Journal of Intellectual Property Rights
Vol 28, November 2023, pp 529-543
DOI: 10.56042/jipr.v28i6.4043

Trends and Patterns of Patent in Agriculture and Allied Sector

Md Ejaz Anwer†, Subash Surendran Padmaja and Ankita Kandpal

ICAR-National Institute of Agricultural Economics and Policy Research, DPS Marg, Pusa, New Delhi—110 012, India

Received: 4th April 2020; revised: 17th July 2023

The present study addresses a knowledge gap by examining global and domestic patent trends in the agriculture sector, with a focus on leading agriculture patenting countries like India, China, and North America. The analysis, spanning from 1990 to 2022 and covering 37 leading agricultural countries, reveals a significant increase in global patent filings across diverse categories, even in the post-pandemic era. Southeast Asia, led by China, emerges as the primary region for agricultural patents globally, followed by North America. China exhibits substantial growth and becomes the leading country in patent filings, while the USA experiences a decline in 2022. India's representation in agricultural patents consistently declines, and sector-specific analysis underscores the importance of chemical compounds and fertilizers, animal husbandry, machinery and implements, horticulture, and new plants in patent filings. The slow progress in agricultural patenting in India highlights the need for a greater focus on technological advancements, research and development investment, protection of agricultural innovations, reduced reliance on imported technology and innovations, and enhanced collaboration. To address these challenges, it is crucial to prioritize agricultural research and development, incentivize innovation through intellectual property protection, and increase investment in research and development, and foster collaboration between the public and private sectors.

Keywords: Agriculture, Patents, Innovations, Intellectual Property, Post-Pandemic, India, China, North America, PCT-WIPO, EAPO, EPO

Indian agriculture, especially in the post-pandemic period, will witness a heightened focus on technology, sustainability, and digitalization. The patent landscape in the sector will undergo changes to address new challenges and priorities. It is imperative for policymakers, researchers, and stakeholders to collaborate and ensure that the patent system supports inclusive growth, technology dissemination, and sustainable agricultural practices after the pandemic.

Additionally, it is widely recognized as a significant factor influencing economic growth and productivity.[1] The patterns and trends observed in patent activity can be utilized for technology forecasting and shaping policies, particularly in developing nations.[2] In the present study, we conducted an analysis of patent patterns and trends in the agriculture and allied sectors across different global regions, specifically focusing on major agricultural patenting countries such as India, China, and North America. Our aim was to assess the level of technological advancement in these fields, particularly in the period from 1990 to 2022, with a specific emphasis on the post-Covid-19 era.

†Corresponding author: Email: dr.ejaz2011@gmail.com

A patent is a type of legal protection for intellectual property that grants exclusive rights to an inventor for a certain period, allowing them to reap the benefits of their invention. It serves as a means to incentivize innovation and attract greater investment in research and development (R&D) activities. Patent rates and patent propensity are employed as indicators to gauge the level of technological advancements.[3]

Patenting in the agriculture sector is limited to few domains. Because, prior to TRIPS, the Indian Patent Act of 1970 permitted process patents but excluded plants, animals, and pharmaceuticals.[4] After the establishment of the World Trade Organization (WTO), its member countries under TRIPS (Trade-Related Aspects of Intellectual Property Rights) agreed on harmonizing Intellectual Property protection and enforcement standards among the member nations. Consequently, the newer mechanism such as protection of plant (propagation materials)or plant varieties under plant variety protection or plant breeders' rights (PBRs) emerged and this schemehave been widely recognized and acknowledged by countries.[5]For other non-biological items (chemicals, foods and drugs) which were previously not under the patent laws were also brought under the patent regime.

The changes in regulations related to agriculture patenting have led to a significant rise in the number of patent filings and grants in the agriculture and allied sectors. Numerous studies have examined the trends in agricultural patenting, focusing on institutes, sectors, or countries level[6] and others have explored the issues and implications of IPR protection and laws.[7] However, across the major agro patenting countries, regions, comparing the trends and patterns of patents, especially after COVID-19 in agriculture is unexplored. In this paper, we have analyzed the trends and pattern in patenting activity during 1990 to 2022across the global regions with different categories of agriculture and allied sector in 37 agriculture patenting countries, with a major focus on India with China and North America along with the post Covid-19 period.

With the following introduction, the paper has been categorized in different sectors. First part of the paper provides the overview of the classification of the IPC (International Patent Classification), which lead to types of IPC. The second section deals with the result and discussion, which provides the trends and pattern of global patenting in agriculture and allied sector across the regions and leading countries of the world. The fourth section emphasizes the category wise trends and pattern of agricultural patents in India and issues and challenges of IPRs related to agriculture. The fifth section concludes the arguments.

Data Sources

There are several databases, which provide information about patents. Among them, World Intellectual Property Organization (WIPO), Google Patents, Free Patents Online, Espacenet and other databases managed by National Patent Office's like United States Patent and Trademark Office (USPTO), Espacenet Patent (EP) Search under European Patent Office (EPO), Indian Patent Office (IPO), Japanese Patent Office (JPO), Chinese Patent Office (SIPO), Korean Intellectual Property Office (KIPO) are open-access databases. Singh et al (2016)[8] provide a detailed discussion about these databases. There are other commercial patent databases such as Thomson Innovation (Thomson Reuters), Orbit (Questel), Total Patent (LexixNexis), Patbase (minesoft), Dialog (ProQuest), STN/CAS(STN), WIPS Global (WIPS), which provides value added data. [9] The databases differ in terms of the patents they include, the types of documentation available, the elements of the documents, the time-periods covered, and additional features such as language translation. In this research, we utilized the WIPO Patentscope database to collect and analyze agriculture patent data from 37 countries. These countries include Morocco, Tunisia, Egypt, South Africa, Dominican Republic, Costa Rica, El Salvador, Cuba, Germany+DDR Data, Denmark, Estonia, United Kingdom, Portugal, Spain, France, Canada, Mexico, United States, Australia, Russian Federation+USSR Data, Argentina, Brazil, Chile, Colombia, Ecuador, Peru, Uruguay, India, Brunei Darussalam, Philippines, Singapore, Vietnam, China, Japan, Republic of Korea, Indonesia, and Malaysia.

IPC Patents Searching Criteria

Field search criteria were used for a combination of International Patent Codes (IPC) in agriculture with country and year (Table 1). For example, the search string would be *IC: A01M AND DP:1990 AND CTR: AR*, where IC refers to the International Patent Codes, such as A01M, DP refers to the date of publications i.e., year of publications (1990), CTR refers to the name of the country; AR (Argentina) (other country codes in Patentscope).

IPC Classification

The data on the number of patents under IPC-classification were aggregated into five sub-categories: (i) Machinery and implements (A01B+A01C+A01D+A01F); (ii) Horticulture (A01G); (iii) New plants/processes for obtaining them (A01H); (iv) Animal husbandry (A01J+A01K+A01L+A01M); and (v) Chemical compounds and fertilizers (A01N+A01P). According to their technical application, structural features, intended use or the resulting product produced by a process.[10] During the data compilation process, we separated the data for conducting agency wise analysis specifically related to patent aggregation agencies such as the European Patent Office (EPO), Eurasian Patent Organization (EAPO), and Patent Cooperation Treaty-WIPO (PCT-WIPO). Additionally, the data from Germany and Germany DDR, as well as the data from Russian Federation and Russian Federation-USSR for the years 1990, 1991, and 1993, were combined and renamed as a new dataset called "Germany" and "Russian Federation," respectively.

