Analysis of the dual network relationship and its evolutionary characteristics of global textile new material technology cooperation R&D in the 21st century

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ABSTRACT – REZUMAT

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Vigorously developing new materials technology is of great significance to improving the high-tech level of the textile industry, enhancing the transformation and upgrading of the textile industry, promoting the sustainable development of the industry and enhancing the comprehensive national strength. In this paper, the data of 6982 invention patents created by global textile new material technology cooperation are chosen as the research object, and the patent technology network analysis method is used to examine the dual network relationship and its evolution features. The results suggest that the core subjects represented by multinational corporations, well-known universities and scientific research institutes integrate resources to conduct technology cooperation research, and the cooperation network's innovation activities in this field tend to be stable, but there is no relatively stable collaborative relationship between innovation organizations. Furthermore, technology nodes, technology subgroups, spillover effects between technologies, diffusion and fusion, and technology correlation strength have greatly improved. At the same time, reasonable division of labor and coordination of the collaborative activities among nodes in the core, middle, and edge layers of the network are crucial, and the division of labor and cooperation within the network are of great significance for improving collaborative innovation efficiency. This study is useful to determine the innovation subjects, network structure and technological evolution of global textile new material technology cooperation research and development, but there is no analysis of the relationship between organizational cooperation network and technological network and its evolution characteristics in this field. As a result, this article tries to supplement existing research in terms of both research object and research content, to fill the gaps in the existing research.

Keywords: *textile, new materials, technology R&D, network structure, patentometrics, evolution characteristics*

Analiza relației rețelei duale și a caracteristicilor sale evolutive privind cooperarea globală în domeniul cercetării și dezvoltării tehnologiei materialelor textile noi în secolul al XXI-lea

Dezvoltarea viguroasă a tehnologiei materialelor textile noi are o mare importanță pentru îmbunătățirea nivelului de înaltă tehnologie al industriei textile, susținerea transformării și modernizării industriei textile, promovarea dezvoltării durabile a industriei și sporirea puterii naționale. În această lucrare, datele din 6982 de brevete de invenție create prin cooperarea globală în domeniul tehnologiei materialelor textile noi sunt alese ca obiect de cercetare, iar metoda de analiză a rețelei tehnologice de brevete este utilizată pentru a examina relația de rețea duală și caracteristicile evoluției acesteia. Rezultatele sugerează că subiecții de bază reprezentați de corporațiile multinaționale, universitățile de renume și institutele de cercetare științifică integrează resursele pentru a efectua cercetări de cooperare tehnologică, iar activitățile de inovare ale rețelei de cooperare în acest domeniu tind să fie stabile, dar nu există o relație de colaborare relativ stabilă între organizațiile de inovare. În plus, nodurile tehnologice, subgrupurile tehnologice, efectele de propagare între tehnologii, difuzarea și fuziunea, precum și puterea corelației tehnologice s-au îmbunătățit considerabil. În același timp, diviziunea rezonabilă a muncii și coordonarea activităților de colaborare între nodurile din straturile central, mijlociu și periferic ale rețelei sunt esențiale, iar diviziunea muncii și cooperarea în cadrul rețelei sunt foarte importante pentru îmbunătățirea eficienței inovării colaborative. Acest studiu este util pentru a determina subiectele de inovare, structura rețelei și evoluția tehnologică a cooperării în domeniul cercetării și dezvoltării globale a tehnologiilor materialelor textile noi, dar nu există o analiză a relației dintre rețeaua de cooperare organizațională și rețeaua tehnologică și caracteristicile evoluției acesteia în acest domeniu. Drept urmare, acest articol încearcă să suplimenteze cercetările existente atât în ceea ce privește obiectul cercetării, cât și conținutul cercetării, pentru a umple lacunele din studiile de cercetare existente.

Cuvinte-cheie: *textile, materiale noi, cercetare și dezvoltare tehnologică, structura rețelei, patentometrie, caracteristici de evoluție*

INTRODUCTION

New materials are the cornerstone of the upgrading of traditional industries and the development of strategic emerging industries, and as a key resource input [1], they play a vital role in promoting the technological revolution and sustainable development of the industry. Compared with the traditional material industry, new materials refer to materials with excellent properties and special properties that are newly discovered or produced through artificial new synthesis or modified by traditional materials, so they have the characteristics of being technology-intensive, large investment in R&D (research and development), and high added value of products.

At present, the global textile industry has shifted from a high-speed growth stage to a high-quality development stage, and textile technology innovation is undoubtedly an important guarantee for high-quality and sustainable development. As a key area of international competition, textile new material technology is a key force in promoting the high-end and intelligent development of the textile industry, and it is also an important engine for realising the modernization of the textile industrial system. Therefore, the research and development of new textile material technology is of great significance for achieving the sustainable development goals of a green, low-carbon, and energy-saving human society.

Technological innovation and development cannot be separated from international R&D cooperation [2]. In the process of innovation and development of textile new materials technology, exploring the cooperative network relationship and evolution characteristics among R&D subjects and analyzing the diffusion, integration, and technological correlation intensity between technologies will help enterprises formulate reasonable R&D cooperation plans and innovation strategies [3], and thus gain the first-mover advantage in technology layout and competition and worthy of scholars' thinking and research.

Furthermore, more and more scholars have paid attention to the introduction of the "network view" to research on technological cooperation in R&D [4, 5]. By analysing the cooperative behavior of different organizations in technology R&D, according to the different nodes' attributes, it can be mainly divided into an organizational cooperation network composed of organizations as nodes and a patent citation network composed of patents as nodes [6, 7]. The former is used to analyze the composition, status and cooperation methods of network members, as well as their relationship with partners and projects, and points out that the research on organizational cooperation network can present the form of cooperation network and clarify the core subjects and relevant participants [8–10]. The latter is mainly used to identify technology and technology development path, show the focus of technology R&D at different stages, and present the development trend of technology diversification and core innovation activities of enterprises from the technological and geographical levels [11, 12].

