.

The authors point out that the scientific efforts carried out by academic institutions stimulated the creation of several biotechnology-based companies (BBC). Given this scenario, Calgene emerged as the main holder of agricultural biotechnology patents deposited in the 1982–1995period. The company represents a spin-off of the University of California – Davis (UCD). The research conducted by Comai, Sen, and Stalker (1983) in USD's department of molecular biology gave rise to the first patents obtained by Calgene in

Table 2. Evolution of the participation of the largest companies in the total world seed market (includes traditional seeds and GMOs)

2A - Pre-commercial phase considering the years 1985 and 1996

1985			1996		
Company	Net Sales (US$ million)	% World seed market	Company	Net Sales (US$ million)	% World seed market
PIONEER	735	4.10%	PIONEER	1500	5.00%
SANDOZ	290	1.60%	NOVARTIS	900	3.00%
DEKALB	201	1.10%	LIMAGRAIN	650	2.20%
ASGROW	200	1.10%	ADVANTA	460	1.50%
LIMAGRAIN	180	1.00%	SEMINIS	375	1.30%
SHELL NICKERSON	175	1.00%	TAKII	320	1.10%
TAKII	175	1.00%	SAKATA	300	1.00%
CIBA GEIGY	152	0.80%	KWS	255	0.90%
VANDERHAVE	150	0.80%	DEKALB	250	0.80%
Participation of the 9 largest companies		12.50¨%	Participation of the 9 largest companies		16.70%

2B - Commercial and post-commercial phases considering the years 2009 and 2012

2019			2012		
Company	Net Sales (US$ million)	% World seed market	Company	Net Sales (US$ million)	% World seed market
MONSANTO	7297	17.40%	MONSANTO	9800	21.80%
DUPONT	4700	11.20%	DUPONT	7000	15.60%
SYNGENTA	2564	6.10%	SYNGENTA	3200	7.10%
LIMAGRAIN	1155	2.80%	LIMAGRAIN	1700	3.80%
KWS	920	2.20%	L&L WINFIELD	1300	2.90%
BAYER	645	1.50%	KWS	1300	2.90%
DOW	635	1.50%	DOW	1000	2.20%
SAKATA	485	1.20%	BAYER	400	0.90%
LAND O' LAKES	N/D	N/D	SAKATA	400	0.90%
Participation of the 9 largest companies		44%	Participation of the 9 largest companies		58.1%

Source: European Parliament; Directorate-general for Internal Policies (2013)

Table 3. Top ten patent holders in each period

Pre-commercial phase 1982-1995 (773 patents)			Commercial phase 1996-2005 (2,913 patents)			Post-commercial phase 2006-2012 (3,548 patents)		
Original Holder	Patents	Patents %	Original Holder	Patents	% Total	Original Holder	Patents	% Total
CALGENE	74	9.57%	PIONEER	449	15.4%	MONSANTO	1462	41.21%
MONSANTO	67	8.67%	MONSANTO	411	14.1%	DUPONT	905	25.51%
PIONEER	65	8.41%	DUPONT	276	9.47%	STINE SEED FARM	295	8.31%
MYCOGEN	59	7.63%	SYNGENTA	141	4.84%	SYNGENTA	159	4.48%
NOVARTIS AG	55	7.12%	STINE SEED	78	2.68%	DUPONT	136	3.83%
ZENECA	38	4.92%	BASF	78	2.68%	BASF	114	3.21%
HOECHST	32	4.14%	BAYER	77	2.64%	BAYER	101	2.85%
CIBA GEIGY	28	3.62%	CALGENE	73	2.51%	SEMINIS	69	1.94%
PLANT GENETIC SYSTEMS	27	3.49%	NOVARTIS	57	1.96%	DOW	50	1.41%
DEKALB	24	3.10%	DOW	36	1.24%	AGRIGENETIC	37	1.04%

Source: Author's elaboration employing the VantagePoint™ software

the 1980s. The initial protagonism of this BBC (as well as Mycogen, a BBC founded by biochemistry professor Andrew C. Barnes in 1982) in the pre-commercial phase of GMOs represents favorable evidence of the importance of American universities in establishing the molecular biology paradigm in agriculture.