The 37 agricultural patenting countries included in this study were categorized into 11 agricultural patenting regions in the world. These regions were identified as follows: Africa (Egypt, Morocco, South

Table 1 — IPC codes in the field of agriculture

IPC codes	Details of the codes
A01B	Soil working in agriculture or forestry; parts, details, or accessories of agricultural machines or implements, in general (making or covering furrows or holes for sowing, planting or manuring (A01C 5/00); machines for harvesting root crops (A01D); mowers convertible to soil working apparatus or capable of soil working (A01D 42/04); mowers combined with soil working implements (A01D 43/12); soil working for engineering purposes (E01, E02, E21)
A01C	Planting; sowing; fertilizing (combined with the general working of soil (A01B 49/04); parts, details or accessories of agricultural machines or implements, in general (A01B 51/00-A01B 75/00)
A01D	Harvesting; mowing
A01F	Threshing (combines A01D 41/00); baling of straw, hay or the like; stationary apparatus or hand tools for forming or binding straw, hay or the like into bundles; cutting of straw, hay or the like; storing agricultural or horticultural produce(arrangements for making or setting stacks in connection with harvesting (A01D 85/00)
A01N	Preservation of bodies of animals or plants or parts thereof (preservation of food or foodstuff (A23); biocides, e.g. As disinfectants, as pesticides or as herbicides (preparations for medical, dental or toilet purposes which kill or prevent the growth or proliferation of unwanted organisms (A61K); pest repellants or attractants; plant growth regulators (mixtures of pesticides with fertilizers' (C05G).
A01G	Horticulture; cultivation of vegetables, flowers, rice, fruit, vines, hops, or seaweed; forestry; watering (picking of fruits, vegetables, hops, or the like (A01D 46/00); devices for topping or skinning onions or flower bulbs (A23N 15/08); propagating unicellular algae (C12N 1/12); plant cell culture (C12N 5/00).
A01H	New plants or processes for obtaining them; plant reproduction by tissue culture techniques
A01J	Manufacture of dairy products (preservation, pasteurisation, sterilization of milk products (A23); for chemical matters, subclass (A23C)
A01K	Animal husbandry; care of birds, fishes, insects; fishing; rearing or breeding animals, not otherwise provided for; new breeds of animals
A01L	Shoeing of animals
A01M	Catching, trapping or scaring of animals (appliances for catching swarms or drone-catching (A01K 57/00); fishing (A01K 69/00-A01K 97/00); biocides, pest repellants or attractants (A01N); apparatus for the destruction of noxious animals or noxious plants
A01P	Biocidal, pest repellant, pest attractant or plant growth regulatory activity of chemical compounds or preparations [2006.01]

Africa, and Tunisia), Caribbean Region (Dominican Republic), Central America (Costa Rica, El Salvador, and Cuba), North America (Canada, Mexico, and the United States), South America (Argentina, Brazil, Chile, Colombia, Ecuador, Peru, and Uruguay), Central Europe (Germany), Europe (Denmark, Estonia, United Kingdom, Portugal, Spain, and France), Southeast Asia (Brunei Darussalam, Philippines, Singapore, Vietnam, China, Japan, Republic of Korea, Indonesia, and Malaysia), South Asia (India), Oceania (Australia), and Russian Federation (Russian Federation + USSR Data).A limitation of this study is that the search criteria relied on IPC codes, which may have resulted in an underestimation of the total number of published patents. However, the overall trends observed align with those of another study.[6,16,24,31] Unfortunately, we were unable to crosscheck or validate our findings with other reviewed studies, as many of them did not disclose the source or approach used to collect their data.

Under the present study, the entire year was divided into four distinct time periods: 1990-2004, 2005-2010, 2011-2019, and 2020-2022. The period from 1990 to 2004 was referred to as the pre-India Patent Period since the Indian patent act was amended and enacted efficiently in2005. The years from 2005 to 2010 were significant as they marked the implementation of the Trademark Amendment Rules of 2010, which aimed to simplify and improve the trademark registration system. These rules introduced various improvements such as the adoption of online filing.[11] To access the latest and most accurate information on trademark rules and procedures in India, it is recommended to refer to the official website of the Indian Intellectual Property Office (IPO) or consult with a qualified legal professional. On the other hand, the period from 2020 to 2022 was referred to as the post-Pandemic Era, during which a multitude of socioeconomic changes were observed.

Global Trends in Patenting in Agriculture and Allied Sector

Over the past decade, there has been a significant increase in the number of patents filed in the agriculture sector. Throughout the period from 1990 to 2022, a total of 2.18 million patent applications were filed in 37 countries in the agriculture and allied sectors, as reported by the World Intellectual Property Organization (WIPO) datasets (Fig. 1). Among the

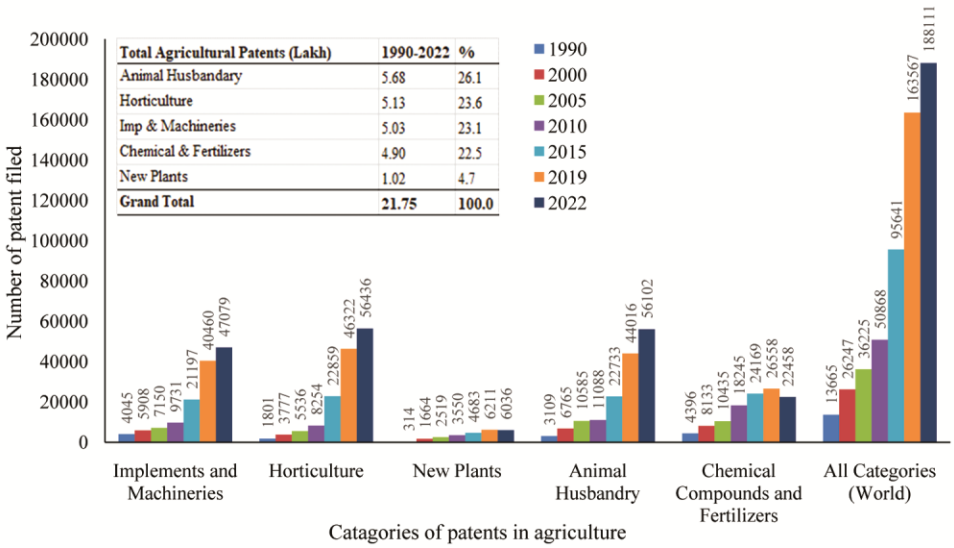

Fig. 1 — Total patents filed in agriculture and allied sector in the world from 1990 to 2022

various sub-categories, the highest number of patents was filed in the field of animal husbandry, amounting to 5,68,000 patents, which accounts for 26.1% of the total. Following closely behind is horticulture, with 5,13,000 patents filed, representing 23.6% of the total. The sub-category of machinery and implements witnessed the filing of 503,000 patents, making up 23.1% of the total. Chemicals and fertilizers accounted for 4,90,000 patents, contributing to 22.5% of the total. Lastly, the field of new plants had 102,000 patents filed, representing 4.7% of the total patents filed worldwide (Fig. 1).