However, existing studies lack the characteristics and evolution trend analysis of the textile new materials technology cooperative R&D network. So, the matching analysis of the technology network and the organizational cooperation network can provide a more accurate and comprehensive technical panorama, to provide a reference for the government's science and technology innovation policy formulation and technology research and development.

Given this, this paper discusses the network relationship and evolution characteristics of global textile new material technology cooperation R&D by constructing an organizational cooperation network and a technical network, aiming to provide theoretical enlightenment and decision-making support for the technical layout and management practice of the textile industry. The significance of this study is as follows: (1) laying a theoretical foundation for the future cooperative R&D and innovation of emerging technologies in the textile industry; (2) while providing academic reference, the global textile new material technology cooperation R&D analysis index can be used to establish the relationship between innovation subjects and technical fields and determine the rules of technology association; (3) by analyzing the organizational cooperation network and technology network, we can discover the evolution process of innovation in this field, predict the future technology research and development trend and development frontier, and help enterprises and governments to formulate relevant industrial policies.

DATA SOURCE

The data in this paper are from the PatSnap patent database platform (https://analytics.zhihuiya.com/). For textile new material technology, its international patent classification (IPC) includes two categories: D (textile) and A41 (clothing). Therefore, the new material industry in the national strategic emerging industry classification is selected in the database, and the patent legal status is selected as "valid" in combination with the IPC D01 Fiber, D02 Yarn, D03 Weaving, D04 Weaving, D05 Sewing and D06 Fabric Treatment. In addition, since the beginning of the 21st century, global scientific and technological innovation has entered a period of unprecedented intensity and activity, and a new round of scientific and technological revolution and industrial transformation is reshaping the global innovation map and the global economic structure. At the same time, the period from invention patent application to publication and authorization is about 18 months, so the search time range is limited to 2000–2021.

Together, the world's Five Intellectual Property Offices (IP5) process about 80% of the world's patent applications and about 95% of all work carried out under the Patent Cooperation Agreement (PCT). Therefore, China, the United States, South Korea, Japan, and Europe are selected as innovation regions for the study. Through the above strategies, the number of applicants was set at least 2 or more, and then the search results were combined to obtain 6982 patent data consistent with this study.

METHODOLOGY

Analysis framework

In this paper, the patent technology network analysis method is used to construct the organizational cooperation network and technical network of textile new material technology. Organizational cooperation networks use organizations as nodes to analyze relationships and structures between different organizations. The technology network takes technology as a node and uses technology keywords and IPC classification numbers instead of specific technologies, which is used to analyze the changes in the layout, development trend, and relationship between technologies of patented technologies. Combined with relevant research [10–12], the analysis framework of this paper is shown in figure 1. Firstly, the downloaded patent data was cleaned and screened, and relevant patent information was used to establish a data matrix. Secondly, the cooperative patents of two or more patentees are selected, and the organizational cooperation co-occurrence matrix and IPC technology co-occurrence matrix are constructed, and the organizational cooperation network and technical network for the research and development of textile new material technology are constructed with the help of Gephi software. Finally, the network structure is analyzed from the aspects of network structure, R&D subject, and technology spillover effect, and the characteristics of the organization and cooperation network of global textile new material technology and the characteristics of the IPC technology network are identified.

Network data metrics

Table 1 shows that the data indicators of the new material technology R&D cooperation network are analyzed from three dimensions: network structure, innovation organization characteristics, and technical characteristics. Among them, the network structure is a quantitative analysis of the overall structure of the network, including the network size, degree, network density, network diameter, and average clustering coefficient, which helps to intuitively understand the development dynamics, structural characteristics, and evolution process of network cooperation. The characteristics of innovative organizations include the identification of core organizations and the analysis of the number and proportion of organizations such as enterprises, universities, and research institutes. The technical characteristics involve the breadth and strength of technology, revealing the degree of correlation and integration among technologies.

In this study, Gephi is used to calculate the nodes, the connectivity between nodes and the relative distance of the R&D collaboration network, which helps to intuitively understand the development dynamics, structural characteristics and evolution process of organizational collaboration, etc. The network metrics in table 1 are calculated as follows:

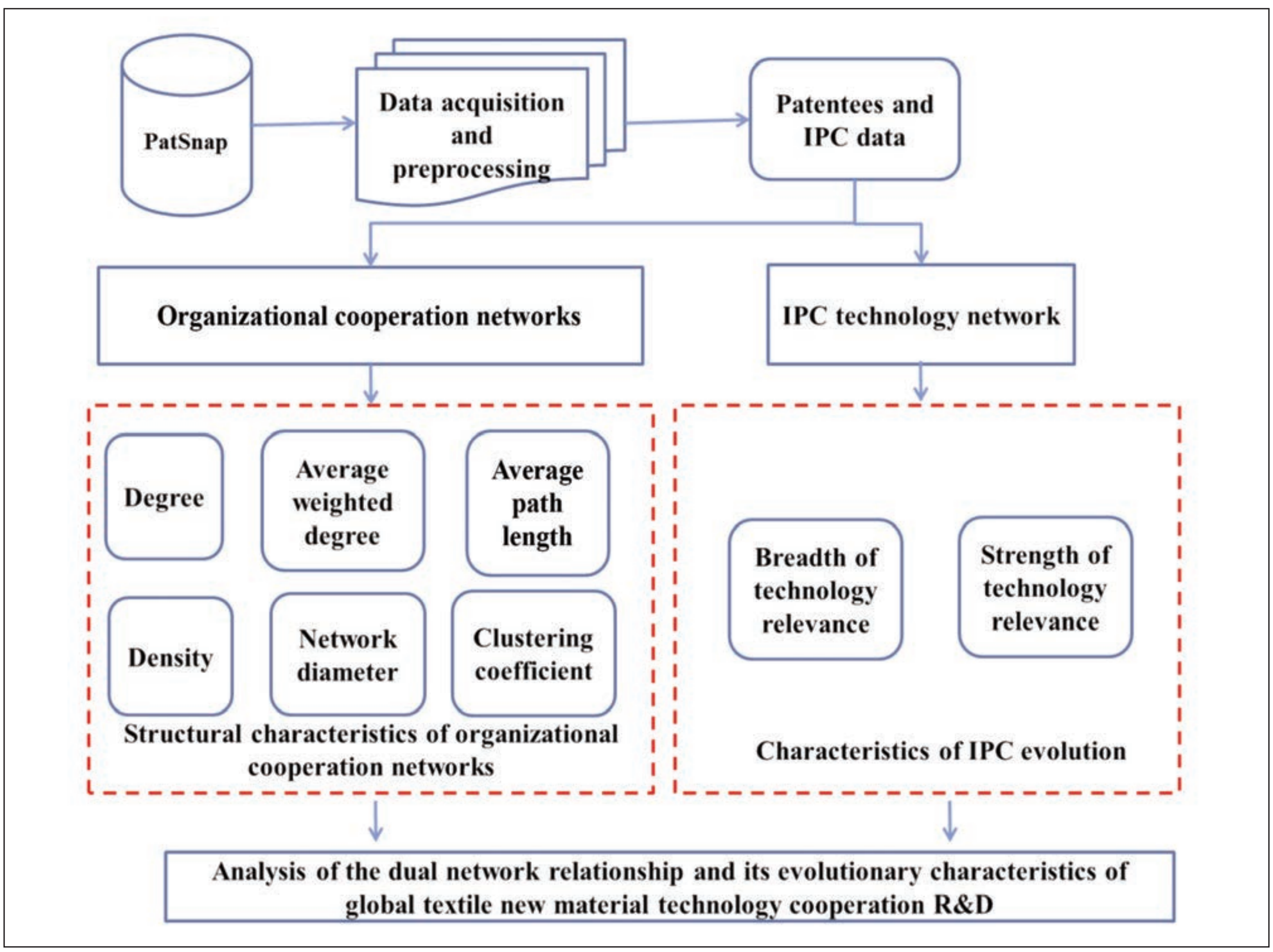

Fig. 1. A dual network analysis framework for collaborative R&D of new textile material technologies

Table 1

DATA INDICATORS OF NEW MATERIAL TECHNOLOGY R&D COOPERATION NETWORK		
Dimensions	**Measurement indicators**	**Explanation**
Network structure	Network scale	The number of network nodes and connections between nodes, the more nodes and edges, the larger the network size
	Average path length	The average of the distances between pairs of nodes where there are connected paths
	Degree	The larger the degree of a node, the higher the degree centrality of the node, and the more important the node is in the network.
	Density	The ratio of the number of connected edges (excluding self-connections) to the total number of nodes in the network is calculated. The results are used to determine the connectivity of the network, i.e., the density of a fully connected network is 1
	Network diameter	The maximum value of the distance between any two nodes in the network is taken to reflect the density of the cooperative innovation network.
	Clustering Coefficient	The average of the clustering coefficients of all nodes in the network
Innovative organizational characteristics	Core organization	The larger the node, the more innovative subjects it cooperates with, and the thicker the connection, the more frequent the number of cooperations between nodes, and the top 10 organizations at different stages are selected.
	Organizational cohesion	The higher the PageRank value, the stronger the cohesion of the innovation subject in the network and the richer the innovation resources it holds
	Proportion of organization types	The proportion of universities, enterprises and research institutes at different stages
Technical characteristics	Breadth of technology relevance	The number of co-occurrences associated with technology domains, a measure of the breadth of technology convergence
	Strength of technical relevance	The strength of the connection between a technology field and other technology fields measures the depth of technology integration

The average path length of the network is the average of the distance between pairs of nodes where there is a connected path, denoted as L, i.e.:

$$L = \frac{2}{n(n-1)} \sum_{i,j} d_{ij} \qquad (1)$$

where n is the number of network nodes, and d_{ij} is the distance between nodes i and j.
Network diameter, the maximum value of the distance between any two nodes in the network, is denoted as D, reflecting the density of the cooperative innovation network.

$$D = \max_{i,j} d_{ij} \qquad (2)$$

Network density is the ratio of the number of edges that have the highest number of connected edges (excluding self-connections) to the total number of relationships between nodes in a given network. The results are used to determine the connectivity of the network, i.e. a fully connected graph with a density of 1 is denoted as ND:

$$ND = \frac{\sum_{i=1}^{N}\sum_{j=1}^{N} d_{ij}}{n(n-1)}, \quad (i \neq j) \qquad (3)$$

where N is the total number of nodes in the network. The Degree refers to the average of the degrees of all nodes in the network, which can reflect the average number of partners owned by all nodes in the network:

$$Degree = \sum_{i,j=1}^{N} a_{ij} / N \qquad (4)$$

a_{ij} is the degree value between the node pairs i and j. Weighted Degree refers to the average value of the weighted w_{ij} of all nodes in the network.

$$WD = \sum_{i,j=1}^{N} w_{ij} / N \qquad (5)$$

The clustering coefficient C refers to the average of the clustering coefficients of all nodes in the network, which can be expressed as:

$$C = \frac{1}{n} \sum_{1}^{N} \frac{2e_i}{k_i(k_i-1)} \qquad (6)$$

Where e_i is the actual number of edges between adjacent nodes of node i, and k_i is the degree of node i.