Commercial phase (1996–2005): The commercial phase of GMOs began with the planting of the first genetically modified soybean, corn, and cotton seeds in 1996. It extends until 2005. Over the course of the aforementioned decade, R&D efforts pertaining to new plant biotechnologies prioritized projects associated with obtaining marketable products. This period is characterized by the strong growth in thepatenting of genetic sequences designed to promote changes in plant physiology. During the commercial phase, the absolute growth of patents protecting technologies that codify herbicide tolerance or insect resistance in plants can be detected. However, the analysis inTable 1 reveals a decreasing percentage of patents related to first-generation GMOs in relation to total patent deposits in the 1996–2005period. This last event represented a reflection of the emergence of new technologies capable of causing other types of changes in plant cells. Consequently, the growth of patents that claim nucleic sequences capable of expressing non-agronomic attributes is observed, especially: i) changes in the lipid metabolism of plants capable of modifying the fatty acid content in vegetable oils; and ii) improvement of the nutritional content of plants (changes in the levels of sugars, carbohydrates, and amino acids). Table 3 suggests that during the commercial phase, large agrochemical companies (Monsanto, Dupont, Syngenta, Dow, Bayer, and BASF) intensified their in-house R&D efforts aimed at the development of plant biotechnologies. These corporations have also adopted an aggressive policy of acquiring BBCs and seed companies. Among the various mergers and acquisitions (M&A) transactions that occurred in the 1990s are Monsanto's acquisition of Calgene and Dekalb, the merger of Pioneer withDupont, and Dow's purchase of Mycogen. As a result of these events, large multinationals from the agrochemical sector held control of most patents that claimed, in the early 2000s, plant biotechnologies developed in previous decades.

The entry of the "Big Six" companies into the world seed market after the start of the commercialization of GMOs in 1996 forever changed the structure of this economic segment. The domination of the ownership of biotechnological patents (Table 3) was followed by market leadership, as revealed in Table 2B. This implies that the M&A transactionsin the 1990s and 2000s successfully coupled the seed industry with the world's leading agrochemical sector, which generated a strong concentration of the global seed market.

Post-commercial phase: The post-commercial phase began in 2006 and extends to the present. During this period, the focus of R&D efforts dedicated to GMOs has undergone strong changes. According to Table 1, research related to the amino acid chains that make up the molecular structure of plant DNA lost ground in the most recent period. At the same time, there has been an absolute decrease in patent deposits related to first-generation GMOs. On the other hand, patenting activities have begun to prioritize the developmentof new soybean, corn, and cotton cultivars. Consequently, the vast majority of patents obtained in the post-commercial phase belong to the germplasm group (CPC number A01H510). These data suggest that much of the R&D efforts performed by companies have been redirected from molecular biology techniques to plant breeding programs based on traditional cultivation and selection methods. The cultivars protected by the patents that are part of the germplasm group were obtained mainly through cross-hybridization procedures, which employ, as genetic donors, several agronomic varieties carrying the transgenes developed during the commercial phase. The transgenic strains were crossed with each other and with non-transgenic varieties belonging to local germplasm banks.

The specialized literature denominates the cultivars obtained through cross-hybridization techniques that carry multiple attributes of transgenic originas stacked GMOs. We can cite as an example plants tolerant to various types of herbicides and seeds that reconcile resistance against insects and tolerance to herbicides. One of the most important characteristics of the post-commercial phase is the growth of stacked GMO planting. In 2006, seeds carrying multiple attributes of transgenic origin were planted on 13.1 million hectares (12.85% of the area planted worldwide with transgenic plants). In 2018, the stacked GMOs occupied 80.5 million hectares, equivalent to 42% of the world's area dedicated to the cultivation of genetically modified plants (ISAA, 2018). A joint analysis of Table 1 and Table 3 suggests that the reorientation of research projects in the sense of prioritizing the patenting of cultivars resulted from strategic decisions implemented by Monsanto and Dupont. The ownership of the 1,733 germplasm patents granted by the USPTO during the post-commercial phase (57% of the 3,040 patents granted between 2006–2012 – Table 1) is, as suggested in Table 3, concentrated in the hands of Monsanto and Dupont. From the perspective of these two companies, the strengthening of germplasm banks would ensure access to genetic material that can be used in cross-hybridization processes involving transgenic donors and traditional lineages. The expansion of the possibilities of crosses between agronomic varieties represents, consequently, a key condition for obtaining competitive advantages in the development of stacked GMOs.