According to Fig. 1, the graph shows a significant rise in the gross number of filed patents of the world over the time. From 1990 to 2005, there was an increase from 13,665 to 36,225 patents. This number further grew to 1,63,567 in 2019. Interestingly, even during the post-Covid-19 period, the filing of patents across all categories continued to increase, reaching 188,111 in 2022 (as shown in Fig. 1), which is quite surprising.

Throughout the entire duration from 1990 to 2022, there has been a remarkable surge in filed patents across various fields. Specifically, the field of horticulture witnessed a substantial increase, with the number of patents rising from 1,801 to 56,436. This was followed by animal husbandry, where the number of patents filed increased from 3,109 to 56,102. Similarly, the field of implements and pieces of machinery saw an impressive growth from 4,045 to 47,079 patents. The areas of chemical compounds and fertilizers experienced a notable rise as well, with patent filings increasing from 4,396 to 22,458. Finally, the field of new plants observed a comparatively smaller but still significant growth, with the number of patents filed increasing from 314 to 6,036.

Analyzing the sub-categories during the post-Covid-19 period from 2020 to 2022 reveals that the majority of patents filed were in the field of animal husbandry, accounting for 29.21% of the total share. Following closely behind is horticulture, with 29.14% of the share. The sub-category of machinery and implements accounted for 24.77% of the patents filed, while chemical compounds and fertilizers made up 13.59% of the total share. Lastly, the sub-category of new plants represented a smaller portion, with 3.29% of the patents filed during that period (Fig. 2).

When analyzing the percentage change in patent filings between the periods of 2011-2019 and 2020-2022, it becomes evident that the horticulture sector and animal husbandry sector experienced the highest changes. In the horticulture sector, the share of patents filed increased from 24.58% during 2011-2019 to 29.14% in 2020-2022, marking a significant rise. Similarly, the animal husbandry sector saw an increase in share, rising from 24.99% to 29.21% during the same time frame. On the other hand, the sectors of machinery and implements and new plants, as well as chemical compounds and fertilizers, had comparatively lower shares of patent filings compared to other sectors. Notably, during the post-Covid-19 period, the share of patent filings in the chemical compounds and fertilizers and

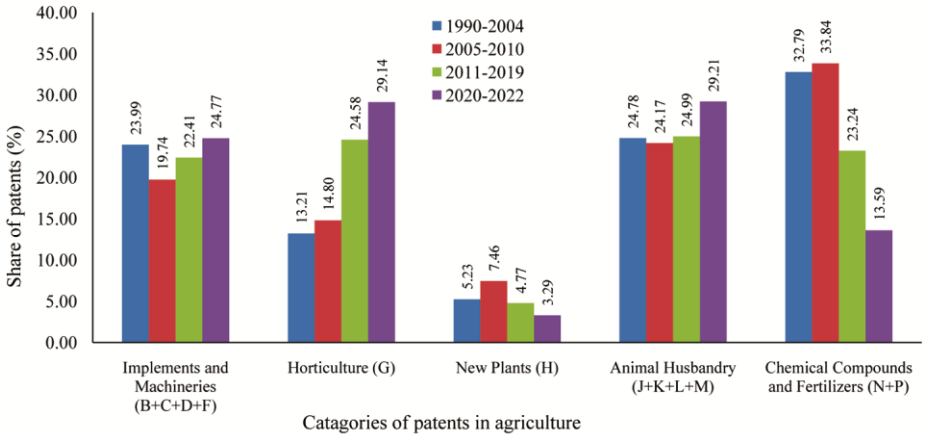

Fig. 2 — Share to total world agriculture patenting

new plants sectors decreased in comparison to other sectors.

The regional analysis of patent filings reveals that Southeast Asia is at the forefront in terms of overall patenting in the agriculture and allied sector, closely followed by North America, South America, Europe, Russia USSR, Central Europe, Oceania, Central America, South Asia, Africa, and the Caribbean Region. When comparing the percentage distribution of patent filings across regions for the years 2020-2022, it becomes evident that Southeast Asia and North America are emerging as the primary regions for agricultural patent filings worldwide during the post-pandemic era.

Nevertheless, in addition to Southeast Asia and North America, there are specific regions that stand out in certain patent filing categories during the post-pandemic era, particularly in 2022. Russia emerges as the top patent filing region for Machinery& Implements, Europe for Horticulture and Animal Husbandry, South America for new plants, and North America for Chemical compounds & fertilizer. It is worth noting that the surge in patent filings in Southeast Asia is primarily driven by China, while in North America, it is largely due to increased patent filings by the USA, both during the post-pandemic period in 2022 (Table 2).[12]

The share of patents in the sectors such as horticulture and animal husbandry, have increased over the period (Fig. 3). However, the share of patents in chemical compounds and fertilizers, new plants and implements, and machinery are continuously decreasing over the period. In 2022, horticulture and animal husbandry contributed the largest share to agriculture patenting followed by machinery and chemical compounds& fertilizers. The decreasing share of patents in chemical compounds and fertilizers and new plants/plant production processes could be attributed to the stringent regulatory norms in these sectors.

Global Trends in Agricultural Patenting across the Regions

Southeast Asia has positioned itself as a prominent global frontrunner in patent filings within the agriculture and allied sector. The cumulative count of patents in this sector has witnessed a significant upsurge in Southeast Asia, rising from 1,151 patents in 1990 to an impressive 1,69,287 patents in 2022 (Fig. 4). This notable increase can be attributed primarily to the heightened level of patenting activities in China. China's surge in patent filings can be attributed to the favorable patenting policies implemented following the era of liberalization, privatization, and globalization that commenced in the 1990s.[4] It is because the China has recently implemented a Foreign Investment Law, effective from 1st January 2020, aimed at establishing an intellectual property (IP) protection framework. The primary objective of this law is to ensure equal protection for both foreign and domestic investors in the Chinese market. It sets the groundwork for multiple institutions, including patent offices, patent law firms, banks, and an IP evaluation agency, to actively promote IP financing and support initiatives in this domain.[13]

Like Southeast Asia, North America has also emerged as the second-largest region for agricultural patent filings worldwide throughout the entire study period. However, its overall share has been consistently decreasing. Despite this decline, North America still maintains its position as the second-largest agricultural patenting region globally (Fig. 4), primarily due to significant contributions from the USA (Fig. 5).