ANALYSIS AND DISCUSSION

Analysis of the development trend of R&D cooperation

According to the technology life cycle theory, the development of industrial technology will go through four stages: embryonic stage, growth stage, maturity period, and decline period [13–15]. In this paper, the cumulative number of patent applications per year is taken as the vertical axis, the year of the patent application is taken as the horizontal axis, and the development trend of global textile new material technology cooperation and R&D is fitted with the help of the Loglet Lab software S-curve (figure 2). The dots in the graph represent the actual number of patent accumulations, and the solid line represents the predicted number of patent applications. The cumulative number of patents with the Saturation (K) value of the saturation point is 509.252, which is the highest value of patent applications, after that, patent growth will enter a period of decline, with little room for technological development and a gradual decrease in the number of applications. The growth time was 7.186 years, and the Midpoint of the S-curve occurred in 2014. It shows that the growth time of global textile new material technology, as estimated by the system, is 7 years, that is, the patent applications continue to grow until 2007, which is the embryonic period. Since 2008, it has entered a period of growth, during which technology research and development cooperation has shown a trend of rapid development. After 2015, the growth rate showed a slowdown trend, especially due to the impact of COVID-19, and after 2020, the international cooperation and innovation activities of enterprises and scientific research institutions in various countries could not be carried out normally, so the number of patent applications showed a downward trend, but the total amount is still increasing, and the global technical cooperation research and development in this field has entered a mature stage.

According to the growth process of global textile new material technology, and considering that the publication of patent documents has a certain time lag, the patent data is divided into three stages: 2000–2007, 2008–2014, and 2015–2021.

Through the analysis of the development trends of the above stages, it is found that the relevant policy documents issued by various countries and market demand changes have a relatively close relationship with the development of this field. At the level of comprehensive strategic planning, since 2000, the United States began to implement the “National Nanotechnology Initiative” (NNI) [16], and the textile new material technology has experienced a slow growth from scratch, at this time the technology is in its infancy, and the market application of this technology is relatively small at this stage. The Materials Genome Initiative launched in 2011 [17], and the National Network for Manufacturing Innovation (now known as Manufacturing USA) [18], launched in 2012, coordinate the participation of all parties at the national level to promote the R&D activities and applications of materials science, nanoengineering, and high-performance computing to ensure that the United States is a world leader in the R&D of new materials technologies. As countries attach great importance to this field and the continuous increase of talent and capital investment, the global textile new material technology has entered a period of rapid growth.

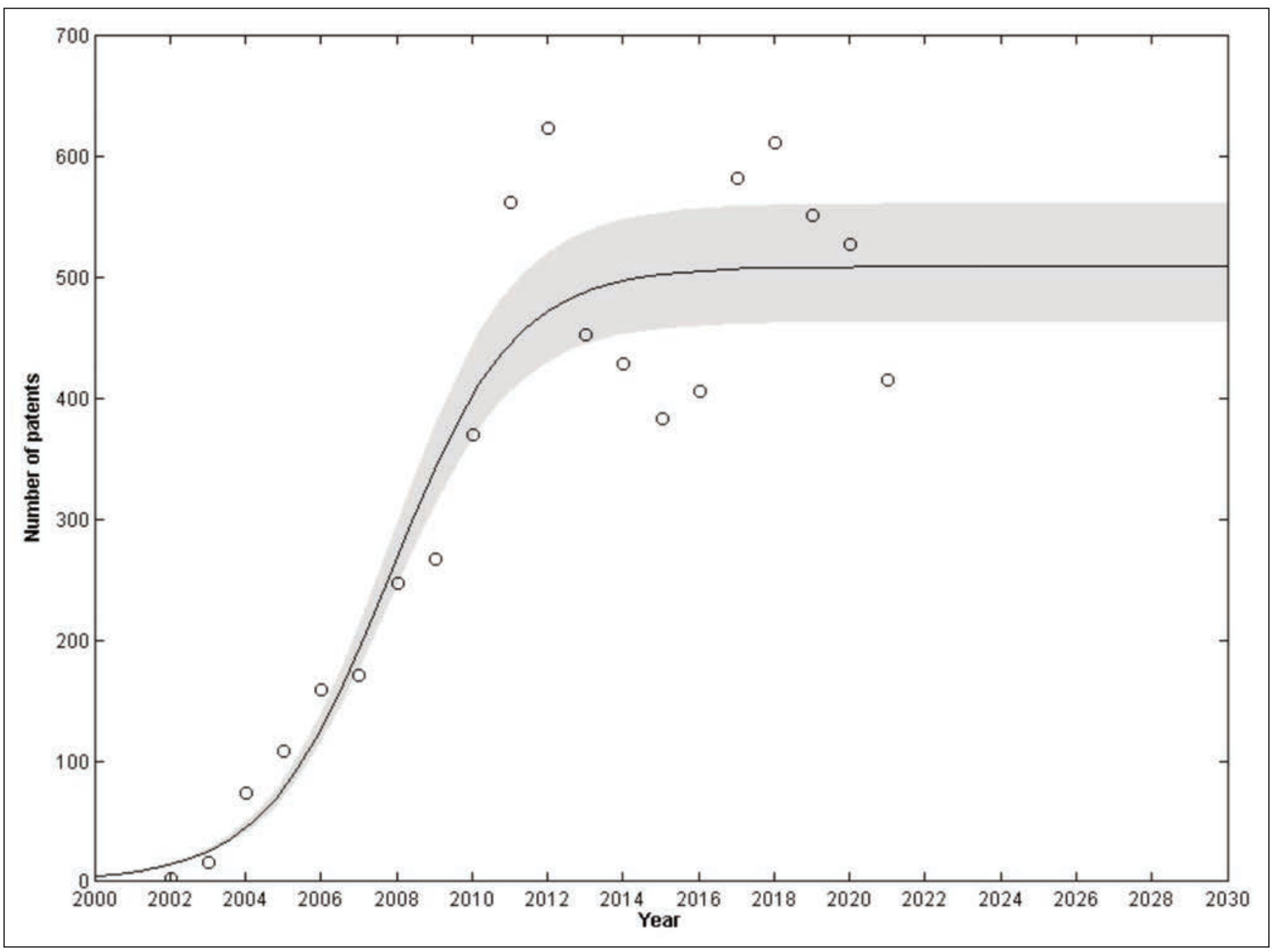

Fig. 2. Development trend of R&D cooperation in textile new material technology

Japan and the European Union closely follow the pace of development of the United States. The former's new materials industry is guided by the industrial policy to occupy the world market, so the focus is to make the new material field with huge market potential and high added value, specialized and industrialized as soon as possible. The latter vigorously promotes the development of ten major material fields, including nanobiotechnology, superconductors, composite materials, and smart textile materials. At the same time, with the development and growth of Chinese and South Korean textile enterprises, especially the huge market competitiveness after China acceded to the WTO, it has played a positive role in promoting the R&D of textile new material technology in the world. Therefore, from 2015 to 2021, the annual number of patent applications was in a state of fluctuating growth, but it remained at a high level, and the global textile new material technology has entered a mature period at this stage.