In practical terms, Monsanto has adopted several measures to strengthen its portfolios of agronomic varieties: i) the reorientation of research projects carried out internally to prioritize the patenting of cultivars; ii) the development of new soybean varieties in partnership with Stine Seed Farm[4]; and iii) the acquisition of seed companies, particularly, Delta & Pine Land Company in 2006—a company that held 50% of the U.S. cotton seed market at the time of the merger. In turn, by taking control of Pioneer, Dupont acquired control of the world's largest corn germplasm bank. In parallel to the search for competitive advantages in the commercialization of stacked GMOs, these strategies also aimed to impose restrictions on the development of new GMOs by competitors. From this perspective, the increasingly exclusive control of Monsanto and Dupont over the agronomic varieties capable of performing the function of host for transgenic origin attributes aimed to block the access of rival firms to the main sources of germplasm used to obtain new genetically modified seeds (Ferrari, Silveira,and Dal-Poz, 2021). The success of this strategy of building barriers to other companies has caused Monsanto and Dupont's participation in the global seed market to expand in the last two decades. As shown in Table 2B, in 2009, the two companies jointly held 28.6% of this market, while this accumulated share increased to 37.4% in 2012. The growth of Monsanto and Dupont's market share caused the industrial concentration to rise over the same period. In 2009, the nine largest seed-producing companies held 44% of the sector's worldwide revenues, and this share jumped to 58.1% in 2012. It seems that Monsanto and Dupont's increasing control over the major soybean, cotton, and corn germplasm banks has managed to restrict the spread of developed and marketed GMOs from the other members of the "Big Six"group. Thus, the other members of the group assumed a minor position in the plant biotechnology and seed industry throughout the 2000s and the first half of the 2010s. Bayer developed new GMOs from 2009 to 2012. Despite this fact, the company's global market share decreased over the same period (Table 2B). The German company only became a major player in the seed industry after Monsanto's acquisition in 2018, a $63 billion purchase. Similarly, Dow was only able to expand its relevance in this economic segment after merging with Dupont in 2015. In turn, BASFwas the last agrochemical company to enter the transgenic seed market. To date, the company has not been able to secure access to quality germplasm banks through internal plant breeding programs or M&A activities. Not by chance, BASF has never been featured among the world's seed producers

CONCLUSION

The main studies published between the late 1990s and the first half of the 2000s had already identified the pre-commercial and commercial stages that characterize the evolution of the plant biotechnology industry (Kalaitzandonakesand Bjornson,1997; De Janvryet al., 1999; Graffetal., 2003). In a way, this article gathered new evidence favorable to the arguments present in such preliminary analyses. In this sense, the proof that the R&D projects conducted by the "Big Six"companies during the 1980s and 1990s prioritized the development of technologies capable of making plants resistant against pests or tolerant in relation to herbicide application represents evidence consistent with the results obtained by Graff et al. (2003). The main contribution of this article to previous studies is pointing out the existence of a third, post-commercial, phase associated with the plant biotechnology industry that begins in 2006 and extends until present. During the post-commercial phase, the focus of R&D projects dedicated to GMOs has undergone significant changes. Much of the research efforts were redirected from molecular biology techniques to plant breeding programs based on traditional cultivation and selection methods. In this period, an intensification of the patenting of cultivars and an increase in the cultivation of stacked GMOs, which exhibit multiple attributes of transgenic origin, are observed. The transition from the commercial to the post-commercial phase occurred mainly due to the strategies implemented by Monsanto and Dupont during the 2000s and 2010s that aimed to gain competitive advantages in the development and commercialization of stacked GMOs. These strategies have also succeeded in restricting the market penetration of seeds that carry agronomic attributes developed by rival firms. Thus, this article provides explanations for the growth inthe concentration of the sector in the first half of the 2010s.

However, the article has an important limitation regarding the period of analysis. The patent bank of Ferrari, Silveira, and Dal-Poz (2021) is composed of intellectual property documents (IPD) granted by the USPTO between 1976 and 2013. This implies that the database does not cover the large M&A transactions that took place in the second half of the 2010s and completely modified the seed and agrochemical industries: i) the merger between Dupont and Dow in 2015 and the subsequent dismemberment of the company's agricultural division in 2018, which gave rise to a new company called Corteva; (ii) the acquisition of Syngenta by state-owned company ChemChina in 2016; and iii) Bayer's purchase of Monsanto, which was completed in 2018. In observing these events, we suggest, for future studies, the construction of a new patent bank including documents granted by the USPTO from 2014. We believe that the application of IPD classification methods used in this study to the latest biotechnological patents could provide a satisfactory answer to an important question that remains valid to this date: how have the M&A activities that have

[4]The Stine Seed Farm has the largest portfolio of soybean varieties in the U.S. (Forbes, March 26, 2014).

disrupted the seed industry since 2015 affected GMO development, patenting, and marketing strategies?

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