Table 2 — Region-wise and category-wise patents (nos, average & its shares) during 1990-20122

Agricultural category	Global region	1990-2004	2005-2010	2011-2019	2020-2022	1990-2004	2005-2010	2011-2019	2020-2022
		Average patents				Share of average patents			
Machinery and Implements	Africa	29	28	57	5	0.5	0.4	0.2	0.0
	Caribbean Region	0	0	1	1	0.0	0.0	0.0	0.0
	Central America	1	1	4	2	0.0	0.0	0.0	0.0
	Central Europe	513	359	423	620	9.5	4.5	1.7	1.3
	Europe	500	511	518	524	9.2	6.4	2.1	1.1
	North America	1095	1123	1812	2626	20.2	14.1	7.2	5.4
	Oceania	252	150	231	404	4.7	1.9	0.9	0.8
	Russia + USSR	735	660	937	948	13.6	8.3	3.7	1.9
	South America	194	260	226	395	3.6	3.3	0.9	0.8
	South Asia	0	36	110	35	0.0	0.4	0.4	0.1
	Southeast Asia	2097	4860	20842	43407	38.7	60.8	82.8	88.6
	World	5417	7987	25161	48967	100.0	100.0	100.0	100.0
Horticulture	Africa	21	23	9	10	0.7	0.4	0.0	0.0
	Caribbean Region	0	0	1	1	0.0	0.0	0.0	0.0
	Central America	0	1	3	4	0.0	0.0	0.0	0.0
	Central Europe	246	114	135	218	8.2	1.9	0.5	0.4
	Europe	280	310	291	391	9.4	5.2	1.0	0.7
	North America	586	669	1102	1431	19.7	11.2	3.9	2.4
	Oceania	196	103	162	262	6.6	1.7	0.6	0.4
	Russia + USSR	281	222	391	323	9.4	3.7	1.4	0.5
	South America	66	68	84	153	2.2	1.1	0.3	0.3
	South Asia	0	29	71	40	0.0	0.5	0.3	0.1
	Southeast Asia	1307	4451	26136	56212	43.8	74.3	92.1	95.2
	World	2983	5989	28385	59047	100.0	100.0	100.0	100.0
New Plants	Africa	26	42	3	4	2.2	1.4	0.1	0.1
	Caribbean Region	0	0	0	0	0.0	0.0	0.0	0.0
	Central America	0	2	4	7	0.0	0.1	0.1	0.1
	Central Europe	11	6	3	2	0.9	0.2	0.1	0.0
	Europe	53	135	93	77	4.5	4.5	1.7	1.2
	North America	648	1489	1634	1442	54.8	49.3	30.8	23.0
	Oceania	176	156	185	160	14.9	5.2	3.5	2.6
	Russia + USSR	48	30	76	54	4.1	1.0	1.4	0.9
	South America	76	187	214	221	6.4	6.2	4.0	3.5
	South Asia	0	42	74	22	0.0	1.4	1.4	0.4
	Southeast Asia	144	930	3013	4264	12.2	30.8	56.9	68.2
	World	1181	3018	5300	6255	100.0	100.0	100.0	100.0
Animal Husbandry	Africa	36	49	7	6	0.6	0.5	0.0	0.0
	Caribbean Region	0	0	0	2	0.0	0.0	0.0	0.0
	Central America	0	3	2	3	0.0	0.0	0.0	0.0
	Central Europe	289	227	284	373	5.2	2.3	1.0	0.6
	Europe	574	748	609	804	10.3	7.6	2.2	1.4
	North America	1862	2378	2504	2887	33.3	24.3	9.0	5.0
	Oceania	579	308	333	395	10.3	3.1	1.2	0.7
	Russia + USSR	363	334	432	377	6.5	3.4	1.6	0.6
	South America	185	223	154	267	3.3	2.3	0.6	0.5
	South Asia	0	58	98	50	0.0	0.6	0.4	0.1
	Southeast Asia	1707	5455	23361	53123	30.5	55.8	84.1	91.1
	World	5594	9780	27785	58286	100.0	100.0	100.0	100.0

(*contd.*)

Table 2 — Region-wise and category-wise patents (nos, average & its shares) during 1990-20122

Agricultural category	Global region	1990-2004	2005-2010	2011-2019	2020-2022	1990-2004	2005-2010	2011-2019	2020-2022
		Average patents				Share of average patents			
Chemical Compounds and Fertilizers	Africa	212	329	70	33	2.9	2.4	0.3	0.1
	Caribbean Region	0	4	15	22	0.0	0.0	0.1	0.1
	Central America	8	91	89	76	0.1	0.7	0.4	0.3
	Central Europe	407	238	58	88	5.5	1.7	0.2	0.4
	Europe	651	646	972	969	8.8	4.7	3.9	4.0
	North America	2541	4046	3622	2322	34.3	29.5	14.5	9.6
	Oceania	952	692	927	803	12.9	5.0	3.7	3.3
	Russia+USSR	149	241	452	296	2.0	1.8	1.8	1.2
	South America	566	872	1125	1569	7.7	6.4	4.5	6.5
	South Asia	0	373	525	196	0.0	2.7	2.1	0.8
	Southeast Asia	1917	6165	17064	17729	25.9	45.0	68.5	73.6
	World	7404	13696	24919	24103	100.0	100.0	100.0	100.0

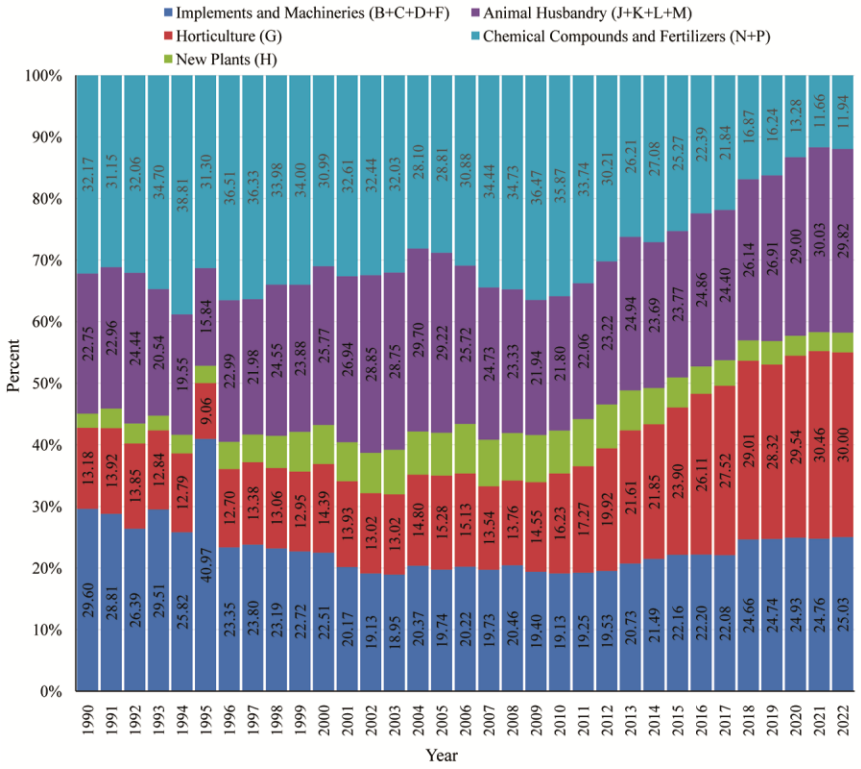

Fig. 3 — Share of global patenting activities during 1990-2022 (11 Regions)

Furthermore, we conducted a comparison of patent filings in the World, China, USA, and India (Table 3). In recent years, there has been a notable increase in patent filings in China when compared to India. In 2005, China accounted for approximately 6,288 patents, which represented around 17.4% of the total global patents. However, by 2022, this number had significantly risen to 155,731 patents, constituting roughly 82.8% of the total world patents (Table 3).