Analysis of organizational cooperation networks

Evolutionary characteristics of network structure

To study the structural characteristics of the global textile new material technology R&D cooperation network, this paper combines the perspective of cooperation among major patent holders and the three stages of R&D cooperation development, and uses Gephi to construct topological evolution maps of the network in different periods, and the results are shown in figure 3. Among them, the larger the node, the more nodes cooperate with it, and the thicker the connection, the more frequent the cooperation between nodes. From 2000 to 2007, there was R&D cooperation carried out by a few key subjects in the cooperative network map, which were closely interconnected, forming a relatively concentrated innovation group and playing a prominent role in the cooperation network. However, during this period, the network scale was relatively small, the network structure was relatively loose, and the market radiation to the international textile industry was limited. After 2008, R&D activities became more active, the network structure showed a multi-node multilateral radiation network state, and the network connection was relatively dense. During this stage, the number of cooperative R&D network nodes continued to increase, and the correlation between key nodes continued to strengthen, and a R&D group of innovative organizations had taken shape. However, with the concentrated role of the reform and reorganization of global multinational corporations and the influence of the international scientific and technological innovation pattern, enhancing the market competitiveness of enterprises through independent innovation has gradually become the main theme of development. In 2020, the United States released its National Strategy for Critical and Emerging Technologies, emphasizing that the United States will ensure its leading position in cutting-edge science and technology through strengthened technology control and global alliances. The EU has also proposed to increase its strategic autonomy to deal with industrial and technological dependence. Therefore, in the third stage, although the scale of the R&D cooperation network is unprecedentedly large, the group of innovative organizations with international influence has decreased significantly, and the radiation ability to the industry is relatively weakened.

The analysis of the indicators of organizational cooperation network helps to sort out the evolution characteristics of different stages of global textile new material technology R&D cooperation. In table 2, the diameter of the R&D cooperation network in the embryonic and growth stages is 9, and it has developed to 13 in the mature stage, which is in line with the proposal of Bettencourt et al. [19] that the cooperative innovation network in the field of science and technology has stabilized in the range of 12 to 14 after development, indicating that the innovation activities of the innovation group cooperation network have become stable.

According to the research results of Watts [20] and Uzzi [21], the average degree, average weighting degree and average clustering coefficient reflect the tightness of the network, and the first two values in table 2 show a significant upward trend, indicating that the scale of cooperative R&D is expanding and

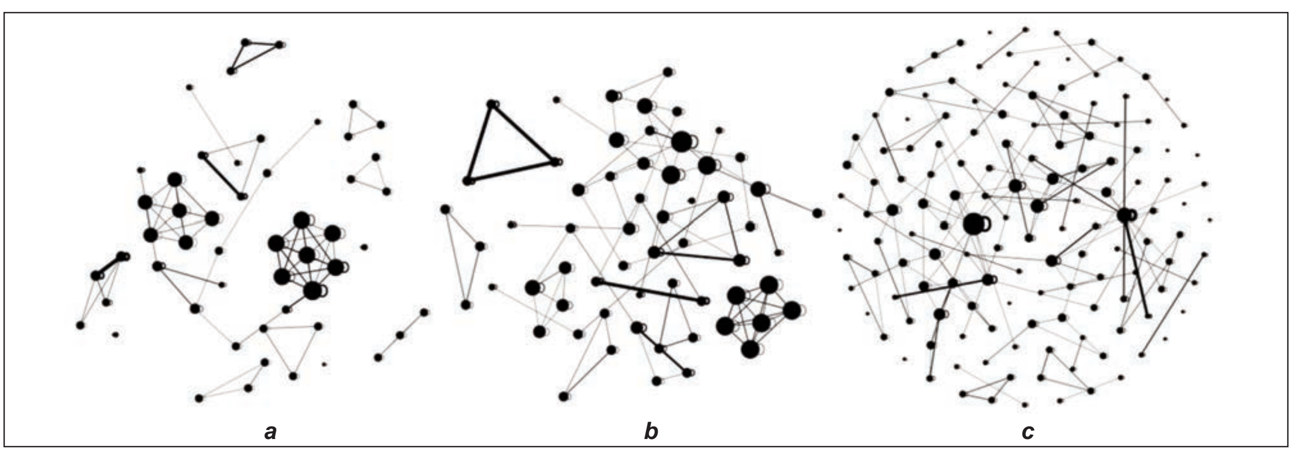

Fig. 3. Evolution mapping of R&D collaboration network topology: *a* – 2000–2007; *b* – 2008–2014; *c* – 2015–2021

Table 2

STRUCTURAL CHARACTERISTICS OF ORGANIZATIONAL COOPERATION NETWORKS			
Network characteristic parameters	**2000–2007**	**2008–2014**	**2015–2021**
Degree	2.657	2.729	2.957
Weighted degree	10.371	35.85	39.8
Network diameter	9	9	13
Network density	0.019	0.02	0.021
Average path length	3.416	3.516	3.687
Clustering coefficient	0.822	0.747	0.777

the number of partners in R&D institutions is gradually increasing. However, the clustering coefficient shows a downward trend, indicating that cooperation between innovative organizations is not close, a relatively stable cooperative relationship has not been formed, and an increasing number of enterprises choose to improve the competitiveness of their products and technologies in the market through independent innovation.