The introduction of TRIPS Agreement under the WTO enforced developing countries to reform their intellectual property laws.[14] TRIPS Agreement aimed at harmonization of IP legislation among all member countries.[15] As a result, the quantity of patent applications submitted in China witnessed a substantial rise from 208 in 1990 to 6,288 in 2005. Moreover, this figure experienced a significant surge, reaching 155,731 by 2022, positioning China as the leading country in terms of patent filings

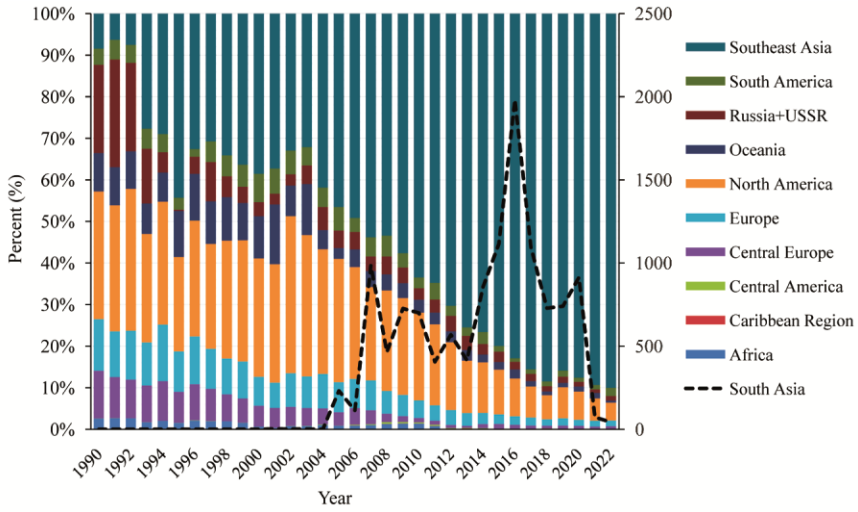

Fig. 4 — Region-wise share of agriculture patents to the total global agriculture patents

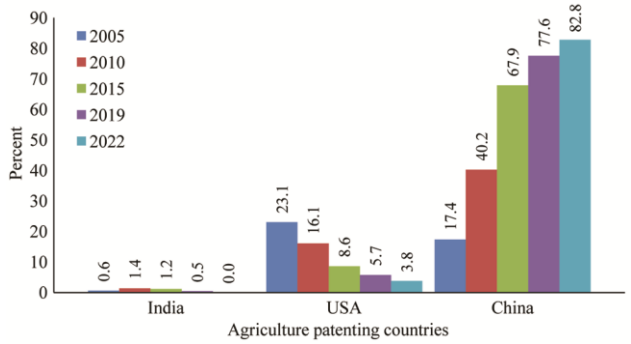

Fig. 5 — Share of patents filed in India, USA and China to total world

globally (Table 3). In the context of the United States, the number of patent filings in the agriculture sector has shown a steady increase, rising from 8,355 in 2005 to 9,401 in 2019. This upward trend did not continue up to the year 2022, its decelerated and reaching at the lowest ever. In the aftermath of the pandemic, the growth rate agricultural patenting in USA slowed down, resulting in a decrease to 7,110 in 2022.

Country-wise Patenting Filed/Granted in Agriculture and Allied Sector

According to Fig. 5, India's proportionate representation in agricultural patent applications has exhibited a consistent decline, dropping from 1.4 percent in 2010 to 0.5 percent in 2019. However, this downward trend was not maintained during the pandemic, and the decline continued until it reached almost negligible levels. Low patenting activity in India's agriculture sector can be attributed to factors such as a focus on agricultural research and new plant varieties, legislation for plant variety protection influencing certain areas, and limited commercialization opportunities in specific sectors like dairy product manufacturing. The dominance of public sector institutions in patenting may restrict involvement from other organizations, and limited patenting activity in certain areas can be influenced by research focus, technological advancements, and commercial viability.[16]

Similarly, the USA has also experienced a deceleration in its share of agriculture patenting since 2005. It accounted for 23.1 percent in 2005, which gradually decreased to 16.1 percent in 2010, 8.6 percent in 2015, 5.7 percent in 2019, and 3.8 percent in 2022. This decline can be attributed to fewer contributions in patenting by Canada and Mexico, along with a consistent downward trend in patenting within the USA, particularly after 2012 (WIPO database). However, the deceleration in 2022 can mainly be attributed to the global pandemic. In contrast, China's case is quite remarkable in terms of agriculture patenting following the COVID-19 pandemic. Despite being the epicenter of the pandemic and heavily impacted by it, China's share in agriculture patenting increased from 77.6 percent in 2019 to 82.8 percent in 2022 (Fig. 5). Notably, its share has been consistently increasing not only in the post-pandemic era but also throughout the entire study period from 1990 to 2022.

Thus, we conclude that the global patenting in the agriculture sector varies among countries, with India, China, and the USA emerging as major players in

Table 3 — Total agricultural patents filed by top patent filing countries in the world

Coun-tries	Year	M&I	Hort	NP	AH	C&F	All	M&I	Hort	NP	AH	C&F
		Number of patents						Share of patents				
China	2005	1313	1363	408	1465	1739	6288	20.88	21.68	6.49	23.30	27.66
	2010	4655	4401	947	4630	5829	20462	22.75	21.51	4.63	22.63	28.49
	2015	14951	18436	2171	15580	13773	64911	23.03	28.40	3.34	24.00	21.22
	2019	32551	40687	3639	34075	15907	126859	25.66	32.07	2.87	26.86	12.54
	2022	39339	51130	3791	47375	14096	155731	25.26	32.83	2.43	30.42	9.05
USA	2005	1230	720	1100	2561	2744	8355	14.72	8.62	13.17	30.65	32.84
	2010	858	498	1290	1687	3851	8184	11.88	7.08	15.96	31.22	33.86
	2015	1466	941	1177	2267	2389	8240	10.91	6.77	17.20	28.66	36.47
	2019	1804	1240	1434	2855	2068	9401	19.19	13.19	15.25	30.37	22.00
	2022	1977	1141	1163	2335	494	7110	10.23	6.30	18.27	23.54	41.66
India	2005	10	0	8	18	195	231	4.33	0.00	3.46	7.79	84.42
	2010	60	44	52	67	477	700	6.19	5.31	7.96	22.12	58.41
	2015	121	59	103	125	708	1116	5.08	5.28	8.12	11.37	70.15
	2019	164	119	25	121	311	740	22.16	16.08	3.38	16.35	42.03
	2022	3	5	7	7	20	42	7.30	5.92	8.40	11.29	67.08
World	2005	7150	5536	2519	10585	10435	36225	19.74	15.28	6.95	29.22	28.81
	2010	9731	8254	3550	11088	18245	50868	20.22	15.13	8.05	25.72	30.88
	2015	21197	22859	4683	22733	24169	95641	19.73	13.54	7.56	24.73	34.44
	2019	40460	46322	6211	44016	26558	163567	24.74	28.32	3.80	26.91	16.24
	2022	47079	56436	6036	56102	22458	188111	19.40	14.55	7.65	21.94	36.47

Where: M&I: Machinery and Implements; Hort: Horticulture; NP: New Plants; AH: Animal Husbandry and C&F: Chemical Compound and Fertilizers.

agricultural innovation and patent filings. India has experienced a rise in agricultural patents due to its focus on research and development in areas like crop improvement, agricultural machinery, and agrochemicals. China, meanwhile, has become a leader in agricultural patenting by implementing policies to foster innovation in agriculture and enhance food security.[17] The United States excels at patenting genetically modified organisms, precision agriculture technologies, agricultural equipment, plants, and microbes. The country has a long history of agricultural innovation. The US patent system is typically regarded as being the most advantageous and beneficial for innovators in the agriculture industry when compared to other nations[18]. Thus, these three countries contribute significantly to global agricultural patenting, their individual strengths, research priorities, and policy frameworks shape their respective patenting landscapes.

The recent surge in patent activity can be attributed to two main factors: the increased investment in research and development (R&D) in China and the significant inflow of foreign direct investment (FDI) into the country. Additionally, the amendment of Chinese patent law in 2000 has played a crucial role in fostering a more favorable patent policy environment in China.[19]

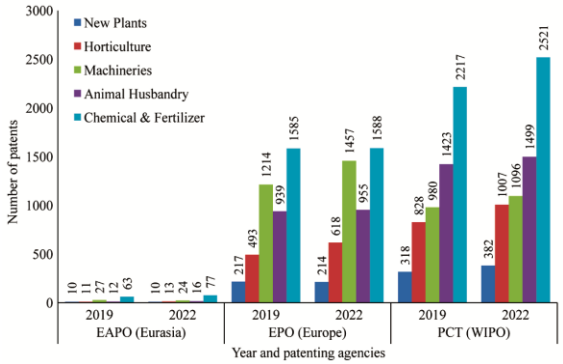

Fig. 6 — Recent trends in patent filing in patenting agencies in the world. Where WIPO refers to PCT (Patent Cooperation Treaty by WIPO), EAPO (Eurasia), and EPO (Europe)

Patenting Activity byPatenting Agencies

A significant number of patents were filed in both the EPO and the WIPO during the recent period (Fig. 6). In the EPO, the chemical and fertilizer category received the highest number of patents, followed by machinery & implements, animal husbandry, horticulture, and new plants in 2022. In contrast, in WIPO, the highest numbers of patents were filed in chemical compounds and fertilizers, followed by animal husbandry, machinery & implements and horticulture with the lowest number of patents filed in the new plants category. However, when considering global trends across 11 regions of the world, the highest number of

patents was filed in the chemical and fertilizer category, followed by animal husbandry, agricultural machinery, horticulture, and new plants (Table 3).

In recent years, the EPO, the Eurasian Patent Organization (EAPO), and the WIPO have observed an increasing interest in patents related to agriculture and related technologies. This includes advancements in crop production, plant breeding, biotechnology, agricultural machinery, and agricultural methods/processes. Both the EPO and WIPO have experienced a rise in the number of patent applications in this field, indicating a growing focus on agricultural research and development, as well as a greater emphasis on protecting and commercializing agricultural innovations. It is likely that the EAPO, which covers Eurasian countries, follows a similar trend with the filing of patent applications related to agriculture and agricultural technologies.

Nevertheless, starting from 2013, China has witnessed a significant surge in foreign direct investment (FDI) inflow, which escalated from 290,928 million USD in 2013 to 187170 million USD in 2019. However, there was a notable decline in FDI in 2022 during the post-Covid-19 era, reaching 180,167 million USD (Fig. 7). As foreign-invested companies expand their manufacturing operations in China, often with established research and development (R&D) activities, there is a growing necessity to safeguard their innovative ideas, leading to an upsurge in patent filings.

Furthermore, the utilization of patents as legal tools by foreign companies may have enhanced the recognition of the strategic significance of patent rights among Chinese firms. On a similar note, the inflow of foreign direct investment (FDI) into the USA has exhibited a high level of volatility, reaching a peak of 483,849 million USD in 2015 and subsequently experiencing a sharp decline to 2,56, 715 million USD in 2019. However, following the pandemic, FDI began to decrease again, and then sharply dropped to 318,370 million USD in 2022. In the case of India, the inflow of FDI has steadily improved from 23,995 million USD in 2012 to 50610 million USD in 2019. Although there was a deceleration in FDI inflow to 44,727 million USD in 2021, it started to increase again and reached 49,915 million USD in 2022 (Fig. 7). Despite this increase, the volume of FDI inflow in India remains considerably lower than that of China and the USA throughout the entire period. This poses a significant concern for Indian policymakers.

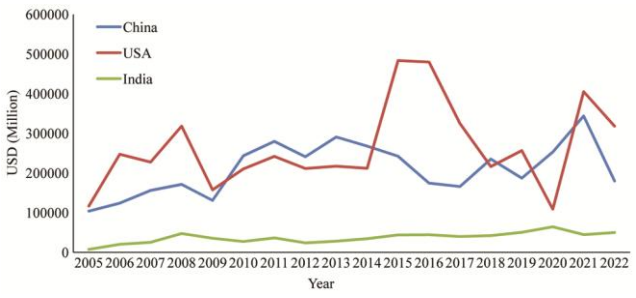

Fig. 7 — FDI inward flow in China, USA and India
Source: OECD Database[20]

From the above analysis, we can infer that the progress observed in agricultural patenting in India can be credited to the revisions made in the Indian Patent Act in 1999, 2002, and 2005.[21] Nevertheless, despite policymakers and scholars acknowledging the importance of innovation in advancing the agriculture sector, India falls behind developed economies in effectively protecting its indigenous technologies through the patent system. This deficiency is evident in the low number of patent filings in various fields such as chemicals, pharmaceuticals, food, biotechnology, biochemistry, microbiology, agrochemicals, textiles, polymers, and metallurgy.[22] The low number of patent filings in areas such as chemicals, pharmaceuticals, food, biotechnology, biochemistry, microbiology, agrochemicals, textiles, polymers, and metallurgy further illustrates this situation.[23]

Moreover, despite the implementation of patent reforms for over a decade, there has been no notable improvement in the growth of patent filings in the agriculture sector. One significant factor behind this trend is that Indian agricultural industries are not effectively leveraging the patent system to generate monetary value. Indian companies and public/private organizations continue to view patent licensing in the agriculture sector as a profitable opportunity. However, the primary focus for Indian firms is to utilize patents as a safeguard rather than aggressively pursuing patent ownership.[24] Their main emphasis now lies in safeguarding innovations and preventing competitors from claiming priority over their inventions. On the other hand, in case of public sector R&D organization; The Indian Council of Agricultural Research (ICAR), through its Intellectual Property and Technology Management (IP&TM) Policy, has outlined a strategy that involves patenting ICAR technology and facilitating its commercialization through Zonal Technology

Management centers and Agri-Business Incubation units. Even though such institutional mechanisms do aid in obtaining financial value from the patent systems, they have yet to be attained.