Characteristics of innovative organizations

According to the type of organizational cooperation, the innovation organizations are divided into companies, scientific institutions, and others, and the results are shown in table 3. The results found that, in terms of organization types, the proportion of companies is the highest in all countries around the world, exceeding 60%. In Japan, from 2000 to 2007, the proportion of enterprises as innovative organizations was as high as 90.00%. It shows that companies have always been the core force of technology R&D, and also the key subject of promoting technological innovation and development. From 2015 to 2021, the number of research projects in universities and institutions has expanded rapidly, especially in China, Japan, and South Korea, and there was a clear differentiation of innovation organizations, and the proportion of universities and institutions has increased by at least 10% compared with the embryonic stage of technology. As an important part of the country's industry-university-research (IUR) collaborative innovation ecosystem, colleges and universities play an increasingly important role in the R&D and sustainable development of textile new material technology [22, 23].

In terms of the number of organizations, the growth rate of innovation bodies in China, Japan, and South Korea is more obvious, especially in the former. The number of companies and scientific institutions has developed rapidly from 74 and 21 in the embryonic stage of technology R&D to 1918 and 946 in the mature stage of technology, becoming an important innovation body in the field of global textile new material technology R&D.

The analysis of the distribution and evolution of innovation bodies in different stages is helpful to analyse the characteristics of subjects in the R&D cooperation network in different periods (the results as shown in table 4). Next, Gephi's PageRank algorithm is used

Table 3

TYPES AND PROPORTIONS OF ORGANIZATIONAL COOPERATION			
Year	**Country: number of companies (rate%)**	**Country: scientific institutions (rate%)**	**Country: others (rate%)**
2000-2007	US: 162 (77.14)	US: 42 (20.00)	US: 6 (2.86)
	CN: 74 (76.29)	CN: 21 (21.65)	CN: 2 (2.06)
	JP: 180 (90.00)	JP: 16 (8.00)	JP: 4 (2.00)
	KR: 43 (74.14)	KR: 15 (25.86)	KR: 0 (0.00)
	EP: 44 (89.80)	EP: 5 (11.20)	EP: 0 (0.00)
2008-2014	US: 875 (81.02)	US: 177 (16.39)	US: 28 (2.59)
	CN: 915 (80.19)	CN: 222 (19.46)	CN: 4 (0.35)
	JP: 566 (80.06)	JP: 123 (17.40)	JP: 18 (2.54)
	KR: 266 (70.93)	KR: 103 (27.47)	KR: 6 (1.60)
	EP: 178 (83.96)	EP: 29 (13.68)	EP: 5 (2.36)
2015-2021	US: 322 (68.80)	US: 130 (27.78)	US: 16 (3.42)
	CN: 1918 (66.46)	CN: 946 (32.78)	CN: 22 (0.76)
	JP: 507 (78.48)	JP: 125 (19.35)	JP: 14 (2.17)
	KR: 294 (60.12)	KR: 187 (38.24)	KR: 8 (1.64)
	EP: 156 (78.79)	EP: 36 (18.18)	EP: 6 (3.03)

Table 4

TOP 10 PAGERANK OF ORGANIZATIONAL COLLABORATION NETWORKS			
No.	**2000–2007**	**2008–2014**	**2015–2021**
	Institutions (Country)	**Institutions (Country)**	**Institutions (Country)**
1	DuPont (US)	Sinopec (CN)	Donghua University (CN)
2	Tsinghua University (CN)	FiberVisions LP(US)	Sinopec (CN)
3	Foxconn (Taiwan, CN)	ES Fibervisions (US)	Wuhan Textile University (CN)
4	Toray (JP)	Daiwabo (JP)	Zhejiang Longsheng (CN)
5	Daiwabo (JP)	Tsinghua University (CN)	Daiwabo (JP)
6	Kuraray (JP)	JNC (JP)	Shinshu University (JP)
7	Mitsubishi Chemical (JP)	KOREA TEXTILE DEV INST (KR)	TB Kawashima (JP)
8	Kao (JP)	Shinshu University (JP)	Soochow University (CN)
9	ES Fibervisions (US)	Yibin Hester Fiber (CN)	Cathay Biotech (CN)
10	FiberVisions LP (US)	Yibin Siliya (CN)	Asahi Kasei (JP)

to count the number of other organizations directly connected to the innovation subject. The higher the PageRank value, the stronger the cohesion of the innovation subject in the network and the richer the innovation resources it holds [24–26]. From 2000 to 2007, Japanese multinational companies played a pivotal role in the technical cooperation and R&D network of textile new materials, and internationally renowned enterprises represented by Toray, Daiwabo, and Kuraray were at the core of the network in the R&D of carbon fiber, functional materials, and rayon, etc. [27]. Together with DuPont in the United States and Tsinghua University in China, the above-mentioned corporations played an important role in the innovation and development of textile new material technology.

With the continuous progress and development of textile technology, China began to emerge as several innovative forces in 2008–2014, with Sinopec, Yibin Hester Fiber, and Yibin Siliya as the representatives of well-known chemical and fiber enterprises emerging in the international textile market. However, the United States and Japan still have strong technological R&D advantages, especially in the field of high-performance fibers, composite fiber materials, and intelligent equipment etc., and the above innovative bodies constitute an important research force in the global textile new material technology R&D network.

However, from 2008 to 2014, the main body of innovation in the R&D of new textile material technology in the world underwent major changes, and China and Japan became the core forces of cooperative research in this field. The former, colleges and universities represented by Donghua University, Wuhan Textile University, and Suzhou University, have gradually become an important part of the organizational cooperation network, which also verifies that the above-mentioned universities are an important part of the national IUR collaborative innovation ecosystem. The latter's innovative organizations remain globally competitive in the fields of green materials, high-performance fibers, and advanced textile products.

Analysis of the IPC technical network

Combined with the time dimension and IPC technology sub-categories, the network evolution analysis helps obtain the development trend and evolution characteristics of global textile new material technology at different stages. Figure 4 shows that in different periods of technical cooperation R&D, there are key technology nodes with more obvious nodes and labels in the IPC network evolution map, and this type of node is interrelated with other technology nodes, forming several technology subgroups.