The foundation of innovation, which speeds up the creation of new products and services, lies in research and development (R&D). Although R&D is crucial, India allocates a smaller budget for it compared to China, the United States, and Japan. In 2015, India's investment in R&D as a percentage of its GDP was merely 0.69 percent, the lowest among developed nations such as the Russian Federation, Brazil, Canada, China, France, the USA, Germany, and Japan (Fig. 8).

In 2018, the proportion of R&D investment in India, measured as a percentage of GDP, declined from 0.69 percent in 2015 to 0.66 percent in 2018. Conversely, during the same period, China experienced an increase from 2.06 percent to 2.14 percent, while the USA saw a significant rise from 2.79 percent to 3.01 percent. Consequently, it can be inferred that India's expenditure on research and development is one of the lowest globally (Fig. 8). The India Innovation Index 2021 further confirms this by highlighting India's comparatively low national R&D expenditures. This is evident in the gross expenditure on R&D (GERD) as a proportion of GDP, which stood at approximately 0.7 percent.[26]

Trends in Patenting Activities in Agriculture in India

There has been about a five-fold increase in the number of patent applications during 2005-2019 i.e., 231in 2005 and 1116 in 2019 while 42 in 2022filed in agriculture and allied sectors in India (Table 3).This expansion is mostly attributable to the increased

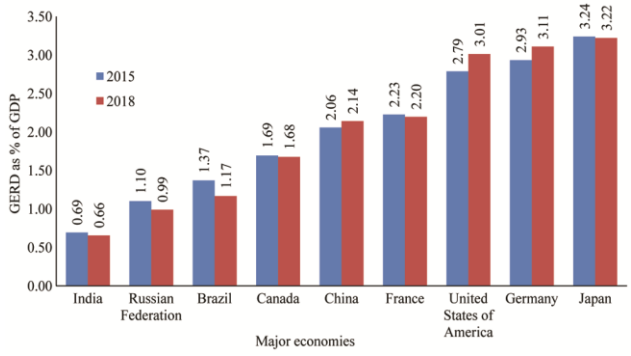

Fig. 8 — Gross expenditure on R&D (GERD) as a percentage of GDP
Source: UNESCO Database[25]

patenting activity in the chemical components and fertilizers sector because of changes to Indian Patent Law. The share of patents for the period 2022 compared to 2005 showed a similar pattern, with chemicals and fertilizers leading the pack, followed by animal husbandry, novel plants, equipment and machinery, and horticulture (Table 3).

IPR and Chemical Components and Fertilizers

The number of patent applications in the chemical compound and fertilizers sector has shown fluctuations over time (Table 3). It increased from 195 in 2005 to 311 in 2019 but then sharply declined to 20 in 2022. Similarly, the proportion of fertilizer and chemical compound patents compared to all agricultural patents registered in India also decreased, from 84.42 percent in 2005 to 67.08 percent in 2022 (Table 3). Despite this decline in numbers and proportion, the chemical compound and fertilizer sector remains the leading category for patents in India's agriculture and related sector. The high patenting activity in this sector can be attributed to factors such as innovation-driven research, technological advancements, commercial viability[27], regulatory compliance, and market competition. These findings align with a previous investigation on chemical patent trends.[28]

IPR and Machinery and Implements

The machinery and implements industry has a relatively low number of patent registrations overall. In 2005, only 10 patents were filed, but this figure significantly rose to 164 in 2019. However, due to the global pandemic, the number of patents dropped sharply to just 3 in 2022 (Table 3). The gradual improvement in the patenting of agricultural machinery and implements in India can be attributed to technological advancements, increased focus on mechanization, supportive government policies, market demand and competition,[29] and international collaborations[30] that contribute to innovation in the sector.

Patenting in Animal Husbandry

Similar to the machinery and implements industry, the animal husbandry sector has experienced a significant increase in the number of patent applications. There has been a consistent pattern in the number of patent applications over the first decade. In 2019, the number of patents reached 121,

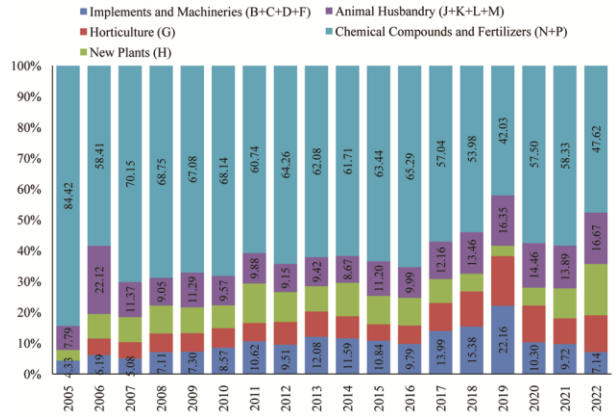

Fig. 9 — Share of patents by its major classification in India from 2005 to 2022

showing a substantial increase from the 18 patents filed in 2005. However, in 2022, following the epidemic, the number of patents registered dropped to just 7. Despite the decline in the overall number of patent submissions, the proportion of animal husbandry patents compared to the total number of patents showed an upward trend. It increased from 22% in 2010 to 16.35% in 2019, before slightly decreasing to 11.29% in 2022 (Table 3).The lower number of patent filings in this industry can be attributed to the fact that most inventions in this sector are related to biological processes, which are not eligible for patent protection. Consequently, we can infer that a significant number of patents were filed in the field of implements and machinery, followed by new plant varieties, animal husbandry, and the horticulture sector in the recent period of 2022 (Fig. 9). Although there has been a consistent upward trend, the number of patents in the animal and animal varieties sector in India remains relatively low compared to other agriculture-related sectors. This is primarily because of animals and animal varieties are not eligible for patent protection in countries like Argentina, Brazil, China, India, and South Africa.[31]

Patenting in Horticulture

Table 3 reveals that the pattern of patent filings in the horticulture sector shows similarities to those filed for implements and machines. The horticulture industry, which encompasses fruits, vegetables, and flowers, experienced a rise in patent applications, increasing from 44 in 2010 to 119 in 2019, before dropping to 5 in 2022. The market share of horticulture patents displayed a steady growth from 5.31 percent in 2010 to 16.08 percent in 2019, but then slowed down to 5.92 percent in 2022. With the exception of the post-pandemic period, the overall increase in market share highlights the growing importance of the horticultural industry compared to other agricultural subsectors. The possible cause of the limited patenting activity in the Indian horticulture sector is attributable to the restriction specified in Section 3(h) of the Patents Act, 1970, as amended in 2002 and 2005. This provision states that methods or processes related to agriculture or horticulture are not considered patentable inventions. Consequently, inventions in the horticulture sector are ineligible for patent protection in India.[32, 33]