Among them, from 2000 to 2007, D01F (chemical characteristics of making rayon filaments and fibers, and equipment dedicated to the production of carbon fiber), D06M (processing fiber products of fibers and fabrics), D04H (manufacturing textiles) and B32B (layered products) and other technologies were more prominent, which has a strong radiation effect on other related technologies during this period, so it is more competitive in the market. With the rapid development of textile technology, compared with the embryonic period, the key technical nodes such as D01D (mechanical method or equipment for making chemical filament and fiber), D03D (woven fabric, weaving method, and loom), C08L (composition of polymer compounds) and D02G (fiber, filament) appeared from 2008 to 2014. After 2015, the global technical cooperation research and development in the field of new textile materials has entered a mature and period, and the overall technical association network has stabilized, and technologies such as C08K (using inorganic or non-polymer organic substances as ingredients) and A41D (outerwear, protective clothing, and clothing accessories) have become an important direction of innovation and development in the textile industry.

The textile new material technology has a prominent spillover effect, and different technical fields in technology R&D have the characteristics of diffusion and fusion [28, 29]. This paper evaluates the evolution of

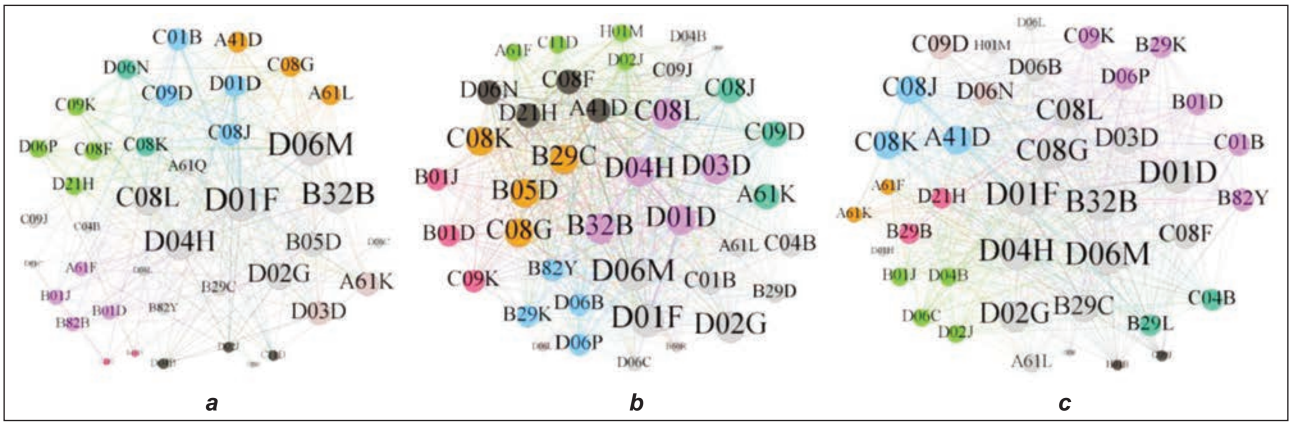

Fig. 4. Evolution mapping of IPC network for global textile new material technology cooperation R&D:
a – 2000–2007; *b* – 2008–2014; *c* – 2015–2021

technology networks in the development process by establishing the matrix of technology convergence and co-occurrence, as shown in table 5 below. The connection strength in the technology field is the ratio of the number of co-occurrences and the number of technology linkages among technologies [30–32].

Since the 21st century, D01F, D06M, D04H, and D01D have been the textile new material technology fields with the largest number of technical associations and the highest technical correlation strength. In the embryonic stage, the number of co-occurrences in the technology field is relatively small, the intensity of technology correlation is not high, the overall technology spillover effect is weak, and the technology diffusion and fusion are mainly carried out within the technology subgroups. From 2008 to 2014, the correlation intensity of IPC network technology increased significantly, and the number of co-occurrences between technologies increased significantly. By the mature stage, C08J (the general process of processing and batching), C08G (polymer compounds obtained by reactions other than carbon-carbon unsaturated bonds), and D06P (dyeing or printing of textiles) and other related technical fields with rapidly increasing correlation strength have appeared, which has played a positive role in promoting the technological innovation and development of textile new materials in the world.

DISCUSSIONS

The findings of this paper help sort out the characteristics of the innovation subjects, organizational cooperation network relationships, and IPC technology networks in the global textile new material technology cooperation and research and development. Although the existing research objects in the academic community involve several emerging industries and technology fields, there is no study on the network relationship and the analysis of the evolution characteristics of technology cooperation and R&D of textile new materials. Therefore, this paper attempts to supplement the existing research from two aspects of the research object and the research content, to potentially fill the gap in existing research.

New materials are one of the key areas of international competition and a key factor in determining a

Table 5

COMPARISON OF ENTROPY, CONTRAST AND EME VALUES WITH EXISTING METHODSEVOLUTION CHARACTERISTICS OF THE GLOBAL TEXTILE NEW MATERIAL TECHNOLOGY FIELD AT DIFFERENT STAGES

No.	2000–2007			2008–2014			2015–2021		
	IPC4	Number of co-occurrences	Strength of association	IPC4	Number of co-occurrences	Strength of association	IPC4	Number of co-occurrences	Strength of association
1	D01F	322	9.47	D01F	1821	46.69	D01F	2186	55.54
2	D06M	249	7.32	D01D	1202	33.39	D06M	1359	34.85
3	D04H	204	6.80	D04H	1102	30.61	D01D	1190	31.32
4	D01D	129	6.14	D06M	1165	29.87	D04H	975	26.35
5	D03D	130	5.65	C08L	829	23.03	C08L	887	25.34
6	C08J	180	5.63	B32B	778	21.61	C08J	684	20.73
7	D02G	133	5.12	C08G	592	16.91	C08G	711	19.75
8	C01B	99	4.71	C08K	549	15.69	C08K	640	19.39
9	D02J	47	4.70	C08J	496	15.50	D06P	432	16.00
10	B29C	65	4.33	B29C	533	15.23	C09B	143	14.30

country's high-end manufacturing and national defense security. The United States and Japan and other developed countries through economic strength, core technology, research and development capabilities and market share and other advantages, the use of large multinational companies to occupy a monopoly position in the global market, and in the textile new materials industry to take the lead in completing the technical layout. In terms of organizational cooperation networks, Japan mainly adopts the "government-industry-academia" R&D and application integration model to promote the innovation and breakthrough of textile new materials. Studies have shown that the more successful the inter-organization R&D collaboration, the higher the quality and quantity of external resources available through the collaboration [33]. In the technology R&D network, put forward the goal of "focusing on the practicality of new materials and considering the harmonious development of the environment and resources", so in the global carbon fiber technology, functional chemical products, chemical new materials and artificial fibers and other cutting-edge materials fields occupy a pivotal international position. Although China's textile new materials technology R&D started relatively late, the development is relatively rapid. Under the guidance of the national IUR collaborative innovation to the innovation consortium policy, by leading enterprises to integrate scientific research institutes, institutions of higher learning and the innovation of the main body of cooperation organizations, to solve the key core technology of industrial development and enhance the level of industrial technological innovation.

With the acceleration of a new round of scientific and technological revolution and industrial transformation, especially for the impact of COVID-19 and global geopolitical factors, the allocation of global technology factors and market factors is undergoing profound changes. In the field of textile new material technology R&D, the United States and Japan have the most competitive technology R&D networks in a relatively mature market around the world. In China and South Korea, the technology R&D network is in a stage of rapid development [34]. From the macro perspective, the focus of the global textile new material technology cooperation R&D network is gradually shifting towards the Asian region, and the technology gap in the global major innovation regions is narrowing as the competition in this field has entered a white-hot stage.

CONCLUSIONS

Theoretical implications

Based on the patent data of global textile new material technology cooperation R&D, this paper uses the patent technology network analysis method to quantitatively analyze the structural characteristics, evolution, and trend of organizational cooperation networks and technology networks. The results of the study are summarized as follows:

- At present, the trend of global textile new material technologies cooperation R&D corresponds to three stages, namely the germination period (2000–2007), the growth period (2008–2014), and the maturity period (2015–2021), respectively. However, under the influence of COVID-19 and global geopolitics, the cooperative innovation activities of enterprises and scientific research institutions around the world cannot be carried out normally, and the global technology cooperation R&D network was seriously disrupted.
- There are a few key innovative bodies in the embryonic stage of the organizational cooperation network. Since 2008, the network structure has shown a multi-node multilateral radiation network state, with a rapid increase in the number of network nodes and a continuous strengthening of the correlation between key nodes, and a R&D group of innovative organizations has begun to take shape. The innovation activities of the organizational cooperation network tend to be stable in the mature stage, but there is no relatively stable cooperative relationship between innovation organizations. Japan's innovation community has always played a key and important role in the collaborative R&D network, occupying a central position in technological fields such as green materials, high-performance fibers and advanced textile products.
- It was discovered that enterprises are the backbone of promoting the innovations and development of global textile new material technologies, however, universities and scientific research institutions play an increasingly important role in China's R&D network, becoming an important part of the national IUR collaborative innovation ecosystem.
- At different times of the IPC technology R&D network, there are key technology nodes and technology subgroups, forming a development process from D01F, D06M, D04H, and other technologies to D01D, D03D, D02G, and A41D. The technology spillover effect, the diffusion and integration within the technology subgroups, and the significant enhancement of technology correlation have played a positive role in promoting technological innovation and the development of new textile materials in the world.

Practical implications

Based on the main conclusions of this article, the following policy implications are proposed for decision-making reference by governments, decision-makers, enterprises, and university research institutions.

Firstly, it is necessary to improve the service platform and service organization of the cooperative R&D network to realize the complementary advantages of the network subjects, to boost the cooperative innovation efficiency, collaborative innovation ability, and technological innovation level among the network subjects, and thus achieving the purpose of reducing R&D risks and saving R&D costs. Secondly, to optimize the innovation environment of the cooperative

R&D network, a good innovation policy environment is an important way to optimize the cooperative R&D network, and the government can help realize the benign evolution and sustainable development of the cooperative R&D network through the construction of policies, legal systems, funds and digital infrastructure. Thirdly, to maintain the stability of a cooperative R&D network structure, it is crucial to strengthen the influence and control of the core subjects within the network. The core nodes within the network play the key role in transmitting information and knowledge interaction among network subjects. Therefore, by enhancing the network power of the core subjects in the network and effectively playing their functions and roles in the network, their cooperative innovation behaviors can be adjusted to achieve the goal of optimizing the network structure. Last but not least, it is essential to divide and coordinate the collaborative activities of the nodes in the core, intermediate, and edge layers of the network rationally. The division of labor and coordination within the network are significant for increasing the efficiency of cooperative innovation. Moreover, it is necessary to strengthen the division of labor and coordination of cooperative innovation activities among cross-level subjects in the network, promote the integration and matching of existing resources by network subjects, maximize the complementarity of resources and knowledge flow between networks, and prevent unhealthy competition in cooperative R&D networks.

Limitations and future research directions

Although this paper has reference significance and value for filling the global textile new material technology cooperation R&D network and its evolutionary characteristics, there are still certain limitations. Due to the shortcomings of patent databases, the function of the technology roadmap cannot be used to more thoroughly study the infrastructures and paths of evolution of the technology R&D network. However, by limiting the scope of the study to the IP5, the research horizon will be subject to some limitations. In the future, more extensive global data will be available to compare different countries for further and more comprehensive analysis.

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DATA AVAILABILITY STATEMENT

The data presented in this study are openly available at: https://analytics.zhihuiya.com (Accessed on 25 January 2024).

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