Patenting in New Plants

Similarly, the new plant sector exhibited a comparable pattern to the horticulture sector in terms of patent applications. The number of patents in this field rose from 8 in 2005 to 103 in 2015. However, it subsequently declined to 25 in 2019 and further dropped to 7 in 2022. The market share of new plant patents also decreased from 3.46 percent in 2005 to 3.38 percent in 2019. However, it experienced a sharp increase to 8.40 percent in 2022. The increase in the number of patent applications for new plants between 2005-06 and 2009-10 was primarily driven by a surge in patents filed in the biotechnology sector.[34] The low patenting of new plants in India can be attributed to legal restrictions under the Indian Patent Act, excluding plants and animals (excluding microorganisms) from patentability, as well as the prohibition of patenting conventional plant breeding methods. The presence of a separate sui generis system for plant variety protection may divert attention from patenting. Limited incentives, commercialization opportunities, and the complex patenting process also contribute to the low activity in this area.[35] There are IPR mechanisms such as, Protection of Plant Varieties and Farmers Right Act, which is not discussed in the present study, which helps in protection of the varieties developed by public, private plant breeders or farmers.[36]

Implications for Indian Agriculture

From the present analysis that confers that, the patenting activity in agriculture sector in India is very sluggish as compared to the other developed nations. The slow expansion of agricultural patenting, both within India and globally, carries significant implications for Indian agriculture. Let's delve deeper into these implications. The sluggish progress in agricultural patenting indicates a slower rate of

technological advancements in the agricultural sector. Patents serve as markers for the development and protection of innovative technologies and practices.[37,38] The small number of patent applications in agriculture sector indicates a potential lack of availability of advanced agricultural technologies that have the potential to improve productivity, sustainability, and competitiveness in Indian agriculture. This constraint hampers the adoption of advanced farming methods, improved crop varieties, precision agriculture technologies, and other innovations that have the potential to drive agricultural progress.

Furthermore, the low occurrence of patenting in the agricultural sector may indicate insufficient investment in research and development (R&D) within the industry. Government support to agriculture is low on innovation and high on distortion.[39] Inadequate funding and support for agricultural R&D impede the progress of novel and enhanced crop varieties, agricultural machinery, and sustainable farming practices. Insufficient financial resources and assistance for agricultural research and development hinder the advancement of new and improved crop varieties, agricultural machineries, and environmentally friendly farming practices.[40] However, the sufficient investment in research and development enhances the efficiency of the production, marketing, and distribution systems. A substantial investment in R&D is crucial for modernizing and transforming Indian agriculture, enabling it to address critical challenges such as food security, productivity improvement, sustainable natural resources management, sustainable development, competitiveness or market development, rural development, rural income generation and livelihood[41] and evolving consumer demands. The scarcity of patenting activity reflects a potential underutilization of R&D resources and represents a missed opportunity to stimulate innovation.

The slow pace of agricultural patenting also implies a reduced number of agricultural innovations being safeguarded by intellectual property rights. This lack of protection can discourage[42] inventors, researchers, and companies from allocating resources to agricultural research and development (R&D), as they may not receive adequate legal protection and commercial benefits for their inventions. Intellectual property rights play a critical role in motivating innovation by offering legal safeguards and exclusive rights to inventors. The inadequate level of protection may diminish the willingness to invest in agricultural research and restrict the commercialization of new technologies, thereby impeding the overall advancement of the agricultural sector.[43]

Moreover, the slow expansion of agricultural patenting can result in an increased reliance on imported technologies and agricultural products. Without substantial domestic patenting and innovation, Indian farmers may have to depend on technologies, seeds, and machinery developed by foreign companies. However, over the past three decades, Brazil, India, and China have experienced remarkable and rapid economic growth, thereby transforming the global economic landscape. These countries are quickly catching up with the leading industrial economies, emerging as a significant economic force that profoundly influences the world economy.[44] This heavy reliance on imports has the potential to affect the country's food security and self-sufficiency. Additionally, it limits the control that Indian farmers have over their farming practices and makes them vulnerable to external influences such as international market dynamics and trade policies.

The limited engagement in agricultural patenting presents challenges in the sharing of knowledge and collaboration among researchers and practitioners. Patents have a crucial role in facilitating knowledge exchange by making patented inventions public. A fundamental aspect of scientific advancement, as emphasized by Dasgupta and David (1994),[45] is the exchange of knowledge among scientists within academic communities. This practice plays a vital role in enhancing the overall effectiveness of the scientific system by making knowledge accessible to others, as highlighted by.[46] This issue is particularly problematic in the agricultural industry, where global knowledge and innovation exchange is vital for driving technological progress. Inter-firm and intra-firm networks, as well as Global Value Chains (GVC), play a significant part in fostering innovation for companies that successfully integrate into these networks.[44]In developing countries like India, where the creation of new groundbreaking innovations is rare and dependence on imported knowledge and technology is high, the absence of patenting further hinders collaboration and restricts knowledge transfer. Consequently, researchers, institutions, and farmers face difficulties in accessing and building upon existing inventions and advancements, ultimately impeding overall innovation and development in agriculture.

To address these implications, it is essential to prioritize agricultural research and development, provide incentives for innovation through intellectual property protection, enhance investment in R&D, and foster collaboration between the public and private sectors. Creating an environment that facilitates technology transfer, knowledge sharing, and collaboration is crucial. Balancing the need for intellectual property protection with the accessibility and affordability of agricultural technologies will ensure that the benefits of innovation are accessible to all and contribute to sustainable agricultural development in India.

Conclusion

The post-pandemic era in Indian agriculture will witness a transformation towards technology, sustainability, and digitalization, necessitating the collaboration of researchers, stakeholders, and policymakers to align the patent system with these objectives. Patents play a crucial role as incentives for innovation and have experienced a significant rise in filings and grants following changes in agriculture-related patenting regulations. This study examines patent trends from 1990 to 2022 across global regions and major categories based on the International Patent Classification, with a specific focus on key agricultural patenting countries such as India, China, and the USA. The analysis reveals a notable surge in global patent filings, particularly in areas such as animal husbandry, horticulture, machinery and implements, chemicals and fertilizers, and new plants. Remarkably, patent filings continued to increase across all categories, even in the post-Covid-19 period. Southeast Asia, led by China, emerged as the primary region for agricultural patents. In contrast, India's representation in agricultural patent applications consistently declined, while China's success can be attributed to favorable patenting policies and frameworks for intellectual property protection. The limited number of patent filings in India's agriculture sector can be attributed to inadequate investment in research and development, insufficient protection and commercialization of innovations, and reliance on imported technologies. These findings underscore the importance of prioritizing agricultural research and development, incentivizing innovation through intellectual property protection, increasing investment in research and development, and promoting collaboration between the public and private sectors. The study recommends policy revisions, including awareness initiatives such as, the National Intellectual Property Rights Policy of 2016,[47] to stimulate investment and utilization of the patent system for economic benefits. The essential role of collaboration in guiding Indian agriculture towards technology, sustainability, and digitalization is emphasized.

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